Book of Abstracts

June 18-21, 2019

Engineering Mechanics Institute 2019 Conference

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Professor George Deodatis, Columbia University, New York City

Dear Participants of the EMI 2019 Conference,

As I complete my second year of service as President of EMI, I would like to express my sincere thanks to the extraordinary dedication, commitment and hard work of the Board of Governors, the EMI staff, the technical committees, and our members in the U.S. and around the globe.

On behalf of EMI, I would like to specifically thank: the Conference Chair, José Andrade (Caltech); the members of the Conference Executive Committee, Giuseppe Buscarnera (Northwestern University), Marika Santagata (Purdue University), and Matt Evans (Oregon State University); and the members of the Local Organizing Committee, Domniki Asimaki, (Caltech), Roger Ghanem (USC), Nadia Lapusta, (Caltech), and Ertugrul Taciroglu (UCLA) for organizing and hosting this year's EMI Annual Conference which is reaching an all-time record participation. The ever-increasing attendance at the EMI conferences reflects EMI's growing reputation as the premier venue for engineering mechanics. In addition to the vibrant technical programs offered over the past eleven years at EMI conferences, our Institute has experienced a healthy increase in its membership and has greatly benefited from the stellar reputation of our flagship publication, the ASCE Journal of Engineering Mechanics, under the inspiring editorship of Roberto Ballarini (University of Houston).

I am very excited to announce that EMI will soon launch a diversity initiative for junior faculty/researchers. We will also soon proceed to update our strategic plan to chart our course over the next five years.

I invite you to get more involved with our institute. EMI will further grow and thrive only if the requisite hard work is shared among its members. Opportunities for engagement include publication in the ASCE Journal of Engineering Mechanics and the Lecture Notes in Mechanics Series, active participation on technical committees, organization of conference sessions and symposia, engagement in the EMI industry collaboration, delivery of webinars, and seeking leadership roles on committees and the Board of Governors. I invite you to take advantage of what EMI has to offer. I also invite you to vote in the election for the EMI Board of Governors which is underway and to take part in the post-conference survey of the attendees. And please, do not hesitate to contact me, any of the members of the EMI Board of Governors, or EMI staff. I wish you an enjoyable and productive conference.

Yours truly,

Deodatis Georgios

George Deodatis
EMI President

Morphing materials in freeform objects, at the micro- and macro-scales

Wednesday, 19th June - 08:30: Plenary 1 (Beckman Auditorium (1,136)) - Oral - Abstract ID: 798

Prof. Chiara Daraio (California Institute of Technology)

Morphing two-dimensional sheets into three-dimensional objects is a classical problem in mechanics, mathematics and art, pursued over centuries of human history. Today, the ability to manufacture materials with an almost arbitrary microstructure, architecture and pre-stress distribution opens the door to new approaches for bending sheets into complex forms or actuating complex three-dimensional structures. In this talk, I will discuss recent progress in the design of micro- and macro-scale, nonuniform materials that can bend into freeform objects, in response to environmental stimuli or with simple application of point loads. Engineering the distribution of residual stresses, stiffness gradients and/or cut patterns, we control the sheets' buckling at both local and global scales. The designed distribution of responsive materials in the sheets provides a time dependent control of the developing shapes. Programming 2D sheets into rigid, 3D geometries expands the potential of existing manufacturing tools for efficient and versatile production of 3D objects and may allow the creation of autonomous soft robots.

2d Simulation of the Bioinspired Dual-Anchor Burrowing Mechanism in Dry Sand

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 890

Mr. Sichuan Huang (Arizona State University), Prof. Junliang "Julian" Tao (Arizona State University)

The Atlantic razor clam achieves motility with exceptional energy-efficiency through inflating its shelled body and distal muscular pedal alternatively during locomotion. Basically, the inflated body serves as a penetration anchor, which provides required reaction force for the protrusion of foot. Similarly, the distal pedal inflates and forms a terminal anchor for the retraction of the shelled body after shell adduction. Using the 2D discrete element method modeling, we are able to capture the detailed interaction between a dual-anchor penetrator and the a granular material at multiple scales. The penetrator is simplified and includes a rectangular 'shell' and an equilaterally triangular 'foot'. The soil is dry sand with uniformly distributed particle size. Both the vertical and horizontal burrowing situations are considered in the simulation by considering or neglecting the gravitational effect. It is found that opening of the 'shell' compresses the soils around the shell, and simultaneously releases the stress around the 'foot'. A pressure gradient is created between the low-pressure zone right below the 'foot' and the distal undisturbed zone. Such a pressure gradient causes the dilation of the soil locally around the cone, therefore affects the foot penetration resistance. Increasing the expansion ratio will amplify the stress relief and corresponding soil dilation. On the other hand, a penetration anchor is formed and sufficient to support a certain amount of foot penetration after slight uplifting of the shell. The stress relief phenomenon in horizonal burrowing is more obvious compared with the vertical burrowing, due to negligible impact from gravitational field.

A Spectral Collocation Method for Finite Deformation Analysis in Sphere-Like Geometry

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 234

Mr. Pei-Chuan Chao (University at Buffalo), Prof. Mettupalayam Sivaselvan (University at Buffalo)

Spectral methods are known to be highly accurate (exponential convergence) for problems with domains of simple geometry and defined by smoothly varying data. This is true for models of biological cells in flow, where the cell geometry is often considered as a smooth deformation of the unit sphere (for cells in suspension) or of the unit hemisphere (for adhered cells). We seek to apply spectral methods to represent entire cells in flow, which for many purposes has been modeled as a porous medium undergoing finite deformation and sustaining solute transport. As a first step toward this goal, we apply a spectral method to a finite deformation problem on a sphere-like geometry in 3D. Spectral methods have been used extensively for the solution of PDEs such as the Poisson equation and the Navier Stokes equation. However, there are fewer instances of their use is solid mechanics problems. This short communication is on the spectral method application for finite deformation analysis on the sphere-like domain. The undeformed geometry and the displacement field are represented as functions in spherical coordinates on the unit sphere. These functions are approximated by spherical harmonic functions in angular direction and the Verkley (one-sided Jacobian) polynomials in the radial direction. Given prescribed body force and traction fields and kinematic boundary conditions, computing the displacement field is formulated as an energy minimization problem, so that (a) it generalizes readily to the finite deformation case, and (b) kinematic boundary conditions can be accounted for as constraints.

Nitsche's Method for the Shape Deformation of a Single Component Vesicle

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 360

Dr. Tae-Yeon Kim (Khalifa University of Science and Technology), Dr. Wen Jiang (Idaho National Laboratory), Dr. Jeong-Hoon Song (University of Colorado Boulder)

We present a Nitsche-type variational formulation of the phase-field model to capture the equilibrium shape of a single component vesicle. The governing equation from the modified phase-field elastic energy is a fourth-order partial differential equation which requires C1- elements with a conforming Galerkin method. We derive the variational formulation to discretize the governing equation based on the idea of Nitsche's method that can be applied to C0-elements. The continuities of higher order derivatives are weakly imposed by adding extra terms and the consistency of the variational formulation is verified. The capability of the formulation is demonstrated through numerical study of equilibrium shapes of axisymmetric single component vesicles along with budding and fission phenomena.

Investigation of the Binding Mechanism in Aggrecan Cleavage Sites: A Molecular Dynamics Approach

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 199

Mr. Deng Li (National Taiwan University), Dr. Shu-Wei Chang (National Taiwan University)

Cartilage is an important biomaterial which provides crucial mechanical properties for our body. Many diseases are associated with abnormal aggrecan degradation in articular cartilage. Aggrecan degradations are mainly controlled by matrix metalloproteinase-8 (MMP8). MMP8 cleaves at the catalytic site of Glu^{373}-^{374}Ala in the aggrecan core protein, with another potential cleavage site at Glu^{419}-^{420}Ala, however, left uncut. The binding mechanism of how the MMP8 recognizes the catalytic site has not yet been revealed.

To investigate this, we use a molecular dynamics approach to explore this conundrum. We found that the two key residues in the vicinity of the catalytic site, arginine in P2’ and glycine in P3’ play an important role in forming a stable binding pose of MMP8-Actual_peptide complex. For the potential cleavage site, the arginine is replaced with Threonine and the glycine is replaced with arginine, resulting in the unstable binding pose of MMP8-Potential_peptide complex. Our results suggest that MMP8 is able to recognize the molecular structure of the catalytic site and only cleave Glu^{373}-^{374}Ala in the aggrecan core protein. We hypothesize that the stable binding structure of the catalytic site of aggrecan core protein makes MMP8 stay in an “active” state, and then hydrolyze the scissile bond of aggrecan core protein. On the contrary, unstably binding between the potential cleavage site of aggrecan core protein and MMP8 makes MMP8 stay in an “inactive” state. Our results provide fundamental insights into the binding mechanism in aggrecan cleavage site at the molecular level.

Joint Calibration of a Hyper-viscoelastic Model for Brain Tissue

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 288

Dr. Patrick Brewick (Naval Research Laboratory), Dr. kirubel teferra (Naval Research Laboratory)

Concurrent with the growing incidence and awareness of traumatic brain injuries (TBI), there has been an increasing emphasis on improved mechanical modeling of brain tissue as a means of understanding these injuries. This has led to numerous studies performing experimental mechanical tests on (typically porcine) brain tissue samples from various regions of the brain. In addition, constitutive models are being developed and calibrated to describe the observed mechanical responses. However, these models typically only utilize samples, possibly from several different specimens, from a certain region of the brain for model calibration or parameter identification. While useful, these models fail to address the possible correlations that may exist, e.g., spatial correlations across regions of the brain.

The results of a study focusing on the development of a Bayesian framework for calibrating the joint posterior distribution function that describes constitutive models for multiple regions of the brain are presented. Mechanical and rheological data collected from four different regions of the brain (corpus callosum, corona radiata, basal ganglia, cortex) are used to build the joint posterior distribution of a hyper-viscoelastic model through a Bayesian model calibration. An initial calibration of model parameters is performed using the Hamiltonian Monte Carlo sampling, a Markov Chain Monte Carlo technique. The empirical Bayes method is then used to find hyperparameters that describe the prior distributions of the constitutive model parameters, including the covariance matrix. The behavior of the model calibration and determination of the joint posterior distribution and its parameters are extensively evaluated and discussed.

Molecular Structure of Nanoscale Hydrogel Base on Glycol Chitosan: Molecular Dynamics and Multiscale Modeling

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 307

Mr. Shun-Chieh Hsu (National Taiwan University), Dr. Shu-Wei Chang (National Taiwan University), Dr. Shan-hui Hsu (National Taiwan University)

Smart hydrogels based on glycol chitosan can serve as promising cell delivery vehicles for wound healing and tissue regeneration in tissue engineering because of the high water content, as well as the response to various environmental stimuli such as temperature, pH, electric field, light, and enzyme. Chitosan is formed by chitin deacetylation and consists of β-(1-4)-linked D-glucosamine and N-acetyl-D-glucosamine. Glycol chitosan is a chitosan derivative conjugated with ethylene glycol branches. It is water soluble at neutral and acidic pH values because pendant glycol branches on the polymer increase the aqueous solubility of the chitosan.

In this study, we aim to explore the molecular structures of glycol chitosan hydrogels with different percentages of protonation. We use full atomistic simulation to investigate the flexibility and conformation of glycol chitosan polymer chains in water solutions by measuring the radius of gyration and end-to-end distance. We also measure the radial distribution functions (RDF) to investigate the arrangement of polymer chains. The number of hydrogen bonds are analyzed to reveal the effects of pH on the molecular interactions. The fundamental insights into the molecular structure and mechanism of glycol chitosan hydrogel suggest that they are good hydrogel candidates for controlled release and drug delivery systems because their properties can be controlled by changing the pH.

Recovery of Tractions Exerted by Cells in Fibrous Extracellular Matrices

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1266

Dr. Dawei Song (University of Southern California), Mr. Nicholas Hugenberg (Rensselaer Polytechnic Institute), Prof. Assad Oberai (University of Southern California)

Tractions exerted by cells on the extracellular matrix (ECM) are critical in many important physiological and pathological processes such as embryonic morphogenesis, cell migration, wound healing, and cancer metastasis. Traction Force Microscopy (TFM) is a robust tool to quantify cellular tractions during cell-matrix interactions. Most applications of this technique have heretofore assumed that the ECM is homogeneous and isotropic, although the native ECM is typically composed of fibrous networks, and thus heterogeneous and anisotropic. In this work, we present a novel 3D nonlinear TFM approach to recover tractions exerted by cells fully encapsulated in fibrous hydrogel matrices that mimic the in-vivo environment of living cells. We pose the problem as an inverse problem, with the objective of determining the traction field that is consistent with the measured displacement field in the ECM. We formulate the inverse problem as a constrained minimization problem and develop an efficient adjoint-based minimization technique to solve it. In particular, we account for the fibrous character of the ECM by employing a homogenization model that links the microscopic features of the fibrous gels to the macroscopic response. We find that there is a significant difference in recovered tractions between models that account for the underlying fibrous structure and those that assume a homogeneous and isotropic ECM.

Self-Adaptive Gel-Point Patch for Myocardial Infarction

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1314

Mr. Yue Liu (Brown University), Dr. Xiao Lin (Soochow University), Mr. Aobing Bai (Fudan University), Mr. Huanhuan Cai (Fudan University), Prof. Huajian Gao (Brown University), Prof. Lei Yang (Soochow University), Prof. Ning Sun (Fudan University)

Acellular epicardial patches for treating myocardial infarction (MI) by increasing the mechanical integrity of damaged left ventricular (LV) tissues exhibit widely scattered therapeutic efficacy. A major challenge in the field is to develop next-generation patches with minimal risk and maximal efficacy. Guided by finite element simulation, we introduce a self-adaptive gel point adhesive patch (GPAP) which outperforms many existing patches in reversing LV remodeling and restoring heart functions in both acute and sub-acute MI in rats. The underlying mechanism of GPAP results from the so-called gel point (G'=G") to balance the fluid and solid properties of the patch material. The fluid property brings the ability for the patch to accommodate the cyclic deformation and the complex geometry of the ventricle, and therefore resolve the issue of choosing appropriate reference state for deformation. On the other hand, the solid property provides the necessary stiffness for the mechanical support. Together they achieve a significantly improved safety and therapeutic efficacy.

Effect of Sand as Medium for Microbial Activities on Healing Concrete Cracks

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 473

Ms. Xijin Zhang (Case Western Reserve University), Dr. Yuan Guo (Case Western Reserve University), Prof. Xiong Yu (Case Western Reserve University)

Cracks can develop in concrete at different stages of service, i.e., early stage plastic shrinkage crack and cracks formed due to thermal cycles, freeze-thaw cycles, and structural loads. While structural cracks directly compromise its load bearing capacity, non-structural cracks indirectly affect the service life by accelerating water and ion infiltration and associated corrosion. Autogenous fixing concrete cracks helps to improve its longevity. This study evaluated the potential of bacteria mediated healing of cracks in concrete. The performance of sand as a carrier material for concrete crack repair is evaluated. The bacterium *Sporosarcina pasteurii* is used in the experiment. The bacteria produce urease, which allows the hydrolysis of urea into ammonium and carbonate that precipitate as calcite in a calcium rich environment. The precipitation of calcite fills the crack space in concrete as well as increases the roughness and bond force between the particles. The healing performance was observed by the microstructural and physical characterization by SEM/EDS analysis as well as needle penetration test. DEM model was developed to simulate the effects of bacteria cementation induced microstructure change on the mechanical properties, where the strength is evaluated by simulated direct shear tests. The influence of the percentage of bio-mediated cementation and particle size distribution on the strength of modified sand are analyzed. The results show that bacteria mediated healing has the potential to mitigate the negative impacts of concrete cracking.

Improving Airfoil Aerodynamics with Shark Skin Inspired Design

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 202

Mr. Joshua Ott (University of California, Berkeley), Mr. Manuel Lazalde (University of California, Berkeley), Prof. Grace Gu (University of California, Berkeley)

Systems that move through fluids like boats, submarines, airplanes, and helicopters all benefit from a reduction in opposing forces, or drag. As a result, there is a significant focus on finding new ways to improve the lift-to-drag ratios of systems that move through fluids. Nature has proven to be an extremely beneficial source of inspiration to overcome current technical endeavors. Shark skin, with its low-drag riblet structure, is a prime example of an evolutionary design that has inspired new implementations of drag reducing technologies. Previously, it has been shown that denticles have drag reducing properties when applied to airfoils and other surfaces moving through fluids. Researchers have been able to mimic the structure of shark skin, but minimal work has been done in terms of optimizing the design of the denticles due to number of parameters involved. In this work, we used a combination of computational fluid dynamics (CFD) simulations and optimization methods to optimize the size, shape, and placement of shark skin denticles on the surface of airfoils in order to decrease drag.Results show that by changing size, shape, and orientation of the denticles, we are able to alter the boundary layer, and thereby reduce drag. With these tools, we can provide design guidelines for commercial aviation in order to maximize fuel efficiency and decrease carbon emissions. These drag reducing properties of denticles can be further expanded beyond commercial aviation and can be used to reshape maritime and automotive travel resulting in an even greater reduction in carbon emissions.

The Mechanics of Bio-Cemented Sands

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 259

Mr. Charalampos Konstantinou (University of Cambridge), Dr. Giovanna Biscontin (University of Cambridge)

The reconstitution of a geological material usually requires the characterisation and laboratory replication of the geological processes that occurred in nature, even if the impossibility of reproducing the effects of geological time must be recognised. There exist two fundamental requirements for artifically cemented samples: uniformity of behaviour and the degree of similarity with average natural behaviour. Several methods have been proposed in literature for creating artificial calcite sandstones. Microbially induced carbonate precipitation (MICP) is a bio-cementation technique used in the last decade to turn loose sand into calcite cemented sandstone. The cementing agent holds the sand particles together and an increase in strength and stiffness is observed (Whiffin, 2004). It is considered be an appropriate method for artificial sandstone preparation because of its relative ability to retain soil permeability.

A parametric study was conducted to create artificial specimens with mechanical properties through MICP. This can be achieved by changing the relevant process parameters, such as injection rate, number of injections, concentration of bacteria, and concentration of chemicals. The purpose of this series of experiments was to investigate the optimum way of producing artificial specimens that have the desired mechanical properties. An increase of calcite content results in an increase in unconfined compression strength (UCS) and decrease in hydraulic conductivity, permeability and porosity. The conjugate changes in the mechanical properties were assessed and compared with the properties of natural weak sandstones.

References

Whiffin, V. S. (2004). *Microbial CaCO3 Precipitation for the Production of Biocement*. PhD thesis.

Internal Curing in Ultra-High Performance Concrete Using Biochar

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 444

Mr. Anjaneya Dixit (National University of Singapore), Mr. Souradeep Gupta (National University of Singapore), Dr. Sze Dai Pang (National University of Singapore), Dr. Harn Wei Kua (National University of Singapore)

This article explores internal curing by pre-soaked bio-char, applied as partial cement replacement in ultra-high performance concrete (UHPC). Bio-char (BC), used in the study was prepared by slow pyrolytic conversion (10˚C/minute) of mixed wood saw dust at 500˚C. BC particles below 125 μm were pre-soaked for 24 hours to achieve saturation, which was then mixed to replace 5% of cement by weight in UHPC mix. Compression tests show that BC addition lead to comparable strengths at 1-day and 28-days. Scanning electron microscope (SEM) images revealed that pores of BC serve as nucleation centre for hydration products. This is further confirmed from isothermal calorimetry (ITC) results, which suggest that presence of BC accelerates hydration kinetics in BC-UHPC mix compared to reference. Degree of hydration calculated by Bhatty's method and thermo-gravimetric analysis (TGA) show a substantial improvement in BC-UHPC mix compared to reference. In summary, the results indicate that bio-char from wood waste can be a potential mineral admixture in UHPC, which might be effective to reduce cement demand and create novel avenue for waste valorisation.

Sustainable Improvement to the Crack Resistance of Clayey Soils

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 811

Mr. Michael Izzo (Auburn University), Dr. Marta Miletic (Auburn University)

Desiccation cracking of clayey soils is the development of cracks on the geomaterial surface as a result of a gradual reduction in moisture content. Thus, the decrease in soil surface area owing to the desiccation cracking could have a severe impact on the performance of clayey soils in various geotechnical, agricultural and environmental applications. Many efforts have been made to overcome the catastrophic consequences of desiccation cracking, such as massive financial damages and even the loss of life. The most popular process to enhance soil strength and resistance to cracking is chemical treatment using additives like cement, but its use raises a number of environmental concerns such as CO_2 emissions, groundwater contamination, vegetation growth prevention, etc. Therefore, the demand for green soil improvement alternatives is increasing.

The main aim of this research is the development of eco-friendly soil improvement techniques and the investigation of their effect on the desiccation cracking behavior. A type of biopolymer, xanthan gum, and recycled nylon fibers were studied as types of sustainable improvement techniques. Improvement of soil crack resistance by eco-friendly reinforcement was investigated by conducting 1D and 2D desiccation tests on the treated and non-treated clay specimens. The soil engineering properties were examined using the unconfined compression and the indirect tensile tests. MATLAB image-processing was conducted to quantitatively describe the effect of reinforcement on the geometrical characteristics of crack patterns. The experimental and image analysis results showed that all the soil improvement techniques significantly enhanced the soil strength and reduced the amount of cracking.

Exploration of a New Methodology for the Application of MICP in Soils

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1231

Mr. Miguel Valencia-Galindo (Departament of Structural and Geotechnical Engineering, Pontificia Universidad Católica de Chile), Mr. Ramón Nazar-Soto (Departament of Structural and Geotechnical Engineering, Pontificia Universidad Católica de Chile), Dr. Esteban Sáez-Robert (Departament of Structural and Geotechnical Engineering, Pontificia Universidad Católica de Chile), Dr. Carlos Ovalle (Research Institute of Mining and Environment, Departament of Civil, Geological and Mining Engineering, Polytecnique Montréal)

The application of MICP has been successfully studied in granular soils due their high permeability. However, in soils with high fines content the injection of MICP has been limited due the difficulty to distribute the additives because of their low permeability. In the present research, an alternative application of MICP is being studied, were the biological additive is included into the compaction water, overcoming the difficulty of application by injection in soils such as silts and clays. Additionally, as a soil improvement method, could help to avoid soil replacement. Two applications are being studied.

Firstly, a silty-sand residual soil called *Maicillo*, which is abundant in coastal mountains of Chile. This weathered material presents significant cohesion in its natural condition. However, once excavated and compacted, shear strength and stiffness are significantly reduced. Our laboratory experimental results (isotropic and triaxial compression with bender elements) show that MICP on remolded *Maicillo* improves its mechanical properties, allowing to recover partially the undisturbed behavior.

Secondly, MICP was applied on a remolded expansive clay. Laboratory consolidation/swelling tests and a field testing facility specially built were used to assess the effectiveness of MICP to reduce swelling. The results suggest that the chemical process involved in calcite precipitation reduces swelling.

Preliminary microstructural characterizations on treated clays indicates a change in the evaporation water temperature on Temperature Programmed Desorption (TPD) and a slight change in the pore distribution with the Nitrogen adsorption-desorption test.

Topology Optimization of Nonlinear Frame Structures Based on Hysteretic Finite Element Modeling

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 820

Mr. Navid Changizi (Pennsylvania State University), Dr. Gordon P. Warn (Pennsylvania State University)

A method for the topology optimization of nonlinear frame structures based on hysteretic finite element modeling is presented. Topology optimization is a mathematical framework to design efficient material layouts while considering engineering constraints that has been mostly limited to linear-elastic for systems composed of discrete elements. A novel method for the topology optimization of structural systems that are expected to undergo inelastic deformations is presented. The method is introduced in the context of frame structures composed of beam elements. The core of the methodology is a hysteretic finite element modeling scheme in which the inelastic deformations are governed by principles of mechanics in conjunction with smooth, first order, nonlinear ordinary differential equations facilitating the derivation of a closed-form gradient. The method is demonstrated for two different design philosophy, specifically one seeking volume minimization with a displacement constraint (e.g. drift) such that the optimized design has sufficient stiffness and a second seeking a design that maximizes energy absorption for a fixed volume and a prescribed displacement constraint. The method is demonstrated through application to the design of cantilever and beam structures with numerical examples to illustrate the resulting topologies for volume minimization formulation and strain energy absorption with limiting displacement constraint.

Robust Topology Optimization of Frame Structures Under Member Imperfections and Manufacturability Constraints

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1269

Mr. Nicholas Valm (University of Massachusetts Dartmouth), Dr. Mazdak Tootkaboni (University of Massachusetts Dartmouth), Dr. Alireza Asadpoure (University of California, Los Angeles)

Topology optimization is a powerful computational design tool that has led to discovery of highly efficient structures. The optimization process for lattice structures, such as frames, usually begins with a dense mesh of interconnected elements. An iterative process then allows for simultaneous resizing and removing of elements throughout the design domain. In recent years there has been a surge in the number of studies that include stochastic variabilities, e.g. uncertainty in external forces, material properties, and geometric imperfections, in the optimization process to avoid sub-optimal or impractical designs under real-world engineering conditions. This study extends our previous work on topology optimization of frame structures under geometric imperfections in the form of elemental crookedness. To avoid the brute-force Monte Carlo approach, an efficient uncertainty quantification engine based on stochastic perturbation is used. Robust design is formulated via the inclusion of variance (to control the variability of performance) which is approximated using up to second order terms in stochastic expansions. To avoid complex topologies and hair-like elements that often emerge as a result of robust topology optimization, manufacturability constraints are enforced through a SIMP-like method to push the outcome toward a more manufacturable yet efficient structure. The effects of the uncertainties are illustrated by comparing the performance of optimized topologies to that of their deterministic counterpart. The functionality of the manufacturability constraints is also examined.

Topology Optimization of Light Stiff Structures with Seeded Hierarchy

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1274

Mrs. Leili Javidannia (University of Massachusetts Dartmouth), Mr. Mohammod Minhajur Rahman (University of Massachusetts Dartmouth), Mr. Seyed Ardalan Nejat (University of Massachusetts Dartmouth), Dr. Alireza Asadpoure (University of Massachusetts Dartmouth), Dr. Mazdak Tootkaboni (University of Massachusetts Dartmouth)

Topology optimization has undergone significant improvements and has evolved along a number of different directions in recent years. Today, the technique is the most widely used computational free-form design tool for discovery of novel structures and material microarchitectures. One of the most common applications of topology optimization is in design of light stiff structures. This includes design in both continuum and discrete domains and design at both structural and microstructural scales. In this presentation we explore the impact of hierarchy in weight-stiffness driven design. We seed different levels of hierarchy in topologically optimized designs trough rationing the weight of the structure at multiple length-scales and examine the potential loss in stiffness and gain in other mechanical performance measures such as strength and toughness. We illustrate the application of the proposed framework for a few benchmark problems.

A Stabilized DG Framework for Dynamic Thermomechanical Contact Mechanics with Interfaces

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 490

Dr. Pinlei Chen (Pennsylvania State University), Ms. Wan Wan (Pennsylvania State University)

Thermomechanical coupling problems of a board range of engineering applications are of great interest today. When studying the life of aircraft structures, the generated heat subjected to the aerodynamic heating results in the gradient of the temperature field on the surface of the structures, and therefore, produces stress and deformation due to the thermal field. Among all the applications in Multiphysics coupling problems, contact problems are classic in various engineering areas, ranging from the cooling process of microelectronics to metal forming processes. Therefore, a robust and efficient computational method which can model the contact problems is essential. To model the interfaces and the corresponding failure modes such as debonding at the interfaces under the existence of thermal stress and the resulting thermal contact resistance, a Discontinuous Galerkin (DG) framework with the jump of both displacement and temperature field at interfaces are proposed. A finite strain primal interface formulation with the fully coupled thermo-mechanical field is developed to model the effects of the thermal field on the interface in a dynamic environment. Employing ideas for Variational Multiscale (VMS) based stabilization, the analytical expression for artificial Lagrange multipliers are extracted via edge bubble functions with the thermal and dynamic features fully embedded. Stability parameters are derived following the ideas of VMS framework, and comparisons are drawn with both penalty method and Nitsche type method. The proposed method is applied to a class of numerical test problems with the discontinuity at the interfaces, and good comparison with analytical and experimental data is achieved.

A Modeling Framework for Coupled Plasticity and Species Diffusion with Applications to Degradation

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 569

Mr. Mohammad Sarraf Joshaghani (University of Houston), Dr. Kalyana Nakshatrala (University of Houston)

We present a modeling framework to study the response of a plastic material due to the presence and transport of a chemical species in the host material. Such a modeling framework is important to a wide variety of problems ranging from Li-ion batteries, moisture diffusion in cementitious materials, hydrogen diffusion in metals, to consolidation of soils under severe loading-unloading regimes. The mathematical model incorporates some of the experimental observations reported in the literature on how (elastic and plastic) material properties change due to the presence and transport of a chemical species. We then present a robust computational framework to solve the resulting coupled partial differential equations. We also establish the need to obtain non-negative concentrations for the diffusant, which is not the case with many popular numerical formulations. These unphysical violations will be particularly predominant when the diffusion process is anisotropic. The proposed computational framework employs an optimization-based numerical approach that will ensure that the concentrations of the chemical species are non-negative. Representative numerical examples will be provided to quantitatively and qualitatively describe the effects of concentration on the degradation of the solid undergoing either small or large plastic deformations. Based on these numerical examples, we also discuss the evolution of plastic zones due to damage or material degradation. The performance of the computational framework (with respect to optimization iterations, time-to-solution) will also be discussed.

Stress States in Tramway Rails, Predicted Through a Principle of Virtual Power-Based, Enhanced Beam Theory Approach

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 792

Ms. Patricia Hasslinger (Vienna University of Technology (TU Wien)), Dr. Stefan Scheiner (Vienna University of Technology (TU Wien)), Prof. Christian Hellmich (Vienna University of Technology (TU Wien))

Tramways are an important means of transport in many urban areas. There, mechanical failures of tramway rails can adversely affect daily life. Surprisingly, studies elucidating the stress states in tramway rails which lead to cracks or even fractures have been neglected so far. Here, we aim at filling this gap. Based on enhanced beam theory, we have developed a versatile, and computationally efficient numerical tool, allowing to quantify stress states throughout tramway rails considering representative boundary and loading conditions. In particular, not only the operation-related loading conditions imposed onto the rail through wheel-rail contact are considered, but also temperature effects, as well as production- and operation-induced eigenstresses. Furthermore, the effect of a non-uniform track bed is taken into account. To that end, a displacement ansatz allowing for consideration of axial, bending, shear, and (primary as well as secondary) torsional loading is formulated, and translated, via the principle of virtual power, into corresponding equilibrium conditions. The such derived system of equations is numerically solved by means of the Finite Element method, in sequential manner: First, force quantities are computed along the beam axis, after which, using these quantities as input, stress and strain distributions are computed in specific cross sections.

Evaluating the model, critical boundary and loading conditions can be identified, potentially leading to rail failures. Compared to full 3D Finite Element simulations, our approach offers the advantages of substantially increased computational efficiency, without compromising the accuracy of the computed quantities.

Numerical Analysis of an ISO Container Subjected to Blast Loadings

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 303

Mr. David Roman Castro (U.S. Army Engineer Research and Development Center), Dr. Catherine Stephens (U.S. Army Engineer Research and Development Center), Mr. Donald Nelson (U.S. Army Engineer Research and Development Center), Dr. Paul Sparks (U.S. Army Engineer Research and Development Center), Dr. Luis Suarez (University of Puerto Rico at Mayaguez)

Intermodal freight shipping containers have multi-functionalities, they can be used for commerce and general storage applications or more specifically for the military as Life Support Areas or Tactical Operations Centers in contingency operations. During these operations, the ISO containers can be subjected to an impulsive load. Consequently, it is important to understand the effects of blast loads on the containers in order to improve the protection of the assets. The primary focus of this research was to develop and validate a finite element model (FEM) of an ISO container with internal finishings subjected to blast loads. The numerical model was validated based on full-scale experimental field tests conducted *a-priori* and they agree reasonably. The maximum deformation of the ISO containers' reflective wall confirms the deformation experienced during the full-scale experimental test.

Effects of Time-Dependent Behavior of Concrete on the Progressive Collapse of Reinforced Concrete Structures

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 603

Ms. Livia Mello (University of Houston), Prof. Roberto Ballarini (University of Houston), Prof. Jia-Liang Le (University of Minnesota)

Efforts towards improved understanding of progressive collapse have drastically increased since high-profile events such as the collapses of the Alfred P. Murrah Federal Building and the World Trade Center towers. Following the initial damage and instantaneous structural response after an extreme event, one might speculate the possibility of further damage leading to a *delayed* collapse. This implies time dependency of load-redistribution mechanisms, further related to various time-dependent material behaviors. In case of reinforced concrete (RC) buildings, such behaviors include viscoelasticity and/or subcritical crack growth in concrete and/or along the steel-concrete interface. To study the effects of time-dependent properties of concrete on a possible delayed structural collapse, a study is performed by proposing a coarse-scale reduced-order computational mode: a set of nonlinear elements is used to model the behavior of potential damage zones in RC structural components. The concrete time-dependent constitutive relation is developed based on a coupled viscoelasticity and static-fatigue damage mechanism. Numerical results of the nonlinear element under constant static loading show continuous loss of stiffness and strength in the material due to accumulated damage over time. This eventually leads to element failure, contributing to overall structural deterioration and ultimately, collapse. Future model extension incorporating the time-dependent bond-slip behavior will contribute to the development of analysis tools for simulating progressive collapse of structural subassemblies and full scale RC buildings. Such tools are not only instrumental for advancing performance-based structural design, but also to guide safe rescue measures in the aftermath of events that have resulted in partial collapse.

Numerical Analysis of Reinforced Concrete Slabs Retrofitted with Fiber-Reinforced Polymer (FRP) and Mechanical Anchors Subjected to Blast Loads

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 656

Dr. Genevieve Pezzola (U.S), Dr. Lauren Stewart (Georgia Institute of Technology)

The ability to retrofit existing structures against extreme dynamic loads such as blast is a critical need for military engineers. A quick survey of the literature shows that reinforced concrete (RC) structural elements retrofitted with fiber-reinforced polymer (FRP) have increased flexural strength and blast resistances. There is little research effort investigating the anchorage behavior in large-scale RC systems retrofitted with FRP subjected to blast. To bridge this gap, two different mechanical anchorage techniques for concrete structures using carbon fiber-reinforced polymer (CFRP) layers were subjected to explosive loading to investigate system behavior with the different mechanical anchorage retrofits: a steel strap retrofit system and a smaller steel plate retrofit system. The results of the two tests were used to develop the initial single degree of freedom (SDOF) analysis and finite element (FE) analysis approaches. These approaches will provide insight into future computational research needed to accurately model the observed behaviors. The FE analysis successfully captured the general behavior of the blast retrofit, which allows for future analyses to be conducted.

Keywords: blast, CFRP, reinforced concrete, debonding, FEA, SDOF
Permission to publish was granted by Director, Geotechnical and Structures Laboratory.

NHERI WOW and RMDT Facilities Collaboration: Hybrid Simulation of Communication Tower Atop a Building

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 527

Prof. Amal Elawady (Florida International University), Prof. Arindam Chowdhury (Florida International University), Prof. James Ricles (Lehigh University), Prof. Peter Irwin (Florida International University), Mr. Thomas Marullo (Lehigh University)

The Natural Hazard Engineering Research Infrastructure (NHERI) Wall of Wind (WOW) Experimental Facility (EF) at Florida International University (FIU) has teamed up with the NHERI Lehigh EF to further the development of Real-Time Hybrid Simulations (RTHS) for wind engineering applications. The developments include utilizing a wind tunnel facility for RTHS of structural systems, where both experimental substructure is coupled with a numerical structure to model the behavior of a complex systems under wind action.

As an example structure used to initiate this collaboration, the teams are applying RTHS in studying the wind response of a 40 m high rooftop telecommunication tower atop a 40-story high-rise building. This example structure has been carefully chosen due to the challenges faced by the industry of rooftop communication towers. The hybrid simulation is based on developing a 3D FEM for the building and the telecommunication mast. In parallel, an aerodynamic experiment, using a relatively small length scale of 1:150, is conducted at the NHERI WOW EF to estimate wind pressure distributions on the building and the mounted mast. Outcomes of the test are time histories of wind pressures that are then used to perform time domain dynamic analysis on the building-model using FEM analysis. Later, FIU and Lehigh teams will establish a hybrid simulation testing setup to investigate the response of the mast tower at a larger scale of 1:25 using an aero-elastic model while simulating the building roof displacements by means of actuators fixed at the base of the monopole communication tower.

Numerical Integration Methods for Real-Time Hybrid Simulation of Structures Subjected to Earthquake Loading

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 892

Mr. Alejandro Palacio (University of Kentucky), Prof. Mariantonieta Gutierrez Soto (University of Kentucky)

Real-Time hybrid simulation (RTHS) is an attractive and cost-effective method for testing of structures subjected to dynamic loading. It allows the representation of a structure into partitioned physical and numerical sub-structures. The displacements of the degrees of freedom (DOF) are obtained through a time-step numerical integration method and the physical sub-structure is subjected to these displacements through an actuator. The stability and accuracy of the simulation is affected by the inevitable delay introduced by actuator dynamics during the simulation and for the participation of high-frequency modes in the response of the structure, especially for structures with large number of DOF. Different robust tracking controllers are investigated for delay compensation and their performance has been evaluated considering noise treatment, actuator control, assessment criteria and stability analysis using a benchmark problem of a three-story building with one-DOF in a virtual RTHS. This paper presents a comparison of numerical integration methods suitable for RTHS when the numerical sub-structure and the performance of the tracking controller using adaptive time series (ATS) compensation are evaluated for each approach. The proposed methodology uses a realistic virtual RTHS provided by the benchmark problem considering numerical and experimental components subjected to earthquake loadings.

A Reproducing Kernel Particle Finite Volume Method for Linear and Nonlinear Mechanics

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 916

Mr. SAILI YANG (The Pennsylvania State University), Prof. Mike Hillman (Penn State)

In the past 20 years, significant effort has been devoted to developing the weak form based Galerkin meshfree methods and the strong-form based collocation meshfree methods. For instance, many treatments have been developed to overcome issues of imposing essential boundary conditions, instability in nodal integration, and quadrature in general. Strong form based meshfree methods do not have these issues, but require other techniques to avoid computing higher order derivatives which incurs a non-trivial cost.

A finite volume method based on the reproducing kernel approximation is proposed and developed for linear and nonlinear mechanics. This method follows the global Petrov-Galerkin formulation with a conforming Heaviside test function. The divergence theorem is applied to transfer the integration to be on the cell boundaries, which avoids higher order derivatives. The variational consistency conditions are inherently satisfied, and it attains optimal convergence rates with low-order quadrature. Furthermore, the essential boundary conditions can be easily imposed by direct collocation, and no instability is observed despite it being a purely node-based method. Finally, the formulation carries an attractive physical interpretation of the balance of linear momentum of each cell. The proposed approach is developed for linear elastodynamics, as well as nonlinear mechanics under the Total and Updated Lagrangian frameworks. Several benchmark examples are presented to demonstrate the efficiency, accuracy, and stability of the method.

Investigation of Self-Sealing Phenomena in the Callovo-Oxfordian Claystone Through Micromechanics Based Numerical Simulations

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 292

Mr. Joffrey Bluthé (Den-Service d'Etude du Comportement des Radionucléides (SECR), CEA, Université de Paris- Saclay), Dr. Benoît Bary (Den-Service d'Etude du Comportement des Radionucléides (SECR), CEA, Université de Paris- Saclay), Dr. Eric Lemarchand (Laboratoire Navier - UMR 8205, CNRS, École des Ponts ParisTech, France), Dr. Luc Dormieux (Laboratoire Navier - UMR 8205, CNRS, École des Ponts ParisTech, France)

After years of research, the French National Radioactive Waste Management Agency (Andra) has determined that the Callovo-Oxfordian formation of eastern France was a good option for radioactive waste storage. One of its most important characteristics is the ability of its claystone to act as a geological barrier against the release of radionuclides in the biosphere. In order to ensure that the claystone indeed plays its expected role, it is necessary to take into account the evolution of pattern and opening of cracks, which will be created by the excavation process, during the resaturation of the post-closure phase.
In this context, we previously proposed a simplified model of the Compression of the Damaged Zone (CDZ) experiment. The cracked claystone was represented by a homogeneous effective medium using the tools of micromechanics, and an analytical solution was found. We then sought to improve on the relevance of our results. First we investigated the performance of several classical homogenization schemes against numerical simulations on 3D representative elementary volumes in terms of homogenized stiffness as well as strain localization in the crack domain. Then, we implemented the non-linear homogenized behavior of the cracked claystone so as to perform numerical simulations at the scale of the drift in the finite element code Cast3M. This allowed to investigate the effects of crack patterns that are closer to those actually observed *in situ* on the variations of crack closure upon hydration,and to assess the relevance of the different simplifying assumptions previously made.

A Hybrid Bayesian and Bézier-Based Solution to Evaluate the Mixed-Mode Fracture of Random Checkerboard Graphene Nano-Platelets Reinforced Composite Media

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1158

Mr. Hossein Kabir (University of Toronto), Mr. Seyed Amir Hossein Hassanpour Matikolaei (University of British Columbia), Prof. Mohammad Mohammadi Aghdam (Amirkabir University of Technology (Tehran Polytechnic))

Abstract:
In this study, the mixed mode fracture of composite sections reinforced with graphene nano-platelets (GnP) is considered in linear elastic region. Crack opening displacement (COD) and stress intensity factor (SIF) are determined at the very crack tip. A robust Bézier-based multi-step method is developed and suggested as a numerical solution to find the stress and displacement fields of the cracked anisotropic elastic media. In point of fact, this novel method is extended to be capable of solving the related nonlinear complex partial differential equation (PDE) proposed by Lekhnitskiĭ (1963). Furthermore, the applied GnP is assumed to be uniformly and randomly dispersed in the composite mix-proportion, with the proposed random checkerboard configuration. In addition, a probabilistic approach is developed using an efficient Monte-Carlo simulation technique for randomly oriented GnP, and the correspondent elastic moduli of the composite sections are determined for different GnP volume fractions. Comparing the evaluated numerical results with that provided from the experimental data suggests the stability and accuracy of the current methodology. A Bayesian technique was coupled with the checkerboard homogenization results to support its superiority over the commonly used micromechanical models including the Halpin-Tasi theory for the elastic moduli estimation of the reinforced media.
Keywords:Bézier-based multi-step, Crack Opening Displacement (COD), Stress Intensity Factor (SIF), Random Checkerboard model, Graphene Nano Platelets (GnP), Bayesian Technique.

Energy Budget of Dynamic Shear Ruptures: Connecting Remote Observations with Local Physical Behavior

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 222

Mr. Valere Lambert (California Institute of Technology), Prof. Nadia Lapusta (California Institute of Technology), Dr. Stephen Perry (California Institute of Technology)

Many studies of dynamic shear ruptures seek to shed light on local physical behavior using averaged quantities from remote observations, such as static stress drop and radiation efficiency in seismology. These inferences rely on the use of idealized rupture models, whereas the actual spatial distribution of slip and local stress change may vary substantially throughout the ruptured area. The relationship between observationally-inferred average rupture characteristics, such as breakdown energy and radiation efficiency, and their actual values is therefore not directly evident. We explore this relationship using fully dynamic simulations of sequences of seismic and aseismic slip incorporating Dieterich-Ruina rate-and-state friction as well as enhanced shear-heating-induced dynamic weakening.

We find that standard energy considerations inspired by dynamic fracture mechanics generally hold for simulations that produce crack-like shear ruptures, in which the local slip is proportional to the overall rupture duration. In contrast, the standard energy budget does not apply to simulations that result in self-healing pulse-like ruptures, which are characterized by much shorter local rupture durations and different characteristic stress variations. If large earthquake ruptures propagate as such self-healing pulses, as have been suggested by a number of studies, then inferences about their energy budget need to be reconsidered.

Buckling and Vibration of Periodically Supported Non-Prismatic Columns under Tip Force using an Integral Equation Approach

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 208

Mr. Jitish Miglani (Virginia Tech), Dr. Rakesh K. Kapania (Virginia Tech)

Buckling is an important failure mode in columns under a load. This phenomenon occurs when mathematically the beam effectively loses all its transverse stiffness at a certain value of the compressive load, called the critical buckling load. Furthermore, to determine a structure's behavior under dynamic loading, it is crucial to find its natural frequencies. The research proposes a semi-analytical integral-equation based method which uses the Euler-Bernoulli beam theory for determining the buckling load and natural frequencies of a periodically supported beam. The proposed method involves application of the Fredholm-Volterra integro-differential equations to satisfy both the essential and natural boundary conditions using a boundary kernel and thus solve for a multiple-bay simply supported non-prismatic rectangular cross-section beam problem. The results were verified with those available in the literature and with those obtained from a commercial finite element method (FEM) software, NASTRAN, to study the effectiveness of the proposed method. The results from FEM agreed with that from the semi-analytical method within 2%. The effect of variation of taper ratio on the non-dimensional critical buckling load, both in width and height, were also investigated. The findings also suggested singularity as the taper ratio reaches close to unity. The proposed method help determine shear and moment distributions, however, the method itself involves complex computations, which can limit the application of the method to specific problems.

Residual Stresses in Thin-Walled, Composite Columns – Influence of Column Shape on Its Buckling Behaviour

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 249

Mr. Pawel Czapski (Lodz University of Technology, Department of Strength of Materials), Prof. Tomasz Kubiak (Lodz University of Technology, Department of Strength of Materials)

The aim of this study is to investigate effect of curing, residual stresses on buckling and post-buckling behaviour of thin-walled composite columns. Under inspection will be taken two types of shapes of thin-walled columns: with open and closed cross-section. The choice are channel and square cross-sections, respectively. Moreover, in the study, it is assumed that composite is made of 8-layer GFRP and several combinations of commonly manufactured ply orientations is taken into account. FEM study is divided into two parts. First one is thermal analysis which target is to mirror the curing process and evaluate residual stresses in the laminate. Scope of the second simulation is to investigate buckling and post-buckling behaviour of the structures. The tubes are subjected to static compression and two models are prepared: one including curing prestress calculated in first simulation while the second one not. Comparison of results from two aforementioned models will enable to draw conclusions how shape of the columns affects residual stress distribution and, as a consequence, its buckling properties.

Experimental Investigation of Rupture Propagation in Cohesionless Backfill against a Rigid Retaining Wall Rotating about its Base

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 372

Mrs. Smita Patel (Indian Institute of Technology Kharagpur), Dr. Kousik Deb (Indian Institute of Technology Kharagpur)

The construction of earth retaining structure in order to ensure a safe and economic design demands knowledge of earth pressure theories and rupture surface development pattern. Experimental investigations pertaining to propagation of rupture surface and its shape are scarce. Visualisation of rupture planes through horizontal dyed sand strips being a crude process fails to render accuracy and precision. In this context, an experimental programme is designed to investigate the failure pattern using Particle Image Velocimetry in a backfill soil supported by a rigid retaining wall when wall is made to rotate about its base. The test is conducted on a 600 mm high retaining wall backing 700 mm long backfill soil with six soil pressure transducers mounted centrally on the wall to record the earth pressure. An open source MATLAB module, GeoPIV_RG generating a full field displacement profile of soil media through a series of images acquired behind transparent window at a chosen interval during test is being used for present image analysis. The obtained strain contours reveals that the rupture surface is no longer linear as suggested by classical theories rather it is curvilinear in shape. The failure surface extends up to backfill length of $0.33H$ for the active case at 50% RD. The rupture plane also makes an agle of 74° with horizontal. The test data shows that the pressure tends to decrease with the wall deflection and eventually becomes constant at a critical rotation of $1\text{x}10^{-4}$ radian. The recorded earth pressure shows a nonlinear distribution with depth.

Dynamic Recrystallization in Adiabatic Shear Banding: An Entropic, Effective-Temperature Model

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 509

Dr. Charles Lieou (Los Alamos National Laboratory), Dr. Hashem Mourad (Los Alamos National Laboratory), Prof. Curt Bronkhorst (University of Wisconsin – Madison)

Dynamic recrystallization (DRX) is often observed in conjunction with adiabatic shear banding (ASB) in polycrystalline materials. The recrystallized nanograins in the shear band have few dislocations compared to the material outside of the shear band. We reformulate the recently developed Langer-Bouchbinder-Lookman (LBL) continuum theory of polycrystalline plasticity and include the creation of grain boundaries. While the shear-banding instability emerges because thermal heating is faster than heat dissipation, recrystallization is interpreted as an entropic effect arising from the competition between dislocation creation and grain boundary formation. We show that our theory closely matches recent results in sheared ultrafine-grained titanium. The theory thus provides a thermodynamically consistent way to systematically describe the formation of shear bands and recrystallized grains therein.

Stability and Collapse of Compressed Channel Section Profiles with Barely Visible Impact Damages

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 995

Mr. Adrian Gliszczynski (Lodz University of Technology, Department of Strength of Materials)

Experimental investigations of channel-section profiles subjected to compression after low-velocity impacts leading to global failure are presented. The columns under discussion were made of an eight-layer GFRP laminate with quasi-isotropic, quasi-orthotropic and angle ply arrangements of layers. An influence of the impact position and the layer arrangement on buckling and failure phenomena, post-buckling behaviour for impacted and non-impacted columns was thoroughly examined and described. It was found that the local degradation introduced by low-velocity impacts did not affect the global behaviour of the analysed structures to a considerable extent. Moreover, it was noted that the failure mechanism was initiated in the impact location in none of the cases analysed. Additionally, it was stated that a number of fracture points did not have any significant impact on the capacity reduction.

Application of Plastic-Damage Model for Stress-Strain Modeling of FRP-Confined Repaired Concrete Columns

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1252

Mr. Ibrahim Ajani TIJANI (City University of Hong Kong), Prof. Yu-Fei Wu (RMIT University, Melbourne, Australia), Prof. CW Lim (City University of Hong Kong)

Existing studies have identified that Concrete Damaged Plasticity Model (CDPM) is capable of modeling the stress-strain behavior of confined concrete. Nevertheless, the accuracy of the model largely depends on the parameters of the model. Up to date, most research works mainly focus on the identification and modification of the parameters for fiber reinforced polymer (FRP) confined concrete prior to damage. It has been established that the FRP-strengthened concrete behaves differently to FRP-repaired concrete. This work presents a modified plastic damage model within the context of concrete damaged plasticity model in ABAQUS for modeling of a uniformly FRP-confined repaired concrete under monotonic loading. The distinct feature of damaged concrete is elastic stiffness reduction; this is included in the model. The dilation model is expressed as a function of the lateral stiffness of the FRP-jacket. The finite element predictions are shown to be in close agreement with the obtained test results of the repaired concrete.

Application of Rubberized Concrete with Expanded Clay Aggregates in Sustainable Non-Auto Transportation Infrastructure

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 755

Dr. Maryam Nazari (California State University, Fresno), Dr. Fariborz Tehrani (California State University, Fresno), Mr. Mojtaba Ansari (California State University, Fresno), Mr. Bhavesh Jeevanlal (California State University, Fresno), Mr. Faiaz Rahman (California State University, Fresno), Ms. Roshanak Farshidpour (California State University, Fresno)

This paper aims to investigate the application of Tire-Derived Aggregates (TDA) in lightweight concrete slabs containing expanded clay (EC) aggregates, used in road pavements and bridge decks serving non-auto traffic, such as bicycle routes. Application of EC and TDA as green, durable, and economically-efficient materials, enhances the sustainability of transportation infrastructure. The TDA, which is obtained from recycles tires, replaces mineral aggregates in concrete. Tires are made of very durable engineered materials in order to provide reliable, safe, and predictable behavior while on the wheels of vehicles. Using these durable materials in combination with EC will lessen the maintenance and rehabilitation needs of concrete products. Further, this application will divert waste tires from landfills. The application of rubberized concrete panels cushions effectively the impact with the ground in case of falls and therefore ensures a safe non-auto transportation system. In this paper, an experimental study has been undertaken to first estimate mechanical properties of lightweight rubberized concrete using 0%, 80%, and 100% TDA replacements by the volume of the coarse EC aggregates. Next, a series of half-cyclic static and impact-fatigue dynamic tests were performed, respectively on simply-supported beam specimens and slab assemblies, to measure their modulus of rupture and durability when subjected to the applied loads. The results confirmed lower flexural strength of the specimens containing TDA; however, they sustained large plastic deformations up to their failure. Using this experimental data, a life-cycle cost analysis was carried to investigate long-term benefits of constructing green and durable infrastructure on transportation investments.

Evaluating Robustness for Design Optimization of Underground Structures in the Face of Uncertainty

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1382

Prof. Lei Wang (University of the District of Columbia), Prof. Sara Khoshnevisan (Clarkson University), Prof. C. Hsein Juang (Clemson University)

This research presents our recent studies and advancements on the robustness-based design optimization of underground structures in the face of uncertainty. Here the design robustness is achieved by carefully adjusting the "easy-to-control" design parameters to make sure that the system response of the structure is insensitive to (or robust against) the variation in the "hard-to-control" uncertain parameters. Design robustness measure is an essential element in the success of the robustness-based optimization framework. This research will present various robustness measures that can be used in robustness-based optimization including variation of the system response, signal-to-noise ratio (SNR), feasibility robustness, gradient-based sensitivity index, and weighted sensitivity index. These measures can indicate the robustness of the system performance against uncertainties, including soil and material variability, load uncertainties, model uncertainties, and construction noises.

These robustness measures will be illustrated with examples for design optimization of underground structures such as supporting systems for deep excavations and tunnels. In the design optimization, the robustness measure will be integrated into a multi-objective optimization framework considering the safety, cost-efficiency and robustness simultaneously. Such optimization often results in a set of "non-dominated" designs and the desire to enhance the design robustness is often accompanied with the increase in the cost. A "knee point" concept will be used to select the most preferred design based on the gain-sacrifice relationship between cost and robustness among the non-dominated designs. The merit of various robustness measures will be examined through design examples and recommendations regarding the choice of robustness measures will be made.

Elastic Crack Propagation with Minimal Remeshing Using the Subregion Generalized Variational Principle and Finite Element Method

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 197

Prof. Minmao Liao (Chongqing University), Mr. Pan Zhang (Chongqing University)

Elastic crack propagation is modelled with minimal remeshing. First, a variational description of the cracked region is established by the subregion generalized variational principle. It divides the whole region into two subregions, a rectangular complementary energy subregion around the crack tip and a potential energy subregion for the rest. Then the asymptotic stress field of the Williams' solution, including the adequate high-order terms, is adopted for the computation of the complementary energy and the standard bilinear finite elements are employed for the computation of the potential energy. After applying the variational principle, the stress intensity factor (SIF) is extracted directly from the coefficients of the stress field with high accuracy. Based on the crack propagation criteria, the crack initiation condition and propagation direction are determined. Finally, once the crack starts propagation, a local minimal remeshing is implemented to repeat the previous computations until the entire crack path is obtained. This proposed approach is validated by modelling several benchmark problems.

Experimental Investigation on the Effect of the State of Stress on the Surface Roughness of Hydraulically-Induced Fractures Using Micro-CT Analysis

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 815

Ms. Gayani Gunarathna (New Jersey Institute of Technology), Dr. Bruno Gonçalves da Silva (New Jersery Institute of Technology)

Hydraulic fracturing is a technique used to increase the permeability of rock formations, therefore allowing the extraction of gas/oil entrapped within shale reservoirs as well as the harvest of heat in enhanced geothermal systems (EGS). In these applications, the surface roughness of the hydraulic fractures is a parameter that plays a major role in the efficiency of hydraulic fracturing operations, as it directly affects the fluid flow in the stimulated rock reservoirs. In this study, the effect of three different triaxial states of stress on the surface roughness of hydraulically-induced fractures produced in granite specimens with pressurized pre-fabricated flaws was investigated. These stress states consist of vertical loads of 1MPa, 2MPa and 4MPa and constant lateral loads of 2 MPa. After being tested, the specimens were scanned using a micro-computed tomography scanner to produce micro-CT images, from which 3-dimensional surfaces of the hydraulic fractures were obtained. Using these surfaces, the directional roughness profiles (i.e., parallel to the pre-fabricated flaw and perpendicular to the pre-fabricated flaw) and their arithmetical average roughness (R_a) and root mean square roughness (R_q) were calculated in the two directions.

The results show that the surface roughness varies depending on the direction considered and tends to decrease from the point of fracture initiation to the edge of the specimens. It was also observed that the surface roughness parallel to the pre-fabricated flaw varies inversely with the magnitude of the vertical load applied.

Tuning Crack-Inclusion Interaction Through T-Stress

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1321

Mr. Bo Ni (Brown University), Dr. Kai Guo (Brown University), Prof. Huajian Gao (Brown University)

Embedding elastic heterogeneities into matrix materials has been applied as an effective way to toughen engineering materials for a long time. From the point of view of fracture mechanics, the interaction between inclusions and cracks brings in various effective toughening mechanisms, such as crack deflection, crack arrest, etc. A rule of thumb in this field is that a softer/stiffer inclusion attracts/repels the crack during its propagation and trigger sequential toughening mechanisms. In this study, through integrated theoretical analysis and numerical simulations, we demonstrate that, surprisingly this interaction trend could be tuned and even reversed by applying a constant stress field parallel to the crack plane, i.e. the so-called T-stress field. Using the Eshelby's equivalent inclusion method, we have analyzed the effect of the T-stress on a heterogeneous inclusion in the vicinity of a crack. The results suggest that T-stress can alter the crack tip driving force only via the presence of inclusion. And under a relatively strong compressive T-stress, the crack can experience a driving force that deflects it away from/towards a soft/hard inclusion in the vicinity. The theoretical predictions have been validated by FEM simulations. This study can throw light on understanding and tuning fracture process in particulate composites, especially those under large compressive stress states, such as composite electrodes in lithium-ion batteries and gas/oil shales underground.

A Novel Lightweight Gelatin-Based Composite Engaging Microbially Induced Calcite Precipitation (MICP) for Infrastructure Applications

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 799

Dr. Jishen Qiu (University of Colorado Boulder), Dr. Juliana Artier (University of Colorado Boulder), Ms. Sarah Williams (University of Colorado), Prof. Chelsea Heveran (Montana State University), Prof. Sherri Cook (University of Colorado Boulder), Prof. Jeffrey Cameron (University of Colorado Boulder), Prof. Wil Srubar (University of Colorado Boulder), Prof. Mija Hubler (University of Colorado Boulder)

Gelatin hydrogel has been used for medical applications for years, but it is rarely used for infrastructure purposes due to its low mechanical stiffness and strength compared to synthetic polymer resins. In this study, a novel type of lightweight composite that uses dehydrated and hardened gelatin as a scaffold to bind fine aggregates was developed. The feasibility of reinforcing the gel scaffold through MICP was studied in the presence of *Synechococcus* sp. PCC 7002 (Syn7002), which can naturally precipitate calcite, or *Escherichia coli* bacteria, which was genetically engineered by introducing genes from urease pathway. Specifically, tensile and shear bond tests were used to determine the binding strength of the gel scaffold. Also, compression of cubes and three-point flexure of notched beams were carried out to assess compressive strength and fracture energy of the gel-scaffolded composites. SEM, EDX, and XRD were conducted to characterize the microstructure and failure mode of the composites. The results indicate that the new composites achieved a compressive strength of 4 MPa and fracture energy of 300 N/m with a light-weight density of 1800 kg/m^3. On the micro-scale, tensile rupture of the gel scaffold controlled the failure of the composites. These findings substantiate that MICP effectively toughened the gel and thus enhanced the mechanical performance of the composites.

Discrete Element Analysis of Slender Reinforced Concrete Columns

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 704

Mr. Kresimir Nincevic (Christian Doppler Laboratory for Life-Cycle Robustness in Fastening Technology University of Natural Resources and Life Sciences Vienna), Mr. Ioannis Boumakis (Christian Doppler Laboratory for Life-Cycle Robustness in Fastening Technology University of Natural Resources and Life Sciences Vienna), Prof. Roman Wan-Wendner (Ghent University)

Many architectural solutions and creative structures tend to use column systems as main loadbearing structural system. In general, columns are structural members that transmit predominantly compressive loads. The column length and slenderness considerably influence the load capacity and trigger different failure mechanisms at different stress levels. Short columns mostly fail due to material failure when the imposed stresses exceed the material strength (i.e. concrete). Unlike short beams, long and slender columns can fail at lower stress levels due to buckling, as a result of sudden lateral deformation. This contribution focuses on the non-linear analysis of slender reinforced concrete (RC) columns. Several RC columns were cast for normal strength concrete and were axially loaded with various load eccentricities until failure. The analysis is carried out using the Lattice-Discrete Particle Model (LDPM). The model parameters are calibrated on material tests, as well as on data of column test of one size. The model validation is performed on column data of different configurations with a very good prediction quality. This validated model is used to investigate (a) the existence of a potential influence of casting direction and aggregate placement (initial imperfections, wall effect), (b) the time-dependent capacity of slender columns due to concrete aging, and (c) reductions in load capacity due to creep and shrinkage phenomena.

Active Poroelastic Imaging of Interfaces in Multiphasic Backgrounds

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1152

Dr. Fatemeh Pourahmadian (University of Colorado Boulder), Mr. Rezgar Shakeri (University of Colorado Boulder)

Motivation. Traditionally, seismic waves are deployed for subsurface characterization thanks to their interaction with buried heterogeneities and discontinuities. Existing seismic imaging solutions, however, rely mostly upon significant assumptions on the nature of wave motion in the subsurface where *multiphasic aspects are typically ignored* and data interpretation is based on propagation modes affiliated with an isotropic elastic solid.

Objective. In this talk, a holistic waveform tomography platform is developed that makes use of poroelastic sensory data – consisting of not only seismic wave measurements but also pore pressure data, for active 3D reconstruction of interfaces and fractures in multiphasic subterranean domains in unconventional reservoirs.

Methodology. The objective is accomplished through the recently developed paradigm of the Generalized Linear Sampling Method (GLSM) applied to poro-elastodynamics. The direct scattering problem is formulated in the frequency domain where the fracture surface is illuminated by a set of surface excitation and point sources in a poroelastic background governed by the coupled Biot's equations. Thus-induced scattered wavefield is captured in terms of pore pressure and seismic wave field over a designated observation surface and will be used to formulated the GLSM cost-functional whose minimizer can be computed without iterations. Such minimizing solutions are then used to construct a robust fracture/interface indicator function, whose performance is illustrated through a set of 2D and 3D numerical experiments.

An Optical Measurement Method for Gravity Water Wave Profiles

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1211

Dr. Kazuhide Dan (National Institute of Technology, Akashi College)

Background of this research

The purpose of this study is to show an optical method to measure gravity wave profiles which are longer than the capillary waves in experiment.

Methodology

When sunlight waves travel into the interface between water and air a part of the sunlight waves refracts at this interface and the fringe pattern in brightness can be observed on the sandy bottom in coast. These fringe patterns related to wave profiles are recorded at the observation board below the acrylic or transparent glass test channel using an artificial light experimentally inside a laboratory. It is possible to calculate the wave profile by applying the light energy balance and the refraction rule, Suzuki-Sumino method to this fringe pattern. It is useful to collaborate an optical method using a plano-convex lens and a calibration method using a capacitance-type wave meter. As the spherical waves illuminated from a single point light source are changed to parallel waves after passing through this lens.

Results and discussion (Numerical simulation and experimental approach)

In order to investigate the results of the Fourier and Inverse Fourier transformations the fringe patterns expressed as a sinusoidal function are supposed. The experiments are also performed. Furthermore it is introduced the correction technique to select the same value at the two ends of calculation range in applying the Fourier transformation, spatial-frequency-process and the Inverse Fourier transformation.

Conclusions

This method is capable to measure the gravity water wave profiles accurately by calibrating the obtained data by the capacitance-type wave meter.

Stress Relaxation Due to Phase Change of Gas Hydrates in Pores

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 6

Dr. Shun Uchida (Rensselaer Polytechnic Institute)

Gas hydrate-bearing sediments are known to exhibit stiffer, stronger and more dilatant behavior than the host sediments. This is because the solid-phase gas hydrate happening in soil pores effectively densifies the host sediments, leading to the increase in the interlocking. Upon hydrate dissociation, the solid-phase gas hydrate turned into gas and water and, in terms of geomechanics, two key features occur. One is that the aforementioned mechanical characteristics of gas hydrate-bearing sediments diminish and converge to the those of the host sediments. The other is that the effective stresses carried by the solid hydrates are released, resulting in stress relaxation under constant strain. Neglecting the stress relaxation term could therefore lead to an inaccurate deformation prediction. This study demonstrates the importance of stress-relaxation term for subsidence through simulation of a cased well heating.

A Coupled Thermo–Hydro–Chemo-Mechanical (THCM) Model for Methane Hydrate Bearing Sediments Using COMSOL Multiphysics*

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 84

Dr. Xiang Sun (University of California, Berkeley), Prof. Kenichi Soga (University of California, Berkeley)

Methane gas extraction from deep wells installed in the hydrate formations in the deep water and permafrost regions is a coupled thermo-hydro-chemo-mechanical (THCM) process. Many simulators have been developed to optimize the hydrate production in recent years. To quantify geotechnical and production risks, a nonlinear THCM model is implemented in the Partial Differential Equation (PDE) and Structural Mechanics modules of the COMSOL Multiphysics® finite element program. This paper describes the implementation method of a nonlinear fully coupled THCM governing equations particularly, with a thermodynamic-based constitutive model, then simulates the multiphysical responses of hydrate-bearing sediment during gas production. The performance of the code was tested by comparing the calculation results with the test data and other simulation results. Many key findings from the production trials and lab tests were modeled using this code.

Triaxial Tests and Constitutive Model for Gas Hydrate-Bearing Clayey Sand

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 333

Dr. Jiazuo Zhou (Institute of Rock and Soil Mechanics, Chinese Academy of Sciences), Mr. Zhoujie Yang (Guilin university of technology), Mr. Lixin Li (Guilin university of technology), Prof. Changfu Wei (Institute of Rock and Soil Mechanics, Chinese Academy of Sciences)

A new multi-functional triaxial testing system for hydrate bearing sediment is developed. The confining pressure is designed to change automatically with the gas pressure so that the net confining pressure is unchanged when the gas is consumed during the hydrate formation. CO_2 was used to form hydrate in artificial clayey sand, in which the particle size distribution is similar to the sediment in Shenhu area, northern South China Sea. The hydrate bearing samples are consolidated isotropically under the net confining pressure of 1, 2 and 4 MPa, and then triaxial tests are conducted. The result of isotropic consolidation shows that the swelling index is independent of hydrate saturation while the yield pressure is significantly influenced by hydrate saturation. The strength are obtained from the triaxial tests, showing that the internal friction angle is independent of hydrate content while the cohesion increases as hydrate saturation increase. Volume contraction and dilatancy, strain hardening and softening occur in the tests and the mechanism is analyzed. The unified hardening (UH) model, a critical state constitutive model, is extended to the hydrate bearing sediment. The modeled results agree well with the experimental results, showing that the extended model captures the main mechanical behaviors of hydrate bearing sediment, such as volume contraction, dilatancy, strain hardening and strain softening.

Permeability Anisotropy in Hydrate-Bearing Sediments

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1199

Prof. Sheng Dai (Georgia Institute of Technology)

Gas and water permeability through hydrate-bearing sediments essentially governs the economic feasibility of gas production from gas hydrate deposits. Characterizing a reservoir's permeability can be difficult because even col-located permeability measurements can vary by 4–5 orders of magnitude, due partly to differences between how various testing methods inherently measure permeability in different directions and at different scales. This study reports the development of a flow anisotropy cell to investigate the permeability anisotropy (i.e., horizontal, k_h, to vertical, k_v, permeability ratio) in hydrate-bearing sediments. Two cores recovered during India's National Gas Hydrate Program Expedition 02 (NGHP-02) are tested, and their permeability anisotropy at in-situ effective vertical stress of □2 MPa is approximately $k_h/k_v = 1.86$ for the "seal core" (from a fine-grained non-reservoir overburden sedimentary section) and $k_h/k_v = 4.24$ for the gas hydrate reservoir core with tetrahydrofuran hydrate saturation $S_h = 0.8$. Permeability anisotropy increases exponentially with vertical effective stress in an oedometer condition. The results imply the measured permeability from permeameter tests with vertical flow may underestimate the reservoir's flow performance, which is mainly horizontal (radial) toward a vertical well.

Numerical Investigation of the Non-Synoptic Wind-Induced Effects on Full-Scale Long-Span Bridges

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 480

Dr. Jianming Hao (Chang'an University), Dr. Teng Wu (University at Buffalo)

The non-synoptic wind events such as downbursts present violent impacts on the long-span bridges located in the thunderstorm-prone areas. To investigate the full-scale, non-synoptic wind-induced long-span bridge response, an efficient three-dimensional (3D) fluid-structural interaction (FSI) simulation approach is utilized in this study. To this end, the bridge motions are solved by 3D computational structural dynamics (CSD), and the downburst wind field, in which the entire structure is immersed, is generated using the finite volume method-based computational fluid dynamics (CFD) and discretized into a series of two-dimensional (2D) slices. The 2D CFD slices are dynamically coupled through the motion of the 3D structure. Compared to the available semi-empirical engineering models for wind field, the CFD-based scheme could capture the downburst unsteady features associated with massive flow separations and reattachments. Compared to the fully-coupled 3D FSI simulation, the 2D CFD-3D CSD analysis framework greatly reduces the computational cost while remains a high accuracy. The developed 2-D CFD-3D CSD FSI analysis framework offers a usable, reliable methodology, which can simultaneously incorporate the oncoming-wind nonstationarity, aerodynamic and aeroelastic nonlinearity, and structural nonlinearity in the simulation of extreme wind effects on flexible structures at relatively high Reynolds numbers.

Effect of Roof Geometry of a Low-rise Building on Tornado-induced Loads

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 576

Dr. Alireza Razavi (Dunwoody College of Technology), Prof. Partha P. Sarkar (Iowa State University)

Vulnerability of low-rise buildings to partial or complete structural failure in extreme-wind events provides motivation to researchers to investigate and continue to refine their knowledge of wind-induced loads on these buildings in such events. One of the extreme-wind events is tornado that has a high probability of occurrence in the mid-west and eastern parts of the United States. It is observed that low-rise building is the most commonly damaged structure in tornadoes, and roof failure is the most common type of damage. In this paper, effect of roof geometry of a low-rise building on tornado-induced wind loads is investigated to help improve the wind resistance of these buildings. Three different roof types, gable, hip and flat, on a one-story building with a rectangular plan (aspect ratio of 2) and a roof pitch of 35^0 for gable and hip roofs were selected and their scaled models were tested in a simulated translating tornado-like vortex using the Iowa State University's tornado simulator. The scaled building models were also tested to see the influence of their relative locations with respect to the tornado's path on the wind loads by placing them at different locations relative to the centerline of the tornado's path of translation. The dynamic loads transferred to the typical building frames for each roof case were analyzed by calculating the shear, axial load and bending moment at their joints for comparison. Finally, the most vulnerable building frame and roof geometry for a low-rise building subject to tornado-like wind were identified.

A Physics-Based Approach for Quantifying Structural Uncertainties of Turbulent Scalar Flux Models

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 689

Mr. Zengrong Hao (Stanford), Prof. Catherine Gorle (Stanford University)

Scalar turbulence modeling in Reynolds-averaged-Navier-Stokes (RANS) simulations is relevant to a variety of problems in environmental engineering, from heat transfer in cooling systems of buildings to urban pollutant dispersion. However, most practical models for scalar fluxes are known to fail in complex flows, and thus methods for quantifying model uncertainties are necessary. This paper proposes a physics-based uncertainty quantification approach for scalar flux models to provide interval predictions of scalar-relevant quantities of interest. The starting point for the approach is that the model for the pressure scrambling term in the scalar flux transport equation introduces considerable uncertainty. Generally, two hypotheses, 'return to isotropy' (RI) and 'isotropization of production' (IP), are used to define the orientation of the rapid and slow components of this term. We assume that the resulting orientation tends to be in the region bounded by RI and IP. Analysis of a simple shear flow with a transversal scalar gradient shows that perturbing the direction of the pressure scrambling term towards the RI (or IP) limit results in a monotonic decrease (or increase) of the transversal component of scalar flux, which indicates that this approach could provide interval predictions for scalar-relevant quantities of interest. Application to RANS simulations of forced heat convection in a pin-fin array heat exchanger confirm promising capabilities to bound both the overall and local heat transfer rates.

A New Computational Model for Turbulence Modelling with Wall Function

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 17

Prof. Andy Chan (University of Nottingham Malaysia), Dr. Kian Chuan Ong (National Taiwan University)

Turbulent flows are substantially affected by the presence of walls through the no-slip boundary condition as well as in other non-trivial factors. Very near to the wall, the tangential velocity fluctuations are moderated by viscous damping, while normal fluctuations are reduced by kinematic blocking. On the other hand, the production of turbulence kinetic energy rapidly generates turbulence due to the high-velocity gradients. The fidelity of numerical solutions is dependent on near wall modelling strategies. Thus, the accurate calculation of the turbulent flow in the near-wall region ensures high-fidelity predictions of wall-bounded turbulent flows. For a wall-bounded flow, a significant number of computational cells are clustered to the wall to resolve the boundary layers. Reynolds-averaged Navier-Stokes (RANS) turbulence models often require the first cell adjacent to the wall to be placed in the viscous sublayer. As a result, numerical stability is constrained by the smallest cell size and hence requires high computational overhead. For RANS turbulence modelling, wall function is proposed to alleviate the stringent requirement. The first cell can be placed in the inertial sublayer, and the number of cells in a mesh can be reduced accordingly. With a wall function, the overall computational efficiency and convergence-rate can be improved.

Coupled CFD-Dem Investigations of Internal Erosion Considering the Role of Confining Pressure

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 904

Mr. Yajing Liu (Zhejiang University), Prof. Lizhong Wang (Zhejiang University), Prof. Yi Hong (Zhejiang University), Prof. Jidong Zhao (Hong Kong University of Science and Technology)

Internal erosion is one of the most common failure modes of embankment dams or foundations. Soils within embankment dams or foundations are usually under different confining pressure, which has a significant effect on the critical hydraulic gradient and the evolution of internal erosion. In the present study, the coupled discrete element method (DEM) and computational fluid dynamics (CFD) simulations are used here to examine the influences of confining pressure (p'), fines content (F_c) and hydraulic gradient (i) on the internal erosion of gap graded sand samples. The simulated results, including the eroded particles mass and samples deformation, are presented and investigated from a micromechanical point of view. It is found that when the fines overfill the voids between coarse particles and play an important role in load-bearing skeleton, the erosion of fines under high hydraulic gradient will result in the collapse of original force transmission structure. During this process, the release of higher strain energy within strong networks due to force chain buckling under higher confining pressure accelerates the particles movement and finally intensifies the internal erosion. While for the case that the fines underfill the voids between coarse particles or the hydraulic gradient is relatively low, the erosion of fines has a negligible effect on the stability of original force transmission structure. Under these conditions, the higher confining pressure is an obstacle to the occurrence of internal erosion due to the stronger interparticle contact bonds.

Unsteady Flow of a Cement Slurry

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1258

Dr. Chengcheng Tao (National Energy Technology Laboratory)

Unsteady flow of a cement slurry

Chengcheng Tao, Eilis Rosenbaum, Barbara Kutchko and Mehrdad Massoudi[1]

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In this presentation, we consider the unsteady flow of a cement slurry inside a vertical wellbore. We assume that cement behaves as a non-linear fluid, where the constitutive relation is based on a generalized form of the second grade fluid, where the shear viscosity depends on the volume fraction of cement particles. We also use a convection-diffusion equation to model the flux vector for the concentration of the cement particles. The time dependent partial differential equations and the boundary conditions are made dimensionless and solved numerically with PDE solver in MATLAB. A parametric study is performed to present the effects of the various dimensionless numbers.

On the Implementation and Application of a Critical State Particle Mechanics Enhanced Drucker-Prager/Cap Model for Biomass Flow

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 203

Dr. Wencheng Jin (Idaho National Laboratory), Dr. Hai Huang (Idaho National Laboratory), Dr. Tyler Westover (Idaho National Laboratory), Dr. Jordan Klinger (Idaho National Laboratory)

Particulate biomass handling problems have been identified as a major contributor to the low production of renewable energy in the US, which achieved only 5% of nameplate capacity in 2017. In this study, we address the challenging issue of plugging, jamming and rat-holing in hopper flow commonly encountered during operation for forest pine residuals. Fundamentally, this issue is caused by over simplifying the mechanical behavior of biomass particles, which exhibit confinement pressure and density-dependent elasticity, plastic hardening/softening behaviors at the bulk level. To account for these phenomena, we enhance the Drucker-Prager/Cap model: (1) by changing modulus linearly dependent on confining pressure; (2) by modifying the hardening/softening law of yield/cap surfaces based on critical state particle mechanics; and (3) by proposing a cut-off plastic potential to limit over dilation at low confining pressure. We calibrate the model against the Schulze ring shear test, the customized large Peschl shear test, and the cyclic consolidation tests with increasing consolidation pressure. After the proposed model is implemented into Abaqus subroutine using return mapping algorithm, we perform Arbitrary-Lagrangian-Eulerian FEM analysis of a modified Johanson shear test to validate the model. Simulation results of the global reaction force – displacement curve is further compared against physical test data to investigate the influence of history consolidation. In addition, we verify the predicted shear band by comparing with experiment results obtained from X-ray. Lastly, we perform sensitivity analysis of a hopper flow with proposed model to optimize hopper design.

Influence of Interparticle Friction on Yielding and Stiffness Degradation

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1297

Mr. Hoang Nguyen (Imperial College London)

The nature of yielding and stiffness degradation of granular is complexand depends upon many factors. Discrete element modelling (DEM) oftrue-triaxial tests were performed to assess the dependency of yield loci andstiffness curve on interparticle friction. The samples considered comprised ofnormally consolidated random monodisperse samples for isolation of inertiaeffects on dynamic response. The simulations were carried out at threedifferent mean stress levels; at each stress, level samples were sheared alongthe stress path where lateral stresses are maintained and only vertical stresscomponents were increased. DEM data obtained confirmed that the extent to whichshear stiffness degrades with the shear strain largely depends on interparticlefriction values and that macro-yielding points are likely to be dragged withincreasing the interparticle friction. In conjunction with triaxial compressiontests, a series of triaxial extension tests were conducted to provide data foran investigation into discrepancies of stiffness curve and yielding pointsbetween two types of conventional triaxial tests. Data obtained reveal that thegap between the stiffness curve tends to expand with reducing the interparticlefriction.

Modelling the Anisotropic Mechanical Behavior of Lower Cromer Till by a Modified Bounding Surface Plasticity Model

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 432

Dr. Jianjun Ma (Sun Yat-sen University), Prof. Linchong Huang (Sun Yat-sen University), Dr. Yu Liang (Sun Yat-sen University)

Modelling the anisotropic mechanical behavior of Lower Cromer Till by a modified bounding surface plasticity model

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ABSTRACT: For the mechanical modelling of the anisotropic characteristics induced by triaxial loading, a modified bounding surface plasticity model is presented. This anisotropic model, based on a macroscopic approach, takes the inclination of yield surface into account, so as to describe the evolution of yield surface drift. The plastic hardening equation has been expressed as a function of both plastic volumetric strain, shape hardening and stress state, with yield surface distortion being accounted while formulating the anisotropy evolution criteria. Model validation has been demonstrated through comparing simulation results with experimental tests on Lower Cromer Till reported in the literature. Good agreement has been achieved for all cases considered.

On Stress-State Dependency of Small-Strain Shear Modulus (Gmax) in Sands

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 788

Mr. Debayan Bhattacharya (Indian Institute of Technology Gandhinagar), Prof. Amit Prashant (Indian Institute of Technology Gandhinagar)

Shear stiffness is a critical parameter in predicting deformations in quasi-static and dynamic loading. Further, the G value used in elastoplastic models is not the same as G_{max}, rather it is an average stiffness over a strain/stress range involving fractional plastic deformations in some sense. These stiffness values also depend on initial void ratio, effective confining pressure, stress history etc. Connection between G of elasto-plastic model and G_{max} is yet to be fully understood, which is required to appropriately model experimentally observed hysteresis during unloading-reloading in oedometer test. While this bigger research question is being explored, the behaviour of G_{max} has been first studied experimentally for its stress-state dependency. Unlike previous investigations on dry sand specimens and drained-triaxial shearing, G_{max} here is estimated along undrained stress pathsusing bender elements. Effect of stress state on G_{max} for isotropically and anisotropically consolidated sand specimens is explored during undrained shearing by matching the initial mean-effective pressure. Estimated G_{max} values considering wave dispersion effects in a fully saturated sand is found to exhibit stress path dependency and it is a function of both mean-effective stress (I_1) and deviatoric stress (J_2). Undrained shearing stress paths has been chosen deliberately so as to decouple the effects of void ratio and stress state on G_{max} values during the carefully performed triaxial tests. The experimental findings are in good agreement with those predicted from a nonlinear isotropic model which is in accordance with the conservation of energy principle and is a function of both I_1 and J_2.

Phase Field Modeling of Shale Fracture Properties from Scratch Test

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 166

Mr. Atul Vaibhav (Texas A&M University), Dr. Sara Abedi (Texas A&M University), Dr. Arash Noshadravan (Texas A&M University)

Scratch Test is one of the oldest concepts for characterizing mechanical properties of a material. The inference of the relationship between scratch force and material property is still a contemporary topic in applied mechanics. Despite the seeming simplicity of the procedure, a fundamental understanding of the underlying mechanism remains indistinct. The complexity lies with the prediction of mechanism that drives the scratch resistance, i.e. the chipping of material. The objective of this research is to revisit the characterization of fracture properties of shale materials from scratch test measurements. This problem of considering scratching as a fracture process has been approached through experiments and theories but there is a gap when it comes to associate the experimental results with a computational approach which is analogous to the actual mechanism. We propose that this phenomenon can be described in a diffuse sense with a phase field approach utilizing a prescribed length scale parameter which takes the chipping off length into account. Through the analysis of several numerical examples reinforced with the experimental data we validate a computational model which can be used to predict the essential failure mechanism.

Planet Rover Wheels Loading Test Development

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 308

Prof. Jiliang Li (Purdue University Northwest), Dr. Jinyuan Zhai (Purdue University Northwest)

Any successful planet exploration such as Moon or Mars exploration is essentially geotechnical exploration which is important for any construction and building structures on either the Mars or Moon. One of the immediate and critical task is efficiently and properly characterizing the moon or Martian surface materials properties such as the Mars surface regolith elastic and plastic strength parameters under rover's own wheels' loading pressure.
Drilling below Mars surface and seismic wave reconnaissance could provide further more insightful information of Mars structures. Martian surface deformation profiles under Rover's wheels own loading pressure could conveniently provide invaluable information. The camera and video images taken are invaluable but not enough. Equally important and invaluable are the recorded analysis of the Mars surface profiling before being run over by the rover and after the rover run across the land. Deformation profile recorded and collected could provide some fast and appropriate estimation of the Mars soil strength parameters based on a strip loading test method developed. Measurement and recording the Martian surface materials deformation profiles under the rover's wheels own loading pressure is important. Though they are only surface materials, properly study and documenting different area's surface regolith strength parameters will be critical for future mankind's construction and building of survival and living structures on Mars.

Understanding Slipping of Wheels in Granular Media Locomotion and Rate Sensitive RFT

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 334

Mr. Shashank Agarwal (MIT), Mr. Andras Karsai (Georgia Institute of Technology), Dr. Daniel Goldman (Georgia Institute of Technology), Prof. Ken Kamrin (MIT)

Slipping of circular wheels at high rotation rates on granular media like sand is a commonly experienced phenomenon. At the same time, granular materials themselves are known to be rate-insensitive for a fairly large range of strain rates. Recent developments in the Resistive Force Theory (RFT) for granular intrusion have resulted in an empirical methodology that gives quick predictions of various dynamic parameters related to the motion of locomotors in granular media. While the RFT methodology has been proven to be promising in the quasi-steady scenarios, it fails to model high-velocity motion like capturing the slipping of wheels at high rotations rates. Hence, identifying the fundamental phenomena responsible for the slipping of wheels at high-rotational rates and the reason for the failure of static-RFT in capturing the phenomenon remains an unsolved question. Thus, a combination of conventional control volume approach along with a plasticity-based continuum modeling verified against experimental findings for a Grousered wheel locomotion are performed for a wide range of rotation rates. A momentum conservation-based argument is found to explain the fundamental reason behind slipping of wheels. Based on three analysis approaches, a rate dependent correction in existing static-RFT is also proposed which makes RFT capable of modeling high-speed granular motion. Verification of this form against the high-speed grousered wheel locomotion experiments is also done.

Billion Body Granular Dynamics Simulation on Commodity Hardware

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Oral - Abstract ID: 1079

Mr. Conlain Kelly (University of Wisconsin – Madison), Mr. Nicholas Olsen (University of Wisconsin – Madison), Prof. Dan Negrut (University of Wisconsin – Madison)

Many materials appear in nature in granular form as large collections of 3D geometries. These systems remain difficult to model and simulate due to their complex frictional contact interactions and large particle counts. To the best of our knowledge, the largest granular dynamics simulation of practical relevance to date contained 2.4 billion bodies. It was run on 16,384 CPUs (131,072 cores) of Japan's K-computer, the 2012 fastest supercomputer in the world and now the 18th in the ranking of the world's supercomputers. This presentation describes an ongoing effort to provide an affordable and efficient alternative for simulating granular dynamics that leverages the computing power of Graphics Processing Units (GPUs), which are relatively cheap and have remarkable memory bandwidth and compute performance.

In this study, we outline the implementation for a granular dynamics solver designed for the GPU. In particular, we discuss how to efficiently map a penalty-based DEM solver for monodisperse spheres onto the GPU architecture and the assumptions and constraints required to do so. This code, called Chrono::Granular, is being developed as a standalone library that can interface with other dynamics libraries via mesh-based co-simulation. A scaling analysis of the code is presented which demonstrates linear scaling for multi-billion degree of freedom problems. We discuss implications and applications for the solver and potential improvements. Finally, we employ Chrono::Granular in a study of hourglass/hopper discharge rates and their sensitivity to material parameters such as particle size, cohesion, and friction.

Reconstituting Granular Test Beds by Fluidization

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1307

Ms. Zhefei Jin (Northwestern University), Prof. Paul Umbanhowar (Northwestern University), Prof. James Hambleton (Northwestern University)

Research examining how machines and animals interact with soils has been performed using a wide variety of laboratory tests. To perform these tests in granular materials, efficiently and repeatably reconstituting the bed to a controlled density is essential. Conventionally, the reconstitution is realized by tamping, vibration, or pluviation despite the drawbacks of potential particle crushing, the narrow range of achievable densities, and low efficiency, respectively. To overcome these limitations, Goldman and co-workers used air-fluidization to prepare dry granular beds, typically composed of ~1 mm poppy seeds. In this study, we apply and assess this method for reconstituting sand beds. First, the structure and design of the device are illustrated. Next, we explore three protocols to achieve a desired density: defluidization only, defluidization followed by vibration, and defluidization concurrent with vibration. By quantifying the post-fluidization density of the bed as a whole and locally, we find that the volume-based relative densities range from 10.4% to 91.7%. Local sand density, measured with a cone penetrometer, is nearly uniform across the bed as demonstrated by coefficients of variation under 13% for the relative density in all cases except for some beds prepared by defluidization only. The variation of local density and penetration resistance measured across the bed is comparable to results from the widely used pluviation method, suggesting that sand beds reconstituted using air-fluidization are suitable for laboratory tests of soil-machine interaction (SMI).

Interfacial Thermodynamic Properties and Size Effects in Nanoparticle-Based Reinforced Polymers

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 653

Dr. Fahmi Bedoui (Sorbonne Université, Université de Technologie de Compiègne, France), Dr. Andres Jaramillo-botero (California Institute of Technology (Caltech)), Prof. William A. Goddard III (California Institute of Technology (Caltech))

The effects of nano-particle size on the "*macroscopic*" mechanical response and the interfacial interaction in the case of model nano-reinforced polymers were investigated by means of molecular dynamics simulations. Different ensembles, based on homogeneous polymer matrices, amorphous silica particles of varying sizes and their binary mixtures were prepared. Binary mixtures were made with two silica nano-particle sizes, namely 3 and 4 nm, embedded in poly(methyl methacrylate) or PMMA polymeric matrix. For both particle sizes, the silica volume fraction was kept constant. At a macroscopic level the mechanical response of nano-composites was evaluated through tensile tests. Interfacial interaction between the NPs and the PMMA matrix was qualitatively evaluated through thermodynamic analysis of nano-composite systems on static and stretched conditions. Entropy (S), free-energy (G), and internal energy (E) were derived from relatively short molecular dynamics trajectories, using the two-phase thermodynamic method (2-PT). The effect of nano-particles size on the macroscopic response along with the interfacial interaction between nano-particle and the surrounding matrix will be discussed.

Magnetically-Tunable Metamaterials for Surface Acoustic Wave Manipulation

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 919

Dr. Antonio Palermo (Cali), Dr. Yifan Wang (California Institute of Technology), Dr. Paolo Celli (California Institute of Technology (Caltech)), Prof. Chiara Daraio (California Institute of Technology)

In this talk, we provide a tabletop-scale realization of a tunable metamaterial platform to control surface acoustic waves (SAWs). Our platform comprises an array of ferromagnetic beads in contact with thin permanent magnets, and positioned at the free surface of an elastic substrate. An additional set of “modulating” magnets, placed at a controlled and variable distance from the beads, can alter the bead-contact force via magnetic interactions and, in turn, can tune the contact stiffness and natural frequencies of the bead-resonators. First, we exploit the bead contact resonances to open large frequency bandgaps via SAW-resonance hybridization; we implement our tuning paradigm via a second array of permanent modulating magnets, and shift the bandgaps’ frequency ranges. The tuned dispersive properties of hybridized SAWs are predicted via numerical models and experimentally reconstructed via Laser Doppler Vibrometer measurements. Then, we discuss the use of electromagnets to modulate the contact stiffness in a time-varying fashion, with the goal of achieving non-reciprocal surface wave propagation.

A Machine Learning Based Framework for Accelerated Design in Architected Materials

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 930

Mr. Chunping Ma (Department of Civil, Environmental and Geodetic Engineering, The Ohio State University), Mr. Zhiwei Zhang (School of Civil Engineering, Harbin Institute of Technology), Mr. Benjamin Luce (Department of Civil, Environmental and Geodetic Engineering, The Ohio State University), Mr. Burak Gul (Department of Civil, Environmental and Geodetic Engineering, The Ohio State University), Dr. Mohammad Rafiei (Department of Mechanical Engineering, Johns Hopkins University), Dr. Nan Hu (Department of Civil, Environmental and Geodetic Engineering, The Ohio State University)

Architected materials are structured materials with high tunability of properties due to the geometry and the assembly of unit cells. Such a unique function has been showcased in a wide range of length scales. Most studies to date commonly started with a periodic pattern, yet the aperiodic patterns varied from a baseline pattern can bring infinite possibilities for achieving highly tailorability in failure mode. As the design domain of geometric pattern expands, it becomes impossible for the conventional intuition-based methodologies to attain feasible patterns of desired properties across the entire domain. Thus, the aim of this proof-of-concept study is to demonstrate a two-way machine learning based computational framework with the capability of accelerated material characterization or pattern generation. The proposed framework started with selecting a relatively small number of representative patterns based on the geometric constraints obtained from clustering results of parameters of interest in the response domain. The validity of the geometric constraints was also verified by uniaxial compression tests of 3D-printed specimens. Then the selected patterns and their responses were used as the training data for machine learning models. Depending on how the data were used, trained models can easily either predict the response of any given pattern within the design domain or provide feasible patterns for targeted response properties. The accuracy of the predictions was verified by simulations. Results showed that our framework can boost the design efficiency of architected materials at unit cell level, and open new avenues for the programmability of function at system level.

Negative Stiffness Inclusions as a Platform for Real-Time Tunable Phononic Metamaterials

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1251

Dr. Ladan Salari Sharif (University of California, Irvine), Dr. Babak Haghpanah (University of California, Irvine), Ms. Anna Guell Izard (University of California, Irvine), Dr. Mazdak Tootkaboni (University of Massachusetts Dartmouth), Prof. Lorenzo Valdevit (University of California, Irvine)

We propose an approach for real-time manipulation of low-frequency phononic band gaps in a metamaterial without affecting the material geometry, microarchitecture, or the crystal structure of the base material. Metamaterials with tunable band gaps are realized by introducing periodically arranged negative stiffness inclusions, the modulus of which can be varied in time in order to modify the metamaterial macroscopic stiffness in certain directions, without bringing the material to the point of elastic instability or inducing extreme geometric change. The evolution of band gaps is investigated numerically, and the proposed concept is verified experimentally in a lattice prototype with magnetic elements functioning as negative stiffness units. Design guidelines for achieving real-time tunable phononic band gap are also presented.

Evaluation of Powder Rheology for SLS and SLM Technology

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 482

Prof. Yuanqiang Tan (Huaqiao University), Mr. Xiang Li (Huaqiao University), Mr. Jiangtao Zhang (Huaqiao University)

Powders are typical feeding materials for Selective Laser Sintering/melting (SLS/SLM). Powders of ceramics, polymers and metals are widely used in above Additive Manufacturing process. At present, due to the lack of understanding the powder rheology, particle sophericity and distribution of particle radium were used to qualify the powder. That results in few kinds of commercial expensive powders are permitted for SLS/SLM. In this study, 6 kinds of powders, including 316L, Nylon 6A, Nylon 6B, coated sand, gypsum and marble, were employed to take rheology test. The physical properties and flow characteristics of 6 kinds of powders were measured and characterized, and the model of material attribute library was established. The similarity between 6 powder materials was established by using the result of principal component analysis (PCA). PCA results clarify above 6 kinds of powder very well. The results show that powder rheology may be a useful method to evaluate the powder materials suitable for SLS/SLM.

Viscoelastic Behavior of SBR Modified Calcium Silicate Hydrate (C-S-H)

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 273

Mr. Jeremy Starr (University of New Mexico), Dr. Eslam Soliman (Assiut University/University of New Mexico), Dr. Mahmoud Reda Taha (University of New Mexico)

This work aims to investigate the effect of incorporating Styrene Butadiene Rubber (SBR) latex on the viscoelastic behavior of synthetic calcium silicate hydrate (C-S-H). Synthetic C-S-H incorporating SBR tends to improved mechanical properties such as ultimate flexural strength, strain at failure, permeability and toughness. On the other hand, the addition of SBR latex during C-S-H synthesis might adversely result in increased viscoelasticity of the polymer modified C-S-H. Synthetic C-S-H/SBR composites were produced by mixing calcinated calcium carbonate (CaCO3) with silica fume (SiO2), deionized water, and styrene-butadiene rubber (SBR) latex. The slurry was mixed and vacuumed to extract the excess water before drying it to 11% relative humidity. The resulting C-S-H/SBR powdered composites were compacted at high pressure to obtain a density range similar to that observed in cement hydration products prior to testing. To characterize the viscoelastic behaviour of SBR modified C-S-H, creep tests were carried out on synthetic C-S-H/SBR composites with various SBR contents using dynamic mechanical analysis (DMA). Creep compliance for various C-S-H/SBR compositions are determined and compared. Furthermore, analytical models were employed to provide further understanding for the effect of incorporating SBR latex on the viscoelastic behavior of C-S-H. Experimental observations and analytical modeling are integrated to explain the mechanism by which SBR alter the viscoelastic behaviour of the synthetic C-S-H composite.

Keywords: C-S-H, SBR, Creep, DMA, Viscoelastic Properties

Integration of Digital Data for Asphalt Mix Design

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 821

Prof. Linbing Wang (Virginia Tech)

The mix design of asphalt concrete is a critical step towards high-quality pavements. Historically, mix designs have been developed using experimental procedures and empirical experiences. The mix designs are typically owned by different researchers, companies and stakeholders and are not shared widely. This presentation will focus on developing methods using artificial intelligences to collect and analyze the published data of mix designs and performances for improving mix designs.

Mitigating Site Effects Amplification Using Seismic Metamaterials

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 520

Dr. Antonio Palermo (California Institute of Technology), Prof. Chiara Daraio (California Institute of Technology), Prof. Domniki Asimaki (California Institute of Technology)

The study of the effects of local site conditions, namely site effects, on the propagation of seismic waves is of crucial importance for the correct design of earthquake isolation systems. Available studies on seismic metamaterials, i.e., underground resonant barriers and/or foundations designed to mitigate the propagation of seismic waves, have not yet considered these effects, leaving open questions about the feasibility, practical implementation and range of applicability of these isolation devices.

In this talk, we discuss the isolation performance of seismic metamaterials accounting for local site conditions, i.e. complex soil profiles, and realistic earthquake ground motions. We perform 1D site response analysis and evaluate the amplification of the ground motion at the soil surface for a representative seismic motion at the bedrock, soil profile, and seismic barrier design. In detail, we consider a set of synthetic soil profiles generated using a sediment velocity model (SVM) conditioned on VS_{30} and model the presence of the resonant barrier using an equivalent resonant layer, with frequency dependent dynamic properties. We utilize random vibration theory and equivalent linear analysis to investigate a large parameter space of barrier configurations and soil profiles. We optimize the barrier for specific design constraints (overall barrier dimensions, mass, material damping) and provide realistic estimates of reduced response spectra at given sites.

Failure Probability Estimates for Low-Rise Steel Buildings Subject to Hurricane Hazard Under Changing Climate Conditions

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 19

Mr. Mirsardar Esmaeili (University of California, Davis), Prof. Michele Barbato (University of California, Davis)

Hurricanes cause every year significant economic and life losses in the US and worldwide. The annual hurricane-induced losses are rapidly increasing because both vulnerability and hazard are increasing. The hurricane hazard increase is mostly caused by climate change. A previous study by the authors developed a simulation model to predict the changes in wind speed probability distribution as a function of the increase in average sea surface temperature. This model used the scenarios proposed in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC) to project possible changes in wind speed distribution along the US Gulf Coast region. This work investigates the effects of climate change-induced hurricane hazard on the reliability of a benchmark steel portal frame designed according to ASCE 7-93 Standard and AISC 2001 specifications, for which failure wind speeds are available in the literature. Assuming Miami, FL, as the building site, and using the IPCC AR5 projection scenarios, the statistical characteristics of the wind hazard are developed using the simulation model for hurricane wind speed. The probability of failure of the benchmark portal frame is estimated via Monte Carlo simulation (MCS) for current wind speed conditions (i.e., compatible with ASCE 7-16 Standard) and with four different climate change scenarios relative to the year 2060. The building's annual failure probabilities for different 2060 projection scenarios are approximately 10 to 30 times higher than that for current wind conditions, suggesting that steel buildings designed according to current standards may be under-designed for future wind conditions.

A Vector-Valued Wind Intensity Measure for the Performance-Based Design of Tall Buildings

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 417

Mr. Haifeng Wang (University at Buffalo), Dr. Teng Wu (University at Buffalo)

The wind design of tall buildings is moving towards performance-based
methodology, where whether a specific building satisfies the performance requirements is statistically assessed. In the current performance-based wind engineering, the intensity measure, which quantifies the wind hazard level, is typically described by the maximum wind speed. The utilization of the scalar intensity measure implicitly assumes that other wind field characteristics (e.g., the vertical profile, spatial correlation, degree of nonstationarity, and storm duration) are identically determined by the maximum wind speed for various wind hazards. This simplification of the wind field characteristics may lead to inaccurate response estimation of tall buildings. In this study, a vector-valued intensity measure where the spatial and temporal characteristics of the wind hazard for a specific site are taken into account, is proposed to improve the performance estimation. A comparison between structural response estimations of a tall building under the conventional scalar intensity measure and the proposed vector intensity measure is conducted. The proposed vector-valued intensity measure is systematically investigated in terms of simulation efficiency and accuracy in the performance-based wind engineering.

Experimentally-Defined Hurricane Loads and Structural Morphogenesis of Green/Grey Structures

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1027

Mr. Mohammad Ghiasian (University of Miami), Ms. Jane Carrick (University of Miami), Dr. Diego Lirman (University of Miami), Dr. Andrew Baker (University of Miami), Mr. Steven Nolan (Florida Department of Transportation), Dr. Brian Haus (University of Miami), Mr. Joel Amendolara (University of Miami), Ms. Julie Ruiz-merchan (Universidad del Norte), Mr. Marco Rossini (University of Miami), Dr. Antonio Nanni (University of Miami), Dr. Nizar Bel Hadj Ali (University of Gabès, Ecole Nationale d'Ingénieurs de Gabès), Dr. Landolf Rhode-Barbarigos (University of Miami)

As the recent impacts of hurricanes revealed, extreme winds and flooding can always be devastating for coastal communities. Considering that average annual temperatures and sea level will continue to rise, the frequency of occurrence of such disasters may not cease to increase. Therefore, research on wind and wave action, as well as on efficient and sustainable shoreline protection systems is critical. Wind and wave actions are common loads in the design of coastal structures, yet they are often described by independent load models with their combination dictated by combination factors. However, there is a clear interaction between wind and waves during hurricanes and storms in general. Therefore, in this study, the combined wind/wave load on coastal structures is experimentally defined through physical testing at the SUrge STructure Atmosphere INteraction (SUSTAIN) Facility at the University of Miami. SUSTAIN can generate directionally varying waves using a 12-paddle system combined with direct wind forces simulating hurricane conditions up to Category 5 hurricane on the Saffir-Simpson scale. A better understanding of the loads can lead to more efficient and sustainable protective structures. However, in the absence of design guidelines for protective structures at the intersection between engineering and ecology, the structural morphogenesis (form finding as well as the relations between form, forces, material and living organisms) for the paradigms of a seawall and an artificial coral reef are also investigated experimentally aiming towards the development of a whole new realm of shoreline protection structures with increased efficiency and enhanced biocompatibility features.

Improved Probabilistic Seismic Performance Assessment Framework for Ordinary Standard Bridges

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1420

Mr. Angshuman Deb (UC San Diego), Dr. Alex Zha (UC San Diego), Dr. Zachary Caamaño-Withall (UC), Prof. Joel Conte (UC San Diego), Prof. Jose Restrepo (UC San Diego)

With the recent advent of performance-based earthquake engineering (PBEE) in seismic design practice of buildings serving as impetus for this work, initial steps towards a fully probabilistic performance-based seismic design (PBSD) method for bridges, a less trodden area in terms of PBEE applications, are taken herein by assembling an improved probabilistic seismic performance assessment framework for Ordinary Standard Bridges (OSBs) in California. This framework is rooted on the PEER PBEE assessment methodology. Improvements from the state-of-the-art literature on the PEER PBEE methodology are incorporated, including: (1) introduction of an improved intensity measure, i.e., average spectral acceleration over a period range, (2) conditional mean spectrum-based hazard-consistent and site-specific ground motion selection, (3) introduction of material strainbased engineering demand parameters, (4) use of practical damage limit-states pertinent to seismic damage evaluation of bridges, and (5) development of strain-based normalized fragility functions for the considered limitstates. The improved framework is applied for the damage hazard assessment of four testbed OSBs. Assessments of parametrically redesigned versions of these OSBs are then conducted to investigate the effect of the primary structural design parameters on the performance measures, thus laying the groundwork for solving the PBSD problem, i.e., an inverse assessment problem. Finally, a comparative study is conducted between closed-form solutions to the risk of limit-state exceedance available in the literature and the numerical results obtained using the probabilistic performance assessment framework assembled here. This is done to assess the potential viability of LRFD-like design formats (based on such closed-form solutions) for the sought PBSD method.

Improved Probabilistic Seismic Performance Assessment Framework for Ordinary Standard Bridges

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1423

Mr. Angshuman Deb (UC San Diego), Dr. Alex Zha (UC San Diego), Dr. Zachary Caamaño-Withall (UC), Prof. Joel Conte (UC San Diego), Prof. Jose Restrepo (UC San Diego)

With the recent advent of performance-based earthquake engineering (PBEE) in seismic design practice of buildings serving as impetus for this work, initial steps towards a fully probabilistic performance-based seismic design (PBSD) method for bridges, a less trodden area in terms of PBEE applications, are taken herein by assembling an improved probabilistic seismic performance assessment framework for Ordinary Standard Bridges (OSBs) in California. This framework is rooted on the PEER PBEE assessment methodology. Improvements from the state-of-the-art literature on the PEER PBEE methodology are incorporated, including: (1) introduction of an improved intensity measure, i.e., average spectral acceleration over a period range, (2) conditional mean spectrum-based hazard-consistent and site-specific ground motion selection, (3) introduction of material strain-based engineering demand parameters, (4) use of practical damage limit-states pertinent to seismic damage evaluation of bridges, and (5) development of strain-based normalized fragility functions for the considered limit-states. The improved framework is applied for the damage hazard assessment of four testbed OSBs. Assessments of parametrically redesigned versions of these OSBs are then conducted to investigate the effect of the primary structural design parameters on the performance measures, thus laying the groundwork for solving the PBSD problem, i.e., an inverse assessment problem. Finally, a comparative study is conducted between closed-form solutions to the risk of limit-state exceedance available in the literature and the numerical results obtained using the probabilistic performance assessment framework assembled here. This is done to assess the potential viability of *LRFD*-like design formats (based on such closed-form solutions) for the sought PBSD method.

Horizontal Displacement Responses of Sloped Rolling-Type Seismic Isolators

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 239

Prof. Shiang-Jung Wang (National Taiwan University of Science and Technology), Dr. Chung-Han Yu (National Center for Research on Earthquake Engineering), Dr. Cho-yen Yang (National Center for Research on Earthquake Engineering), Dr. Wang-chuen Lin (National Center for Research on Earthquake Engineering), Prof. Jenn-shin Hwang (National Center for Research on Earthquake Engineering)

The sloped rolling-type isolation bearings feature the constant transmitted horizontal acceleration performance (or zero post-elastic stiffness) owing to the fixed-angle sloped rolling surface design. In engineering practice, the constant acceleration level can be simply designed and predicted by the equation of motion. Nevertheless, for the bearings that possess zero post-elastic stiffness, the equivalent lateral force procedure might not be adequate for predicting their maximum horizontal displacement responses under a given seismic demand. To address this problem, several parameters for bearing designs and seismic demands are numerically and statistically studied to discuss the effect on the displacement responses. Such parameters include the sloping angles and friction damping forces for bearing designs, as well as the corner periods and effective peak accelerations (EPA) for characterizing the seismic design response spectra. Therefore, considering a small number to many coefficients, several statistics-based empirical formulas which can approximate the maximum horizontal displacement responses are proposed. Not only the accuracy but the conservative property of the proposed empirical formulas is discussed by comparing their predictions with the nonlinear response history analysis results. To efficiently determine the horizontal displacement capacity of sloped rolling-type seismic isolators during the preliminary design stage, the statistics-based empirical formula considering a reasonable number of coefficients is recommended.

Shock Response Mitigation with an Inerter-Based Control Device

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 659

Mr. Abdollah Javidialesaadi (University of Tennessee), Prof. Nick Wierschem (University of Tennessee)

Various inerter-based vibration absorbers have been recently proposed and developed. These inerter-based vibration absorbers typically consist of spring, damper, and inerter elements in different combinations and configurations. The inerter, which is the key shared feature in these configurations, is a mechanical device which converts relative translational motion to rotation and is capable of producing large effective inertia mass with only a small amount of physical mass. Inerter-based vibration absorbers have shown effectiveness at reducing the dynamic response of structures and vehicles subjected to a range of different excitations; however, the use of these systems to mitigate shock-type loads with very short time-scales has not received much attention. This work investigates response mitigation with inerter-based vibration absorbers placed as part of the interface between a shock loading and the primary system. The optimum design and performance evaluation with different configurations of inerter-based vibration absorbers is performed. The results of this study demonstrate that significant shock response mitigation performance can be realized with inerter-based vibration absorbers.

Dynamic Coupling of Nonlinear Equipment Isolation Systems and the Supporting Structure

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 749

Mr. Mohammad Tehrani (University of Oklahoma), Prof. P. Scott Harvey (University of Oklahoma)

Passive floor-mounted isolation systems are used to mitigate seismic damage to sensitive building contents and equipment. Traditionally, the isolated object and the primary structure (PS) are analyzed independently. Dynamic coupling can be assumed negligible when: a) the mass ratio of the equipment to the PS is small and b) the isolator and PS frequencies are not close (detuned). This assumption is based on and limited to linear response regimes. Dynamic coupling may be non-negligible when nonlinearities are present. This study investigates the influence of dynamic coupling between the PS and the isolated object in the presence of a smooth nonlinearity (cubic hardening). A nonlinear reduced order model of the combined isolator-PS system is developed by coupling the nonlinear isolation system to a condensed model of the PS. Using harmonic balance, the steady-state responses of the coupled system (displacements of the PS and total accelerations of the isolated object) are obtained under harmonic base excitations. The effects of varying the strength of nonlinearity in the isolation system, the excitation intensity, and the mass and frequency ratios (isolator-to-PS) are assessed and compared with the equivalent uncoupled (linear) system. Results of this study shed light on understanding the valid range that the decoupled approach can be reliably applied. Moreover, it is shown that the isolation system can be tuned in such a way to mitigate seismic responses of the supporting PS under strong shaking in addition to protecting the isolated equipment at low to moderate shaking.

Test Results of Cyclic Testing on Ductile Precast End-Diaphragms of Slab-on-Girder Concrete Bridges

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1306

. Esteban Villalobos-Vega (University of Costa Rica)

The present work proposes the use in concrete bridges of ductile precast end-diaphragms made with the so-called hybrid system (unbonded post-tension in combination with mild steel reinforcement), that act as a fuse, or passive structural control, in the transverse direction by having a yield resistance less than the substructure resistance. The project includes the proposal of a simplified seismic analysis and the cyclic test of a full-size 0,6 m end bridge length in laboratory. This solution could be implemented in new bridges as a part of Accelerated Bridge Construction (ABC) solutions, or in the case where it is necessary to develop feasible solutions in order to seismically retrofit concrete bridges when they get old or damaged. The hysteretic results of the test showed an adequate energy dissipation performance; however, the envelopes obtained in both load directions evidenced a marked difference: the negative enveloped showed a more noticeable ductile behavior and close enough to the predicted monotonic curve. The maximum ductility value achieved was 2,80 taking into the account that the test was finished without achieving the failure of the specimen. The damage showed by the precast diaphragm beams was negligible, and the concrete deterioration was concentrated in the corners of the connections. Even if the bridge girders showed cracking both due to shear and flexure, the residual crack width was in average 0,10 mm. Despite the proposed system showed some issues that have to be revised, it has the potential to show an outstanding performance under lateral seismic load.

Fluid Mechanics and Transport of Contaminated Sediment during Hurricanes

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 649

Dr. James Kaihatu (Texas A&M University), Dr. Mikyoung Jun (Texas A&M University), Ms. Krisa Camargo (Texas A&M University), Dr. Anthony Knap (Geochemical and Environmental Research Group and Texas A&M University), Dr. Terry Wade (Geochemical and Environmental Research Group and Texas A&M University)

While the prediction of hurricane-induced surge has matured, modeling the resulting sediment motion during these events has not kept pace. The focus of these predictions has generally been on the water level since they can be more easily validated. However, sedimentation is relatively unstudied, and it is not necessarily clear how larger-scale velocities from many hydrodynamic adequately represent the small-scale near bottom velocities from both waves and hurricane-induced currents.

We will present investigations into the use of a coupled modeling system (Delft3D) to simulate hurricane induced surge over Galveston Bay in Texas during a hurricane event. Sediment transport during these events will be investigated both with the 1) larger scale Delft3D model; 2) a Delft3D implementation at higher resolution nested inside the larger scale Delft3D; and 3) a model capable of representing the phase-resolved waves and surge forced by Delft3D. Each of these implementations will be examined to determine how well the driving forces behind sediment transport are represented.

A Physically-Statistically-Based Hybrid Simulation Scheme of Coupled Nonstationary Wind and Wave Fields in Hurricanes for Offshore Floating Structures

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 488

Mr. Shaopeng Li (University at Buffalo), Dr. Teng Wu (University at Buffalo)

Offshore floating structures such as floating wind turbines and long-span bridges with floating towers have recently drawn great attention of the engineering community. Due to their sensitivity to the winds and waves under hurricanes, accurate and efficient simulation tools for hurricane-associated winds and waves are needed for improved understanding of the complex dynamics of the fully-coupled wind-wave-structure interaction system. Conventional simulation schemes usually generates winds and waves separately, and hence cannot capture the intense wind-wave interactions during hurricanes. In this study, a physically-statistically-based hybrid simulation scheme of nonstationary hurricane wind and wave fields is presented, where the winds and waves are coupled in both large and small scales. To simulate the large-scale wind and wave fields, a height-resolving hurricane wind model is coupled with a parametric hurricane wave model through a dependence between sea surface roughness and surface wind speed. In the small-scale simulations, the nonstationary wind fluctuations are statistically obtained by a Hilbert-wavelet-based scheme in which the target parameters (e.g., fluctuation intensity) are estimated based on the local sea state, while the nonstationary wave surface elevations are physically acquired by solving the governing equation of the nonlinear wave evolution under the action of winds. The simulation efficiency and fidelity of the proposed physically-statistically-based hybrid scheme are demonstrated by generating the coupled nonstationary wind and wave fields approaching to a long-span bridge with floating towers under a hurricane event.

Nature Matters: A Coupled Human-Nature System-Based Framework for Assessing Coastal Storm Risk along U.S. Atlantic Coast

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1355

Mr. Muhammad Sajjad (Princeton University), Prof. Ning Lin (Princeton University), Prof. Johnny C. L. Chan (City University of Hong Kong)

As hard adaptive measures to coastal storms can induce false sense of security and inadvertently lead to increased vulnerability, nature-based solutions are gaining more attention as adaptation measures. In this paper, we provide a coupled human-nature system-based framework for risk assessment to coastal storms. This framework is applied to 168 coastal counties along the U.S. Atlantic coast. Several bio-geo-physical data (e.g. coastal geomorphology, spatial natural habitats layers, relief, and historical sea level rise trends, wind, and wave) are used to calculate a hazard index under with and without coastal natural habitats (CNHs) scenarios. This information combined with social-economic-ecological data is used to calculate a coastal risk index for each county. The results show significant difference in risk under the two scenarios. Besides the geographical disparities in risk distribution under the two scenarios, the without-habitat scenario overestimates the population in the highest risk category by 10% and the number of counties by as much as 40% as compared to with-habitat scenario. This not only signifies the incorporation of CNHs into risk assessment frameworks, but also highlights where and to what extent CNHs reduce exposure of communities to coastal storms. This also provides broader incentives for hybrid (natural and engineered) infrastructure development to adapt to coastal storms. Moreover, the proposed framework could be incorporated with coupled hydrodynamic modelling under future climate projections (providing future hurricane information) to signify the role of coastal natural habitats in reducing the exposure to future hurricane-induced flooding.

The Role of Clay-Fluid Molecular Interactions on the Shear Strength of Swelling Clays

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 264

Mr. Keshab Thapa (North Dakota State University), Prof. Dinesh Katti (North Dakota State University), Prof. Kalpana Katti (North Dakota State University)

Swelling clays are extensively found throughout the world. The volume of swelling clay increases when it comes in contact with water. Sodium-montmorillonite (Na-MMT) is one of the main constituents of swelling clay minerals. These clays can exert high stresses on civil infrastructure and lose strength due to swelling, resulting in enormous damage to buildings, roads, bridges, embankments, irrigation canals, etc. Shear strength is a critical engineering property that controls the bearing capacity of clays, and the swelling also affects the shear strength of clays. Understanding of shear failure mechanism of swelling clays is essential to predict the shear strength parameters and thus avoid their detrimental effects and utilize the benefits in geotechnical and geoenvironmental applications. This study provides insight into the importance of clay-fluid interactions on the shear strength of swelling clays with a wide range of organic fluids, acetone, methanol, water, and formamide, using constant-force steered molecular dynamics simulations. Our results show that the polarity of fluids, high through low polar fluids, plays a significant role in the interlayer spacing, interlayer modulus, nonbonded interactions between clay and fluids, and conformation of the fluid molecules in the interlayer upon externally applied stresses. Thus, the reliable prediction of shear strength by taking account into the clay-fluids interactions is essential for effective analysis and economic design of infrastructures as well as for enhancing public safety in the swelling clays regions.

A 3D Phase Field Dislocation Dynamics Model for Body-Centered Cubic Crystals

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 141

Ms. Xiaoyao Peng (Carnegie Mellon Univ), Dr. Nithin Mathew (Los Alamos National Laboratory), Prof. Irene Beyerlein (University of California, Santa Barbara), Prof. Kaushik Dayal (Carnegie Mellon Univ), Dr. Abigail Hunter (Los Alamos National Laboratory)

In this work, we present a 3D phase field dislocation dynamics model for body-centered cubic (BCC) metals. The model is designed to treat the motion of dislocations on three possible families of slip systems expected for BCC metals: {110}<111>, {112}<111>, and {123}<111>. The PFDD BCC model accounts for the dependence of Peierls barrier on screw/edge character. For demonstration, we apply the model to simulate the case of a dislocation loop expansion and kink-pair motion.

Duality of Consistent Couple Stress and Continuous Defect Theories

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1074

Dr. Ali Hadjesfandiari (University at Buffalo), Prof. Gary Dargush (University at Buffalo)

Size-dependent couple stress theory (CST), based upon fully compatible displacement and rotation fields, has its origins in the work of Mindlin and Tiersten (1962), Toupin (1962) and Koiter (1964). Several years later, continuous defect theory (CDT) was developed in Anthony (1970) and deWit (1970) by exploiting the duality with CST. However, as is well-known, the original couple stress theory is indeterminate (Eringen, 1968), which suggests that the original CDT also may have issues. Here, by investigating the benefits and shortcomings of the existing form of continuous defect theory and using recent advancements in size-dependent continuum mechanics, we develop a fully coherent theoretical framework, denoted as Consistent Continuous Defect Theory (C-CDT). Among several important potential applications, C-CDT may provide a proper foundation to formulate a continuum theory of crystal plasticity. The theoretical development provided in this presentation includes an examination of the character of the bend-twist tensor, Weingarten's theorem, Burgers and Frank vectors, continuous dislocation and disclination density tensors, and the dualism between the geometry and statics of C-CDT based on the consistent couple stress theory (C-CST), as defined in Hadjesfandiari and Dargush (2011).

Electro-Chemo-Thermo-Mechanical Coupled Model for Lithium-Ion Batteries

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 975

Mr. Yitao Qiu (Stanford), Dr. Xiaoxuan Zhang (Stanford University), Prof. Christian Linder (Stanford University)

Lithium-ion batteries are important energy storage devices with a wide range of applications. Developing advanced multi-physics model to describe the complex physical processes happening in batteries is crucial for understanding different aging mechanisms, improving cell design, and better controlling cells in a battery management system. In this work, we developed an electro-chemo-thermo-mechanical coupled model to study how mechanical deformation affects the electrochemical performance of lithium-ion batteries. In this model, an electro-chemical (so-called DualFoil) model is coupled with a thermo-mechanical model. Mechanical deformation impacts cell electro-chemical properties via the porosity change in the electrodes and the separator due to interrelation induced volume change of the active materials and externally applied mechanical loading. The model can be used to efficiently study three dimensional cells with large geometry and resolve the spatial variation of interested fields.

A Computational Approach to Model Cone Penetration and Dynamic Pile Loading Tests for Improved Interpretation of Pile Capacity

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1041

Mr. Binyam Bekele (The University of Nebraska-Lincoln), Dr. Chung Song (University of Nebraska–Lincoln)

Interpretation of pile capacity from cone penetration test (CPT) usually follows statistical correlation between data collected from actual pile loading test results (static or dynamic) and cone penetration test conducted near the piles. Although useful, the accuracy of these methods relies on the size of data sets collected. In most cases, pile loading tests being costly, obtaining many CPT and pile loading test results concurrently is seldom. To overcome this problem, this study adopted physics-based approach based on a computational modeling technique using $FLAC^{2D}$ to understand the relationship between cone penetration and dynamic pile loading test results for improved interpretation of pile capacity. The Mohr-Coulomb failure criterion was adopted to mimic the plastic behavior of the soils and Hooke's law was adopted to mimic the behavior of the pile and the cone. The cutting criterion was employed to allow large scale sliding of the cone and updated Lagrangian formulation was adopted to simulate large deformation of the soils. Using the same calibrated model, a dynamic loading test was conducted to obtain velocity and force traces at the pile head. Using these values, pile capacity was interpreted and compared with the CPT results. This approach ensured proper dynamic soil-structure interaction. Finally, from this study a foundation may be laid down for continued and further improved computational investigations for an accurate and more reliable estimation of pile capacity based on CPT results.

Stabilization of Calcareous Sand in Coastal Area by Applying the Admixture of Alkali-Activated Slag and Biochar

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 412

Mr. Xiaole Han (University of Hawaii at Manoa), Dr. Ningjun Jiang (University of Hawaii at Manoa)

In the past decades, efforts have been made to substitute Portland cement by developing novel cement materials using industrial byproducts such as ground granulated blast slag (GGBS). When GGBS reacts with alkali-activators such as hydrate lime and sodium silicate, alkali-activated slag (AAS) reaction can be generated, which produces cementitious materials to bind granular grains and fill gaps between aggregates. So far, numerous studies on AAS materials have proved better resistance to adverse conditions like sulfate attack, compared with Portland cement. Therefore, AAS materials can be potentially applied for stabilization of calcareous sand in coastal area, which is vulnerable to seawater intrusion and coastal erosion. By adding biochar, an extremely internally porous organic material, into the AAS system, the water retention capacity of the admixture can be greatly enhanced, leading to enhanced degree of hydration of AAS materials with the continuous water release from biochar during the curing period.

Currently, the engineering properties of the biochar-enhanced AAS stabilized soils including strength, permeability, shrinkage etc. have not yet been investigated, which are largely related to the nature of the GGBS, alkali activator, biochar, and the curing condition. In this study, the admixture of GGBS, hydrated lime and biochar is applied to stabilize the calcareous sand. The mechanical properties of the biochar-enhanced AAS stabilized calcareous sand are measured. The results show that the addition of biochar in AAS system improves its ductility without compromising its strength. The carbon sequestration effect of biochar is also confirmed through physicochemical and microstructural observations.

Investigation of Sulfate-Driven Deterioration in Hardened Cement Paste Using Integrated Microstructural-Nanomechanical-Chemical Characterization

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1059

Mr. Hani Alanazi (U. Nebraska), Prof. Yong-Rak Kim (U. Nebraska), Prof. Jiong Hu (U. Nebraska)

Many macroscopic properties of concrete such as strength and durability are governed by the properties of hydration reaction products of Portland cement. The chemical and microstructural changes of the reaction products, when exposed to sulfate environments, become significantly complex and require fundamental understanding in multiple length-time scales with multiphysical aspects associated. This paper is to examine sulfate-driven deterioration in hardened cement paste by integrating nanomechanical properties with scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) spectroscopy at different levels of sulfate exposure. Nanoindentation was used to measure and monitor the changes in the nanomechanical properties of Portland cement paste after exposure to $MgSO_4$ solution. The statistical deconvolution of nanoindentation results revealed that the elastic modulus of C-S-H gel gradually decreased, and the volume fraction of porosity gradually increased with an increased exposure time to $MgSO_4$ solution. Nanoindentation results indicated a total leaching of CH. A good linear relationship between Ca/Si molar ratio of chemical composition of C-S-H gel and changes in the elastic modulus was noted. Formations of microcracks and new phases due to sulfate attack were also observed. The experimental investigation attempted in this study implied that the decalcification of C-S-H gel, which was mechanically-morphologically-chemically characterized, is one of main causes of reduction in the macroscopic properties in cement concrete mixtures when they face $MgSO_4$ solution attack.

A Three-Dimensional Computational Homogenization Framework for Reconstructed Microstructures

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 666

Dr. Alp Karakoc (Aalto University), Prof. Jouni Paltakari (Aalto University), Prof. Ertugrul Taciroglu (University of California, Los Angeles), Dr. Arttu Miettinen (ETH Zurich)

Image processing methods combined with scanning techniques—e.g., X-ray microtomography, 3D scanning and transmission electron microscopy methods—are now being frequently used for reconstructing the microstructures that can be used as representative volume elements (RVEs) to investigate the behavior of materials such as particle and fiber reinforced composites. As a complement to these investigations, the present study introduces a computational homogenization framework bridging the RVE and material-scale properties. In this framework, Euclidean bipartite matching method is implemented to overcome the challenge of periodic boundary condition assignment for the reconstructed domains with irregular grids. By means of the bipartite matching, a virtually generated control node set bounding the RVE is matched and kinematically coupled to the existing RVE boundary nodes. Thereafter, the periodic boundary conditions are enforced at the generated control nodes to determine the 3-D effective stiffness properties of the investigated composites with known micromechanical matrix and reinforcement properties. The proposed framework should be useful to applications in image-based material characterization and computational homogenization.

Multi-Site Structural Damage Identification using Constrained Independent Component Analysis and Pattern Recognition

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 352

Mr. Zhiming Zhang (Louisiana State University), Dr. Chao Sun (Louisiana State University)

This paper presents a solution to the multi-site structural damage identification problem using pattern recognition combined with constrained independent component analysis (cICA). While existing studies in this field presented encouraging results for single-site damage identification, limited research effort has been devoted to identifying multi-site damage due its complexity. Features that are effective for single-site damage identification may be inefficient in case of multi-site damage occurrence. In this study, damage sensitive features are extracted from the ICA outcome of the structural response under certain excitations. Through enforcing identical independent components to that of intact structures, the information of structural damage contained in the responses is compacted into the mixing matrix, which largely reduces the feature dimension and preserves all the valuable information. A numerical study indicates that the Mahalanobis distance of the feature vectors consisting of the mixing matrix elements can be used to distinguish multi-site damage cases and locate the single-site damage. Furthermore, the mixing matrix columns of multi-site damage cases have distinct correlation with that of the corresponding single-site damage cases. Therefore, the proposed method can locate the structural damage progressively. Moreover, the data-driven method proposed in this study has the merit of identifying multi-site damage without requiring multi-site damage data as a reference. This relieves the burden from data incompleteness when using the pattern recognition approach for structural damage identification.

A Time-Frequency Domain Approach for Identification of Non-Stationary Systems under Non-White Wind Excitations

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 415

Mr. Yue Dong (Colorado State University), Dr. Yanlin Guo (Colorado State University)

Identification of structural dynamic properties such as frequency and damping is critical for evaluating the performance of structures under extreme winds. Due to the non-stationary nature of strong winds and the potential changes of structural dynamic properties, the corresponding structural response is often non-stationary. Classical output-only system identification (SI) methods based on the stationary response may fail in this case. The present study proposes a novel time-frequency domain approach to track the time-varying structural properties under non-stationary and non-white wind excitations. One challenge for applying time-frequency representations in SI is that the short window required to capture the temporal information will amplify the bandwidth of spectra and cause considerably overestimated damping ratios. To address this challenge, our earlier study has introduced a modified frequency response function, within which the short window effect is explicitly modeled. This approach can identify time-varying frequency and damping of structures under white noise excitation successfully. Nevertheless, wind excitations typically are non-white and wind spectrum is not constant at the vicinity of the structural natural frequencies. Hence, in this study, the original approach is modified by directly modeling the wind spectrum to handle the SI problem of wind-excited structures. Several spectral estimators are adopted for SI, including the instantaneous or marginal spectrum of the wavelet or short time Fourier transform. The accuracy and uncertainties of this approach are assessed through numerical examples of time-varying SDOF and MDOF systems. The parametric analysis including the selection of spectral estimator and SI on closely spaced modes are also investigated.

Breaking wave load identification from vibrations on offshore wind turbines

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 708

Dr. Anela Bajric (University of Oxford), Prof. Manolis Chatzis (University of Oxford), Prof. Ross Mcadam (University of Oxford), Prof. Thomas Adcock (University of Oxford)

Design models of breaking wave loads on offshore wind turbines have advanced theoretically and experimentally, such that the breaking time and the nonlinear hydrodynamics may be predicted more accurately. However, the key dynamical aspects encountered in offshore structures are impractical to measure directly and must be inferred from measurements of the structural response to assess the validity of the proposed theory in the field. A force identification framework is developed which is based on measurements of the discontinuous structural dynamic response associated with offshore wind turbines exposed to breaking waves. The identification is achieved implementing the recent developments in augmenting non-linear Kalman Filters for input estimation and discontinuous dynamics. The effectiveness of the algorithm is demonstrated by numerical simulations of the dynamic response of wind turbines due to breaking wave loads for a variation of breaking time and breaking wave load models. It is furthermore demonstrated that the flexibility of the foundation improves the force estimation.

KPCA-based Damage Identification of Nonlinear Civil Structures

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 998

Ms. Khaoula Ghoulem (University of Carthage, Ecole Polytechnique de Tunisie), Dr. Tarek Kormi (University of Gabès, Ecole Nationale d'Ingénieurs de Gabès), Dr. Nizar Bel Hadj Ali (University of Gabès, Ecole Nationale d'Ingénieurs de Gabès)

Data-driven SHM methods benefit from new concepts in statistics for the development of statistical models used for structural diagnosis. The development of data-driven SHM methods owes much to the availability and affordable sensing techniques that made continuous structural monitoring physically feasible and cost-effective. In data-driven approaches, statistical models are generated based on data collected from a baseline condition corresponding to a presumably healthy state of the structure. Anomalous structural behavior is thus detected if new measurements sufficiently deviate from the baseline.
The most commonly used data-driven techniques for system monitoring utilize feature extraction approaches relying on principal component analysis (PCA). In many cases, PCA-based methods succeed in detection of anomalous structural behavior. However, the use of this approach is limited to linear response features, a shortcoming which may be overcome via recombination of PCA with non-linear kernel functions. Kernel principal component analysis (KPCA or Kernel PCA) is a nonlinear generalization of principle component analysis. Kernel PCA has been used in a variety of applications. However, few applications are found for the diagnosis of civil structures. The aim of the presented work is to fill this gap by proposing a simple, straightforward, and effective framework for early damage identification for nonlinear civil structures.

Application of Machine Learning Techniques to Probabilistic Seismic Collapse Assessment

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 76

Mr. Jalal Kiani (University of Memphis), Prof. Charles Camp (University of Memphis), Prof. Shahram Pezeshk (University of Memphis)

Machine learning is an extensive and continuously developing field, offering a wide range of regression and classification-based techniques that can be used with probabilistic seismic collapse assessment. The main objective of this paper is to use classification-based techniques to predict the probabilities of collapse at alternative ground motion intensity levels. For this purpose, modeling uncertainty and record-to-record variability are propagated through nonlinear dynamic analyses under a suite of earthquake ground motions. In addition, a method is suggested for feature selection owing to characterization of features representing ground motion variability. Then, the relative merits and demerits of classification-based techniques are discussed and investigated using the structural responses of three steel moment resisting frame buildings. The results of the study demonstrate that classification-based methods increase the efficiency of probabilistic seismic collapse assessment. In other words, the classification-based methods perform very well in estimating the overall collapse fragility curve as well as the annual exceedance rate of collapse. However, feature selection for classification-based techniques is challenging owing to characterization of features representing ground motion variability. To make the implementation of classification-based techniques easier, a method is suggested for feature selection.

Rapid Damage Assessment of Structures after Earthquakes Using Machine Learning – A Sensitivity Analysis

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1221

Mr. Mohamadreza Sheibani (University of Utah), Prof. Ge Ou (University of Utah)

The estimation and realization of the building damage conditions are critical to post-earthquake rescue and reinforcement efforts. This information can be obtained through physical inspection of the affected buildings in the seismic region. Physical inspection can be time-consuming, but it provides an accurate representation of the building damage states. Using supervised machine learning methods, based on limited observations of inspected buildings, one can train a model to predict the damage conditions of other buildings in the whole seismic region. The health condition is predicted in the form of a label based on the defined thresholds in the nonlinear behavior of the structure. In this paper, Gaussian Process Regression (GPR) is used for prediction and the sensitivity of the GPR accuracy to different earthquake engineering, building information, and damage assessment variables is investigated. The algorithm is implemented on a regional earthquake simulation platform of Japan, adopting observed ground motions from previous seismic events (Tohoku, M9.0, Fukushima, M6.6, etc.). A number of building types are considered and distributed in the earthquake region and the number of variations is studied in the simulation. Supervised learning is primarily using the features extracted from ground motion signals and the influence of these features on the prediction accuracy is investigated. Moreover, the effect of the number of observations which form the training examples is studied in the numerical simulations. Finally, it is shown that one can predict the health condition of buildings in a region with promising accuracy, using only a limited number of observations.

Surrogate Modeling and Global Sensitivity Analysis towards Efficient Simulation of Nuclear Reactor Stochastic Dynamics

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 428

Mr. Gregory Banyay (University of Pittsburgh), Dr. John Brigham (Durham University)

For the modeling and simulation of the structural dynamics of a nuclear reactor assembly, surrogate modeling is used to support global sensitivity analyses (GSA) to demonstrate both the pertinence of such methods to this application as well as the significant physical insights provided by GSA. The coupled use of surrogate modeling and GSA reduces the number of full-order (i.e., computationally expensive finite element analysis) simulations required, substantially reducing total computational cost. This work focuses on the use of Gaussian Process surrogates in particular, and examines the robustness of these techniques to evaluate sensitivity by considering a variety of design of experiment strategies used to create the surrogate models.

Numerical experiments based upon a system finite element model for a pressurized water reactor subjected to non-stationary loss of coolant accident loads, are used to evaluate the relationship between sensitivities computed from a full-order model versus those computed from a surrogate model. For large sample sizes,negligible variation in the resultant sensitivities is shown with respect to the particular method by which a computational design of experiment is constructed to train the surrogates, which demonstrates stability of the results. For small sample sizes, the use of Latinized Partially Stratified Sampling provided surrogates and associated sensitivities with lower error as compared to Latin Hypercube Sampling and sampling via the Fourier Amplitude Sensitivity Test. Differences in GSA results imparted by examining time-domain versus spectral acceleration results,as well as increasing model parameter variation further illustrated the effectiveness of advanced sampling methods.

Physics-encoded Sparsity-promoted Deep Learning for Data-driven Discovery of Nonlinear Governing Laws

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 525

Mr. Zhao Chen (Northeastern University), Prof. Hao Sun (Northeastern University)

Harnessing data to discover the governing equations and scientific laws of complex systems remains a critical challenge in many science and engineering areas. Although the explosive growth of data and advances in computation make possible to use AI algorithms (e.g., machine learning) for exploration of mathematical governing laws in a data-driven manner, intractable issues arise associated with the preparation of massive data for complex physical systems and the inevitable noise of acquired data. Thus, there is an urgent need to develop transformative AI techniques, grounded with available physics information, to address this discovery issue in the presence of scarce/sparse, noisy data. To this end, we develop an innovative, rigorous data analytic pipeline, within the framework of deep learning and based on sparse representation theory, for discovering nonlinear governing laws termed as a set of partial differential equations in a data driven manner. The parameterized governing equations will be encoded into the deep learning model through augmenting the loss function. Determination of the unknown parameters will rely on a sparsity representation which bypasses a brute-force large search over all possible candidate solutions. We will demonstrate the generalizability and scalability of the proposed approach on a wide range of physical systems with different complexities, under various scenarios of rich, scarce/sparse, and noisy data, including dynamical structural systems, fluid transport, chaotic dynamical systems, etc.

Bayesian operational modal analysis using data from mobile sensor networks

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 678

Mr. Rajdip Nayek (Univeristy of Waterloo), Prof. Sriram Narasimhan (Univeristy of Waterloo)

Recently, there has been a growing interest in the use of mobile sensors for structural system identification and health monitoring. Mobile sensor networks are groups of sensors that have the ability to record data in time while simultaneously changing measurement locations in space. Thus a network of mobile sensors can collect spatially dense data providing a more cost-effective solution to structural health monitoring than a dense network of fixed sensors. However, due to a continuous location-changing nature of the mobile sensors, the recorded dataset is incompatible for processing with traditional structural identification schemes and hence modifications to the existing structural identification framework are needed to be used with mobile sensor data.

In this study, a modal-state model is proposed to assimilate the changes in mobile sensors' location into a mathematical model. A Bayesian framework incorporating the modal-state model is introduced to allow scalable modal identification and uncertainty quantification using the mobile sensor data. Two Bayesian computational schemes, namely Gibbs sampling and variational Bayes, have been adopted to obtain the posterior distributions of the modal parameters. A numerical study on a beam shows the efficiency of the proposed model to obtain modal identification results using mobile sensor data. An assessment how different parameters of a mobile sensing network (such as number of mobile sensors, velocity of mobile sensors) affect the uncertainty in the identified modal parameters has also been performed.

Identifying microstructural features that drive stress hot-spots using a data mining approach

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 506

Mr. Ankit Shrivastava (Carnegie Mellon Univ), Prof. Hae Young Noh (Carnegie Mellon University), Prof. Kaushik Dayal (Carnegie Mellon Univ)

Strength is governed by the microstructure (grains and grain boundaries) in polycrystalline materials. While models for computing strength of a given microstructure are available, there is much less understanding of what features of the microstructure are important in governing the strength. We use a convolution neural network to understand the role of microstructural features in leading to high-stress regions ("hot spots") that eventually limit the strength. Convolution neural network (CNN) is a class of deep networks that are useful for automatically extracting essential features from high dimensional data. Our microstructure information is represented by very high dimensional image data. Thus, we use CNN to efficiently extract features that influence the material strength. The inputs to this network are images of the microstructure with information about grain's misorientation and grain boundaries. The output to this network is the area fraction (or count of those pixels) in a stress image whose value is above a defined threshold; a low count implies less high-stress hot-spots and correspondingly better performance.

We find that CNN can classify the propensity of the microstructure to form localized hot spots, and that the weights of the convolution layer learned while training CNN can provide insights into the physics of the localization by grains and grain boundaries.

Random Field Representation of Anisotropic Material Properties for use in Simulating Fracture

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 791

Prof. Katherine Acton (University of St Thomas), Mr. Connor Sherod (University of St. Thomas), Dr. Reza Abedi (University of Tennessee)

Some materials, such as rock with bedding planes, exhibit macroscale anisotropy. A great many other materials exhibit local anisotropy but are isotropic in bulk. An isotropic limit scale may be considered a characteristic feature of a given composite. Fracture simulation depends on the accurate representation of localized defects that affect crack initiation and propagation. Therefore it is important to capture local material anisotropy in many applications, including but not limited to applications where anisotropy exists at the macroscale.

Accounting for material anisotropy in fracture models is a multivariate, multiscale problem. Elastic properties and material strength properties may have disparate isotropic and heterogeneous limits. In this work, material properties are characterized as random fields using Statistical Volume Elements (SVE). Methods are developed to capture material property variability at multiple scales, including variability in properties with angular dependence. These methods increase accuracy and computational efficiency when implementing a material description into a fracture simulation.

A Bibliometric Analysis of the Structural Health Monitoring Research Field

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1286

Dr. Kaitlyn Kliewer (LERA Consulting Structural Engineers), Prof. Edward Melcer (University of California Santa Cruz), Prof. Branko Glisic (Princeton University)

This research provides an analysis of the academic landscape of the structural health monitoring (SHM) research field through a co-word analysis. SHM is a rapidly growing and broad research field, making it challenging for researchers to determine the current state of the research field and the existing gaps in current research. While there have been many literature reviews on SHM research that help provide an overview of field, literature reviews are limited in nature and typically cover no more than 100 papers. They tend to be more focused on a sub-community within SHM, as opposed to an analysis of the interrelations among research themes in the field. The goal of this research is to provide a broader analysis of the field as a whole through a data-driven approach with a bibliometric analysis of SHM literature. This research quantifies and describes the evolution of the research field based on the bibliometric data collected from over 21,000 conference and journal papers in SHM during the period 2003 to 2017, producing over 40,000unique keywords. Utilizing graph theory and social network analysis methods, a data driven approach using co-word and co-venue analysis was employed based on keywords to reveal the patterns of the field. The analysis was conducted for three time periods (2003-2007, 2008-2012, and 2013-2017) and a comparison between the time periods shows the relationships between research themes and the evolution of those themes in the SHM research community.

Formal Concept Analysis for Modularisation and Sustainability of Infrastructure Systems

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 181

Mr. Tanmay Vora (VJTI, University of Mumbai), Mr. Ojas Vora (Carnegie Mellon University)

Out of 17 Sustainable Development Goals which in turn have 169 targets as announced by United Nations, 33% are about Infrastructure Systems. Many infrastructure management software tools address the increasing complexity of infrastructure systems, however, most of them lack an integrated and comprehensive view to the infrastructure management process, especially from the perspective of sustainability. While sustainability addresses the time-continuous impacts on the economy, society, and environment, resilience focuses on the impact that the service failure of the infrastructure can have in case of disasters. Modularisation in the design as well as construction is one of the solutions to manage these complementary concepts. Modular construction has economic advantages and high construction as well as replaceability quality of the modules but the same thing cannot be stated for complex infrastructure systems, each one being a system of systems. Formal Concept Analysis (FCA) is a theoretical framework which structures a set of objects described by properties. FCA extracts relations between the objects and categorizes commonalities and variability in a canonical form. Studying variability in domain is a key issue of product line engineering which is the ultimate goal of modularization. Concept Lattices are core structures of FCA for extracting an ordered set of concepts from a dataset composed of objects described by attributes, called a Formal Context. This data analysis framework is then applied to support various tasks, such as information retrieval, data mining, building or maintaining module hierarchies, pattern matching and modular design and maintenance of infrastructure systems for sustenance.

Deep Learning-Based Detection of Seismic-Vulnerable Buildings for Improving City Resilience

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 528

Dr. Zheng Yi Wu (Bentley Systems, Incorporated), Mr. Maadh Hmosze (Bentley Systems, Incorporated), Dr. Rony Kalfarisi (Bentley Systems, Incorporated)

To ensure and improve city resilience under natural hazards, such as an earthquake, many existing buildings must be retrofitted to reduce the risk of potential damages and loss of human life. Among different types of seismic-vulnerable buildings, the multi-story buildings with wide opening at first or ground floor, so-called Soft Story (SS) buildings, are the most vulnerable for earthquakes. To identify SS buildings, engineers are walking block by block to assess each building and subsequently notify building owners to retrofit for meeting the city resilience ordinance. Although engineers have classified thousands of SS buildings, it is too time consuming and costly to conduct SS building classification block by block. In this project, the deep convolutional neural network models have been trained with the images of engineer-classified SS buildings and applied to city-scale SS building detection. The results are then geocoded in 3D GIS map for intuitive visualization and quick verification. The deep learning-based method has proven to be cost-effective for detecting SS buildings and a promising approach for detecting other types of hazard-vulnerable buildings for better city resilience.

A Novel Method for Bridge Monitoring Using Smartphones and Blind Source Separation

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1139

Mr. Qipei Mei (University of Alberta), Dr. Farid Ghahari (University of California, Los Angeles), Dr. Hamed Ebrahimian (SC Solutions Inc.), Dr. Mustafa Gül (University of Alberta), Prof. Ertugrul Taciroglu (University of California, Los Angeles)

As we seek to attain the smart, sustainable, and resilient infrastructure systems and cities of the future, the demand for continuous sensing and monitoring of infrastructure systems is increasing. Bridges are one of the most critical components of our transportation infrastructure system, and improving their performance with novel continuous monitoring technologies is of the utmost importance. In this context, this paper proposes a novel crowdsourcing-based bridge monitoring method using the vibration data collected from the smartphones in passing-by vehicles. In the proposed approach, the data from multiple smartphones are collected as the vehicles cross the bridge. Then, blind source separation (BSS) technique is applied to recover the vibration of the bridge from the coupled vibration of bridge and vehicle. Afterwards, Mel-frequency cepstral coefficients (MFCCs) are extracted from the separated signal. Finally, the damage is assessed by conducting a statistical analysis of the damage features calculated using MFCCs from the baseline and unknown states. The results of the numerical and experimental cases studies are presented to demonstrate the effectiveness of the proposed method.

Long-Term Degradation of Plain and Reinforced Concrete Due to Alkali-Silica Reactivity Damage

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 220

Mr. Hadi Aryan (University of Southern California), Dr. Bora Gencturk (University of Southern California), Dr. Jianqiang Wei (University of Massachusetts, Lowell), Mr. Yahan Zuo (University of Southern California)

In this study the influence of alkali-silica reaction (ASR) on the concrete mechanical properties is investigated. Two groups of concrete samples were prepared from mixes containing a reactive sand from El Paso, Texas. Extra alkali, 1.25% by weight of cement, was added to the second concrete to increase the ASR rate. Cylinder and prism samples were prepared and conditioned in indoor and outdoor conditions, and inside an environmental chamber for a year. The degradation in concrete properties including compressive strength, elastic modulus, tensile strength, and the modulus of rupture was monitored over time. Moreover, the prism samples from the mix with reactive aggregate and the mix with reactive aggregate and additional alkali were kept in the same three environments for expansion measurements. Each group of prisms contained a prism with no rebar and three prisms with 1.23%, 2.18%, and 3.41% area ratio of steel reinforcement. Results showed that ASR does not affect all the above-mentioned properties of the concrete to the same extent. Tensile strength and modulus of rupture were found to be more susceptible to ASR damage compared to compressive strength and elastic modulus. The concrete samples from the mix with additional alkali showed lower quantities of mechanical properties and higher expansions compared to those with only reactive aggregate. Reinforcing the concrete has proved to have an effective restraining effect against the macro-scale expansion of concrete due to ASR.

Stable Force Identification Using Gaussian Process Model Based Kalman Filtering

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 692

Mr. Rajdip Nayek (Univeristy of Waterloo), Prof. Sriram Narasimhan (Univeristy of Waterloo)

In many civil engineering systems, measuring the operational external forces is not practical and this gives rise to the problem of inversely estimating the unmeasured input forces, commonly termed as the force identification problem. There has been a growing interest in developing and applying stochastic joint input-state estimation algorithms for tackling such force identification problems in the recent years.

In this study, a novel methodology using Gaussian process latent force models (GPLFM) is proposed to tackle the problem in a stochastic setting. The unknown input forces acting on a structure are modelled as Gaussian processes with some chosen covariance functions which are combined with the mechanistic differential equation representing the structure to construct a GPLFM. The GPLFM is then conveniently formulated as an augmented stochastic state-space model with additional states representing the latent force components, and the joint input and state inference of the resulting model is implemented using Kalman filter. The augmented state-space model of GPLFM has been shown as a generalization of the class of input-augmented state-space models, is proven observable, and is robust compared to conventional augmented formulations in terms of numerical stability. To assess the performance of the proposed GPLFM method, several cases of state and input estimation are demonstrated using numerical simulations on a 10-dof shear building. Results obtained indicate the superior performance of the proposed approach over conventional Kalman filter based approaches.

A Sequential Decision Process for Broadly and Efficiently Comparing a Large Set of Designs Characterized by Probabilistic Decision Criteria

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 696

Prof. Gordon Warn (Penn State University), Dr. Jaskanwal Chhabra (Penn State University)

Uncertainty is an integral part of decision-making in engineering design. Performance-based earthquake engineering provides a probabilistic framework to assess the performance of engineered structures threatened by seismic events, and this framework has been applied to other hazards, such as wind and tsunami. However, when the decision criteria are obtained from a computationally intensive numerical analysis, e.g., assessing the seismic performance of buildings, it might not be feasible to derive precise distributions of the decision criteria for a large number of design alternatives. As such, performance-based earthquake engineering has largely been used for assessing a detailed design rather than for exploring different concept designs early in the process. The presented methodology is motivated by the desire to efficiently explore large sets of design alternatives when the decision criteria are probabilistic and computationally intensive to generate. It is hypothesized the availability of precise distributions of decision criteria for all designs under consideration is not necessary at all points in time during the design process, and appropriate decisions can be made on the basis of imprecise distributions of decision criteria by using confidence intervals to bound their imprecision. To that end, a sequential decision process employing mean-risk and stochastic dominance is presented, where models of increasing fidelity are used in a sequence to discriminate dominated designs from the design space on the basis of imprecise distributions of decision criteria. The modeling fidelity is sequentially increased while decreasing imprecision in the decision criteria. The utility of the methodology is demonstrated through two design examples.

A Probabilistic Quantification of Hurricane-Induced Loss for Building Portfolio

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 746

Mr. Asim Bashir Khajwal (Texas A&M University), Dr. Arash Noshadravan (Texas A&M University)

Hurricane hazard is one of the major causes for the loss of life and property and has recently led to an enormous economic loss and social disruption specifically in the coastal regions. Monetary loss of damage to buildings represents a significant portion of overall hurricane-induced damage. A detailed simulation of hurricane damage at regional scale requires large amount of specific information about building vulnerability, which can be poorly understood or is not available with sufficient level of certainty for a large spatial extent. Moreover, the simulation of portfolio of buildings can be computationally costly or prohibitive. The existing wind damage models often assume a prescribed mathematical structure to describe the dependency between aggregated loss and the hazard intensity in an average sense. The effect of uncertainty may then be introduced by treating model parameters as random variables. Here a new approach to tackle this problem is introduced, which relies on a more rigorous and reliable quantification of the involved uncertainties. In particular, building portfolio loss induced by wind is modeled as a non-stationary stochastic process for which a probabilistic representation is constructed using polynomial expansion. As a case study, the damage data collected after the recent hurricane events such as the hurricane Harvey and Irma is used to calibrate and test the predictive capability of this stochastic loss model. This representation has the advantage of being based on minimal prior assumptions and constraints, in addition to being computationally less demanding since it generates the vulnerability at a coarser regional level.

Non-Parametric Stochastic Subset Optimization for Reliability-Based Importance Ranking of Bridges in Large-Scale Transportation Networks

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 873

Mr. Zhenqiang Wang (Colorado State University), Prof. Gaofeng Jia (Colorado State University)

The importance ranking of bridges used to guide effective seismic risk mitigation of transportation networks is usually identified by evaluating and comparing the corresponding network performances through removing each individual bridge from the network. This process doesn't take into account the uncertainties in the damage states of bridges and the residual capacities of damaged bridges. Moreover, the importance ranking is usually obtained with low efficiency (e.g., using direct Monte Carlo Simulation and repeating it for each bridge), especially for large-scale networks. This study proposes a non-parametric stochastic subset optimization (NP-SSO) algorithm for efficient reliability-based importance ranking of bridges for large-scale transportation networks. It extends the existing NP-SSO algorithm (which is for continuous design variables) to discrete variables. It relies on generation of failure samples from an augmented failure distribution and these failure samples are used to efficiently estimate the updated network reliability if any of the bridge in the search space is retrofitted, with no need to repeat the analysis for each bridge. Uncertainties in the damage states of bridges and the residual capacities of damaged bridges are explicitly considered. An iterative approach is proposed to improve the overall efficiency by restricting the search space to the subset of bridges with smaller failure probability. Adaptive stochastic sampling algorithm, which uses failure samples from the previous iterations to establish better proposal densities, is used to improve the sampling efficiency. The proposed NP-SSO algorithm is applied to identify important bridges for the transportation network of Los Angeles and Orange counties.

Efficient Uncertainty-Aware Management of Power Distribution Systems Using Polynomial Models

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1122

Dr. Negin Alemazkoor (University of Illinois at Urbana-Champaign), Prof. Hadi Meidani (University of Il)

With ever increasing penetration of distributed renewable energy generation that are more susceptible to uncertainties, voltage control has become a new challenge for distribution networks. Conventionally, to control the system, perturb-and-observe or Jacobian matrix inversion approaches are used to evaluate the impact of active and reactive power of distributed generators on voltage magnitudes. However, these approaches require constantly updating the Jacobian matrix or running several power flow simulations for different system states, which can be computationally cumbersome. In this work, we propose developing polynomial surrogates that approximate the voltage level as a function of power consumption, distributed power generation and power factor of distributed generators. Polynomial surrogates can be efficiently used for probabilistic analysis and control of the distribution network. The effectiveness of the proposed surrogate-based method is demonstrated on the IEEE 33-bus system, in the presence of a large number of correlated random inputs.

Deep Learning Based Damage Detection for Infrastructure Health Assessment

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 805

Ms. Min Hwang (Columbia University, Thornton Tomasetti), Dr. Badri Hiriyur (Thornton Tomasetti, Inc), Dr. Mahesh Bailakanavar (Thornton Tomasetti, Inc)

The 2017 ASCE Infrastructure Report Card provided a grade of D+ and C for the overall state of infrastructure and bridges, respectively, in the United States. These ratings indicate a strong need for improving the efficiency of inspection, assessment, and repair of infrastructure. Conventional methods of inspecting infrastructure involves thorough, but tedious and fallible manual inspections of the structures. Recent technological advances in drones, deep learning, and computer vision enable rapid large-scale inspection of infrastructure by rapidly processing photographic data resulting in improved time and cost efficiencies. To enable autonomous inspections, Thornton Tomasetti has developed and trained deep learning based damage detection pipelines to detect and classify damage in various types of structures. Our damage detector uses object detection frameworks such as Faster R-CNN and Single Shot Multibox Detector (SSD) with standard convolutional neural networks such as Inception V2 and MobileNet as the underlying feature extractors. Starting with the aforementioned models pre-trained with COCO datasets, we used transfer learning to re-train the models to identify various damage classes relevant to structures such as cracks, spalls, exposed rebar in concrete, corrosion in steel, and so on. The retrained models show excellent performance both qualitatively in terms of comparison with previously unseen test images as well as quantitatively in terms of Intersection-Over-Union (IOU) scores – a widely used measure of object detection and localization accuracy. We also present a mobile deployment of our pipeline that enables rapid manual inspections of structures including spatial geo-tagging of damage onto 3D models of the structure.

Autonomous Post-Disaster Reconnaissance of Reinforced Concrete Buildings Through Deeplearning-Based Multi-Class Damage Detection

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1133

Mr. Tarutal Ghosh Mondal (Purdue University), Dr. Mohammad Jahanshahi (Purdue University)

Structural resilience is measured by the infrastructure's capacity to restore full functionality post extreme events. Timely assessment of damages induced to buildings due to an earthquake is essential for ensuring life-safety, mitigating financial losses and expediting the rehabilitation process. As manual inspection is expensive, time consuming and risky, low-cost unmanned aerial vehicles (UAVs) or robots can be leveraged as a viable alternative for quick reconnaissance. Visual data captured by the sensors mounted on the robots can be analyzed and the damages can be detected and classified autonomously. The present study proposes a deep learning-based approach to this end. Region based convolutional neural network (Faster RCNN) is exploited to detect four different damage types, namely, surface crack, spalling (which includes façade spalling and concrete spalling), severe damage with exposed rebars and severely buckled rebars. The performance of the proposed algorithm is evaluated on manually annotated image data collected from reinforced concrete buildings damaged under several past earthquakes such as Nepal earthquake (2015), Taiwan earthquake (2016) and Ecuador earthquake (2016). The detector can predict the class levels and positions of the damaged areas with reasonable accuracy. Several experiments are conducted to evaluate the capabilities as well as the limitations of the proposed approach. The proposed technique can be potentially integrated into UAVs or inspection robots to autonomously survey buildings damaged by earthquake, which will help plan retrofit operations quickly, minimize the damage cost and restore the essential services in no time.

Autonomous and Quantitative Damage Chronology

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1137

Mr. Tarutal Ghosh Mondal (Purdue University), Dr. Mohammad Jahanshahi (Purdue University)

This study presents a computer vision-based approach for representing time evolution of structural damages leveraging a database of inspection images. Spatially incoherent but temporally sorted archival images are exploited to chronicle the damage evolution over a long period of time. To this end, a sequence of time-stamped inspection data is used. Identification of a structural defect in the most recent inspection data set triggers an exhaustive search into the images collected during the previous inspections looking for correspondences based on spatial proximity. This is followed by a view synthesis from multiple candidate images resulting in a single reconstruction for each inspection round. Cracks on concrete surface is used as a case study to demonstrate the feasibility of this approach. Once the chronology is established, the damage severity is quantified at various levels of time scale documenting its progression through time. The proposed approach is a stepping stone towards the prediction of damage severity at a future point in time providing a scope for preemptive measures against imminent structural failure. On the whole, it is believed that the present study will immensely benefit the structural inspectors by introducing the time dimension into the autonomous condition assessment pipeline.

Experimental Shaker Input Estimation for a Full-Scale Concrete Frame Structure

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 132

Dr. Yang Wang (Georgia Institute of Technology)

This presentation discusses input estimation of a full-scale concrete frame structure. With acceleration response measured from dynamic testing, the natural frequencies and mode shapes of the concrete frame are first identified. The experimentally identified modal properties are compared with those obtained from a finite element (FE) model using nominal material properties. The FE model is then used to construct state-space system matrices for input estimation. With only acceleration measurements, an unbiased minimum-variance estimator combined with an on-line drift filter is used to estimate the dynamic input generated by a shaker. The estimation results show acceptable performance of the proposed algorithms for application on the full-scale two-story two-bay concrete frame with both simulated and experimental measurements. The effect of sensor locations on input estimation performance is also discussed.

Knowledge-Enhanced Deep Learning for Simulation of Tropical Cyclone Boundary-Layer Winds

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 487

Mr. Reda Snaiki (University at Buffalo), Dr. Teng Wu (University at Buffalo)

physics-informed deep learning algorithm was developed here to simulate the spatial distribution of tropical cyclone wind field with high computational efficiency and simulation accuracy. It can be used as part of the early warning system to effectively predict wind hazard. The Navier-Stokes equations governing the wind fields of tropical cyclones are utilized to provide essential information that facilitates the effective regularization of the neural networks. More specifically, the governing equations as well as the boundary conditions are employed as part of the loss function in the deep learning algorithm. Since the physical properties imposed by the Navier-Stokes equations are ensured by model predictions, the simulation accuracy of the developed deep neural networks is greatly enhanced. In addition, the proposed physics-informed deep learning only needs a small number of training datasets to guarantee the convergence of networks. To differentiate the neural network with respect to the model parameters and assess the derivatives of the governing equations, the automatic differentiation technique, known to be more accurate and efficient compared to the standard numerical differentiation, is utilized. The performance of the physics-informed deep learning algorithm in terms of the relative -norm was first assessed using two nonlinear numerical examples (1-D and 2-D), where several key features related to the number of training and collocation points and the neural network topology were systematically discussed. Then, it was employed to rapidly predict the spatial distribution of tropical cyclone wind field based on the standard storm parameters provided by the National Hurricane.

Structural Health Monitoring Using Low Cost Measurement Devices with Bayesian Methodologies

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 671

Mr. Alejandro Duarte (Universidad del Norte), Dr. Albert Ortiz (Universidad del Norte)

The development of low-cost measurement devices for Structural Health Monitoring (SHM) has gained significant attention in the last decades. Particularly, the high cost of traditional acquisition systems has generated the appearance of a wide range of affordable equipment accessible to more engineers. This article seeks to evaluate the feasibility of using low-cost measurement devices for system identification in several types of structures. The use of Bayesian methodologies is proposed to quantify the uncertainties in the identification process. The devices used in this study were smartphones and Raspberry Pi. Different types of structures such as pedestrian bridges, stadium grandstands, and a 9-story building were instrumented. The results show the feasibility of using low-cost measurement devices to identify the dynamic properties. Bayesian methodologies are an adequate tool to be used in conjunction with these devices due to their ability to quantify the uncertainty of the identified parameters.

Numerical Simulation of Wave Propagation in Concrete with ASR Induced Microcracks

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 945

Mr. Hossein Ariannejad (University of Nebraska–Lincoln), Prof. Jinying Zhu (The University of Nebraska-Lincoln)

Alkali-Silica Reaction in concrete is a detrimental chemical reaction between the alkali in cement paste and silica available in aggregates. This chemical reaction forms a gel inside the concrete that tends to expand, and this expansion eventually causes a network of cracks inside the concrete which can significantly decrease its strength and durability. Since the cracking starts from the inside, there is no easy way to identify and evaluate ASR damages in the early stage. In this paper, a numerical method to model the ASR affected concrete in different damage stages is proposed. First, a finite element model of a concrete sample that includes mortar and random set of polygon-shaped aggregates is simulated. In each damage stage, a series of randomly sized and oriented cracks that are partially filled with the ASR gel is added to the sample. Each damage stage can be quantified based on the number of cracks in a normalized surface area. At each stage, an elastic wave is sent through the sample, and the Coda Wave Interferometry (CWI) is then used to compare the velocity change of the receiving signal. Results suggest there is a direct relationship between the velocity change and the damage stage inside an ASR-affected concrete sample. The proposed method can be used for nondestructive evaluation and quantification of the damage due to ASR in concrete structures.

Acoustoelastic Effect for Evaluation of Prestress Losses in Concrete Using Self-Referenced Ultrasonic Waves

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1078

. Bibo Zhong (University of Nebraska–Lincoln), Prof. Jinying Zhu (The University of Nebraska-Lincoln), Prof. George Morcous (University of Nebraska–Lincoln)

Evaluation of prestress loss is still a challenging topic for in-service prestressed concrete structures. This paper presents preliminary experimental results of using acoustoelastic effect to evaluate stress change in concrete samples. The acoustoelastic effect refers to the linear relationship between ultrasonic velocity variation and stress change in materials. Since velocity change due to prestress loss is typically less than 2%, it cannot be accurately measured with the conventional ultrasonic methods. In this study, coda wave interferometry (CWI) is used to measure the very subtle velocity change in concrete due to stress change, with a sensitivity of 0.1% per MPa stress change. Because the reference signal in unstressed condition is not available in practice, the proposed setup is applied in orthogonal directions: one is in prestress direction, and the other one can be considered as unstressed state, in which the reference signal can be obtained, and the temperature effect is canceled due to the simultaneous testing. The test setup was applied and validated on both small and medium-scale concrete specimens.

Test of Ship Impact Non-Navigable Span of Cross-Sea Bridges

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1149

Prof. Jian Guo (Zhejiang University of Technology), Ms. Liqi Qiu (Zhejiang University of Technology), Prof. Zhongdong Duan (Harbin Institute of Technology), Prof. Feng Xu (Harbin Institute of Technology), Mr. Yangfei Zheng (Zhejiang University of Technology), Mr. Jiangxuan He (Zhejiang University of Technology), Dr. Haibin Zhang (Harbin Institute of Technology)

The frequently occurred ship-bridge collision is regarded as one of the most important threats to bridge safety. The purpose of this research was to determine the experimental design of conducting reduced-scale experimental ship impact testing of the Liuheng Bridge in Zhoushan, Chian and to establish the design parameters of the proposed testing program. The parameters were determined according to the principle of stiffness similarity included the construction of superstructure, substructure and experimental ships. Experimental design was carried out through the use of dynamic finite element impact simulation using theLS-DYNAcode. Finite element simulations were conducted for a range of impact scenarios in order to select optimal parameters for the test. Dynamic impact simulations resulted in the selection of a ship weight and a set of impact velocities for use in the reduced-scale test. In addition, the impact force predicted by dynamic impact simulation were compared to the results of experimental tests. Finally, the impact energy is analyzed according to the tests.

Development of a Non-Contact Activation Method for Shape Memory Alloy Concrete Structures Using Magnetic Nanoparticles

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 549

Prof. Moochul Shin (Western New England University), Prof. Chang Hoon Lee (Western New England University), Prof. Ijung Kim (Hongik university)

This study focuses on the feasibility of adopting magnetic nanoparticles (MNPs) as a new means of activating shape memory wires by introducing a magnetic field, i.e. a non-contact method. SMA exhibits two unique characteristics: 1) shape memory effect depending on temperature or stress, and 2) superelasticity. In order to utilize the shape memory effect of SMA by generating a high enough temperature of SMA above austenite finish temperature (Af), two general methods have been used in practice: 1) passing an electric current through SMA wires via a power supply, or 2) applying a direct heat source e.g. a fire torch. These direct contact methods are especially challenging when SMA is embedded inside of concrete as reinforcement. Therefore, a new method of activating the shape memory effect of SMA via controlling and/or increasing a temperature of SMA is needed. This study presents an innovative way of activating shape memory alloy phase transformation by utilizing the inductive heating property of MNPs which respond to the magnetic field. By generating magnetic fields near a concrete structure with MNPs, we can manage to control and increase the temperature of the structure, thereby the shape memory phenomenon can be achieved without making SMA wires directly connected to heating sources. A set of laboratory tests are conducted to demonstrate the feasibility of the new method of utilizing SMA to improve mechanical properties of concrete structures by introducing a non-contact activation method based on the inductive heating of MNPs.

Sample-Based Approach for Effective Seismic Risk Mitigation of Large-Scale Transportation Networks

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 870

Mr. Zhenqiang Wang (Colorado State University), Prof. Gaofeng Jia (Colorado State University)

Seismic risk mitigation of transportation networks through retrofitting critical bridges in advance could effectively reduce the impact of seismic hazards on social and economic activities. However, identification of the seismic retrofit priorities/strategies usually entails significant computational challenges. Besides performing a large number of evaluations of the network model due to too many potential combinations, especially for large-scale network, the quantification of high-dimensional uncertainties in intensity measures at each bridge site as well as in the damage states of each bridge intensify the challenge. To address these challenges, this work proposes an efficient sample-based approach for effective seismic risk mitigation of transportation networks. The approach relies on only one set of simulations of the network model, and uncertainties in intensity measures and the damage states of each bridge are explicitly considered. This set of simulations are used to estimate a probabilistic sensitivity measure called relative entropy which can provide importance ranking for all bridges in terms of their contributions towards the seismic risk of the network. Based on the importance ranking, three selection approaches are proposed to guide an effective search of the retrofit priorities rather than explore all combinations. The set of simulations are also used to efficiently evaluate the seismic risk for any given mitigation strategy through simply updating the probability of damage states of the retrofitted bridges and no additional simulations of the network model are required. The proposed approach is applied to effective seismic risk mitigation of the transportation network of Los Angeles and Orange counties.

Structural Sensitivity Analysis of Transmission Tower's Finite Element Model for Power Outage Prediction

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1165

Mrs. Jiayue Xue (University of Utah), Prof. Ge Ou (University of Utah), Ms. Yuanrui Sang (University of Utah), Prof. Mostafa Sahraei-ardakani (University of Utah)

Keywords: Sensitivity Analysis, Power Outage Under Hurricanes; Dynamic Analysis; Refined Finite Element Model

Hurricane is one of the main extreme weather events that causes a large blackout. This paper integrated the wind field information, structural vulnerability model and power system model to investigate the sensitivity of power outage on different transmission tower design capacities or failure thresholds.

To understand structural design and failure thesholds impact to transmission system failure probabilities, and the predicted power outage, nine transmission towers with different transmission voltage levels and locations are designed and modeled. The corresponding transmission towers' capacity curves are determined through nonlinear static pushover analysis, which provides different tower strength based on different failure thresholds. A series of fragility curves of transmission towers during a hurricane are generated based on these failure criterions.

Later, the failure probability of a transmission line, during a hurricane, is calculated based on 1) locations of transmission towers in a transmission line, 2) individual transmission tower fragility curve, and 3) wind field information (intensity and direction) of the hurricane. Eventually, the outage of the power system can be predicted by combining the failure conditions of transmission lines and a power network model. With a series of structural fragility curves of transmission towers, we aim on estimating the variation in the predictions of the transmission lines' failure conditions, as well as the variation in the predicted power outage. Two case studies are conducted to simulate the power system in Texas under Hurricane Harvey and in Florida under Hurricane Irma.

James Webb Space Telescope: Microvibration Predictions and Recent Test Results

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1012

Mr. Greg Walsh (NASA Goddard Space Flight Center), Mr. Michael Akkerman (Orbital ATK), Dr. Carl Blaurock (Nightsky Systems), Mr. David Guernsey (Orbital ATK), Dr. Parker Lin (Stinger Ghaffarian Technologies Inc), Mr. Evan Ruderman (University of Maryland, college park), Mr. Tony Sanders (Vantage Systems Inc)

The James Webb Space Telescope, operating with 6 reaction wheels and 2 cryo-cooler pumps, relies on passive vibration isolation to limit operational vibration on its 18 primary mirror segments to nano-meter displacement levels. Adding to the challenge, damping levels are expected to drop to as low as 0.02% of critical as optical components operational temperatures dip into the 20-30 Kelvin range. This paper describes the F.E. model based operational jitter predictions for JWST and the associated test program aimed at validating the complex JWST F.E. model consisting of approximately 7.3 million nodes. Data is presented showing the system damping levels as a function of temperature from room down to 25 Kelvin. Lastly, test data is presented for the highly sophisticated primary mirror assembly which shows the true nature of the primary mirror dynamics appears, at least in an air environment, to involve complex (and not normal) modes of vibration.

Evaluating Structural Behaviors of Connected Structures in an Integrated Academia-Industry Research Environment

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 595

Mr. Andrew Meier (Clakson University), Ms. Jill Porretta (University of Michigan, Ann Arbor, MI), Dr. Zhaoshuo Jiang (San Francisco State University), Dr. Jenna Wong (San Francisco State University), Dr. Juan Caicedo (University of South Carolina), Mr. David Shook (Skidmore, Owings & Merrill LLP), Mr. Ricardo Henoch (Skidmore, Owings and Merrill LLP), Ms. Joanna Zhang (Skidmore, Owings & Merrill LLP)

With a call in recent years to increase safety and enhance the value of emerging high-rise building clusters, skybridges as linking systems are attacking interest by urban designers and could play a key role in the development of our future cities. While the functional and economic benefits of the skybridges are realized, the effects of skybridges on structural systems are not widely understood. Researchers and practitioners in both academia and industry have been investigating the potential of the skybridge serving to increase the resiliency and sustainability of the connected structures. However, there is a significant gap between engineering science in academia and engineering practice in industry which has previously limiting the research outcomes from becoming built realities.
To address this important issue, San Francisco State University and University of South Carolina collaborated with industrial partners to establish a Research Experience for Undergraduates (REU) Site program, focusing on academia-industry collaborations in Smart Structure Technology (SST). Partnering with Skidmore, Owings & Merrill LLP, a world leader in designing high-rise buildings, this study sought to better understand how coupling behaviors between high rise structures using a skybridge affect various aspects of the individual structures. Extensive parametric data including modal information, displacement, shear, and overturning moment were gathered from typical high-rise structure models to evaluate structural performance under static and dynamic loading when the skybridge is installed at various locations along the height of the structures. Results confirmed the potential of using skybridges to improve the performance of the connected structures.

Engaging Undergraduate Students with Integrated Academia-Industry Research Experience in Topology Optimization

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 597

Ms. Alex Donner (Louisiana State University), Ms. Kaitlyn Chin (University of Michigan), Mr. Alec Maxwell (San Francisco State University), Dr. Zhaoshuo Jiang (San Francisco State University), Dr. Juan Caicedo (University of South Carolina), Ms. Haley Sims (Arup North America Limited), Mr. Nick Sherrow-Groves (Arup North America Limited)

Integrating topology optimization into the workflow of structural engineering projects is a challenge that many modern engineers face. The significance of including this critical step in the design process lies in important insights as to where building materials can be allocated to produce the most economic and efficient designs, an issue that resonates with many of the current movements toward more economical and sustainable structures. However, due to the lack of automated processes, implementation of topology optimization has often been simplified in such a way that hinders the true power of this tool.

Attempts have been made in both academia and industry to seek solutions to this problem. However, due to a significant gap between the engineering science in academia and engineering practice in the industry, research outcomes on each side are not typically leveraged. As an attempt to bridge this gap, San Francisco State University and University of South Carolina collaborated with industrial partners to establish a Research Experiences for Undergraduates (REU) Site program, focusing on academia-industry collaborations in Smart Structure Technology (SST). Through this effort, an automated topology optimization platform has been developed together with Arup, a world leader in the design of tall buildings. The developed platform harnesses the power and versatility of commercially available software packages to provide an automated solution to perform structural topology optimization under various case scenarios. A twisting high-rise building under wind excitations is used as an example to demonstrate the performance and robustness of the developed platform.

NSF REU with Integrated Academia-Industry Research Experience in Smart Structure Technology

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 599

Dr. Zhaoshuo Jiang (San Francisco State University), Dr. Juan Caicedo (University of South Carolina), Dr. Robert Petrulis (EPRE Consulting LLC)

With increasing demands for high performance in structural systems, Smart Structure Technology (SST) is receiving considerable attention as it has the potential to transform many fields in engineering.

Currently, there is a significant gap between the engineering science with fundamental research in academia and engineering practice with potential application in the industry. To respond to this challenge, San Francisco State University and University of South Carolina collaborate with industrial partners to establish a Research Experiences for Undergraduates (REU) Site program, focusing on academia-industry collaborations in SST. The program features innovative research experience through engagement in projects with scientific and practical merits in both academic and industrial environments. This REU program intends to (i) increase the diversity of professionals in the engineering field by recruiting a highly diverse student population, including underrepresented students, and encouraging them to pursue graduate-level training and careers in science and engineering; (ii) train students in both engineering science and engineering practice thereby producing mature, independent, informed, and globally competitive engineering graduates to meet the demand for skilled STEM professionals; (iii) establish a sustainable collaboration model between academia and industry that is designed for adoption/adaption throughout the various engineering disciplines.

In this work, the details of the program will be described together with feedback from the first year's implementation. The challenges and lesson-learned on the collaboration between the two participating universities, communications with industrial partners, recruitment of the students, setup of the evaluation plans, and development and implementation of the program will be discussed.

Amplifying Floor Vibrations Using a Resonator

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1376

Ms. Kaitlyn Faust (The University of Oklahoma), Mr. Justin Kim (Texas A&M University), Dr. Juan Caicedo (University of South Carolina), Dr. Zhaoshuo Jiang (San Francisco State University)

New techniques for the analysis of floor vibrations have been proposed with the purpose of determining activities such as people falling and gait characteristics. These new techniques provide an opportunity to expand the use of structural monitoring systems, usually designed to determine structural characteristics, to other disciplines such as healthcare.

This new techniques require sensing floor vibrations created by people walking or similar activities. These vibrations can be order of magnitude smaller than other activities used for structural monitoring. This paper proposes the use of a mechanical resonator to amplify these structural vibrations. Numerical and experimental studies in the mechanical resonator are performed. Results show that acceleration records can be amplified over 10 times with a single degree of freedom resonator. Challenges and opportunities related to signals collected from the resonator will be discussed during the presentation.

Damage Diagnosis for Historic Marine Infrastructure: Documentation, Numerical Modeling, and Structural Health Monitoring of Morris Island Lighthouse

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 475

Ms. Anna Blyth (University of Minho), Ms. Rebecca Napolitano (Princeton University), Prof. Branko Glisic (Princeton University)

Heritage structures embody engineering, historical, and architectural feats and serve as records for future generations provided that they are well documented and well maintained. Often historic structures come under the care of nonprofits or the governments who face funding constraints that dictate the extent of preservation and documentation. Thus, it is important to investigate the best tactics to obtain a complete structural assessment of a structure while conserving time and budget. This work aims to provide clear documentation of a successful analysis workflow for heritage preservation efforts through a case study on the Morris Island Lighthouse in South Carolina. In terms of documentation, a DJI Phantom 4 Pro drone was flown around the lighthouse to map existing crack patterns and other forms of damage. Additionally, aerial photogrammetry was used to document the as-built structure of the lighthouse. Using the as-built model of the structure, a simplified 3D model of the lighthouse was constructed. Diverse environmental loads such as earthquakes, wind, and waves were applied to the structure and the resulting crack patterns were calculated using distinct element modeling. In addition to understanding how the cracks formed on the structure, structural health monitoring was used to understand the stability of the lighthouse with the existing damage. Lastly, these heterogenous datasets were aggregated into a virtual tour and informational modeling environment composed of spherical panoramas for dissemination across the pertinent parties.

Exploring the Time-Dependence of Source Properties of Asperity-Type Foreshock-Like Events in a Rate-And-State Fault Model

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 598

Prof. Natalie Schaal (Loyola Marymount University), Mr. Junheng (Carl) Li (Loyola Marymount University)

Many earthquakes are preceded by observable foreshocks, which occur closely in both space and time to the mainshock that follows. The mechanism responsible for the occurrence of these smaller-scale precursory seismic events within the nucleating region of the mainshock is uncertain and, furthermore, the physical relationship between foreshocks and mainshocks is unknown. In this study, we explore the time-dependence of source properties from foreshock-like events that occur at asperities within a rate-and-state fault model. These fault asperities in the model are created by an elevated compression and produce smaller-scale seismic events within a larger-scale seismogenic region over multiple mainshock cycles. Our goal is to determine whether or not the protracted nucleation process of the mainshock, and thereby the relative timing of these smaller-scale events, affects the source properties of these precursory events. Utilizing the data from the long-term numerical simulations, our approach is to group smaller-scale seismic events into bins based on their relative timing within the recurrence interval of the mainshock, and to compare representative source property values between bins. Our preliminary results show that changes in rupture dimension late in the mainshock recurrence interval may indicate the advancement of the mainshock. If a trend in the properties of individual smaller-scale seismic events exists that can be observed, then this understanding could be a key ingredient in the potential for mechanics-based earthquake forecasting.

Simulation of failure mechanisms in wooden boards with knots as a basis for timber engineering design concepts

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 663

Dr. Markus Lukacevic (Vienna University of Technology (TU Wien)), Prof. Josef Füssl (Vienna University of Technology (TU Wien)), Prof. Josef Eberhardsteiner (Vienna University of Technology (TU Wien))

Increased use of wood has led to complex timber constructions and new types of wood-based products. In simulations, however, mainly simplified models are used to describe this material with strongly varying properties. Thus, to exploit the full mechanical potential of wood, a more accurate prediction of the mechanical behavior, especially when it comes to failure, is needed.

Therefore, we developed a multi-surface failure criterion, which is able to describe brittle and ductile failure mechanisms of wood, based on simulations on several length scales. Combined with a geometric reconstruction algorithm for knots, such a tool can be used to determine effective strength properties of knot sections. Due to the highly orthotropic failure behavior of wood and the strong variations of material directions close to knots, this task is very challenging. Widely used methods in fracture mechanics all have drawbacks when applied to such a material. For example, XFEM is limited by frequently occurring geometric incompatibilities, or the use of plasticity models easily encounters numerical problems due to the quasi-brittle nature of wood failure. Here, the emergence of the phase field method in recent years seems to be a promising solution for these problems.

Subsequently, such strength properties of wooden boards are condensed into so-called strength profiles. By applying this approach to a large set of wooden boards, probabilistic material models can be developed and used in simulations of wood-based products. Such a framework for sensitivity analysis and robust design optimization should help engineers to design efficient timber structures.

Multiscale modeling of the competition between mechanical damage and healing in salt polycrystals

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Oral - Abstract ID: 369

Ms. Tingting Xu (Georgia Institute of Technology), Dr. Chloe Arson (Georgia Institute of Technology), Mr. Xianda Shen (Georgia)

A micro-macro approach is developed to model the competition between damage and healing processes in salt polycrystals. We represent the polycrystal as an assembly of hollow spherical inclusions, which are split by three orthogonal weakness planes. Each inclusion is characterized by its initial pore size and its orientation. A self-consistent homogenization scheme is applied to calculate the mechanical properties of the Representative Elementary Volume (REV).

Damage accumulation is modeled as the propagation of mode I ring fractures along the weakness planes. Micromechanical stress concentration factors are modified to account for crack interactions, evaluated numerically with the Finite Element Method. A non-associative flow rule is adopted to update the inclusion damage tensor, defined as a crack density tensor. The damaged compliance tensor of the inclusion is calculated from micro-mechanical principles.

Due to pressure solution, solid salt dissolves along the fracture planes that are under compression, and precipitates at the pore wall, which acts as a sink. The reduction of the pore size increases the inclusion stiffness – a phenomenon called mechanical healing.

We then propose a closed formulation based on the self-consistent method to calculate the REV stiffness tensor for a uniform distribution of inclusion orientations. We also present a numerical algorithm to extend the homogenization scheme to an anisotropic matrix. The coupled micro-macro damage-healing model is calibrated and validated against published experimental data. Comprehensive sensitivity analyses are performed to characterize damage and healing regimes.

Pros and cons of the Mori-Tanaka scheme for modeling damage propagation due to biotite weathering in granite

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Oral - Abstract ID: 371

Mr. Xianda Shen (Georgia Institute of Technology), Dr. Chloe Arson (Georgia Institute of Technology), Dr. Sébastien Brisard (Université Paris-Est, Laboratoire Navier (UMR 8205))

Biotites are silicate sheets connected by potassium cations. In the presence of water, the interlayer of potassium cations is replaced by hydrated exchangeable cations, inducing an expansion of the biotite minerals. The goal of this study is to formulate a multi-scale approach to predict micro-crack propagation induced by these stress concentrations. Specifically, we discuss the feasibility of using the Mori-Tanaka homogenization scheme to model damage propagation induced by biotite weathering in granite.

The granite Representative Elementary Volume is a continuous matrix that contains ellipsoidal biotite inclusions. Eigenstrains are introduced in the inclusions to simulate biotite chemical expansion. The matrix is assigned a Continuum Damage Mechanics constitutive model, in which damage propagates beyond a given strain threshold. Sensitivity analyses indicate that damage propagation depends on biotite volume fraction and orientation relative to the loading directions.

The proposed homogenization scheme presents some limitations: (i) Biotite inclusions are assumed to be ellipsoidal; (ii) Inclusion size effects cannot be accounted for; (iii) The stress and strain fields in the matrix are assumed to be uniform. To check whether these limitations affect the prediction of the macroscopic response of weathered granite, we simulate the expansion of biotite inclusions of various shapes and sizes embedded in a continuous matrix, using Janus, a code that discretizes the Lippmann–Schwinger equation with periodic boundary conditions and solves for local field variables based on the Fast Fourier Transform (FFT) method. We compare Mori-Tanaka and FFT results and discuss the impact of the assumptions made in the homogenization scheme.

Modeling the anisotropic behavior of natural rock salt during creep tests using dislocation density-based crystal plasticity

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Oral - Abstract ID: 665

Dr. Timothy Truster (University of Tennessee), Mr. Amirsalar Moslehy (University of Tennessee), Mr. Sunday Aduloju (Un), Prof. Khalid Alshibli (University of Tennessee)

Rock salt, a sedimentary rock classified as an evaporate, forms as a result of evaporation of inland seas or any enclosed bodies of water and can be found in nature as bedded or domal formations. Salt caverns within underground salt deposits can potentially serve as a long-term and safe repository for carbon dioxide, nuclear waste, and the waste of oil drilling operations. Also, drilling through rock salt to reach oil reservoirs poses many challenges. The accuracy with which the fracture behavior of any material can be simulated, including geological materials like rock, hinges upon the fidelity of both the engineering model and the geometrical representation of the cracked body. The anisotropic response of rock salt during creep deformations is stress and temperature dependent, and the accumulated creep strain influences fracture nucleation. A key limitation of existing phenomenological creep models is that rock salt's anisotropic response is not represented at the microstructural level. Our proposed research thrust is to combine nondestructive 3D x-ray diffraction (3DXRD), 3D synchrotron micro-computed tomography (SMT) in-situ experimental measurements, and 3D crystal-plasticity modeling to enhance current understanding of creep, crack formation and growth mechanisms in polycrystalline rock salt. A dislocation density-based crystal plasticity model is introduced then to capture the anisotropic creep strain of rock salt. The present work summarizes experimental results from confined and unconfined tests across a range of temperatures and validates the introduced crystal plasticity model against the measured creep response.

A multiscale FE-FFT approach for modeling crack initiation and propagation in polycrystalline rock salt

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Oral - Abstract ID: 738

Dr. Ran Ma (Columbia University), Prof. Wai Ching Sun (Columbia University)

Rock salt formations are widely considered as potential sites for underground repositories for nuclear wastes due to the low permeability and high thermal conductivity. Nevertheless, the nearly impermeable rock salt may exhibit material failures, such as strain localization and fractures such that leakage may occur within the excavation distributed zone. Crack initiation and propagation within these regions are difficult to predict using conventional damage-plasticity model, due to the anisotropic nature originated from the microstructures of the polycrystal salt. While the phase field fracture model may be effective to reproduce complex fracture patterns at small scales, the length scale material parameter nevertheless limits the mesh size and hence not suitable for field-scale simulations. In this work, we provide an FE-FFT multiscale method for polycrystal rock salt. In the microscale, a fast Fourier transform (FFT) based method is employed to explicitly model the interaction between microcrack and grain boundary, while the microscale quantities are homogenized to investigate the macroscale damage distribution within bulk rock salt. By introducing modification on the Hill-Mandel lemma for the phase field energy-conjugate pair, we introduce upscaling procedure such that the anisotropic responses can be captured. Numerical examples on polycrystal are used to demonstrate the accuracy, robustness, and efficiency of the proposed scheme.

Material Point Method for Beam Structures with Frictional Contact

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1233

Dr. Jingu Kang (Lawrence Livermore National Laboratory), Dr. Michael Homel (Lawrence Livermore National Laboratory), Dr. Eric Herbold (Lawrence Livermore National Laboratory)

Highly slender components such as rods, beams, and shells, are encountered frequently in various engineering applications. Using continuum solid elements to simulate the flexural behavior of these slender materials leads to extremely expensive computations and is still not economically feasible in the existence of numerous beam components.

In this research, a new particle type is developed to represent beam elements in the context of Material Point Methods (MPM). The MPM is being used to solve dynamic solid mechanics problems including those with large deformations and impact contact responses. A solid body is discretized into a finite set of Lagrangian material points, called particles. The continuum equations of motion are solved on a fixed Eulerian background grid. The current work extends second-order convected particle domain interpolation (CPDI2) MPM, which tracks particle domains as hexahedra in 3-D. The beam particle developed herein behaves like a beam and has three translational and three rotational degrees of freedom in 3D. The position of the beam particle is defined by the position vectors at the centroid of the particle domain. The rotation of the beam element is obtained by updating angular accelerations and velocities on the grid traditionally used to update linear momentum. In addition, a new contact model is developed for beam elements. Such beam elements are non-volumetric, which is a challenge to detecting collision and contact. To address this, we introduce phantom nodes representing the spatial extent of the beam, which allow for lateral impact contact with frictional slip between beam elements.

Implementation and Validation of a Liquefiable Soil Model in LS-DYNA

Wednesday, 19th June - 09:30: Poster Display (Beckman Mall) - Poster - Abstract ID: 1282

Dr. Kevin Stanton (Arup), Dr. Yuli Huang (Arup)

Liquefaction refers to the phenomenon in which excess pore water pressure reduces the contact pressure between grains of sandy soil (and thereby reduces the shear strength) causing global behavior to resemble that of a liquid. Efforts to capture the onset of liquefaction as well as the behavior of soils after they liquefy have revealed that this is a physically complex problem involving many factors. This paper presents validations for an implementation of a new material model in the finite element program LS-DYNA. The material formulation is based on a model proposed by Taiebat and Dafalias (2008) known as SANISAND and is designed to simulate the behavior of liquefied soils. The name refers to a family of Simple ANIsotropic (SAND) constitutive models within the frameworks of critical state soil mechanics and bounding surface plasticity. The model renders the slope of the dilatancy stress ratio (i.e. the phase transformation line) such that, at the critical state, the dilatancy stress ratio coincides with the critical state failure stress ratio. The bounding surface formulation enables cyclic loading response simulation. The model also accounts for inherent anisotropy effects and the effects of fabric changes during the dilatant phase of deformation on the subsequent contractive response upon load increment reversals. By limiting the compression curve and employing a properly closed yield surface, the model predicts plastic strains during any type of constant stress-ratio loading. This implementation is successfully validated against empirical data from a simple shear test performed in a centrifuge for the VELACS test program.

Nonlinear Finite Element Model Updating of Partially Identifiable Models Using Bayesian Filtering

Wednesday, 19th June - 10:30: MS80 - Structural Identification and Damage Detection; Part 1 (Ramo (371)) - Oral - Abstract ID: 1422

Mr. Mukesh Kumar Ramancha (University of California, San Diego), Mr. Ramin Madarshahian (University of California, San Diego), Dr. Rodrigo Astroza (Universidad de los Andes), Prof. Joel Conte (UC San Diego)

Model updating by combining nonlinear mechanics-based Finite Element (FE) models with advanced Bayesian inference methods has emerged as a powerful technique for structural health monitoring and damage prognosis of complex civil infrastructure systems. However, for the precise inference to be possible, the selected model must be identifiable. The non-identifiability might result in non-unique parameter estimates when the inference is performed using Bayesian point estimation techniques such as Kalman filters. This work first employs the unscented Kalman filter (UKF), an advanced nonlinear Bayesian filtering method, to update (using simulated noisy input and output seismic measurement data) material constitutive model parameters of a 2D plane strain nonlinear FE model of Pine Flat dam (a concrete gravity dam on King's River near Fresno, California). Non-unique parameter estimates yielding the same earthquake response prediction are observed because of structural non-identifiability of the selected model. To decipher the non-unique UKF estimates, Bayesian inference is also performed using Markov chain Monte Carlo methods to explore the joint posterior probability distribution of the parameters. A flat peak in the posterior distribution of the compensating parameters was observed (due to structural non-identifiability of the model) and all the non-unique estimates of the UKF correspond to the peak of the posterior. A local identifiability analysis using Fisher Information Matrix (FIM) is then performed to rank the parameters according to their identifiability. The subsets of FIM are also analyzed to identify the compensating parameters. The non-identifiable parameters are then removed from the estimation phase resulting in unique UKF estimates.

Non-Convexity in Finite Element Model Updating Problems

Wednesday, 19th June - 10:45: MS80 - Structural Identification and Damage Detection; Part 1 (Ramo (371)) - Oral - Abstract ID: 133

Dr. Yang Wang (Georgia Institute of Technology)

Finite element (FE) model updating is known to fine-tune parameter values of an FE model so that the model generates properties close to these from field measurements. In order to perform updating, an optimization problem is usually formulated to minimize the difference between the simulated properties and the measured properties. When an optimization problem is non-convex, solution algorithms in general cannot guarantee finding the global optimum. A local minimum is usually taken as the solution, without providing any knowledge on how close the local minimum is to the global minimum. While finite element (FE) model updating has been widely applied for decades, little has been investigated regarding the non-convexity of the associated optimization problem. This presentation will start by investigating a few example structures to reveal the degree of nonconvexity that exists in FE model updating problems.

Model Updating and Modeling Error Estimation of Nonlinear FE Models through a Sequential Bayesian Filtering Approach

Wednesday, 19th June - 11:00: MS80 - Structural Identification and Damage Detection; Part 1 (Ramo (371)) - Oral - Abstract ID: 909

Mr. Mingming Song (Tufts University), Dr. Hamed Ebrahimian (SC Solutions, Inc.), Dr. Babak Moaveni (Tufts University), Prof. Costas Papadimitriou (University of Thessaly)

A sequential Bayesian filtering approach is proposed for model updating and modeling error estimation of nonlinear dynamic systems of civil structures based on a sequential maximum a posteriori (MAP) estimation approach. The proposed algorithm is capable of estimating time-invariant model parameters and the parameters of model-prediction errors, e.g., mean and covariance of errors. The sequential filtering approach can be applied either in a data-point manner (similar to the classic Kalman filter), or in a windowing manner (sequential windows with/without overlap) to speed up the updating process and reduce the computation effort. The mathematical formulation of the method is first presented in the paper and then numerically applied to a nonlinear cantilever steel pier. A mechanics-based nonlinear finite element (FE) model of the cantilever steel pier with unknown time-invariant parameters for steel constitutive model is created for demonstration of the proposed algorithm. The acceleration measurement at the top of the cantilever pier subjected to an earthquake excitation is simulated using the true nonlinear model and polluted with noise. Then a similar nonlinear FE model with modeling errors in the boundary condition at the base of the pier is created for model updating. The proposed sequential Bayesian filtering is implemented to estimate the model parameters and modeling errors using the simulated time domain input-output data.

Bayesian Operational Modal Analysis Based on Modal Component Sampling

Wednesday, 19th June - 11:15: MS80 - Structural Identification and Damage Detection; Part 1 (Ramo (371)) - Oral - Abstract ID: 596

Dr. Heung Fai Lam (Department of Architecture and Civil Engineering, City University of Hong Kong), Dr. Jia-Hua Yang (Department of Disaster Mitigation for Structures, College of Civil Engineering, Tongji University), Prof. Jim Beck (California Institute of Technology)

A Bayesian operational analysis method based on modal component sampling is developed in this paper. This method can efficiently identify the modal parameters of civil engineering structures under operational conditions even when the number of measured degrees of freedom is large. The mathematical model of a dynamic system is constructed with the modal parameters being the system parameters and the posterior PDF of the modal parameters is formulated using Bayes theorem. Bayesian modal analysis is conducted through generating samples of the modal parameters in the important regions of the posterior PDF. The modal component sampling algorithm is tailor made to efficiently generate samples of modal parameters from the high-dimensional posterior PDF. Sampling is conducted iteratively among different modal components, so that the problem dimension can be reduced. This paper first discusses the theoretical development of the proposed method. Experimental verification under laboratory conditions is then presented. Applications of the proposed method for operational modal analysis of full-scale structures are also covered. Interesting dynamic properties of the target structures were obtained. The experimental studies show good performance of the proposed method.

Robust Bayesian Optimal Experimental Design for Structural Identification and Response Predictions

Wednesday, 19th June - 11:30: MS80 - Structural Identification and Damage Detection; Part 1 (Ramo (371)) - Oral - Abstract ID: 901

Prof. Costas Papadimitriou (University of Thessaly), Ms. tulay ercan (University of Thessaly)

Optimal experimental design (OED) techniques provide guidance on the test to be performed in order to maximize the amount of information contained in the measurements for accomplishing the goals for which the experiments are set up. Such goals include the selection of the most appropriate physics-based models to simulate a system, its subsystems and their components, the estimation of the parameters of the models, the improvement in the confidence of the predictions caried out by the models, as well as the reliable identification of damage (location and severity). A Bayesian framework for optimal experimental design in structural dynamics is developed which is suitable in addressing these goals. The information contained in the data is measured using information-based measures such as mutual information, Kullback-Leibler divergence and relative entropy. The optimal design is based on an expected utility function (EUF) formed from these measures. The EUF is extended to make the OED design robust to uncertainties in model selection, structural model parameter and modelling errors. The design variables include type, location and number of sensor, as well as type, location and excitation characteristics (e.g. frequency content and amplitude) of actuators. Theoretical and computational aspects for estimating the multidimensional integrals arising in the formulation of the expected utility function are addressed using sampling techniques and asymptotic approximations. The framework is demonstrated using selected applications from structural dynamics. Acknowledgements: The author gratefully acknowledge the European Commission for its support of the Marie Sklodowska Curie program through the ETN DyVirt project (GA 764547).

Bayesian Information Fusion for Fatigue Crack Growth Diagnosis Using Lamb Wave Scattering

Wednesday, 19th June - 11:45: MS80 - Structural Identification and Damage Detection; Part 1 (Ramo (371)) - Oral - Abstract ID: 839

Dr. Pranav Karve (Vanderbilt University), Prof. Sankaran Mahadevan (Vanderbilt University)

Guided ultrasonic wave NDE methods to detect fatigue cracks in metallic structures has been shown to be a promising methodology for aerospace and structural engineering applications. However, these methods are prone to inaccuracies due to aleatory uncertainty in system parameters as well as physics model discrepancy. Probabilistic treatment of the diagnosis faces two key challenges: a large parameter space, and computationally expensive numerical models of the governing physics. In this work, we discuss a probabilistic crack diagnosis framework to overcome the aforementioned challenges; and to tackle the aleatory and epistemic uncertainties in the process. We build a Bayesian network that describes a Lamb-wave pitch-catch NDE method using a low-fidelity, physics-based model of the same. We perform global sensitivity analysis to quantify the contribution of various parameters to the variance of the damage-sensitive features using this model. We retain the parameters with higher contribution, and build a medium-fidelity, one-way coupled, multi-physics (piezoelectric effect, wave mechanics) finite element model. We use the finite element model to generate training data to train a Gaussian process (GP) surrogate model that can output the damage sensitive signal feature for given values of pertinent system parameters. We use the GP surrogate to perform Bayesian diagnosis of crack growth considering data corrupted by measurement and process noise. We fuse the information obtained from various actuator-sensor paths in a PZT network to sequentially update the crack growth estimate. The proposed Bayesian estimation and fusion method can potentially improve the performance of Lamb-wave pitch-catch NDE methods for metallic structures.

A Data-Driven Machine-Learning Framework for Intelligent Self-Aware Aerospace Systems

Wednesday, 19th June - 10:30: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 1322

Prof. Fotis Kopsaftopoulos (Rens)

The next generation of intelligent aerospace systems and aerial vehicles will be able to "feel", "think", and "react" in real time based on high-resolution state-sensing, awareness, and self-diagnostic capabilities. They will be able to observe phenomena at unprecedented length and time scales allowing for improved performance, adaptability, autonomous operation, increased safety, reduced mission costs, and complete life-cycle monitoring and management. One of the main challenges of the current state-of-the-art research is the development of technologies that will lead to autonomous self-aware aerial vehicles able to (i) sense the external environment (temperature, humidity, etc.), (ii) sense their flight and aeroelastic state (airspeed, angle of attack, aerodynamic loads, etc.) and internal structural condition (stresses, damage), and (iii) effectively interpret the sensing data to achieve real-time state awareness and health monitoring.

The aim of the present study is the introduction and critical assessment of data-driven machine-learning (ML) framework for self-aware aerospace systems. The cornerstone of the proposed approach lies on the use of a functionally-pooled time-series-model representation that drives the ML scheme. The experimental evaluation and assessment is based on a simulated data and a series of wind tunnel experiments under varying operating and structural states. The recorded signals are subsequently used for the stochastic identification of the structural and aeroelastic response via "global" Vector-dependent functionally pooled (VFP) models. These models are used in the first phase of the ML framework in order to provide "explainable" statistical features. Next, a supervised ML approach enables the real-time structural awareness and monitoring of the system.

A Sampling Method for Structural Reliability Assessment Based on Deep Reinforcement Learning

Wednesday, 19th June - 10:45: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 145

Mr. Zhengliang Xiang (Harbin Institute of Technology), Prof. Yuequan Bao (Harbin Institute of Technology), Mr. Zhiyi Tang (Harbin Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

The prediction accuracy of surrogate model for structural reliability assessment is heavily determined by the selection of the representative samples used to train the surrogate model. Most sampling methods try to fill the sampling space with representative samples, and the surrogate model may lose accuracy around the limit state surface, which is the key area in sample classification. Therefore, a new sampling method is needed to select representative samples along the limit state surface and increase the accuracy of the surrogate model in this area. Deep reinforcement learning (DRL) is an area of machine learning, which is widely used recently. Such as the *AlphaGo Zero* software application uses DRL to conduct sampling optimization. Inspired by this, we propose a sampling method based on DRL, which uses DRL to select representative samples. The proposed process for sampling is as follows. First, the sampling space and the existing samples are transformed into an array that is treated as the *state*. Second, a deep neural network is designed as the *agent* to observe the sampling space and select new representative samples, which are treated as *actions*. Finally, a *reward function* is proposed to guide the deep neural network to select representative samples along the limit state surface. Two numerical examples demonstrate that the proposed method learns to select representative samples along the limit state surface. The results show that the proposed method can achieve higher accuracy than the uniform sampling method in sample classification and structural reliability assessment.

Semi-Supervised Structural Damage Detection Using Sparse Identification

Wednesday, 19th June - 11:00: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 284

Dr. Zhilu Lai (Rice University / ETH-Zürich), Prof. Satish Nagarajaiah (Rice University), Prof. Eleni Chatzi (ETH-Zürich)

As a useful class of techniques for structural health monitoring, vibration‐based structural damage detection has been intensively studied in the civil engineering community for decades. Structural damage is commonly treated as a local linear stiffness reduction, which may not account for nonlinear damage, as is typically the case for real world structures. Characteristic instances of such nonlinearity include plastic deformation, cracking, and loose connections. Methods relying on machine learning, such as novelty detection or supervised classification‐based methods have been used for nonlinear damage detection, but in most cases a direct physical interpretation of the damage cannot be accessed.

To address this limitation, this work aims to deliver a framework for detecting and physically characterizing linear/nonlinear‐type structural damage in a semi‐supervised way. The proposed method adopts a previously proposed sparse identification algorithm to establish a baseline (undamaged) model. Then, damage is considered as a variation of restoring forces in the structural system, or alternatively assumed as a pseudo force acting on structural system. The damaged system is then transformed into a superposition of an equivalent linear system and a nonlinear restoring force term. By comparing the corresponding outputs from the prediction of the baseline model and the newly acquired data, a variation of the mass‐normalized restoring (pseudo) force is identified, which can be used for further damage characterization. An illustrative numerically simulated example and an experimental case study of a small-scale wind turbine blade are overviewed in this work to verify the effectiveness of the proposed method.

Probabilistic Fault Diagnostics Using Ensemble Time-Varying Decision Trees Learning

Wednesday, 19th June - 11:15: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 639

Dr. Imad Abdallah (ETH Zurich), Dr. Vasilis Dertimanis (ETH), Prof. Eleni Chatzi (ETH Zurich)

In the context of optimized Operation & Maintenance of wind energy infrastructure, it is important to develop decision support tools, able to guide operators and engineers in the management of these assets. This task is particularly challenging given the multiplicity of uncertainties involved, from the point of view of the aggregated time-varying data, the available knowledge with respect to the wind turbine structures, and sub-components, as well as the constantly varying operational and environmental loads. Wind turbines are equipped with sensors monitoring structural, electrical and mechanical components. The first problem is, at time t, to predict which readings will be reported in the future $t+i$ taking into account readings before time$t$, in the hope of diagnosing precursors to faults before they occur. The second problem is to discover (either online in real-time or offline) the root causes or sequence of events that lead to faults when they occur. We propose a supervised ensemble Bagged decision tree classification algorithm to diagnose time-varying faults, errors, damage, patterns, anomalies, abnormal operation, and perform automated root cause discovery. The use of decision trees is motivated by the fact that they tend to be easier to implement and interpret than other quantitative data-driven methods. We demonstrate the method on a toy example of a wind turbine undergoing simulated turbulent wind loading in the Matlab/Simulink environment. Various faults scenarios are simulated by injecting fault conditions and respective patterns into the sensor model, actuator model, control model or system dynamics.

Deconvolution Seismic Interferometry-Based Monitoring of Short Masonry Structures

Wednesday, 19th June - 11:30: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 762

Dr. Debarshi Sen (Massachusetts Institute of Technology), Prof. Hao Sun (Northeastern University), Mr. James Long (Massachusetts Institute of Technology), Prof. Oral Buyukozturk (Massachusetts Institute of Technology)

Continuous monitoring of infrastructure systems is essential for detecting damages in a timely manner in order to avert catastrophic failure events. Structural health monitoring (SHM) entails the deployment of an array of sensors on a structure of interest, structural response acquisition, followed by condition assessment based on the acquired data. In recent years, deconvolution seismic interferometry has emerged as an effective approach for continuous monitoring of structures. This approach estimates the impulse response functions (IRFs) of the structure as a function of its height from structural response data, for characterizing structural dynamic properties. From the IRFs, we can estimate the variation in velocities of propagating waves in the structure, when it is subjected to external excitation. We use these changes as a metric to measure damage in the structure. This approach has been successfully implemented for tall steel or reinforced concrete structures. In this paper, we focus on short masonry structures. This work is motivated by the monitoring of historic masonry structures that are affected by oil and gas exploration induced seismic loads. The short height and stiffness properties of these structures pose new challenges for implementing this approach. We use data from shaking table tests on a two-story full-scale masonry structure as well as long-term field measurements, and demonstrate the efficacy of the methodology in detection of structural changes (e.g., damage).

Machine Learning on Large Guided Wave Structural Health Monitoring Data Sets

Wednesday, 19th June - 11:45: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 908

Prof. Joel Harley (University of Florida), Mr. Kang Yang (University of Florida), Dr. Sungwon Kim (University of Utah)

Structural health monitoring systems can collect large, nearly continuous streams of data over years of time. This data is important to better understand structural integrity and structural variations from use and aging. Yet, analyzing large data streams can be a challenge, particularly with limited computational resources. For guided wave data, this challenge is exacerbated since each measurement consists of a high frequency ultrasonic waveform that is rich with information. As a result, there are few studies that examine guided wave behavior over extended periods of time.

This work studies various machine learning and data science techniques applied to guided wave data from more than one year of time. We discuss strategies based on random projection theory for analyzing the data without the need for a supercomputer framework. We then study several machine learning and data science techniques for learning about trends and characteristics of the data. These techniques include correlation analysis, matrix decomposition techniques, clustering methods, and neural network-based data mining.

We apply these computational techniques to more than 1 TB of guided wave data from a 0.53 m by 0.53 m aluminum plate in outdoor conditions in Salt Lake City, UT. Over a year, the plate is subjected to sun, rain, ice, and other uncontrolled environmental variations that alter the data. We study how these environmental variations affect the data. Synthetically produced realistic damage signatures are then mixed into the data. We show that we can isolate the effects of these signatures through our data analysis methods.

Quantifying Uncertainty in Structural Reliability Estimates in the Presence of Sparse Data

Wednesday, 19th June - 10:30: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 494

Prof. Michael Shields (Johns Hopkins University), Dr. Dimitrios Giovanis (Johns Hopkins University)

Over the past several decades, major advances have been made in probabilistic methods for assessing structural reliability. However, a key-point of these methods is that probability models of random variables are assumed to be known precisely. Moreover, it is often assumed that a unique mapping exists such that reliability calculations can be performed in the space of standard normal random variables. When data are scarce though, this assumption is clearly not valid since one cannot identify a unique probability distribution that fits the data. This fact introduces uncertainty into the estimation of the probability of failure. In this work, we proposed a method to realistically assess the uncertainty in probability of failure estimates using the First Order Reliability Method (FORM) when data are sparse. Multimodel Bayesian and information theoretic inference methods are utilized in order to address the problem of uncertainty quantification and propagation when data for characterizing probability distributions are scarce. These methods are applied to identify (1) a set of plausible candidate probability densities and the associated probabilities that each model is the "best" model; and (2) the joint parameter densities for each plausible model. The full set of candidate probability models is then utilized in a FORM analysis that leverages an efficient importance sampling reweighting scheme. The result is an imprecise estimate of probability of failure in the form of probabilities of probabilities that allows us to probabilistically bound our reliability estimates and therefore adequately assess our confidence (or lack thereof) in these estimates.

Stochastic Sensitivities Across Scales and Physics

Wednesday, 19th June - 10:45: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 716

Mr. Zhiheng Wang (University of Southern California), Prof. Roger Ghanem (University of Southern California)

The polynomial chaos expansions (PCE) provide stochastic representations of quantities of interest (QoI) in terms of a vector of standardized random variables that represents all uncertainties that influence the QoI. These uncertainties could reflect statistical scatter in estimated probabilistic model (of which the mean, variance, or PCE coefficients are but examples), or errors in the underlying functional model between input and output (eg physics models). In this presentation, we will show how PCE permit the evaluation of sensitivities with respect to all the uncertainties, provide a rational paradigm for resource allocation aimed at model validation. We will demonstrate the methodologies on examples drawn across science and engineering.

A Computational Framework for Regional Earthquake Loss Estimation

Wednesday, 19th June - 11:00: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 739

Dr. Wael Elhaddad (NHERI SimCenter, University of California, Berkeley), Dr. Frank McKenna (NHERI SimCenter, University of California, Berkeley), Dr. Michael Gardner (NHERI SimCenter, University of California, Berkeley), Dr. Adam Zsarnóczay (NHERI SimCenter, Stanford University), Dr. Matthew Schoettler (NHERI SimCenter, University of California, Berkeley), Dr. Chaofeng Wang (NHERI SimCenter, University of California, Berkeley), Prof. Sanjay Govindjee (NHERI SimCenter, University of California, Berkeley), Prof. Gregory Deierlein (NHERI SimCenter, Stanford University)

A major challenge in natural hazards engineering is the determination of the effects of a given natural event on an entire region. Regional impact estimates of this type are central to effective planning efforts by city and regional planners. For maximum utility, these estimates need to be conducted at as fine a scale as is practically possible. In this presentation we describe a computational framework that was developed at the NSF NHERI SimCenter to study the effects of natural hazards on communities at a regional scale. The modular and extensible framework allows researchers to simulate the response of structures using multiple fidelity models and perform damage and loss estimation for all structures in a region of interest. These large-scale simulations provide aggregated and granular damage and loss estimates for the region taking into account both the uncertainty in the structural material properties and the loading on the structures due to the natural hazard.

Two testbed simulations demonstrate the capability of the framework: one for the San Francisco Bay Area subjected to a synthetic magnitude 7.0 earthquake and another for the magnitude 7.0 earthquake in Anchorage, Alaska that occurred on November 30, 2018. These simulations demonstrate the workflow which couples the finite element modeling software OpenSees with the uncertainty quantification software DAKOTA. The extensibility of the framework is demonstrated by characterizing the earthquake hazards using different models, viz. seismic hazard analysis and stochastic earthquake loading models. Results from both regional studies are compared to damage and loss estimates obtained using HAZUS.

Surrogate Based Sensitivity Analysis of Models with High-Dimensional Outputs

Wednesday, 19th June - 11:15: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 838

Ms. Min Li (Colorado State University), Prof. Gaofeng Jia (Colorado State University)

Sensitivity analysis has been widely used to quantify the impact of uncertain inputs on model outputs. Typically, sensitivity analysis requires large number of model evaluations. This poses significant challenge to sensitivity analysis for computationally expensive/demanding system models. On the other hand, when the outputs of the expensive models have extremely high dimensions, sensitivity analysis for such system models has additional challenge in high computational effort and memory requirements. To address these challenges, an efficient dimension reduction and surrogate based approach is proposed. In this approach, surrogate model is used to replace the expensive model for efficient sensitivity analysis. To ease the additional computational burden caused by high-dimensional outputs, a dimension reduction technique is applied to transform the original high-dimensional outputs to low-dimensional latent outputs. To carry out the sensitivity analysis, the surrogate model is first constructed in low-dimensional latent output space and used to calculate the relevant covariance matrices for the low-dimensional latent outputs. These covariance matrices are then used with the derived transformation to efficiently establish the sensitivity indices for the original high-dimensional outputs. To demonstrate the accuracy and efficiency of the proposed approach, two examples will be presented. In the first example, an analytical function with high-dimensional outputs is used to validate the proposed method. The second example applies the proposed approach to investigate the sensitivity of peak water level over large coastal regions in San Francisco Bay with respect to the construction of levees at different counties under projected sea level rise.

Multi-Fidelity Gaussian Process Model Integrating Low-Fidelity Data and High-Fidelity Data Considering Censoring

Wednesday, 19th June - 11:30: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 844

Ms. Min Li (Colorado State University), Prof. Gaofeng Jia (Colorado State University)

For engineering problems where a large number of model evaluations are needed, direct adoption of expensive high-fidelity models is impractical. Efficient surrogate models built based on a set of high-fidelity training data have been proposed. However, the number of high-fidelity data is often limited by cost and/or time, which might result in compromised accuracy of the surrogate model. In addition, in many engineering applications, the outputs of high-fidelity models are not always the exact values of interest; rather, the outputs correspond to censored data. This work proposes a general multi-fidelity Gaussian process model with explicit consideration of censoring in data. To alleviate the cost associated with establishing high-fidelity data, the proposed model integrates a small number of expensive high-fidelity data and a large number of cheap low-fidelity data. The model parameters are established using Bayesian updating. Data augmentation algorithm is adopted to address computational challenge in estimating the likelihood function when considering censored data. Closed form conditional posteriors are derived for all the model parameters. Samples are then efficiently generated from the posterior distributions using Gibbs sampling to establish posterior statistics for the model parameters and the resulting model predictions. To validate the effectiveness and efficiency of the proposed model, the proposed model is used to establish a predictive model for the deformation capacity of reinforced concrete columns using a limited number of high-fidelity experimental data (the majority of which are censored data) and a large number of low-fidelity data established from analytical and numerical modeling.

Adaptive Design of Experiments for Kriging Metamodeling Through Cross-Validation Information

Wednesday, 19th June - 11:45: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 882

Mrs. Aikaterini Kyprioti (University of Notre Dame), Dr. Alexandros Taflanidis (University of Notre Dame)

Kriging has emerged as a popular metamodel (surrogate model) for uncertainty quantification (UQ) applications. Part of its popularity can be attributed to its probabilistic features and the fact that it provides an estimate for the variability of its predictions, what is frequently referenced in the literature as Kriging predictive variance. This variance is commonly leveraged in the design of experiments (DoE) informing the metamodel development, establishing an adaptive DoE where the current metamodel informs what additional experiments provide greater expected utility. Beyond the predictive variance, the metamodel bias, corresponding to the error of the predictive mean, also provides useful information for any DoE strategy. Evidently utility of new experiment is higher in input domains where the bias is large. As this bias is unknown, though, leveraging such information requires some form of an approximation. This contribution investigates how leave-one-out cross-validation (LOOCV) can be used to inform the adaptive DoE. Information from both the predictive variance and LOOCV squared error are combined and emphasis is placed on computational efficiency, so that the additional burden through the incorporation of the LOOCV information is small. Discussion of the advantages of combining both the predictive variance and LOOCV are also offered, focusing on overestimation of error at the boundary when predictive variance is ignored. The benefits of the adaptive DoE are showcased through implementation to storm selection for hurricane risk assessment applications. Comparison extends to both the accuracy of the metamodel itself as well as to the risk predictions facilitated through the metamodel.

Application of the Tuned Inerter Technology to Wave Energy Converters

Wednesday, 19th June - 10:30: MS59 - Innovations and Advances in Passive Structural Control; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 243

Ms. Momoka Inoue (University of Tsukuba), Ms. Ruriko Haraguchi (University of Tsukuba), Ms. Ryoko Sawada (University of Tsukuba), Mr. Keita Sugiura (University of Tsukuba), Prof. Takehiko Asai (University of Tsukuba)

Passive vibration control devices with the tuned inerter have been introduced for civil structures subjected to external loadings such as earthquakes. The effectiveness has been shown and tuned inerter devices have gotten more attention recently. This idea utilizes a tuning spring, damper, and rotational mass which produces an amplified mass effect due to a ball screw mechanism, i.e., inerter. These three components are attached to the primary structure system and by designing the stiffness of the tuning spring so that the amplified mass is in tune with the primary system, significant energy dissipation of the damper can be achieved.In this study, we propose a novel point absorber wave energy converter with the tuned inerter, which is capable of significantly increasing the energy absorption and broadening the effective bandwidth. Considering typical point absorbers modeled as a mass-spring-dashpot system with a linear damper used as the power take-off (PTO) system, the application of the tuned inerter can be expected to have a significant effect in terms of energy absorption. In this research, numerical simulation under random sea waves and wave tank experiment of a small-scaled prototype under regular waves are conducted to verify the performance of the proposed device. The amplitude response and power generation performance are compared with the conventional point absorber. It is shown that by applying the tuned inerter, the power generation is dramatically enhanced compared to the conventional point absorber, while the effective bandwidth is broadened at the same time.

Earthquake Response Analysis of Structures Equipped with Inerters

Wednesday, 19th June - 10:45: MS59 - Innovations and Advances in Passive Structural Control; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 320

Prof. Nikolaos Makris (Southern Methodist University), Mr. Gholamreza Moghimi (Southern Methodist University)

This study investigates the seismic response of a two-degree-of-freedom structure with supplemental rotational inertia at its first story. The proposed response modification strategy employs an inerter–a mechanical device that its resisting force is proportional to the relative acceleration between the first story and the ground. This arrangement complements the traditional supplemental damping strategies, also examined in this work. The paper develops a time-domain and a frequency-domain formulation for the response analysis and shows that the seismic protection of structures with supplemental rotational inertia suppresses effectively inter-story drifts at the expense of transferring appreciable forces at the support of the inerter. Both cases of a single inerter and pair of inerters that can only resist the motion of the structure are examined. The paper proceeds by examining to what extent a compliant support of the inerter affects the dynamics of the structure and concludes that as the compliance of the support frame increases, a single inerter may lead to more favorable response. The proposed response modification strategy is attractive for cases with large relative displacement demands.

Damping Enhancement Equation and Design Strategy of Inerter System

Wednesday, 19th June - 11:00: MS59 - Innovations and Advances in Passive Structural Control; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 574

Dr. Ruifu Zhang (Tongji University/Department of Disaster Mitigation for Structures), Dr. Chao Pan (Yantai University/College of Civil Engineering), Prof. Kohju Ikago (Tohoku University/International Research Institute of Disaster Science), Mr. Zhipeng Zhao (Tongji University/Department of Disaster Mitigation for Structures)

The damping enhancement effect is an important characteristic of an inerter system, as found in previous study. However, the enhancement mechanism has not been clearly considered in the design theory of the inerter system. In this study, damping enhancement is adopted as an efficient design strategy for structures with inerter systems under dynamic excitations. The enhancement effect of an inerter system is presented by the damping deformation enhancement factor (DDEF). Closed-form stochastic responses, including DDEF and response mitigation ratio (RMR), of a single-degree-of-freedom (SDOF) structure with an inerter system are derived. The relationship between DDEF and RMR was found and expressed in a simple equation, which is named damping enhancement equation. This relationship equation reveals the theoretical essence of the damping enhancement phenomena of the inerter system explicitly. The detailed design procedure of an SDOF structure with an inerter system was proposed based on damping enhancement mechanism. Some design cases were also carried out to illustrate this strategy. The study results show that the damping enhancement equation provides an intuitional and clear explanation of the damping mechanism of an inerter system. And key parameters of the inerter system can be conveniently determined according to the proposed strategy subject to the performance demand.

Passive Control of Nonlinear Single-Degree-Of-Freedom Structures Utilizing Tuned Mass Damper-Inerter

Wednesday, 19th June - 11:15: MS59 - Innovations and Advances in Passive Structural Control; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 606

Mr. Abdollah Javidialesaadi (University of Tennessee), Prof. Nick Wierschem (University of Tennessee), Prof. Mark Denavit (University of Tennessee)

This paper investigates the optimum design of the tuned mass damper-inerter (TMDI) for the vibration control of single-degree-of-freedom structures considering nonlinearities in the structure. The TMDI consists of a tuned mass damper (TMD) with an inerter that is connected between the TMD secondary mass and a fixed support. The inerter is a mechanical device that features a rotational mass that can harness relative motion and produce large mass effects even when the physical mass of the device is small. The TMDI, which has been recently proposed and investigated, has been found to be highly effective, in comparison to a TMD with an equal amount of physical mass, in reducing the dynamic response of structures under various excitations. However, all previous investigations have been conducted with the assumption of a linear base structure. As the real behavior of structures under extreme loads can feature important nonlinearities, the control of the nonlinear response of structures with the TMDI should be considered. In order to study the control of structures featuring nonlinearities with TMDI, the "inerter element" is developed by the authors in the Open System for Earthquake Engineering Simulation (OpenSees) software framework. A numerical optimization was undertaken to determine the optimum design values of the TMDI and its effectiveness was evaluated in comparison to the TMD. The results of this work demonstrate that the nonlinearity in the base structure is an important factor effecting the performance of the TMD and TMDI and that the TMDI provides additional robustness when considering these nonlinearities.

Multi-Criteria Design of Inerter-Based Vibration Suppression Devices

Wednesday, 19th June - 11:30: MS59 - Innovations and Advances in Passive Structural Control; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 778

Dr. Alexandros Taflanidis (University of Notre Dame), Dr. Agathoklis Giaralis (City, University of London), Mr. Dimitrios Patsialis (University of Notre Dame)

In recent years a new generation of seismic protection devices has emerged, incorporating within traditional passive vibration control systems the inerter, a two-terminal mechanical device developing a resisting force proportional to the relative acceleration of its terminals. Examples of such inerter-based protection devices include the Tuned-Inerter-Damper (TID), the Tuned-Mass-Damper-Inerter (TMDI) and the Tuned-Viscous-Mass-Damper (TVMD). Previous work has shown that when properly tuned/designed such devices can provide significant performance enhancement for seismic applications, though at the expense of increased forces transferred by the device to the protected structure. A multi-objective design approach is examined in this study to investigate the compromise between these two competing objectives. Seismic excitation is modeled as stochastic stationary process and structural behavior as a linear dynamical system, utilizing a state-space formulation. The first objective, representing the vibration suppression efficiency, is quantified according to current performance-based earthquake engineering standards using first-passage reliability criteria, considering failure modes associated with floor accelerations and inter-storey drifts. A variant, simpler, formulation is also considered using as performance quantification the sum of variances. The second objective, representing the local strengthening of the protected structure required to accommodate the inerter-based protective device implementation, corresponds to the standard deviation of the force transferred by the device to the structure. The illustrative example shows that the proposed design approach supports a comprehensive understanding of the compromise between the aforementioned objectives. Comparison of the performance between stationary and non-stationary excitation conditions validates the use of the simpler, stationary excitation at the design stage.

Parametric Optimization of Universal Accelerated Oscillator Damper in Vibration Control of Bridge Subjected to Seismic Excitation

Wednesday, 19th June - 11:45: MS59 - Innovations and Advances in Passive Structural Control; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 1250

Prof. Yonggang Tan (Dalian University of Technology), Mr. Xiaofeng Yan (Dalian University of Technology)

Recently, a novel inertial mass damper termed accelerated oscillator damper (AOD), which is capable of generating amplified inertance, enlarged spring force and magnified viscous damping and providing a controllable enhanced system damping has been used as an energy dissipation device for seismic response control. Structural vibration energy induced by external loading is transfer to the secondary mass via the accelerated transmission device. Investigations show that the AOD system is superior to the tuned mass damper (TMD) system for short input durations and the maximum seismic response, even adopting significantly smaller mass ratio. However, the AOD system requires that the transmission device, the secondary mass, the springs and the viscous damper must be fixed on the foundation. This is not always the convenient and available case for most bridges and civil buildings. This paper proposed an improved and generalized type of AOD system called universal accelerated oscillator damper (UAOD), in which the third system including another set of mass, springs and viscous damper was introduced between the accelerated transmission device and the foundation. The girder of approach bridges, piers and nearby structures can be used as the third system for the UAOD-structure system. More independent structures and more parameters make it possible to obtain multiple optimal vibration control designs. Moreover, conventional oscillator dampers such as TMD, inerter and AOD can be regarded as the special forms of the UAOD system by assigning different parameter values and can be analyzed within the unified framework of UAOD.

Experimental Investigation on Explicit Thermal Creep Behavior of Transverse Welded Lap Joints in Fire

Wednesday, 19th June - 10:30: MS65 - Emerging Topics and New Developments in Structural Fire Engineering (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 109

Mr. Ahmad El Ghor (American University of Beirut), Dr. Elie Hantouche (American University of Beirut), Dr. Ali Morovat (The University of Texas at Austin), Dr. Michael Engelhardt (The University of Texas at Austin)

Welds are key elements of most steel connections, and can affect the governing failure modes of steel connections in fire. Despite their importance, very limited studies have been conducted to examine and characterize the creep behavior of welds and welded joints at elevated temperatures. To address this knowledge gap, preliminary results of an extensive experimental program on thermal creep behavior of transverse welded lap joints at elevated temperatures are studied. Steady-state temperature creep tests are performed at 500 °C and 600 °C to examine explicitly the creep behavior of weld material in transverse welded lap joints in fire. Hence, two series of experimental work are conducted. In the first series, the test specimen is heated up to a target temperature (500 °C and 600 °C) and then loaded with a fast loading rate of 0.01in./min until failure to estimate the peak load that the test specimen can withstand at each temperature. In the second series and after the specimen is heated up to a specified temperature (500 °C and 600 °C), a load equals to a fraction of the ultimate load predicted in the first series of analysis (50%, 75%, and 90% of peak load) is applied and kept constant throughout the test. This study provides an overview of the test program, with a detailed description of the test specimens, test procedures and test results. The experimental results provide an improved understanding of creep deformation and strength characteristics of welded connections at elevated temperatures due to fire.

Implementation of a Hybrid Model for Steel Connections in Structural Fire Engineering Practice

Wednesday, 19th June - 10:45: MS65 - Emerging Topics and New Developments in Structural Fire Engineering (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 110

Mr. Muhammad Ali (American University of Beirut), Dr. Elie Hantouche (American University of Beirut), Mr. Kevin LaMalva (Simpson Gumpertz & Heger Inc.)

Previous research focused on studying and analyzing steel connections that have a critical role in resisting thermal loads under fire scenarios. One of the most commonly used steel connections is shear tab connection. The behavior of shear tab connections under thermal loads has been rigorously studied using finite element modeling with solid elements, component-based modeling, and experimental work. Very limited research, however, has been conducted on hybrid modeling. The purpose of this study is to develop an efficient method that combines finite element with component modeling to design shear tab connections subjected to fire temperatures. The beam-column shear tab connection is modeled in Abaqus where columns are assigned as line elements, beams as either solid or line elements, joints as connectors. These connectors are defined with axial and rotational stiffnesses. The hybrid model is validated against experimental and finite element results, and component-based models. The proposed hybrid model offers engineers an efficient method for designing shear tab connections that can sustain thermal loads.

Simulation of Weld Fracture in Steel Connections at Elevated Temperatures

Wednesday, 19th June - 11:00: MS65 - Emerging Topics and New Developments in Structural Fire Engineering (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 275

Dr. Wenyu Cai (Tongji University), Dr. Ali Morovat (The University of Texas at Austin), Dr. Michael Engelhardt (The University of Texas at Austin), Prof. Guo-qiang Li (Tongji University)

Accurate predictions of the ultimate strength and deformation capacities of steel welded connections under fire conditions require the ability to simulate fracture behavior of welded joints. However, due to lack of comprehensive elevated-temperature test data on welds and welded connections, and the complex stress state in these connections, predictions of the fracture behavior of welds and welded connections are still uncertain and difficult. Therefore, there is a need for an improved tool for computational prediction of fracture for welded connections at elevated temperatures.

This paper proposes an approach to simulate fracture phenomenon of steel welded connections at elevated temperatures. A triaxiality-based ductile fracture model was selected to simulate fracture behavior of welded connections at elevated temperatures. The model was successfully used in past studies to predict the fracture failure modes in steel bolted connections subjected to fire. The parameters of this fracture model were calibrated using test data on welded connections together with numerical simulations of connections in finite element analysis program Abaqus. Due to lack of sufficient test data on steel welded connections at elevated temperatures, parameters of the fracture model were calibrated by a trial and error process using available data from tests on steel welded connections. Various sets of parameters for the model were input into Abaqus to simulate the tests until the simulated load-deformation results and fracture failure modes reasonably matched those from tests. Recommendations are also given as how to determine model parameters for fracture simulation of steel welded connections at elevated temperatures.

Full-Scale Burning on Vertical Greenery System

Wednesday, 19th June - 11:15: MS65 - Emerging Topics and New Developments in Structural Fire Engineering (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 362

Prof. W.K. Chow (The Hong Kong), Dr. C.l. Chow (City University of Hong Kong)

Although vertical greenery systems (VGSs) are more popular, their fire hazards have not yet been thoroughly studied. Vegetation grown along building façades provides fuel for the spread of fires. The direct action of a window flame plume from a post-flashover room fire would ignite VGS as observed from scale models reported on a small green plant Bermudagrass. Full-scale burning tests on vertical upward fire spread over a 7 m tall green façade were performed and will be reported in this talk. Experiments were carried out on part of a real-scale VGS with three plants commonly used. These are Buxus microphylla; Fragrant Plantain Lily; and Matteuccia struthiopteris.
The following key points observed will be reported:

- Window flame plume from a post-flashover room fire would act on the VGS and ignite the plants.
- Wet plants are not easy to be ignited.
- Dry plants can be ignited readily with flame spread rapidly.
- Irrigation is important to provide wet plants.
- Burning broad leaves plants would give a bigger fire.

Results are useful for deciding fire tests for the assessment of VGSs. Appropriate fire protection, fire-fighting and rescue strategies for buildings with VGSs can then be recommended.

Keywords: vertical greenery system, window flame plume, full-scale burning tests

Acknowledgement

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Numerical Analysis of a Steel-Frame Building with Composite Floors to Enable Performance-Based Fire Design

Wednesday, 19th June - 11:30: MS65 - Emerging Topics and New Developments in Structural Fire Engineering (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 426

Prof. Thomas Gernay (Johns Hopkins University), Prof. Negar Elhami-Khorasani (University at Buffalo)

Performance-Based Fire Engineering (PBFE) is gaining traction in the US, with the aim to provide safe, resilient, and cost-effective design solutions for structural systems in our evolving communities. Steel-framed buildings with composite steel-concrete floors are widely used in practice and offer opportunities for achieving robust fire performance through PBFE. Meanwhile, in order to understand how structures behave under realistic fires, there is a need to systematically quantify and assess nonlinear performance of buildings under several design fires, and to determine the entire range of behavior up to failure in a systematic manner. This presentation demonstrates an integrated system-level structural fire analysis method for a prototype multi-story building with a steel frame, designed based on PBFE. The 3D computational model of the frame is used to perform nonlinear finite element analyses and investigate (a) the activation of tensile membrane action in the composite floors under various fire scenarios including multi-story fires, (b) residual deflections in the floor system under different fire scenarios, and (c) scenarios leading to potential collapse of columns, for assessment of possible progressive collapse mechanisms. The analysis is extended to study robustness of the PBFE when fire occurs as a secondary hazard and after a column loss. The results show that PBFE is a viable approach to obtain safe design solution for fire while target performance objectives can be defined and satisfied during the design process.

Experimental Investigation of the Post-Fire Mechanical Behavior of High-Strength Steel Suspension Bridge Wires

Wednesday, 19th June - 11:45: MS65 - Emerging Topics and New Developments in Structural Fire Engineering (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 378

Mr. Jumari Robinson (Columbia University), Dr. Matthew Sloane (Parsons), Prof. Raimondo Betti (Columbia University), Dr. Adrian Brügger (Columbia University)

The performance of suspension bridges exposed to fire conditions is severely under-studied—so much so that no experimental data exists to quantify the safety of a suspension bridge at high temperature. At the most fundamental level, bridge performance and safety rely on the integrity of the constituent high-strength steel wires. As such, our recent work has focused on the general thermo-mechanical profile of the high-strength steel wires in a range of elevated temperature environments. We are now focused on determining the remaining safety factor of a suspension bridge that survives a fire and is returned to service. Specifically, this work determines the mechanical properties (from both static and dynamic testing) of wires that undergo significant heating without mechanical failure. This is likely to happen for the case of uneven heating of the cable wherein hot wires shed load to cool wires as they undergo thermal expansion. The test results show an alarmingly high reduction in yield strength, ultimate strength, and plastic deformation at failure, varying with temperature and time of exposure. Furthermore, we scale the problem to the strand and full cable level in order to better understand the structural implications of this damage to the global safety and stability of the structure. This involves heat transfer studies at the 61-wire strand and 9,000-wire cable level. This multiscale testing program, combined with companion finite element modeling, serves to empirically and numerically characterize a previously under-studied public safety hazard.

Stochastic Modeling of Non-Gaussian Material Parameters on Nonconvex Geometries

Wednesday, 19th June - 10:30: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 128

Ms. Shanshan Chu (Duke University), Prof. Johann Guilleminot (Duke University)

Stochastic multiscale analysis includes the definition and simulation of random fields of material properties on complex domains. The consideration of connected phases, which is relevant to most fiber-reinforced composites, generally requires generating spatially varying properties on nonconvex domains. In this talk, we present a methodology to efficiently model and sample non-Gaussian random fields of material parameters on such geometries. The relevance of the computational framework is finally evaluated by applying the strategy to a polydisperse random microstructure.

Strong Form Meshfree Collocation Method for Signorini Frictional Contact Problems

Wednesday, 19th June - 10:45: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 394

Mr. Ashkan Almasi (University of Colorado Boulder), Prof. Tae Yeon Kim (Khalifa University of Science and Technology), Dr. Jeong-Hoon Song (University of Colorado Boulder)

For past decades, computational contact mechanics has engendered considerable interest in the engineering communities. Numerous studies have been performed in the field of computational contact mechanics to develop robust and efficient numerical methods that can predict mechanical contact phenomena with accuracy. However, most of those studies are based on traditional weak-form based finite-element methods.

In this study, we use the particle difference method (PDM) [1,2], a strong-form point collocation method, to model two-dimensional frictional contact problems. The novelty of the proposed method involves that governing partial differential equations are directly discretized based on Taylor series approximation and the moving least squares approach. Consequently, the PDM neither performs domain integration nor constructs a mesh, thus saving computational time. To demonstrate the effectiveness of the method, benchmark problems in frictionless and frictional contact problem for irregular distributions of the collocation points are provided. These numerical examples are also compared with those obtained from the conventional finite element method and analytical solution to verify the efficiency and accuracy of the proposed method.

References

[1] Y.C. Yoon and J.H. Song, Extended particle difference method for weak and strong discontinuity problems: part I. derivation of the extended particle derivative approximation for the representation of weak and strong discontinuities, *Computational Mechanics*, **53**(6):1087–1103, 2014.

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Computational Modeling of Slip Patterns on Heterogeneous Frictional Interfaces

Wednesday, 19th June - 11:00: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 756

Ms. Kavya Sudhir (Caltech), Prof. Nadia Lapusta (California Institute of Technology)

Predicting the strength and stability of heterogeneous interfaces is an outstanding problem, relevant to a broad range of fields – from biology and nano-mechanics to geophysics. Earthquake faults have a lot of inherent heterogeneity, both in geometry and constitutive properties. Understanding the dependence of the interface slip patterns on geometry and constitutive behavior of the frictional interface remains an important challenge. We focus on interfaces with rate-and-state friction that mix instability-promoting velocity-weakening (VW) regions and instability-suppressing velocity-strengthening (VS) regions. Both quasi-static and dynamic slip events could occur in such surfaces, depending on the fractional area, connectivity, and the size of the VW patches with respect to the nucleation size, i.e., the critical size for the initiation of dynamic instability. Overall, we aim to understand how local heterogeneities in friction properties translate into larger-scale behaviors, both in terms of stability and slip patterns.

To that end, we study slip patterns on the interfaces with fractal-like distributions of frictional properties, using 3D simulations of a 2D interface embedded in a homogeneous elastodynamic space, with an efficient and rigorous numerical procedure. With incorporating more complex heterogeneity into the model and matching the observations, we could potentially start to constrain the level of heterogeneity on natural faults. The important questions we aim to address are: 1) How important is smaller-scale heterogeneity of the friction properties to the large-scale response? 2) Is there a physically-motivated upscaling of the effect of smaller-scale heterogeneity on larger scales that allows to maintain the statistics of the slip events?

Layered Soil Parameter Estimation from a Moving Load

Wednesday, 19th June - 11:15: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 377

Dr. Hamidreza Mashayekh (The University of Texas at Austin), Prof. Loukas Kallivokas (The University of Texas at Austin)

We discuss a rapid full-waveform inversion method for estimating parameters of horizontally-layered soils using recordings of soil motion induced by the passing of trains or other moving loads. The approach rests on the Thin Layer method for modeling the layered soil, and on a recently-developed inversion methodology that uses the soil's dispersive characteristics as a constraint. We discuss how the method can be used for field applications, while demonstrating its capabilities with numerical experiments based on synthetic data.

Poroelastodynamic Finite Integration Technique for Analysis of Pavement Structures

Wednesday, 19th June - 11:30: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 1370

Prof. Lev Khazanovich (University of Pittsburgh), Mr. Zhe Wan (University of Pittsburgh)

Excess moisture in unbonded base and subbase layers may significantly affect pavement behavior. Traffic loading leads to development of pore-water-pressure that could be high enough to reduce the shear strength of the underlying granular layers resulting in premature damage. Available numerical methods for the analysis of pavements do not model this phenomenon directly.

This presentation introduces generalization of the Elastodynamic Finite Integration Technique (EFIT) for analysis of poroelastic medium subjected to dynamic modeling. The basic equations of Biot's theory of interactions between mechanical deformations and fluid flow in a porous media are presented in an integral form to obtain the discrete equations on a staggered grid. Central differences are used to discretize the equations in the time domain. This results in the velocity vectors and stress tensor components for both elastic skeleton and fluid being staggered in both time and space. This formulation results in a computationally efficient procedure for analysis of multilayered poroelastic systems.

Several numerical examples of analysis of pavement systems subjected to moving axle loading will be presented. The effect of cracks and joints in the top layer on the elastic deformations and movement of water in the base layer will be discussed.

A Pore-Network Model to Simulate the Behavior of Tight Geological Formations

Wednesday, 19th June - 11:45: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 1224

Mr. Haohao Guo (Tsinghua University), Prof. Liming HU (Tsinghua University), Prof. Jay Meegoda (New Jersey Institute of Technology), Mr. Di Zhang (New Jersey Institute of Technology)

It is necessary to study the nano/micro mechanics of the porous geo-materials to simulate the behavior of tight formations such and shale. From the nano/microscopic point of view, a pore-network model is a convenient tool to investigate such formations. Based on 2D images series of the porous media produced from CT or micro-CT technology, the 3D structure can be reconstructed by advanced computational graphics technology. Rather than assuming each solid region as a single sphere, sampling and re-meshing, each particle can be approximated to a model with overlapping multi-spheres. Then it is easy to extract the particles and pores by appropriate triangulation method, and test results show that the accuracy and efficiency are higher than direct extraction. Then based on the pore size and connectivity distribution obtained from the extraction, and the seepage can be estimated by developed micro-mechanics seepage model. To increase the simulation efficiency, a random connected network based on the extracted pore network was constructed using the relationship between connections in network and its statistical parameters. Then a generating algorithm was developed to create corresponding connections with a better accuracy relating them to physically meaningful the input parameters. The experimental data of various porous media agreed well with the permeability calculated by numerical simulation, which demonstrates the potential accuracy and capability of the proposed pore-network model.

A Stable Generalized/Extended FEM with Discontinuous Interpolant for Fracture Mechanics

Wednesday, 19th June - 10:30: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 684

Mr. Alfredo Sanchez Rivadeneira (University of Illinois at Urbana Champaign), Prof. Carlos Duarte (University of Illinois at Urbana Champaign)

The successful development of an optimally convergent Generalized FEM (GFEM) with conditioning not worse than FEM for fracture mechanics problems has been mostly limited to first-order accurate approximations. Numerical studies with quadratic GFEM approximations are presented, showing errors that are orders of magnitude smaller than the FEM with quarter-point elements, which in general is not the case for first-order GFEM approximations. However, they lead to severely ill-conditioned systems of equations. Enrichment modifications able to address the ill-conditioning of quadratic GFEM approximations while preserving optimal convergence are proposed. An enrichment modification strategy based on a discontinuous finite element interpolant is proposed to control the conditioning of branch function enrichments, while a combination of enrichment shifting by its nodal value and a local finite element mesh modification in the neighborhood of the crack surface is used to address the lack of robustness of Heaviside enrichments. The discontinuous FE interpolant is a generalization of the continuous one used with the Stable GFEM (SGFEM). It is shown that SGFEM spaces based on p-hierarchical FEM enrichments are the same as their GFEM counterparts. This guarantees that both GFEM and SGFEM spaces will lead to the same solution, which is not the case for the other classes of second-order spaces. The robustness of the proposed approximation spaces with respect to the position of the mesh relative to the crack is demonstrated numerically.

An Efficient Hypercomplex Finite Element Method for Progressive Fracture

Wednesday, 19th June - 10:45: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 906

Mr. Daniel Ramirez Tamayo (The University of Texas at San Antonio), Mr. Andres Mauricio Aguirre Mesa (The University of Texas at San Antonio), Dr. Arturo Montoya (The University of Texas at San Antonio), Dr. Harry Millwater (The University of Texas at San Antonio)

The complex-variable finite element method, ZFEM, calculates sensitivities with respect to the variables of interest based on the complex Taylor series expansion, CTSE. CTSE is numerically equivalent to finite differencing, but the step issue sizes associated to finite differencing are circumvented. Through a systematic complexification of an existing finite element code, the response variables and their sensitivities with respect to input variables of interest are obtained in a single finite element run. In a first order analysis of ZFEM, the energy release rate, an important fracture parameter, can be computed as the first order derivative of the strain energy with respect to the crack size. A traditional first order ZFEM approach uses a Cauchy-Riemann representation of the stiffness matrix, resulting in a (2N x 2N) system of equations, where N is the number of real degrees of freedom. Hence, the computational expense for a ZFEM run is 2-3 times a real valued analysis.
However, by using a stiffness derivative approach, only an assembly of a complex-valued stiffness matrix at the element level and the solution of a real-valued finite element run is needed to compute the energy release rate. This, approach results in a computational overhead of 1-2% with respect to a real analysis. By constructing a first order Taylor series approximation of the strain energy, a linear crack increment is predicted with a 4% of overhead in a single ZFEM analysis.

The proposed approach was compared to experimental data and numerical solutions.

A Massively-Parallel Solver for Large-Scale Simulation of Fluid-Driven Fracture Propagation

Wednesday, 19th June - 11:00: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 1082

. Bianca Giovanardi (Massachusetts Institute of Technology), Mr. Anwar Koshakji (Massachusetts Institute of Technology), Prof. Raul Radovitzky (Massachusetts Institute of Technology)

Fluid-driven fracture propagation concerns several areas of engineering, including structural, geotechnical, and petroleum engineering. The development of simulation tools for pressurized cracks propagating in realistic scenarios needs to tackle the extraordinary complexity of the problem in a suitable framework for large-scale applications. The problem requires, indeed, an adequate description of the coupling between the fluid flow inside the cracks, the deformation of the solid surrounding the cracks, and the propagation of the cracks as a result of the pressure exerted by the fluid on the crack walls. The inherently three-dimensional nature of the problem, where cracks can propagate in arbitrary directions, branch and merge, and the large gradients near crack tips require large-scale analysis, imposing the additional requirement of massive parallel scalability.
We present a computational framework for the coupling of the fractured solid mechanics with the fluid flow in the cracks, governed by Reynolds lubrication equation. In our framework, a Discontinuous Galerkin finite element discretization of the solid enables a direct description of the crack opening between adjacent mesh elements and induces a lower dimensional finite element discretization for the fluid problem. Crack propagation is then modeled via hybrid cohesive-lubrication interface elements, whose cohesive traction-separation law is activated upon fracture initiation and lubrication flow is activated upon complete interface failure. Several benchmarks in 2D and 3D are presented to demonstrate the ability of the computational approach to successfully deal with a priori unknown and arbitrarily intricate crack paths.

Thermo-Hydro-Mechanical Modeling of Microstructural Representation of Dissipative Particulate Porous Composite Materials

Wednesday, 19th June - 11:15: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 1108

Mr. Aimane Najmeddine (Virginia Tech), Prof. Maryam Shakiba (Virginia Tech)

A general thermodynamic-based framework is proposed to derive coupled thermo-hydro-mechanical induced damage constitutive relationships for dissipative particulate porous composite materials. Water inside partially or fully saturated porosity (i.e., cracks and voids) of multi-phase viscoelastic porous media induces extra stresses due to pore water pressure and freezing within the material which accelerates cracks evolution and propagation. The well-known (Kachanov, 1958) effective (undamaged) configuration and the concept of effective stress space are extended to thermo-moisture-susceptible materials to couple the detrimental effects of temperature fluctuation and moisture to the mechanical responses of materials. Physically-based damage internal state variables are introduced to account for the thermo-hydro-mechanical aggravation effects in multi-phase viscoelastic porous media. The resulting constitutive relationships describe the coupled effects of mechanical loading, moisture, and temperature fluctuation which can predict the response of saturated viscous porous media under various mechanical loading and environmental conditions. Microstructural representations of asphalt concrete as an example of dissipative particulate porous composite materials consist of elastic aggregate, viscoelastic mastic, and saturated pores are produced and simulated to illustrate the capabilities of the developed models. The outcome sheds light on our understanding of how thermo-hydro-mechanical coupling affects the overall response of asphalt concrete materials under environmental conditions.

A Novel Hybrid Numerical Finite Element-Spectral Boundary Integral Scheme For Modeling Earthquake Cycles

Wednesday, 19th June - 11:30: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 1377

Mr. Mohamed Abdelmeguid (University of Illinois at Urbana-Champaign), Mr. Xiao Ma (University of Illinois Urbana Champaign), Prof. Ahmed Elbanna (University of Illinois at Urbana-Champaign)

Modeling earthquake ruptures is a complex challenge due to the eclectic sources of nonlinearities, such as friction law, plasticity, and material damage. In addition to the nonlinearities, another challenging aspect of modeling earthquake processes is the multi-scale nature of the problem, both spatially and temporally. Here, we present a hybrid scheme that combines finite element method (FEM) and spectral boundary integral method (SBIM) to simulate earthquake cycles with rate and state fault subjected to slow tectonic loading processes of long duration intermittent by episodes of dynamic fracture in the presence of near-field heterogeneity. On a spatial level, regions of small-scale heterogeneity and complex fault geometry are handled using a FEM approach, while the linearly elastic bulk with a known Green's function is modeled using SBIM. Accordingly, we benefit from the flexibility of FEM in handling nonlinear problems, while retaining the superior performance and accuracy of SBIM. We handle the intricacies associated with this time evolution using an alternating explicit-implicit scheme, such that during dynamic rupture an explicit time integration is utilized for computational efficiency, with the implicit time integration being specific only to inter-seismic periods where larger time steps are required. The presented approach is validated using a benchmark problem. We further demonstrate the capabilities of this computationally efficient scheme by modeling earthquake cycles for a 2D in plane problem with different parameters. Finally, we discuss the potential of our approach in modelling a wide class of problems in geophysics and engineering.

Thermo-Mechanical Fracture Modeling with the Phase-Field Approach

Wednesday, 19th June - 11:45: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 1089

Dr. Wen Jiang (Idaho National Laboratory)

Ceramic fuel pellets used in nuclear light water reactors experience significant fracture due to the high thermal gradients experienced under normal operating conditions. This has important effects on the performance of the fuel system. Because of this, a realistic, physically based fracture modeling capability is essential to predict fuel behavior in a wide variety of normal and off-normal conditions. The phase field fracture method is an attractive method to model complicated crack propagation. The model is developed and implemented in open source software MOOSE (Multiphysics Object Oriented Simulation Environment). The phase field fracture employs a linear fracture surface energy that results in a compact support crack profile. The irreversibility condition is enforced by variational inequalities based Newton's method. The random distribution of defects is based on a KL-expansion approach that accounts for flaws correlations. The numerical examples demonstrate random initiation and subsequent propagation of interacting thermally induced cracks during an initial ramp to full power with fresh fuel.

Stability and Frequency Analysis for Beams via a New Static Beam Bending Approach

Wednesday, 19th June - 10:30: MS22 - Stability and Failure of Structures and Materials; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 887

Mr. Zhenyu Chen (City University of Hong Kong), Prof. CW Lim (City University of Hong Kong), Prof. Yang Xiang (Western Sydney University)

The stability and natural frequencies of different buckling and vibration modes are useful for the understanding of mechanical properties of engineering structural systems. This study presents a new static approach for solving some stability and free vibration structural systems to determine the buckling and natural frequencies of beam with different boundary conditions. In general, any static structural systems can be considered as special cases of more general dynamic structural systems. For vanishing time-depended variables, the governing equations of motion can be reduced to static problems. Starting with the basic governing equation for beams subject to a harmonic load and resting on elastic foundation, the beam bending problem is solved and applied directly to yield the critical or free vibration eigenvalue solutions. Specifically, the key idea is to assume a positive or negative generalized elastic parameter using the static approach to correspond to the real and imaginary critical load or frequency parameters via stability or free vibration analysis, respectively. Consequently, an appropriate negative elastic foundation parameter is determined and the critical load or natural frequencies can be obtained. The basic assumption is in the presence of a concentrated load, the deflection of a beam becomes infinite when the stiffness approaches zero. A comparison with respect to the classical free vibration solutions is presented and excellent agreement is illustrated. Furthermore, fast numerical convergence of the new approach has also been demonstrated. This static approach for stability or free vibration problems can be extended to the dynamics of more complicated structural systems.

Buckling Loads of Simply Supported Anisotropic Columns using First Order Shear Deformation Theory

Wednesday, 19th June - 10:45: MS22 - Stability and Failure of Structures and Materials; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 67

Dr. Rund Almasri (WSP, USA), Prof. Hayder Rasheed (Kansas State University)

A generalized buckling formula is developed for simply supported anisotropic laminated composite columns considering first order shear deformation theory. The formula yields results applicable to moderately thick to thick constructs. It reduces down to the generalized formula of thin-walled simply supported columns when the out of plane shear stiffness is set to infinity. Finite element solutions are also developed using Abaqus and compared to the predictions of the analytical formula.

Comparative Stability and Failure Study of Top-Hat-Shaped GLARE Columns

Wednesday, 19th June - 11:00: MS22 - Stability and Failure of Structures and Materials; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 104

Mr. Dominik Banat (Lodz University of Technology/Department of Strength of Materials), Prof. Radoslaw Mania (Lodz University of Technology/Department of Strength of Materials)

The subject of this research are top-hat-shaped thin-walled columns made of glass reinforced aluminium laminate (GLARE) subjected to axial compression. Considered 7-layered GLARE structures consist of alternating thin layers of aluminium alloy sheets and unidirectional glass fibre-reinforced prepregs. Laboratory damage tests were performed by the static testing unit that provided displacement control loading. During experimental tests, deformations were measured by Aramis 3D non-contact optical equipment based on digital image correlation (DIC). This allowed to investigate failure behaviour of compressed member in full load range until fracture. Experimental results were compared with numerical simulations wherein failure analysis was performed by means of various failure criteria. Due to the hybrid nature of considered GLARE structure, failure study in aluminium and composite layers were considered separately. Application of various criteria allowed to track failure initiation and predict collapsed mode shapes of GLARE top-hat members. Additionally, progressive failure model was applied in FEA to investigate failure propagation in composite plies. Hashin failure criterion was used to monitor the initiation of damage, whereas material degradation method (MPDG) was applied in FRP layer to define the damage evolution law. Load carrying capacity of top-hat members was predicted based on the post-buckling equilibrium paths. Results from numerical simulations were found to be in a good agreement with experimental evidences.

Improved Structural Efficiency of a Curved Stiffened Panel Through Modal Nudging

Wednesday, 19th June - 11:15: MS22 - Stability and Failure of Structures and Materials; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 211

Ms. Olivia Leao (University of Bristol), Dr. Rainer Groh (University of Bristol), Dr. Alberto Pirrera (University of Bristol)

Recent studies have shown a revival of interest in nonlinearities and instabilities, both as a source of smart functionality and a means for lightweighting. An example of the latter is the recently introduced concept of *modal nudging*, which uses information from the post-buckling regime to tailor the nonlinear response of a structure. The first step in *modal nudging* consists in finding a stable region of interest in a structure's equilibrium manifold beyond the first onset of instability. This stable deformation mode is then extracted and seeded into the initial baseline geometry. The new equilibrium path is consequently *nudged* to the targeted stable region in a manner similar to seeding imperfections. The described strategy can be used to enhance structural performance based on a measure of choice. In the current work, *modal nudging* is used to improve the load-carrying capacity of a curved stiffened panel under compressive loading. The stable regions of interest are found on the fundamental load path but are naturally unobtainable as they are separated by unstable equilibrium segments. The effects of nudging are analysed within a nonlinear finite element and numerical continuation framework. With manufacturability in mind, the effects of perturbing only certain features of the baseline geometry are also explored. It is observed that, in all cases, the nudged structure can converge to the stable region with greater load-carrying capacity at the expense of a marginal increase in mass due to the small perturbation in initial geometry.

Stability of Multiple-Crossarm Prestressed Stayed Columns with Additional Stay-Groups

Wednesday, 19th June - 11:30: MS22 - Stability and Failure of Structures and Materials; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 228

Mr. Luke Lapira (Imperial College London), Prof. Ahmer Wadee (Imperial College London), Prof. Leroy Gardner (Imperial College London)

Prestressed stayed columns have an enhanced resistance to buckling through the effective use of crossarms and pretensioned stays when compared to conventional columns. The initial pretension in the stays effectively braces the column at the location of the crossarm, thereby increasing its buckling load. However, the application of an external conservative load reduces the tension in the stays which, in turn, causes a reduction in the effectiveness of the lateral restraint provided. The behaviour of the prestressed stayed column system is demarcated into zones that are defined by the initial pretension where the stays are effective in increasing the buckling load of the column beyond the classical Euler buckling load, and where all of the stays go slack simultaneously; the latter defining the maximum buckling load.

The inclusion of an additional stay-group to the prestressed stayed column introduces an additional independent parameter that affects the system buckling load. The influence of this parameter on the behaviour of the stayed column is determined by considering the linear pre-buckling deformations of such configurations. The minimum, linear optimum and maximum initial pretension forces for such configurations are subsequently defined.

The analytical findings are validated through comparisons with finite element models developed in the commercial package ABAQUS. The influence of the initial pretension on the load-carrying capacity of the configurations considered is also analysed. This provides insight into the actual optimum initial pretension force for the configurations by investigating the system post-buckling behaviour by through the inclusion of geometric nonlinearities.

A Novel Analytical Approach for Delamination Buckling in Composite Plates

Wednesday, 19th June - 11:45: MS22 - Stability and Failure of Structures and Materials; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 263

Dr. Anton Köllner (Technische Universität Berlin), Prof. Christina Völlmecke (Technische Universität Berlin)

An analytical modelling approach is presented which is capable of determining the post-buckling responses as well as the onset of delamination growth of multi-layered composite plates with an embedded circular delamination. In order to overcome current drawbacks of analytical models regarding embedded delaminations [1], the model employs a problem description in cylindrical coordinates and a novel geometric representation of delamination growth in conjunction with a Rayleigh-Ritz formulation and the so-called crack-tip element analysis [2, 3]. The problem description enables the analysis of the energy release rate along the entire boundary of the delamination as well as mode decomposition. As a consequence, the onset of delamination growth can be determined precisely during the post-buckling response. The modelling approach is applied to study the compressive response of composite plates with thin-film delaminations loaded under radial compressive strain. Post-buckling responses and the onset of delamination growth are determined for several layups (unidirectional, cross-ply and angle ply laminates) showing very good agreement with finite element simulations.

Keywords: Delamination Buckling, Energy release rate, Composites, Plates, Post-buckling

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Nonlinear Fastener-Based Modeling of Cold-Formed Steel Shear Walls Under Earthquake Events

Wednesday, 19th June - 10:30: MS23 - Robustness of Infrastructures (151 Crellin (50)) - Oral - Abstract ID: 148

Ms. Fani Derveni (University of Massachusetts, Amherst), Dr. Simos Gerasimidis (University of Massachusetts, Amherst), Dr. Kara Peterman (University of Massachusetts, Amherst)

As cold-formed steel (CFS) has increasingly been used in low-and mid-rise construction across United States, it becomes necessary to capture and evaluate its lateral response in both, sub-system/member level and system level. The main lateral resisting system in cold-formed steel construction is shear walls; shear walls are the focus of this work. In particular, the present study aims to shed light on the response of wood sheathed cold-formed steel(CFS) shear walls exposed to earthquake events through nonlinear high fidelity fastener-based modeling. The numerical approach is fastener-oriented including nonlinear experimental-determined connector elements for steel-to-sheathing connections, orthotropic oriented strand board (OSB) modeling for sheathing material, contact implementation and linear spring hold-down simulation for preventing uplift. The numerical results are compared and validated by a previous experimental study, assessing the efficiency of fastener-based modeling to capture the peak load and displacement, the failure mechanisms and the overall structural behavior of sheathed cold-formed steel shear walls. The main goal of this work is to introduce a robust computational tool capable of demonstrating how wood sheathed cold-formed steel framed shear walls behave during a lateral load event with potential use in any cold-formed steel screw-fastened connection system, such as diaphragms and in any fastener-based cold-formed steel full building simulation.

Optimization Procedures for Risk Mitigation Strategies in Power Grid by a Genetic Algorithm

Wednesday, 19th June - 10:45: MS23 - Robustness of Infrastructures (151 Crellin (50)) - Oral - Abstract ID: 231

Mr. Mohamed Salama (McMaster University), Dr. Mohamed Ezzeldin (McMaster University), Prof. Wael El-Dakhakhni (McMaster University), Prof. Michael Tait (McMaster University)

Recently, the world has become deeply dependent on infrastructure networks. These infrastructure networks are not isolated but interdependent in multiple levels. Although these interdependencies improve the network efficiency, it also increases its vulnerability. Where small damage in one network can lead to cascading failures and propagate from a local (component-level) to a global (network-level) scale. Hence, simulating infrastructure networks attracts researchers from different domains to enhance the performance of their networks through support decision platform. Particularly, energy infrastructure is one of the most critical, challenging, and interesting complex network to study. This paper presents model of the power grid based on network science theory. This model aims to simulate the cascading failure processes and identify the critical network components. Thence, two risk mitigation strategies are proposed to suppress the cascading failure propagation. The concept of these strategies is re-routing the cascading failure scenario by switching off a few selected transmission lines. The optimization problem is picking the best number and set of transmission lines to switch off after the initial failure to minimize the cascading failure size. In order to search for the optimal set of transmission lines, a genetic algorithm with integer chromosomes is applied. Two case studies have been used to evaluate the proposed risk mitigation strategies.

Full-Scale Test of a Steel Moment-Resisting Frame with Steel-Concrete Composite Floor under a Column Removal Scenario

Wednesday, 19th June - 11:00: MS23 - Robustness of Infrastructures (151 Crellin (50)) - Oral - Abstract ID: 566

Mr. Junjie Wang (Tongji University), Prof. Wei Wang (Tongji University)

This study investigates the structural behaviors and loading-resisting mechanisms of a typical steel-concrete composite floor system subjected to the penultimate edge column removal scenario. A 2 × 1 bay full-scale composite floor system is quasi-statically tested to failure under the displacement loading scheme. Moment-resisting connections, continuous trapezoidal steel decks, and full scale are three main features of this test. Based on this test, the loaddeflection response, the load-carrying mechanisms, deformation manners, and the failure modes are discussed. The maximum load-carrying capacity is achieved at the flexural stage before the fracture of the girder-column connection. After fracture of the girder-column connection, the resistance is slightly decreased and kept in a steady platform at about 850kN, which is contributed by the tensile membrane action and residual catenary action. After the total rupture of the girder section, the system can sustain an applied vertical load of 732kN by the tensile membrane action. Compared with the extraordinary load combination, the load-carrying capacity of this specimen is 4.2 times and 3.6 times higher than that under static and dynamic scenarios, respectively. The yield lines of the slab are both located among the hogging moment region and the sagging moment region. All the yield lines in the sagging moment area are linked to the removed column. The damages of the composite floor system are concentrated at the sagging moment area, especially the area neighboring to the removed column.

Robustness of Air Traffic Networks

Wednesday, 19th June - 11:15: MS23 - Robustness of Infrastructures (151 Crellin (50)) - Oral - Abstract ID: 1167

Mr. Yassien Yassien (McMaster University), Dr. Moataz Mohamed (McMaster University), Dr. Mohamed Ezzeldin (McMaster University), Prof. Wael El-Dakhakhni (McMaster University)

Air traffic networks facilitate tourism and trade through the movement of people and goods. In the current study, Complex Network Theory (CNT) is utilized as an efficient tool to study the topological characteristics of air traffic networks. CNT employs different measures to quantify the characteristics of networks including betweenness, closeness, clustering and connectivity. These four measures are crucial in estimating network robustness. Although these four measures have been extensively used in the literature, they all depend on two main parameters, namely the shortest path and link weight. That said, previous studies failed short in incorporating key factors in estimating these two parameters such as travel time, travel distance, link capacity and the integration between these factors, this is to name just a few. For this reason, we developed new measures of betweenness, closeness, clustering and connectivity to cover this research gap. As a case study, the proposed CNT measures were used in investigating the topology and the characteristics of the Canadian Domestic Air Traffic Network (CDATN) and were compared against the existing measures in literature. Ranking-maps were also established to highlight the importance of the cities with respect to the CDATN based on the proposed and the existing measures. Overall, combining the different parameters in the proposed measures affected the ranking maps remarkably. Therefore, the study is expected to enable policymakers to identify the critical CNT measures to better understand the network topology.

Time-Variant Reliability and Redundancy of Corroded Prestressed Concrete Bridges considering Damage Mechanisms at Material, Component, and System Levels

Wednesday, 19th June - 11:30: MS23 - Robustness of Infrastructures (151 Crellin (50)) - Oral - Abstract ID: 158

Dr. Bing Tu (Guangxi University), Prof. You Dong (Hong Kong Polytechnic University), Prof. Dan Frangopol (Lehigh University), Prof. Kaizhong Xie (Guangxi University)

System-level performance of bridges is a topic of paramount importance to prevent progressive failure and assess structural redundancy. Additionally, performance of individual girders as well as the overall bridge system may decrease with time due to structural deterioration (e.g., corrosion). This paper proposes a computational framework for time-variant reliability and redundancy assessment of multi-girder prestressed concrete bridges. Sectional nonlinear analysis is performed to obtain constitutive relationships of prestressed concrete sections and girder components, in which the adverse effects of reinforcement corrosion on structural capacity and ductility are assessed. Subsequently, nonlinear finite element analysis is conducted to capture time-variant probabilistic resistance of the overall bridge system using the developed section- and component-level constitutive relationships. Time-variant redundancy of the corroded bridge is computed considering both serviceability and ultimate limit states. The capabilities of proposed approach are illustrated on an existing highway bridge. Results demonstrate that it is important to assess structural ultimate capacity, ductility, and redundancy of corroded structures considering damage mechanisms at different levels including material, components, and system levels.

Experimental Investigation of Planar 3-Storey-4-Bay Steel Moment Frame Under Static Column Removal Scenario

Wednesday, 19th June - 11:45: MS23 - Robustness of Infrastructures (151 Crellin (50)) - Oral - Abstract ID: 450

Dr. Zhiyang Xie (State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University), Prof. Yiyi Chen (State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University)

To acquire a deeper insight into the redistribution pattern of the internal force as well as deformability of the steel moment frame structure under column removal condition, an experimental study of a planar 3-storey-4-bay steel moment frame in reduced scale of 1:2 has been conducted. To achieve a flexible loading process, a novel vertical loading device is adopted to impose the approximately equivalent gravity load on the individual beams. Meanwhile, a cradle-like loading device is utilized to automatically switch the loading mode from releasing the original support beneath the bottom of mid-column and then to imposing the additional vertical loading on the top of mid-column under the monotonic vertical downward displacement by the actuator. The experiment results suggest that the vertical resisting mechanism of the first floor would be gradually transformed from the bending mechanism to the catenary mechanism, whereas the bending mechanism would be consistently dominated within the upper two floors. That observation could be verified though the comparisons among axial mean strain data of different beams within three floors and be explained by the decrease of the horizontal stiffness along the floor of the frame structure. It would be concluded that the discrepancy in the horizontal stiffness could cause the transformation of the vertical loading mechanism and accordingly result in the redistribution of the internal force as well as deformation, that would negatively impose additional vertical load on the structural elements within the lower floor.

Isogeometric Methods for Solids, Structures, and Fluid-Structure Interaction: From Early Results to Recent Developments

Wednesday, 19th June - 10:30: KEYNOTE / MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 1 (103 Downs (50)) - Oral - Abstract ID: 1425

Prof. Yuri Bazilevs (Brown University)

This presentation is focused on Isogeometric Analysis (IGA) with applications to solids, structures, and fluid-structure interaction (FSI), starting with early developments and results, and transitioning to more recent work. Novel IGA-based thin-shell formulations are discussed, and applications to progressive damage modeling in composite laminates due to low-velocity impact and their residual-strength prediction are shown. A novel framework for air-blast-structure interaction (ABSI) based on an immersed approach coupling IGA and RKPM-based Meshfree methods is presented and verified on a set of challenging examples. The presentation is infused with examples that highlight effective uses of IGA in advanced engineering applications.

Three-Dimensional Large Deformation Micromorphic Elastostatics with Microstructural Linkage and Comparison to Micropolar Elastostatics

Wednesday, 19th June - 10:30: MS73 - Generalized Continua, Gradients, and Nonlocal Mechanics (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 207

Prof. Richard Regueiro (University of Colorado Boulder), Dr. Farhad Shahabi (University of Colorado Boulder), Dr. Volkan Isbuga (Hasan Kalyoncu University)

A three-dimensional (3D), large deformation, finite element analysis (FEA) framework accounting for material micro-structure is presented for micromorphic continuum mechanics. A fundamental assumption of the theory is that material micro-structure satisfies the governing equations of classical continuum mechanics within a "micro-element." The micro-element deformation with respect to a mass-centered macroscopic continuum point (called a "macro-element") is governed by an independent micro-deformation tensor. Assuming that proper constitutive models may be formulated, and material parameters calibrated, the theory may fill the gap between microstructural and macroscopic continuum length scales. The aim of the paper is to provide insight into micromorphic continuum mechanics, including the linkage between micro- and macro-element deformation, through numerical examples comparing static micromorphic and micropolar elasticity, while investigating the effects of boundary conditions which will influence the "length-scale effect." A 3D large deformation FEA framework for materially-linear isotropic micromorphic elastic materials is developed and applied to illustrate the effects of independent microstructural deformation on the macroscopic micromorphic and micropolar continuum-scale responses.

An Extended Gradient Nonlocal Flexibility-Based Beam-Column Element Formulation Framework

Wednesday, 19th June - 10:45: MS73 - Generalized Continua, Gradients, and Nonlocal Mechanics (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 771

Mr. Mohammad Taghi Nikoukalam Mofakham (Texas A&M University), Dr. Petros Sideris (Texas A&M University)

In this presentation, a novel flexibility-based beam element formulation is proposed that addresses, in a fundamental and holistic manner, challenges in the connectivity of elements incorporating (implicit) gradient nonlocal constitutive relations to describe material damage and overall member softening and collapse. These inconsistencies emanate from the lack of “information transfer” between nonlocal variables over adjacent elements. From a practical point of view, this prevents mesh of a physical entity, e.g. a concrete member, using multiple elements, which hinders use of such tools in structural design and performance assessments.

This study addresses this challenge by extending the flexibility-based element formulation to include the nonlocal section deformation variables as nodal quantities; thereby introducing direct “information transfer” via the connecting nodes. Introduction of nonlocal variables as nodal quantities, despite doubling the number of element degrees of freedom, provide a consistent and computationally stable framework to integrate any type of nonlocal constitutive relations within the element formulation. Furthermore, unlike displacement-based elements, for which a two-field approach is employed resulting in satisfaction of the equilibrium and gradient nonlocal equations in an average sense within the element (weak form), in the present approach, both the equilibrium and gradient nonlocal conditions are explicitly satisfied within the element (strong form), and, this is also the case for the strain-displacement equations. The proposed element formulation framework together with a nonlocal hardening-damage constitutive model recently developed by the authors is used to study axial and bending problems and simulated the response of experimentally investigated reinforced concrete columns.

A Micromorphic Filter for Determining Macro-Scale Stresses from Poly-Crystalline Elasto-Plastic DNS

Wednesday, 19th June - 11:00: MS73 - Generalized Continua, Gradients, and Nonlocal Mechanics (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1038

Mr. Nathan Miller (Los Alamos National Laboratory), Prof. Richard Regueiro (University of Colorado Boulder), Dr. Farhad Shahabi (University of Colorado Boulder), Dr. Joseph Bishop (Sandia National Laboratories, New Mexico)

A micromorphic filter is presented for the extraction of stress and deformation measures from underlying Direct Numerical Simulation (DNS) of microstructural mechanical response. The filter is consistent with the micromorphic continuum theory of Eringen and Suhubi [1964], and allows the interrogation of a DNS to generate higher order constitutive models. The filter adopts aspects of the overlap coupling techniques for atomistic-continuum scale-bridging in order to update the nodal degrees of freedom of the finite-element-based filter. Two methods for the extraction of quantities of interest from the underlying DNS are presented. The first is a least squares fitting technique which is appropriate for finite-element-style macro-scale domains, and the second is a variationally-based approach which generalizes the method to any macro-scale domain which has a variational form. No restrictions on the form of the micro-scale simulation are inherent to the approach, provided that the required quantities (stress, position, etc.) can be provided. The filter is applied to a simple homogeneous medium undergoing homogeneous deformation to demonstrate the null case, and then is applied to the same homogeneous medium undergoing non-homogeneous boundary conditions to demonstrate micromorphic effects. Another, materially heterogeneous, DNS is filtered to provide a case for which the micromorphic degrees of freedom become noticeably active under homogeneous loading.

Phonon-Based Pseudocontinuum Representations for the Finite Monatomic Chain with Harmonic Nearest-Neighbor Interactions

Wednesday, 19th June - 11:15: MS73 - Generalized Continua, Gradients, and Nonlocal Mechanics (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 679

Dr. Miguel Charlotte (University of Toulouse, Institute Clement Ader, CNRS – UMR 5312 INSA/UPS/ISAE-SupAero/Mines Albi)

This work is primarily concerned with the derivation of the spatially nonlocal pseudo-continua inspired by the elastodynamics of a simple finite particle chain with nearest neighbor interactions. Currently, similar elastodynamic models are widely used to deduce new mathematical dispersive and filtering metamaterial or/and phononic models interesting for applied mathematicians and engineers, but that are out of reach for the classical continuum modeling. Due to the interaction-at-distance and localized inertial forces, the proper account of boundary (and initial) conditions raises up however fundamental difficulties. This work tries notably to account for features that are rarely (or else not sufficiently) investigated up to now in most derivations of spatial nonlocal pseudo-continuum modeling of elasticity, based on Hamiltonian energies:
the influences of the type of imposed boundary loading conditions and related inertial effects on the identification of the apparent material and geometric parameters. Those ones are often ignored or minimized in the current concepts of nonlocal elasticity in spite of their critical importance.
An alternative (wave-mechanics) viewpoint is developed wherein phonon transport properties can play the dominant role. This calls for a paradigm shift in the underlying kinematical and material description of the lattice elastodynamics. It also relies on a bulk-and boundary-dependent, multi-modal and -displacement field description of the periodical mass-spring lattice motions. This yields a non-classical pseudo-continuum elastodynamics whose the nonlocal inertia and nonlocal elasticity depend naturally on the non-trivial interplay between the atomic bulk interactions and the loading device 'imposing' boundary conditions.

Fractional-Order Elastodynamic Models for Nonlocal Media

Wednesday, 19th June - 11:30: MS73 - Generalized Continua, Gradients, and Nonlocal Mechanics (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 116

Mr. Sansit Patnaik (Purdue University), Dr. Fabio Semperlotti (Purdue University)

Theoretical and experimental studies have shown that transport processes in complex media such as layered or porous materials, cracked or damaged structures, natural soil, and biomedical materials like bones and tissues are often characterized by either hybrid or anomalous transport mechanisms. This unconventional behavior stems from a combination of factors including scale effects, nonlocality, frequency- and wavelength-dependence, and even memory. Classical elastodynamics cannot capture these hybrid field transport processes which are characterized by simultaneous propagative and diffusive mechanisms. Here, we present a generalized elastodynamic theory, based on space-fractional order operators, capable of modeling the propagation of elastic waves in nonlocal solids and across complex nonlocal interfaces. The proposed continuum mechanics formulation offers unparalleled capabilities to predict transport mechanisms in the most diverse combinations of multiscale, nonlocal, dissipative, and attenuating elastic solids. In this work, we focus on the behavior and modeling capabilities offered by space-fractional derivatives and on their effect on the elastodynamic response. This theory serves also as the basis to derive a generalized fractional order version of the Snell's law of refraction and of the corresponding Fresnel's coefficients. Numerical results will be presented to show how the theory is capable of predicting the behavior of fully coupled elastic waves interacting with complex and/or nonlocal interfaces. The fractional formulation can offer significant advantages to improve predictive capabilities in a variety of applications ranging from elastography, to seismology, to biomedics and to composite applications.

Ritz Spline Method for Consistent Couple Stress Elastic Analysis

Wednesday, 19th June - 11:45: MS73 - Generalized Continua, Gradients, and Nonlocal Mechanics (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1069

Prof. Gary Dargush (University at Buffalo), Dr. Georgios Apostolakis (University of Central Florida), Dr. Ali Hadjesfandiari (University at Buffalo)

One of the primary challenges for developing computational formulations in size-dependent mechanics is the requirement for higher order continuity of the displacement field due to the presence of second order derivatives in the energy functional, associated with curvatures. In particular, for consistent couple stress theory (Hadjesfandiari and Dargush, 2011), mean curvatures contribute to the potential energy and are energy conjugate to the couple stress tensor, which is skew-symmetric. Previous finite element formulations have circumvented the requirement for C^1 continuity for the displacements by first introducing independent displacement and rotation degrees of freedom and then enforcing the displacement-rotation relation through either Lagrange multipliers (Darrall et al, 2014) or penalty functions (Chakravarty et al., 2017). While both of these approaches provided convergent algorithms, the former is indefinite and the latter requires specification of the penalty parameters. In the present work, a new spline-based Ritz formulation is developed from the Principle of Minimum Total Potential Energy for couple stress elastostatics in two- and three-dimensional domains. For well-defined boundary value problems, the resulting overall system stiffness matrix is symmetric, positive-definite. Beyond details of the formulation and numerical implementation, the presentation will include convergence studies for the solution of several example problems, which highlight the size-dependent characteristics of the underlying couple stress theory.

Laminated Piezoelectric-Piezomagnetic Composites with Imperfect Interfaces

Wednesday, 19th June - 10:30: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 124

Prof. Hsin-Yi Kuo (National Chaio Tung University), Mr. Tien-jung Wu (National Chaio Tung University), Prof. Ernian Pan (The University of Akron)

We use a micromechanical approach to invstigate the macroscopic properties of a laminated piezoelectric-piezomagneitc composites with imperfect interfaces. The imperfect interface can be either the generalized interface stress type or the generalized linear spring type. In the former type, the potential fields are continuous at the interface, whereas the normal components of fluxes udergo a discontinuity. On the other hand, in the latter type the normal components of fluxes are continuous at the interface, wherease the potential fields undergo a discontinuity. Concise matrix expressions of the overall behaviors of the layered piezoelectric-piezomagnetic composite with contact imperfection are presented. Numerical calculations are presented for a $BaTiO_3$-$CoFe_2O_4$ laminate, and are shown in good agreement with the two-level recursive scheme with Mori-Tanaka method.

Characterization and Modeling of Carbon Nanotube Dispersed in Asphalt Binder by the Foaming Process Toward Self-Heated Pavements

Wednesday, 19th June - 10:45: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 299

Mr. Mehdi Zadshir (Columbia University), Dr. Liangliang Zhang (Columbia University), Dr. Xiaokong Yu (Columbia University), Prof. Huiming Yin (Columbia University)

The recently proposed self-heated pavement technology requires a better conductivity of asphalt materials for effective heat transfer. The effective thermal conductivity of carbon nanotube (CNT) with different volume fractions in asphalt binder is studied based on a micromechanical model, and the results are validated with experiments. When the volume fraction of CNTs increases to a certain level, the discrete CNTs connect with each other and form a network that plays a significant role in the thermal conductivity of the mixture. The eight-chain model has been used to predict the thermal conductivity of the composite, in which the contact resistance between the CNTs has been considered. Furthermore, this model can take into account the mixing process, CNT length, and diameter. For experiments, mixtures of 3% and 6% wt. of CNT with a non-ionic surface agent in water are prepared, and the resulting solutions are mixed with a PG 64-22 asphalt binder using a foaming technology. A scanning electron microscope is used to observe the agglomeration of carbon nanotubes in the asphalt binder, and the results show how the CNTs form a micro-network with each other. The Nanoflash and differential scanning calorimeter are used to measure the thermal conductivity and heat capacity of the samples, respectively. The modeling results of the effective conductivity are compared with the experimental results of the asphalt binder incorporating the carbon nanotubes at different content. The findings can be deployed to improve the thermal conductivity of pavement to avoid low-temperature cracks and rutting due to high temperatures.

MD-XFEM Model of HMWM Epoxy-Concrete Interface

Wednesday, 19th June - 11:00: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 397

Mr. Koochul Ji (Georgia Institute of Technology), Dr. Chloe Arson (Georgia Institute of Technology)

The goal of this study is to predict the stiffness and strength of damaged concrete repaired by High Molecular Weight Methyl methacrylate (HMWM), and epoxy used as crack sealer. We simulated the debonding of a concrete/HMWM interface with LAMMPS, a Molecular Dynamics (MD) software. The molecular structure of HMWM was modeled considering an initiator (Cumene hydroperoxide) and a monomer (Methyl methacrylate) and the molecular structure of concrete was represented as a silica crystal (alpha-quartz). A uniaxial tension test was conducted at molecular scale to understand the interface debonding process. The stress-strain curves of the interface were obtained by calculating van der Waals forces during the pullout test in the MD simulations. We calculated the fracture energy and the cohesive strength of the interface by fitting a traction-separation curve to the MD force-displacement predictions. We then employed the fracture energy and strength parameters in a cohesive segment model at the macro-scale, and simulated fracture propagation in concrete repaired by HMHW epoxy with the eXtended Finite Element Method (XFEM). We analyzed the sensitivity of this multi-scale approach to the MD model size and recommended scaling rules. We then compared the macroscopic force-displacement curves and the fracture patterns obtained during the XFEM simulations to measurements and observations collected during physical experiments, both for plain and repaired concrete. Lastly, we discuss the performance of multi-scale model and the mechanical recovery potential of epoxy-repaired-concrete.

Design Smart Materials via Additive Manufacturing

Wednesday, 19th June - 11:15: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 553

Prof. Qiming Wang (University of Southern California)

Designing smart materials with unprecedented properties is a long-lasting endeavor of science and engineering. The emerging additive manufacturing technologies offer new opportunities for designing innovative materials with architectures forbidden by traditional manufacturing methods. Here we present design strategies for novel smart materials using a state-of-the-art stereolithography-based additive manufacturing system. For example, by means of a model system of magnetoactive lattice structures, we demonstrate stimuli-responsive acoustic metamaterials to repeatedly switch signs of constitutive parameters with remote magnetic fields. It is shown for the first time that effective modulus can be reversibly switched between positive and negative within controlled frequency regimes through lattice buckling modulated by theoretically predicted magnetic fields. As another example, we show that molecular-scale integration of two chemical groups can enable rapid additive manufacturing of self-healing structures. We demonstrate rapid additive manufacturing of single- and multi-material structures for self-healing 3D soft actuators, self-healingstructural composites, and self-healing architected electronics.

Cure Dependent Loading Rate Effect on Strength of Thermoset Polymers

Wednesday, 19th June - 11:30: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 680

Ms. Gilda Daissè (University of Natural Resources and Life Sciences, Vienna - LiCRoFast CDL), Dr. Marco Marcon (Christian Doppler Laboratory for Life-Cycle Robustness in Fastening Technology University of Natural Resources and Life Sciences Vienna), Mr. Michele Zecchini (Christian Doppler Laboratory for Life-Cycle Robustness in Fastening Technology University of Natural Resources and Life Sciences Vienna), Prof. Roman Wan-Wendner (Ghent University)

Thermoset polymers are extensively employed in engineering, especially in aerospace and automotive. However, in these fields they are typically thermally treated to obtain optimal material properties and avoid post-curing effects. Recently, thermosets can be also found in structural engineering applications such as e.g. bonded anchors. In these cases thermal activation is typically not possible resulting in an undefined curing state. One of the most crucial design problems is the long-term behavior under sustained load. In order to accurately predict the tertiary creep behavior of a viscoelastic material, the loading rate effect needs to be characterized. In case of thermosets, also the curing degree dependence of the aforementioned material properties has to be accounted for. In this study the loading rate effect on strength is analyzed for different curing states which are derived from relevant in-situ conditions. Two adhesive products have been studied, one epoxy based and one vinyl ester based. The materials are characterized through tensile tests at different rates. The strain was monitored using digital image correlation (DIC). Four degrees of cure, assessed by means of DSC measurements, has been obtained by curing and post-curing the materials at different temperatures. The results reveal that the loading rate effect on strength is strongly dependent on the curing degree of the polymer. Interestingly, opposite trends are observed for the two adhesives. Finally, a simplified model able to describe the curing-degree dependent rate effect on strength is proposed as essential element for realistic numerical simulations of tertiary creep in incompletely cured thermosets.

Formation Process and Time Evolution of Creases in Elastomers and Gels

Wednesday, 19th June - 11:45: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 720

Mr. Berkin Dortdivanlioglu (Stanford University), Prof. Christian Linder (Stanford University)

Hydrogels are polymeric networks swollen with water and they can undergo large nonlinear deformations. As a result, various unique phenomena, such as pattern formation, can be observed as combined effects of transient and inhomogeneous swelling and nonlinear elastic deformations. In general, swelling follows the diffusion of water inside the hydrogel. In the transient state, maximum amount of isotropic swelling is observed on the surface neighboring the water solvent. This differential swelling initially results in very fine transient surface instabilities forming localized self-contacting cusps referred to as creases. With further swelling, they coalesce and form similar, but successively coarser patterns. Stimuli-responsive polymeric gels that display transient patterns with controlled critical conditions such as onset, geometry, and evolution are useful in applications ranging from sensors and responsive coatings, to bioadhesives and cell substrates.
Numerical modeling of hydrogels requires strong coupling between the deformation of the solid matrix and the diffusion of the water. Here, we adopt the mixed variational formulation for finite elasticity coupled with diffusion to model hydrogels. The objective of this presentation is to understand and identify mechanisms leading to coalescence of creases upon diffusion-driven swellings. Furthermore, this study systematically investigates the pattern formation dynamics for the characteristic size of these patterns such as the wavelength, amplitude, and contact length of growing and disappearing creases. Our proposed framework and numerical results allow a better understanding of pattern formation in hydrogels as well as structurally similar biological tissues, and consequently promote novel engineering and biomedical applications.

How Refined Should Seismic Response Analysis Models Be? A Rocking Structures Example

Wednesday, 19th June - 10:30: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 621

Dr. Jonas A Bachmann (ETH Zurich), Mr. Mathias Strand (NTNU Trondheim), Prof. Michalis Vassiliou (ETH Zurich), Dr. Marco Broccardo (ETH Zurich), Prof. Bozidar Stojadinovic (ETH Zurich)

Numerical models developed to predict the seismic response of structures deforming into the inelastic range often fail the conventional validation test: they fail to reproduce the experimentally obtained response to a particular ground motion with acceptable accuracy. This paper claims that this is too strict of a test for seismic response modeling. The Earthquake Engineering design problem involves predicting the statistics of the response to an ensemble of ground motions characterizing a given seismic hazard; not to a single ground motion. This is a weaker model validation test that requires that the structural model to only to be unbiased and to introduce less uncertainty than the uncertainty of the excitation itself. In this paper, we propose a weak form of seismic response analysis model validation. As an example, we use the 1963 Housner dynamic response model of a rocking structure. We performed 600 shaking table seismic response tests using a well-defined and repeatable rocking structure as well as 600 numerical simulations of these tests, and compared both the individual test response and the statistical aggregates of these response focused on predicting limit states such as overturning or maximum tilt angle. We show that the 1963 Housner model passes the weak validation test even though it fails the strong validation test. Therefore, the model is good enough for the scope of Earthquake Engineering. In conclusion, we propose broader application of weak validation models and outline possible acceptance criteria consistent with probabilistic seismic performance objectives for design and evaluation of structures.

The Influence of Low Frequencies on the Seismic Performance of Unanchored Blocks

Wednesday, 19th June - 10:45: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 699

Mr. Danilo D'Angela (Department of Engineering Science, University of Greenwich, Central Avenue, ME4 4TB Chatham), Prof. Gennaro Magliulo (Department of Structures for Engineering and Architecture, University of Naples "Federico II", Via Claudio, 21, 80125 Naples), Prof. Edoardo Cosenza (Department of Structures for Engineering and Architecture, University of Naples "Federico II", Via Claudio, 21, 80125 Naples)

The seismic performance of unanchored nonstructural components is affected by the low frequencies. The dynamic response of such elements is often governed by the rigid block motion, with more sensitivity to rocking periods rather than to elastic vibration frequencies. The rocking frequency only depends on the geometry of the block, and it may easily be lower than the elastic vibration frequency for relatively rigid components.

Shake table testing is the preferred way to assess the dynamic response of nonstructural components.The existing shake table protocols are not conceived for unattached components,and the generated inputs are often lacking in low-frequency content. This content is rarely considered as an explicit input feature for the selection of the real records. The combination of (a) potential lack in low frequencies of shake table inputs, and (b) low-frequency sensitivity of freestanding components, represents a topical issue for earthquake and structural engineering, especially if the equipment is included within critical facilities such as hospitals.

The study investigates the significance of low frequencies on the performance of unattached blocks, with particular regard to shake table testing. Incremental rigid block analysis is performed considering a wide range of block geometries, and both real and artificial records. The frequency content of the inputs is defined considering (a) the peak ground velocity to peak ground acceleration ratio (PGV/PGA), and (b) other derived parameters based on both acceleration and velocity. The quantitative influence of the input frequency content on rocking and overturning performance of the blocks is finally assessed.

Modelling of the Planar Dynamics of Rocking-Sloshing Systems

Wednesday, 19th June - 11:00: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 782

Mr. Hujing Liu (University of Oxford), Prof. Manolis Chatzis (University of Oxford), Prof. Christopher Macminn (University of Oxford)

The dynamics of sloshing vessels have been introduced in the pioneering works of Ibrahim, which have illustrated the rich dynamics of such systems. A common assumption in previous works studying such systems is that the vessels can either experience a translation with respect to their supporting medium or rotate under a well-defined harmonic motion. However, there are several cases where a vessel containing a fluid is not anchored, as in the case of water tanks or even cups of coffee found. When subjected to excitations such vessels can experience a rocking motion, with the fluid experiencing sloshing. The combined system exhibits a rocking-sloshing response where the rocking and sloshing dynamics are well coupled.

This work will introduce a model for the planar response of rigid rectangular vessels containing fluids expanding the Inverted Pendulum Model introduced by Housner. The equations of motion of the system are derived for the dynamic patterns of rocking with respect to a corner of the vessel.

The conditions for initiating rocking of the vessel to be initiated are formulated. The effect of impacts in the velocities of the components is studied. The use of a hard impact assumption allows to illustrate the interesting effects of combining hard constraints with deformable continuous media. An efficient numerical scheme is presented for solving the equations of motions over time. Suitable examples illustrate the rich dynamics of the system and the effect of impact on the response of the vessel and the fluid.

The Effect of Different Types of Modelling on Rocking Response

Wednesday, 19th June - 11:15: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1135

Mr. Nikhil Agrawal (IIT Kanpur), Prof. Suparno Mukhopadhyay (IIT Kanpur)

Rocking of unanchored objects is a well-recognized complex dynamic problem, and has attracted extensive research efforts towards its modelling. Starting from the first attempt by Housner, several, increasingly refined, models have been proposed to capture the various complexities associated with rocking. In this study a set of such models is considered, with the models differing with respect to how they incorporate the effects of ground deformability, impacts and sliding. The models are compared based on the rocking response of free standing blocks, subjected to trigonometric pulses, as well as typically observed directivity-type pulses represented by the Mexican hat function and its integral. The comparison is used to illustrate how modelling affects the rocking response, ultimate stability, as well as modes of failure by overturning (without impact vs. with one/multiple impacts). An attempt is made to interpret the results using the energy dissipation characteristics of the different models. The effect of changing pulse parameters on the stability and energy dissipation characteristics is also studied.

Lack of Repeatability on the Response of Free-Standing Cylindrical Casks under Different Ground Motion Characteristics

Wednesday, 19th June - 11:30: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 859

Prof. Luis Ibarra (University of Utah), Dr. Sharad Dangol (University of Utah), Dr. Chris Pantelides (University of Utah)

Dynamic experiments of free-standing cylindrical casks showed lack of repeatability in the cask response under very similar input system conditions. This study summarizes several methods used to detect potential chaotic behavior regarding the pure rocking response of cylindrical casks, including phase-space plot, Fourier spectra, and Poincaré sections. These analyses determine if the system's response is non-harmonic and/or non-periodic when the system is subjected to a harmonic excitation.

The sensitivity of the cask response is also evaluated by obtaining the analytical rocking response for a baseline cask, and then analyzing the effect of small input parameter variations. Previous analytical and finite element analyses demonstrated that the rocking response of 2D blocks under single-cycle sinusoidal response is repeatable. The results of this study indicate that rocking displacement time histories of systems with minute differences in the input parameters start to drift apart from each other after several cycles. The outcome is relevant when distinguishing between Far-Field- and Near Field Ground Motions (FFGMs and NFGMs), given that the latter motions may be exposed to just a couple of significant pulses during the event.

The effect of small changes in input parameters is also investigated by Monte Carlo simulations. A sensitivity analysis of rocking motion is used to assess the effect on the response of minute parameter variations. The results show that FFGMs, with multiple large pulses, produce larger displacements than NFGMs. Moreover, the dispersion is larger for FFGMs that for NFGMs because multiple significant cycles result in a more unpredictable response.

Mechanical Properties of Multi-Layer Graphene and Bio-Inspired Nanocomposites

Wednesday, 19th June - 10:30: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 86

Dr. Zhaoxu Meng (Northwestern University), Prof. Sinan Keten (Northwestern University)

Multi-layer graphene (MLG) and its derivatives, such as graphene oxide (GO), with advantage of their exceptional mechanical properties, have emerged as ideal building blocks for constructing high performance bioinspired nanocomposites. To harness the superior mechanical properties of graphene/polymer nanocomposites, it is crucial to understand the mechanical properties and deformation mechanisms of the constituents and also the interfacial mechanics between them, starting from nano-scale.

Taking advantages of our recently developed coarse-grained molecular dynamics (CG-MD) models of MLG and GO, we have investigated both the quasi-static and dynamic (e.g. ballistic impact) mechanical properties of MLG sheets, as well as other constituents. Specifically, we have found that the hysteresis during nanoindentation loading and unloading of MLG sheets is due to a recoverable atomic-level interlayer sliding process. We have also examined the ballistic impact response of MLG sheets. We revealed that the reflected cone wave and spalling-like failure mechanism during ballistic impact both result in easier perforations, which decreases their ballistic resistance. Additionally, we have reported a comparative analysis of the dynamic behavior of nanoscale thin films made from MLG, polymer, gold, and aluminum. This study clearly illustrated how material properties and geometrical factors relate to ballistic penetration energy, thereby allowing a quantitative comparison of the nanoscale ballistic response of different materials. Finally, I will show our effort on the nacre-inspired design of MLG-polymer nanocomposites, where we characterized the interfacial behaviors of the designed system as well as identified critical sizes that govern failure modes.

A Simple Mechanical Model for Synthetic Catch Bonds

Wednesday, 19th June - 10:45: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 154

Prof. Sinan Keten (Northwestern University), Mr. Kerim Dansuk (Northwestern University)

A quintessential feature of cells is their ability to reversibly bind to other cells and surfaces through the use of catch bonds, which is typically facilitated by allosteric proteins. Unlike regular bonds, proteins that form catch bonds with their ligands become more difficult to break with larger applied force, a counterintuitive phenomenon that is yet to be reproduced in synthetic systems. Here, we show that a minimal tweezer shaped mechanical system, which is subject to Brownian dynamics, can exhibit force-enhanced binding like a catch bond. When bound to a ligand subject to a constant tensile force, our system can transition to a high-ligand-affinity state stabilized by secondary interactions that form between the tweezer and the ligand. The transition is regulated by a force-sensitive Morse potential based switch that is serially connected to the ligand. Applying kinetic theory to a two-mass-two-spring idealized model of the ligand-switch serial system, we show that when the switch energy landscape is chosen to be wider than ligand landscape, it tilts more strongly under force relative to the ligand's, which activates the switch more frequently at large forces. This enables greater dwell times in the higher affinity state, and thereby results in a catch-bond. We validate our theory with molecular dynamics simulations of the tweezer system and produce a characteristic lifetime curve reminiscent of catch bonds. Our analysis reveals minimal design guidelines to reproduce the catch bond phenomenon in synthetic systems such as molecular switches, DNA linkers, foldamers or nanoparticle networks.

Bioinspired Design of Anisotropic Porous Structural Components Based on Adaptive Centroidal Voronoi Tessellation

Wednesday, 19th June - 11:00: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 959

Mr. Babak Salarieh (University of Alabama in Huntsville), Dr. Hongyu(Nick) Zhou (University of Alabama in Huntsville)

In this research, a bioinspired approach is developed to design anisotropic/ gradient porosity patterns on load-carrying structural components that adapt to a given set of physical settings and conditions such as varying external forces and boundary conditions. Anisotropic porous structures will be designed following the distribution of stress field, adaptively tailoring local properties of the design domain by optimally tuning the composition and/or architecture of materials in order to achieve, e.g., high strength-/stiffness-to-weight ratio. Firstly, stress gradient analysis is performed based on finite element analysis (FEA) results obtained from commercial FEA software (ABAQUS); then, the design domain is discretized and partitioned based on a stress-gradient driven Adaptive Centroidal Voronoi Tessellation (ACVT) method developed in this research. Lastly, the local attributes of each Voronoi cell (e.g. porosity, orientation) are optimized based on the averaged stress intensity. The porosity generation algorithm developed herein mimics many biological organisms observed in nature (e.g., bamboo culm, turtle shell, trabecular bone and human femur), where high-density building materials are anisotropically orientate towards high stress regions (e.g., locations with stress concentrations) while removing inefficient materials from low stress areas. Subsequently, a set of experimental tests were carried out to validate the mechanical properties of load-carrying components designed based on the method developed in this research. The adaptive nature of this method opens up new perspectives in the design and optimization of high performance and multifunctional components.

Circadian Cycle-Driven Protein Modifications Define Fabrication Boundaries to Improve Biomechanical Properties

Wednesday, 19th June - 11:15: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 324

Dr. Malcolm Snead (University of Southern California)

Enamel is the bioceramic composite covering teeth and despite repeated use/abuse it rarely fails. Enamel biomineralization involves cells which secrete along their migration a protein mix into which hydroxyapatite (HAP) deposits. Enamel extracellular proteins must self-organize and spatially segregate to regulate inorganic crystallites. Enamel's embryonic origin as soft-proteins is converted in mature enamel into a hard-, brittle-, composite-ceramic composed of high-aspect ratio HAP crystallites arranged as bundles modulating toughness. Enamel is collagen-free, instead amelogenin protein with highly conserved domains facilitate protein self-assembly into polymeric nanospheres that guide biomineralization. Unlike mesoderm-derived bone that remodels, enamel is ectoderm-derived and cannot remodel: it must be created with no errors.

Enamel 24 hr markings are due to the circadian clock with daily rhythms of gene expression modulated by transcription factors *Per2* and *Bmal1,* regulators of the circadian clock. *Amelogenin* oscillates with a ~24hr rhythm and ~2 fold decrease during the dark period. Biomineralization proteins for bicarbonate (*Car2*) and transport (*Slc4a4*) are more highly expressed during the dark period. The a*melogenin* gene contains circadian responsive E-box that control transcription. Ameloblastin, the second most abundant enamel protein, redistributes to the lateral boundaries of the matrix following secretion and defines formation boundaries for HAP bundles imparting fracture toughness. A proteasome subunit interacts with secreted ameloblastin at secretory ends of cells. Co-immunoprecipitation identified each reciprocal protein partner corroborating the interaction. Protein engineering show only the ameloblastin C'-terminus interacts with proteasome. Proteasome members exert control over protein distribution by degrading proteins that regulate interactions essential to biomineralization.

Fracture Assessment of Cortical Bone at Microscopic Length-scale

Wednesday, 19th June - 11:30: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 346

Dr. Ange Therese Akono (Northwestern University)

The research objective is to understand the fracture behavior of bovine and porcine cortical bone at the microscopic length-scale. We rely on scratch tests, in which a sphero-conical probe is pulled across the surface of a material at depths ranging from tens to hundreds of microns while prescribing a linearly increasing vertical force. Advanced imaging such as white light optical microscopy and scanning electron microscopy are utilized to investigate material failure micro-mechanisms. In order to understand the origin of energy dissipation, whether strength-driven or fracture-driven, we pay attention to the scaling of the force. In particular, in the asymptotic strength-driven regime, the nominal strength is invariant with respect to the penetration depth. However, in the asymptotic case of a fracture-driven regime, the nominal strength is inversely proportional to the square root of the penetration depth. Using the energetic size effect law to represent this transition from ductile to brittle behavior, we can extract the fracture characteristics (fracture energy, and characteristic length) of the specimen . In this study a specific care is given to the specimen preparation procedure and its effect on the measurements. Furthermore, we contrast the measured values of the fracture toughness and the observed fracture mechanisms for bovine cortical bone, and porcine cortical bone while focusing on the effect of orientation, local composition and morphology.

Modeling of Mechancial Behavior of Bio-Inspired Nacre-Like Materials Using Discrete Element Simulations

Wednesday, 19th June - 11:45: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 453

Ms. Kaoutar Radi (Univ. Grenoble Alpes, CNRS, Grenoble INP, SIMaP, F-38000 Grenoble), Prof. David Jauffres (Univ. Grenoble Alpes, CNRS, Grenoble INP, SIMaP, F-38000 Grenoble), Prof. Christophe L Martin (Univ. Grenoble Alpes, CNRS, Grenoble INP, SIMaP, F-38000 Grenoble), Mr. Hassan Saad (Laboratoire de Synthèse et Fonctionnalisation des Céramiques, UMR 3080 CNRS / Saint-Gobain CREE, Saint-Gobain Research Provence, Cavaillon), Prof. Sylvain Deville (Laboratoire de Synthèse et Fonctionnalisation des Céramiques, UMR 3080 CNRS / Saint-Gobain CREE, Saint-Gobain Research Provence, Cavaillon)

Nacre is considered the perfect example of nature's design of damage-resistant materials. Due to its brick and mortar structure, nacre achieves high strength and toughness simultaneously. Inspired by this structure, a new all ceramic composite, alumina nacre, has been designed from brittle constituents for high temperature applications [1]. Going beyond the proof-of-concept requires now a better insight on the reinforcement mechanisms and on the microstructure/properties relationships together with microstructural optimization. Using the Discrete Element Method (DEM), we have developed a numerical model to study the influence of microstructural parameters on fracture and toughness. Thanks to the capability of DEM to account for topological modifications (crack growth, branching, ...), we investigate both intrinsic and extrinsic reinforcement mechanisms. This improves on previous models that only consider intrinsic reinforcement, whereas our model allows for the increase in fracture resistance with crack propagation (R-curve effects) to be investigated. The model is validated for elasticity and strength against analytical models on a 2D periodic unit cell of an idealized brick and mortar geometry [2]. Building on this model, simulations of crack propagation over dozen of bricks are conducted to assess toughness and R-curve effects as a function of mechanical and microstructural parameters. As a result, mortar reinforcement appeared to be the secret to the material optimization. We determine a set of mechanical and microstructural parameters that allows for optimizing strength, toughness initiation, and extrinsic reinforcement mechanisms (R-curve).

[1] Bouville et al. (2014), Nat. Mat., DOI: 10.1038/NMAT3915

[2] Radi et al. Submitted to JMPS.

Analysis of Penetration Problems in Geomechanics with the Particle Finite Element Method

Wednesday, 19th June - 10:30: KEYNOTE / MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 1 (142 Keck (72)) - Oral - Abstract ID: 1414

Wednesday, 19th June - 10:30: KEYNOTE / MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1414

Prof. Antonio Gens (Universitat Politècnica de Catalunya), Mr. Lluis Monforte (niversitat Politècnica de Catalunya), Dr. Marcos Arroyo (Universitat Politècnica de Catalunya), Dr. Josep Maria Carbonell (International Center for Numerical Methods in Engineering (CIMNE))

Activities involving the penetration of rigid bodies into a soil mass (e.g. probing, sampling, pile installation) are ubiquitous in Geomechanics. In this type of problems, large displacements and deformations of the soil mass invariably occur and they are often accompanied by rapidly changing boundaries. The complexity of the problem is increased by the nonlinear nature of soil constitutive models and the contact formulation as well as by the coupled nature of the hydromechanical response of the soil. An appealing modelling approach to tackle this type of problems is the Particle Finite Element Method (PFEM). PFEM is based on an updated Lagrangian approach, but one that avoids severe mesh distortion by frequent remeshing. The nodes discretizing the analysis domain are treated as material particles the motion of which is tracked during the numerical solution. Remeshing in PFEM is based on Delaunay tessellations and uses low-order elements. In addition to the description of the method, particular attention is given to the formulation of PFEM in a coupled hydromechanical framework and to the mixed-formulation strategies developed to overcome the volumetric locking of the low-order elements that are typically used in PFEM. The successful performance of the method is demonstrated by a series of applications to different geomechanical penetration problems with special focus placed on the cone penetration test. ~

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Pattern Transformations via Instabilities in Soft Heterogeneous Materials with Applications for the Design of Functional Metamaterials

Wednesday, 19th June - 10:30: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 54

Mr. Jian Li (Technion-Israel Institute of Techology), Dr. Tarkes Dora P (Karlsruhe Institute of Technology), Dr. Viacheslav Slesarenko (Technion-Israel Institute of Techology), Prof. Stephan Rudykh (University of Wisconsin – Madison)

We investigate the instability-induced pattern transformations in soft heterogeneous materials, and their applications in the design of functional metamaterials. We identify the onset of instabilities by numerical Bloch-Floquet techniques and experiments on 3D-printed specimens. We first realize the instability-induced pattern transformations in 3D-printed soft composites consisting of stiff inclusions and voids periodically distributed in a soft matrix [1]. These soft auxetic composites are prone to elastic instabilities giving rise to negative Poisson's ratio (NPR) behavior. Upon reaching the instability point, the composite microstructure rearranges into a new morphology attaining a NPR regime. Remarkably, identical composites can morph into distinct patterns depending on the loading direction. We illustrate a potential application of these reversible pattern transformations as tunable acoustic-elastic metamaterials. Next, we investigated the instability-induced domain formations and its transition to wavy patterns in the system of stiff inclusions periodically distributed in a soft elastomeric matrix [2]. We experimentally observe the formation of microstructures with anti-symmetric domains, and its geometrically tailored evolution into a variety of patterns of cooperative particle rearrangements. Through our experimental and numerical analyses, we show that these patterns can be tailored by tuning the initial microstructural periodicity and concentration of the inclusions.

References

[1] Li J, Slesarenko V, Rudykh S. Auxetic multiphase soft composite material design through instabilities with application for acoustic metamaterials. Soft Matter 2018;14:6171–80.

[2] Li J, Tarkes Dora P, Slesarenko V, Goshkoderia A, Rudykh S. Domain formations and pattern transitions via instabilities in soft heterogeneous materials. Adv. Mater. 2019; Accepted, doi: 10.1002/adma.201807309.

Mechanical Response of Heterogeneous Materials Using the Recursive Projection Method

Wednesday, 19th June - 10:45: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 118

Ms. Xiaoyao Peng (Carnegie Mellon Univ), Dr. Dhriti Nepal (Carnegie Mellon Univ), Prof. Kaushik Dayal (Carnegie Mellon Univ)

The original FFT method, developed by Moulinec and Suquet to solve local and global response of composite, is limited by the convergence properties of the fixed-point iteration on which it is based. For composite with high (10^4) contrast material properties, as occurs in soft elastomers reinforced by nanoparticles, the method shows very poor convergence. In this work, we apply the Projection Method to the original FFT method to recover the convergence. Comparisons between the original FFT method, and the accelerated FFT method, and the method proposed here, have been made and discussed here.

Strength of Additively Manufactured Brittle Cellular Materials

Wednesday, 19th June - 11:00: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 688

Ms. Sirui Bi (Johns Hopkins University), Mr. Enze Chen (Johns Hopkins University), Prof. Stavros Gaitanaros (Johns Hopkins University)

Cellular solids, such as honeycombs and foams, have unique properties and are thus often used as thermal, acoustic and/or shock absorbers. Nonetheless, the mechanical properties of brittle cellular materials have been largely understudied. We will present here a series of tension-compression experiments on lattices and foams in order to understand their fracture strength and connect it to the underlying microstructure. In particular, additively manufactured specimens with controlled morphological characteristics are used to quantify the effect of relative density, disorder and node connectivity to the fracture properties of both regular and random cellular materials.

Architected Granular Materials With Adaptive Energy Absorption

Wednesday, 19th June - 11:15: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 853

Dr. Yifan Wang (California Institute of Technology), Dr. Brian Ramirez (California Institute of Technology), Mr. Kalind Carpenter (Jet Propulsion Laboratory, California Institute of Technology), Dr. Christina Naify (Naval Research Laboratory), Dr. Douglas Hofmann (Jet Propulsion Laboratory, California Institute of Technology), Prof. Chiara Daraio (California Institute of Technology)

Energy absorption materials are widely used in wearable protectives to prevent the wearer’s body from injury due to impact and shock. Existing energy absorbing systems are passive and typically effective in mitigating impact loads under predefined velocities or energies. However, if these velocities change, they are rendered ineffective. In our work, we develop adaptive architected foam composites by incorporating granular materials in an 3D-printed soft lattice. By changing the confinement pressure on these lattices and creating jamming in the internal granular materials, the stiffness and modulus of the structure could be tuned by over an order of magnitude. We further show that the architected lattices could adapt their damping properties to varying impact energy to minimize damage. This work opens opportunities for building architected structures with soft materials with adaptive functionalities.

Imperfections by Design: Tunable Interactive Buckling and Postbuckling in Architected Actuating Units

Wednesday, 19th June - 11:30: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 864

Mr. Yinghao Zhao (Department of Civil Engineering, South China University of Technology), Mr. Amal Jerald Joseph Maria Joseph (Department of Mechanical and Aerospace Engineering, The Ohio State University), Mr. Chunping Ma (Department of Civil, Environmental and Geodetic Engineering, The Ohio State University), Mr. Zhiwei Zhang (School of Civil Engineering, Harbin Institute of Technology), Mr. Burak Gul (Department of Civil, Environmental and Geodetic Engineering, The Ohio State University), Dr. Nan Hu (Department of Civil, Environmental and Geodetic Engineering, The Ohio State University)

Harnessing elastic instabilities in materials have recently enabled new classes of tunable systems and devices, such as soft fluidic actuator, metamaterial-based artificial muscle, gating mechanism, origami-inspired artificial muscles, nonlinear force sensor, biomimetic actuators at architectural scale, and soft robotics, etc. The common feature of those instability-induced smart systems is the amplifying force and augmented motion compared to their traditional stiff counterparts. Achieving these amplifying effects usually relies on harnessing tailorable architected materials (also known as mechanical metamaterials) as the building block. One of the ongoing challenges is how defects change the properties of mechanical metamaterials to achieve targeted functionalities with aperiodic materials. In response to such need, we introduce a class of shell structures which undergoes interactive buckling induced by strategically controlling the number and distribution of geometric defects. By combining finite-element simulations and desktop-scale experiments, we found that the interactive buckling can be induced by strategically controlled the number and the distribution of defects, leading to a deterministic actuation response compared to the one without geometric defects. Our study thereby opens avenues for the design of the next generation of actuators and robots with high fidelity and low sensitivity over a wide range of length scales.

Topological Dynamics of Structural Maxwell Lattices

Wednesday, 19th June - 11:45: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 914

Dr. Jihong Ma (University of Minnesota), Dr. Di Zhou (University of Michigan), Prof. Kai Sun (University of Michigan), Prof. Xiaoming Mao (University of Michigan), Prof. Stefano Gonella (University of Minnesota)

In this work, we investigate the dynamic phononic and topological characteristics of a family of topological metamaterials based on Maxwell lattice architectures. These metamaterials have been the object of extensive theoretical investigation in recent years, but the main interest has typically been limited to ideal (lumped-parameter) configurations and confined to the static limit. Here, we explicitly explore the realistic scenario in which the ideal hinges that appear in the theoretical models are replaced by ligaments capable of supporting bending deformation, which can be described using the framework of continuum elasticity. This is the scenario practically observed in physical lattices obtained using fabrication techniques such as 3D printing, lithography, or water/laser cutting. This change in configuration results in a frequency upshifting of the lattice response and in a migration of many of the most defining response features to the dynamic regime. Through a systematic, laser-assisted experimental characterization, we reveal how the zero-energy floppy edge modes predicted for ideal configurations morph into finite-frequency modes that localize at the edges, while qualitatively preserving the topological attributes originally predicted for the static case, and overlap with the bulk phonon modes. The experiments also reveal that the topological polarization endows the lattices with pronounced asymmetric wave transport capabilities available over broad low-frequency ranges.

Inflow and Model-Form Uncertainty Quantification in CFD-Enabled Aerodynamic Shape Optimization

Wednesday, 19th June - 11:00: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 2 (103 Downs (50)) - Oral - Abstract ID: 414

Ms. Fei Ding (University of Notre Dame), Prof. Ahsan Kareem (University of Notre Dame)

Uncertainties exist in the CFD modeling of wind flow around structures, which can be customarily categorized into aleatory and epistemic uncertainties. For instances, inflow uncertainty associated with the inherent variability of atmospheric flows falls in the category of aleatory uncertainty. While the model-form uncertainty maybe induced by the mathematical approximation for the unresolved small-scale turbulent eddies is a type of epistemic uncertainty. Those uncertainties could largely impact the reliability of CFD-based optimization and result in building forms that are aerodynamically sub-optimal. Therefore, both aleatory and epistemic uncertainties need to be appropriately quantified and propagated into the aerodynamic shape design cycle.
The focus of this study is on developing a strategy to enable inflow and model-form uncertainty to be quantified in a coupled fashion using surrogate modeling techniques. Particularly, inflow uncertainty can be characterized as the probability density function of the inflow parameters. Now with the advances in high-performance computing, parallel programming will be explored to generate turbulent velocity fields characterized by the inflow parameters on the inlet patch through harnessing the power of the computer's graphics process unit (GPU). While model-form uncertainty is represented by the multi-fidelity CFD model discrepancy between Reynolds-averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES). A case study demonstrates the efficacy of the proposed approach and the application of uncertainty propagation in the aerodynamic shape optimization of civil structures.

Uncertainty Quantification in LES of Wind Loading

Wednesday, 19th June - 11:15: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 2 (103 Downs (50)) - Oral - Abstract ID: 271

Mr. Giacomo Lamberti (Stanford University), Prof. Catherine Gorle (Stanford University)

Extreme wind-induced loads can be critical for the structural integrity of the glazed panels that are often employed to cover high-rise building facades. Wind tunnel tests on a model of a high-rise building in the boundary layer wind tunnel of Politecnico di Milano have observed strong negative pressure peaks with different spatial-temporal characteristics. Some of the peaks are extremely localized in space and time and thus unlikely to cause damage to the panels; others have a larger spatial-temporal extent and should be accounted for when establishing the design wind pressure.

In the present work, we employ large eddy simulations (LES) to improve our understanding of the flow physics that cause these negative pressure peaks and support a more accurate characterization of the design loads on facade panels. Since LES results will be influenced by the characteristics of the incoming atmospheric boundary layer, the effect of uncertainties in the inflow boundary condition is investigated by performing a sensitivity analysis. We consider three uncertain input parameters: the roughness length of the terrain, the turbulence kinetic energy and the streamwise integral time-scale. We run 27 LES simulations using different combinations of these input parameters to quantify their influence on the pressure distribution on the building facade, the design pressure and the extreme pressure events, and we compare the results to the available wind tunnel measurements.

Inflow Boundary Conditions for Urban Flow Predictions Using Data Assimilation

Wednesday, 19th June - 11:30: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 2 (103 Downs (50)) - Oral - Abstract ID: 1131

Dr. Jorge Sousa (Stanford University), Prof. Catherine Gorle (Stanford University)

The natural variability of atmospheric boundary layer flows is one of the factors limiting the predictive capability of computational fluid dynamics simulations for urban flow predictions. The objective of this study is to investigate the use of data assimilation to define the inflow boundary conditions for Reynolds-averaged Navier-Stokes (RANS) simulations of urban flow. We employ the ensemble Kalman filter to iteratively estimate the probability density functions of the incoming wind direction and magnitude based on data from urban wind sensor measurements. Subsequently these densities are used for forward predictions of the urban flow field, providing a prediction for the mean velocity with 95% confidence intervals. To support this analysis, a full-scale experimental campaign was carried out on Stanford's Campus. We deployed six sonic anemometers at roof and pedestrian level; two of the sensors were used for assimilation, while the remaining ones were used for validation. The results obtained using the proposed Bayesian inference method are compared to results obtained when defining the inflow boundary conditions based on wind data from a nearby weather station, demonstrating significant improvements when using the inference method. An analysis of the impact of the number of sensors and their location indicates that the assimilation approach can consistently improve the predictions, as long as the inlet flow properties are identifiable by the sensor. The results indicate that data assimilation provides a promising route for improving the predictive capabilities of RANS simulations of urban flow.

Empirical Approach for Assessment of Tornado-Induced Loads on Transmission Towers by Using Their Aerodynamic Coefficients

Wednesday, 19th June - 11:45: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 2 (103 Downs (50)) - Oral - Abstract ID: 1145

Mr. Saransh Dikshit (Iowa State University), Dr. Alice Alipour (Iowa State University), Prof. Partha P. Sarkar (Iowa State University), Dr. Alireza Razavi (Dunwoody College of Technology), Mr. Mohammad Jafari (Iowa State University)

Transmission tower systems are susceptible to failure due to extreme winds in tornado events. This urges prediction of tornado-induced loads in design phase of these tower systems. Prediction of these loads requires access to tornado simulators, which makes analysis difficult due to the limited number of tornado simulators worldwide. In this paper, an empirical approach is proposed to characterize tornado-induced loads on a 500-kv transmission tower by using aerodynamic coefficients of the tower. For this purpose, a scaled model of the transmission tower is tested in ABL wind tunnel and its drag and lift coefficients are measured for all possible angles of attacks (0-360^o) with angular displacement of 10^o; then, analytical equations of velocity profiles of a simulated tornado are used along with the translation speed of the tornado to find load time histories. To validate the empirical approach, transmission tower is placed in the path of a simulated translating tornado at Iowa State University Tornado Simulator and its load time histories are measured. Comparison of the load time histories from the experiment with the results of the empirical approach shows a close match, marking the procedure promising.

Deep Convolutional Neural Networks for Heterogeneous Material Homogenization

Wednesday, 19th June - 11:00: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 955

Mr. Yanhui Jiang (Northeastern University), Mr. Chengping Rao (Northeastern University), Dr. Ruiyang Zhang (Northeastern University), Prof. Yang (Emily) Liu (Northeastern University)

Homogenization, which passes information from a lower scale (e.g., microscale) to a higher scale (e.g., macroscale), exhibits a critical component in multiscale computational modeling of heterogeneous materials. Typically, homogenization is performed on unit cells and yields effective material properties upon volume averaging based on the asymptotic theory. Recent advances in machine learning and data-driven methods offer an alternative to determine the homogenized properties of heterogeneous materials. We herein present a deep learning approach, based on 3D convolutional neural networks (3D-CNN), to map the unit cell property structured in a 4D matrix to the homogenized connectivity matrix with 21 independent components, for composite materials with various types of microstructures (e.g., randomly distributed inclusion/fiber-reinforced polymer/ceramic matrix composites). The model is trained with datasets prepared through computational modeling and simulations. Generalizability and robustness of the proposed method are tested and illustrated through a few examples.

A Machine Learning-Based Paradigm to Model Granular Materials

Wednesday, 19th June - 11:15: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 11

Dr. Utkarsh Mital (Caltech), Prof. José Andrade (Caltech)

In this work, we show how machine learning can be deployed to learn the physics of grain-scale behavior. We have repurposed computer vision algorithms to (a) learn and predict macroscopic properties (imposed stress) as a function of microscopic attributes (contact forces), and (b) generate synthetic microscopic attributes (force chains) that mimic real data. These results open the door to unleash the full power of computer vision in modeling heterogeneous geotechnical systems. Exciting possibilities include cross-domain learning where (a) grain-scale information from one boundary value problem could be mapped to another, and (b) grain-scale information from simple spherical assemblies could be mapped to assemblies of complex shapes. Such advances can enable a new framework for hierarchical multiscale modeling. Multiscale approaches typically necessitate conducting grain-scale simulations in series with continuum simulations, effectively creating a bottleneck. Our work shows that it may be possible to implement machine learning to learn the grain-scale behavior in advance and then inform the continuum model during a simulation.

Machine Learning Based Multiscale Modeling of Backward Erosion Piping

Wednesday, 19th June - 11:30: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 238

Dr. Alessandro Fascetti (The University of Waikato)

The state of the nation's infrastructure calls for immediate action to minimize the effect of natural hazards on our communities. The presented research advances knowledge in the broad area of Infrastructure Engineering by defining a novel multiscale modeling approach to simulate the evolution of Backward Erosion Piping (BEP) process in Flood Protection Systems (FPSs). Numerical simulations are performed at the "local" scale using a multiphase description of the erosion process. Results of these simulations are used as the training set for a two-layer Machine Learning (ML) model to bridge the information between the local and system scales. Accuracy of the trained ML algorithms is demonstrated by comparing results obtained from detailed physics-based numerical models. The multiscale approach is also employed in the construction of lookup tables for system response, as well as the simulation of infrastructure systems of massive size. The proposed methodology allows for real-time predictions of the overall response at the system scale, and a case study is presented where a portion of the Nashville Metro Levee System is analyzed over the span of a year, to assess the likelihood of BEP in the infrastructure.

Bootstrapping Critical State Plasticity Models for Predicting Cyclic Undrained Responses of Granular Materials with a Hierarchical Knowledge Polytree

Wednesday, 19th June - 11:45: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 793

Mr. Nick Vlassis (Columbia University), Prof. Wai Ching Sun (Columbia University)

Predicting cyclic responses of undrained granular materials is a notoriously difficult task. Despite the significant progress made in constitutive modeling, the most advanced elasto-plastic material models typically only yield qualitatively matching predictions on the stress path and pore pressure time history. In this work, we attempt an alternative approach in which multiple material models, each with different strengths and weaknesses are collectively used to make ensemble predictions with an adaptive weighting function. This weighting function is inferred from a hierarchical knowledge graph generated by unsupervised learning. In particular, a set of experimental data is decomposed into multiple subsets via data clustering applied multiple times across scales. These clustered data are then used to train specific models with desirable traits tailored to each cluster. Predictions are then made by weight-averaging these highly specialized models in which the weight evolves to maximize an objective function that estimates the accuracy of the predictions. This divide-and-conquer approach enables complex behaviors to be replicated by simpler predictions propagating through a hierarchy of knowledge mathematically represented by a directed graph. K-fold validation exercises are used to compare this big data approach with the established constitutive laws to analyze the robustness, accuracy, and efficiency of the proposed method.

Large Deformation Modeling of Soil-Fluid Mixture - Macro and Micro Scales

Wednesday, 19th June - 13:00: Plenary 2 (Beckman Auditorium (1,136)) - Oral - Abstract ID: 322

Prof. Kenichi Soga (University of California, Berkeley)

Geological and geotechnical hazards, such as landslides, debris flows and excavation collapses, involve rapid and large mass movement of granular solids, water and air as a multi-phase system. The momentum transfer between the discrete and continuous phases significantly affect the dynamics of the movement. This study aims to understand the ability and limitation of continuum and discrete models in capturing the micro and macro mechanisms of soil-fluid coupled dynamics such as pore pressure generation and dissipation, hydrodynamic instabilities under large deformation. Two methods to simulate soil-fluid coupled dynamics at two different scales are introduced. The Material Point Method (MPM), a hybrid Lagrangian and Eulerian approach, is used to describes the continuum behavior of large deformation soil-fluid dynamics, whereas the Discrete Element Method coupled with the Lattice Boltzmann Method (LBM) is used to examine the fluid grain interactions at particle contact scale. The effect of pore fluid force on the large deformation behavior of a soil-fluid mixture is investigated by examining the mechanisms of evolution behavior and energy dissipation.

Damage Identification in Steel Buildings Using Nonlinear Structural Models and Seismic Networks

Wednesday, 19th June - 14:00: MS80: Structural Identification and Damage Detection; Part 2 (Ramo (371)) - Oral - Abstract ID: 434

Mr. Filippos Filippitzis (California Institute of Technology), Dr. MONICA KOHLER (California Institute of Technology), Prof. Thomas Heaton (California Institute of Technology)

Damage identification methods applied to structures are motivated by dense and continuous building response data collected from low-cost strong-motion networks such as the Community Seismic Network. Damage in a structure is assigned by modifying the material properties in a targeted number of structural components. To account for the sparsity of the damage, L1 regularization techniques or sparse Bayesian learning tools are found to be suitable for identifying the location and severity of damage. In the vast majority of studies, such techniques have been applied to linear models of structures using modal properties as the measured quantities. In this study the damage identification problem is formulated in the time domain, and it is configured so that near-real-time strong motion acceleration time histories recorded by dense arrays can inform assessment of structural condition. Furthermore we extend these methods to handle model nonlinearities that reflect damage to the structure. Guided by observed steel-moment frame damage patterns, we consider the behavior of cracks in beam-column connections. For the structures under consideration, high-fidelity nonlinear finite element models are developed in OpenSees using force-based fiber elements, allowing for realistic behavior associated with the opening and closing of cracks to be incorporated into the modeling. The effectiveness of the proposed method is demonstrated using a number of different imposed damage scenarios and simulated acceleration data from a multi-story theoretical steel building as well as an existing, fully-instrumented 15-story building in downtown Los Angeles.

Cepstral Coefficients, a New Feature for Structural Damage Assessment

Wednesday, 19th June - 14:15: MS80: Structural Identification and Damage Detection; Part 2 (Ramo (371)) - Oral - Abstract ID: 499

Dr. Marcello Morgantini (Columbia University), Prof. Raimondo Betti (Columbia University)

The main objective of *Statistical Pattern Recognition*in structural health monitoring is to identify some patterns that can be used to classify structures in one of two possible states: the healthy state (undamaged) and the damaged state. In order to solve this classification problem, it is important to rely on features that are sensitive to damage so that, from their variations, information on the occurrence of damage can be inferred. Most commonly used features are natural frequencies, mode shapes, derivatives of mode shapes, and so on.

In this paper, some features characterizing the system dynamic response in the quefrency domain, referred to as cepstral coefficients, are considered as potential damage sensitive features. These coefficients can be easily extracted from the records of the structural response (e.g. displacements, accelerations). The main advantage of working in the quefrency domain versus the frequency domain consists in a massive dimensionality reduction. In this paper, a convenient (in terms of damage assessment) mathematical representation of the cepstral coefficients has been derived and used in a Principal Component Analysis (PCA) to assess structural damage.

The effectiveness of these damage sensitive features and of their PCA implementation has been tested through a numerical test on a simulated 8-DOF shear-type mock-up. Its robustness to external disturbances and different excitation conditions is analyzed, together with a comparison of the results with those obtained through AR coefficients. Finally the methodology have been also tested using real experimental data from the sensors placed on the Z24 Bridge in Switzerland.

Streamlined Long-Term Structural Monitoring with Dense Instrumentation via Model Reduction

Wednesday, 19th June - 14:30: MS80: Structural Identification and Damage Detection; Part 2 (Ramo (371)) - Oral - Abstract ID: 1277

Dr. Rodrigo Sarlo (Virginia Tech), Dr. Serkan Gugercin (Virginia Tech)

Several challenges exist in the system-identification (Sys-ID) and structural monitoring of densely instrumented structures in realistic operational conditions. In particular, traditional Sys-ID practices are not well suited for data from dense sensor networks. One example is the iterative fitting of dynamic models of various complexities in search for the optimal choice, often implemented through a stabilization diagram approach. Another example is the indiscriminate use of *all* sensors without regard for redundancies in the measurement signals. Here, the limitations of these practices are demonstrated through the two-year operational testing of a 'smart' building on the Virginia Tech campus with a network of 225 accelerometers. The case study shows that more efficient techniques are necessary to avoid the prohibitive computational burden imposed by the application of the standard practices mentioned above. Preliminary work by the authors has shown that model reduction techniques can be leveraged to streamline the Sys-ID process. This paper further leverages these techniques by incorporating them into a fully automated Sys-ID strategy which yields a two-year modal history of unprecedented resolution. Specifically, the Stochastic Subspace Identification algorithm (a Sys-ID technique) is augmented through observability-based model reduction, which dramatically reduces the computational requirements of stabilization diagram generation. The model reduction process also ranks the observability of model states from the data, thus this information is used to select an appropriate model from the stabilization diagram in an automated fashion. The end result is an automated Sys-ID process which runs orders-of-magnitude faster than the traditional approach with little reduction in performance.

Investigations into Inverse-Based Local Damage Identification on Large Scale Truss Structure Using Sparse Vector Recovery

Wednesday, 19th June - 14:45: MS80: Structural Identification and Damage Detection; Part 2 (Ramo (371)) - Oral - Abstract ID: 1364

Mr. Chandler Smith (University of Vermont), Prof. Eric Hernandez (University of Vermont)

In recent years, finite element model updating methods which target sparse solutions have been suggested as a means to quantify and locate spatially local damage from highly incomplete modal information. Despite the growing number of sparsity approaches to damage identification, most proposed methods were tested on numerical simulations and experiments comprised of simple model structures. In this paper, the authors investigate the application of sparse vector recovery methods on a large scale truss structure strictly using shifts in the identified natural frequencies. Three sparse vector recovery algorithms are considered: l1-norm optimization, non-negative constrained least squares, and a novel approach l0-norm optimization. The algorithms are tested on vibration data taken from a 17.4(m) long three dimensional aluminum highway sign support truss in various damage states.

Application of a Sub-Structuring Approach for Enhanced Change Detection, Localization, and Quantification in a 52-Story Building Model

Wednesday, 19th June - 15:00: MS80: Structural Identification and Damage Detection; Part 2 (Ramo (371)) - Oral - Abstract ID: 448

Dr. Mohamed Abdelbarr (Cairo University / University of Southern California), Dr. Anthony Massari (The Ohio State University), Dr. MONICA KOHLER (California Institute of Technology), Prof. Sami Masri (University of Southern California)

This study utilized a high-fidelity 3D finite element model of a 52-story high-rise office building, located in downtown Los Angeles, in which the model was created based on structural engineering drawings. The model was then validated using vibration data acquired from a state-of-the-art strong-motion network that collected continuous measurements from accelerometers located at each floor. In order to gauge the effectiveness of the sub-structuring approach presented here to detect various scenarios of real (physical) damage at different locations in the building, synthetic damage scenarios were developed, in which different locations, orientation, and levels of damage (simulated as stiffness reduction in selected structural members) were generated. The sub-structuring approach was then applied to the synthetic data sets for the 52-story building (based on broad-band random base excitation) to evaluate the effectiveness of the method for identifying damage-induced changes in the dynamic properties of the 52-story building model. The results indicate that the approach not only yields identification results that match well-known global (linear) system identification methods, such as NExT/ERA, but it also provides additional benefits that global identification approaches suffer from. These benefits include: (1) enhanced sensitivity to small structural parameter changes, (2) ability to provide location information about the region in the large structure where damage has occurred, and (3) not assuming that the underlying structure is linear. Thus, the approach is capable of detecting, quantifying and classifying nonlinear changes if they do occur if the actual building is subjected to strong earthquake ground motion.

Probability of Detection Using Dense Sensor Networks

Wednesday, 19th June - 15:15: MS80: Structural Identification and Damage Detection; Part 2 (Ramo (371)) - Oral - Abstract ID: 135

Ms. Jin Yan (Iowa State University), Dr. Simon Laflamme (Iowa State University), Mr. Jonathan Hong (Iowa State University), Dr. Jacob Dodson (Air Force Research Labortory Eglin AFB), Dr. An Chen (Iowa State University)

A performance evaluation methodology is proposed for structural health monitoring (SHM) using dense sensor networks (DSNs). The methodology consists of assessing the damage detection sensitivity through a probability of detection (POD) process integrated with a physical surrogate of the monitored system. First, the physical surrogate is constructed from a given DSN configuration. Second, the surrogate is updated using a model reaching adaptive system algorithm that leverages field measurements. Third, the updated surrogate is used to develop POD curves as a function of considered damages and uncertainties. Last, the POD curves are used to assess the performance of the DSN configuration. Here, the methodology is demonstrated using data from a cantilevered beam test bed. Results show that the methodology can be used to 1) create accurate physical surrogates of a monitored system, and 2) quantify the performance of a given DSN configuration.

Deep Actor-Critic Reinforcement Learning for Life-Cycle Control of Large-Scale Structural Environments

Wednesday, 19th June - 14:00: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 928

Mr. Charalampos Andriotis (Pennsylvania State University), Dr. Kostas G. Papakonstantinou (Pennsylvania State University)

Efficient life-cycle management of the built environment requires advanced decision frameworks that are able to account for real-time data, partial information, model unavailability and resource limitations, providing effective solutions in large-scale multi-component domains and long-term planning horizons. Markov Decision Processes (MDPs) and Partially Observable MDPs (POMDPs) provide sound mathematical formulations for sequential decision problems and have been shown to reach competent management policies for optimal stochastic control related to structural maintenance and inspection planning, surpassing the performance of conventional life-cycle methodologies. The main challenges in this class of decision problems are that the system states and actions scale exponentially with the number of components, and the environment state space dynamics may not be able to be explicitly described. To address these issues in this work, we present a Deep Reinforcement Learning (DRL) approach using newly developed policy gradient actor-critic algorithms with off-policy learning and experience replay. The proposed DRL formulations are specifically tailored to the needs of large engineering systems and infrastructure management, as they have the modeling capacity to handle immense state spaces through highly nonlinear deep network parametrizations, and to reduce the complexity related to the action space at the system level through factored representations of the actor network. The developed models provide model-free approaches with regard to system state dynamics, in both MDP and POMDP cases. Numerical experiments in structural and engineering system applications are presented, showcasing that the developed algorithms provide superior maintenance and inspection life-cycle strategies compared to standard approaches.

Deep Learning Enabled Nonlinear Structural Response Modeling and Fragility Analysis

Wednesday, 19th June - 14:15: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 952

Dr. Ruiyang Zhang (Northeastern University), Mr. Zhao Chen (Northeastern University), Prof. Oral Buyukozturk (Massachusetts Institute of Technology), Prof. Hao Sun (Northeastern University)

Classical methods such as physics-based models for nonlinear structural time history analysis typically require excessive computational efforts, especially when numerous simulations are required to account for stochastic uncertainties of external loads (e.g., Monte Carlo simulations or incremental dynamic analysis for fragility analysis). To address this issue, we present a deep learning framework for surrogate modeling of dynamical structural systems with nonlinearities. Two deep architectures, including a temporal convolutional neural network (TCNN) and a long short-term memory (LSTM) network, are proposed for data-driven structural seismic response modeling. The networks are trained against a limited number of datasets that consist of both ground motions and the corresponding structural responses, collected from either simulations or field sensing. The trained models are capable of accurately predicting both elastic and inelastic dynamic behaviors of buildings in a data-driven fashion. Our approach also enables efficient structural fragility analysis within a Monte Carlo simulation framework, through feeding a vast number of seismic inputs to the trained deep learning model that produces the corresponding nonlinear responses (e.g., inter-story drifts) for comparison to the limit states. The performance of the proposed method is demonstrated on various linear/nonlinear buildings with both synthetic data and field measurements.

Vision-Based Bridge Component Recognition and Position Estimation Toward Rapid Automated Inspection

Wednesday, 19th June - 14:30: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 1016

Mr. Yasutaka Narazaki (University of Illinois at Urbana Champaign), Mr. Vedhus Hoskere (University of Illinois), Mr. Tu Hoang (University of Illinois at Urbana-Champaign), Prof. Billie F. Spencer (University of Illinois at Urbana Champaign)

Bridge is one of the important transportation infrastructure which needs to be maintained appropriately both in normal and emergency times. On the other hand, bridges spread over broad areas, which makes the visual inspection by human inspectors time-consuming and labor-intensive. The demands for the efficiency of bridge inspections are particularly difficult to meet after natural hazards, such as earthquakes and typhoons, because limited number of inspectors need to evaluate bridges in the entire affected area within a limited amount of time. To facilitate rapid inspection under the scarcity of time and resources, automation of one of the most time-consuming and labor-intensive part of the bridge inspection is desired, namely, accessing and navigating through the bridges to collect visual information of the structural components of interest.

Implementation of human inspector's perception during the bridge inspection is a key step toward autonomous navigation and data collection for rapid bridge inspection. This research investigates the recognition of structural component types and their positions using video data. The recognition of structural component types is implemented using fully convolutional networks (FCNs) combined with recurrent neural networks (RNNs), which provides consistent recognition results both in time and space. The estimation of position is implemented using CNN-SLAM algorithm, which estimates depth maps from the image sequences. The perception of bridge components implemented in this study will be a building block for the autonomous navigating agents for rapid bridge inspections.

Identification of Brittle and Ductile Fracture in Metals Using Supervised Machine Learning

Wednesday, 19th June - 14:45: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 831

Dr. Dayakar Lavadiya (North Dakota State University), Dr. Ravi Yellavajjala (North Dakota State University)

Manual identification of brittle and ductile fracture regions in fractographic images of metals is cumbersome, time consuming and a highly subjective process. Supervised machine learning classifiers in conjunction with texture recognition algorithms are employed to automatically identify the fracture type and evaluate their area fractions in fractographic images in this study. Texture is one of the unique visual characteristics possessed by an object in an image that distinguishes it from other objects. In the context of this study, brittle fracture and ductile fracture regions in a fractographic image are assumed to possess unique textures. To quantify texture, Local Binary Pattern (LBP) texture quantification algorithm is employed and the corresponding set of statistical metrics referred to as textural features are evaluated from both ductile and brittle fracture training images. These textural features are then used to train four machine learning classifiers (Naïve Bayes, K-NN, Linear Discriminant Analysis and decision trees) and their performance is assessed using cross-validation technique to determine the best classification algorithm for the problem at hand. The best classification algorithm is then employed to identify the brittle and ductile fracture regions in fractographic images that are not used for training purposes. The LBP algorithm, performance assessment of classifiers and the predictions on test fractographic images will be discussed in the talk.

Nonlinear Seismic Response Reconstruction and Performance Assessment of Instrumented Wood-Frame Buildings - Validation Using NEESwood Capstone Full-Scale Tests

Wednesday, 19th June - 15:00: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 1190

Mr. Milad Roohi (University of Vermont), Prof. Eric Hernandez (University of Vermont), Prof. David Rosowsky (University of Vermont)

The authors present a methodology to reconstruct nonlinear seismic response and assess seismic performance of instrumented wood-frame buildings subjected to earthquakes. The paper proposes the use of a nonlinear model-based state observer that combines global acceleration measurements and a nonlinear model of the building to estimate the complete dynamic response and its uncertainty, including displacements, velocities, accelerations at all degrees of freedom of the model and internal forces in all structural members. From the estimated dynamic response, engineering demand parameters are obtained and compared with performance-based acceptance criteria to determine post-earthquake building occupancy classification. The methodology is successfully verified and validated using seismic response measurements and photographic records from the 2009 NEESWood Capstone full-scale tests. Three levels of ground motion intensity were tested, in all cases the proposed methodology performed satisfactorily.

New Advance in Full-Field Imaging and High-Fidelity Characterization of Structural Dynamics

Wednesday, 19th June - 15:15: MS90 - Machine Learning and Data Analytics for Infrastructure Integrity Assessment; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 18

Dr. Yongchao Yang (Argonne National Laboratory), Mr. Charles Dorn (California Institute of Technology)

In this study we present the new advance for the blind extraction and realistic visualization of the full-field, high-resolution, dynamics behaviors of operating structures from its digital video measurements, possibly temporally-aliased (sub-Nyquist), using advanced computer vision and machine learning techniques. We show that this high-resolution, full-field structural dynamics characterization framework opens up a variety of applications that used to be challenging. We demonstrate and discuss our laboratory experiments on bench-scale structures and real-world case study.

Efficient Approach to Performance-Based Design Optimization of Dynamic and Uncertain Structural Systems Under System-Level Constraints on Wind-Induced Losses

Wednesday, 19th June - 14:00: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 929

Ms. Arthriya Suksuwan (University of Michigan), Dr. Seymour Spence (University of Michigan)

Severe damage due to windstorms is responsible for the majority of natural hazard induced losses worldwide. Urgent need to reduce losses has prompted decision makers and engineers to develop risk mitigation strategies that aim to improve structural performance at reasonable costs. Design optimization offers a powerful approach for the identification of optimal cost systems that satisfy sets of performance targets. This paper presents an efficient performance-based design optimization methodology for dynamic and uncertain building systems subject to system-level constraints on expected wind-induced losses. In particular, the proposed method can solve design problems involving high-dimensional design spaces coupled with stochastic simulation-based performance assessment models involving high-dimensional uncertain spaces. An innovative strategy is proposed to decouple the performance assessment from the optimization process by transforming the stochastic optimization problem into a sequence of approximate optimization sub-problems. Each sub-problem is constructed from the results of a single stochastic simulation and is scalable to high dimensional design and uncertain spaces. By using gradient-based schemes to solve a limited sequence of sub-problems, each formulated from the solution of the former, a solution to the original problem is efficiently identified. To demonstrate the effectiveness and the scalability of the proposed method, two examples of design optimization of wind-excited systems are presented. The first example involves a simple system constrained by the annual exceedance rate of the expected repair cost. The second example involves a large-scale system subject to performance constraints on annual exceedance rates of expected repair cost and time.

A Stochastic Simulation Framework for the Efficient Performance Assessment of the Building Envelope of Engineered Systems

Wednesday, 19th June - 14:15: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 936

Mr. Zhicheng Ouyang (University of Michigan), Dr. Seymour Spence (University of Michigan)

Performance-based design of wind excited engineered structures is experiencing a period of rapid development. In particular, a number of frameworks have been developed for characterizing the damage and losses caused by the excessive dynamic response of the structural system. While damage induced by structural response is fundamental, arguably the most important contribution to overall damage and losses comes from the inadequate performance of the building envelope when subject to local wind pressures and wind-driven rain. While various frameworks have been developed to estimate this loss in the case of low-rise residential buildings, few models exist for engineered systems. In response to this need, this paper introduces a stochastic simulation-based framework for estimating damage and losses to the envelope of engineered buildings stemming from both excessive dynamic responses as well as local envelope pressures. In particular, wind pressures are modeled through a proper orthogonal decomposition-based stochastic simulation model with non-Gaussian features captured through translation models based on mixture distributions. To capture the non-linear dependency between wind direction and speed, nonparametric kernel estimated copulas are employed. Wind driven rain is modeled through computational fluid dynamics based multiphase models. Subsequent damages are modelled through coupled fragility-based analysis. To estimate performance in a fully probabilistic setting, a variance reducing conditional stochastic simulation scheme is proposed based on the decomposition of the site-specific hazard curve, therefore enabling accurate estimation of low probability events with minimal runs of the high-fidelity models. A full-scale example is developed to illustrate the framework

Uncertainty Quantification for Power and Telecommunications Infrastructure Exposed to Hurricane Hazards

Wednesday, 19th June - 14:30: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 156

Dr. Shuoqi Wang (University of Washington), Prof. Dorothy Reed (University of Washington)

Power and telecommunications infrastructure systems often fail during hurricanes and winter storms. Various numerical modeling approaches of the performance of the physical underpinnings of these systems have been developed. In this paper, a system-level performance approach to modeling power and telecommunications inoperability derived from in situ data [1] [2] [3] will be discussed for recent extreme wind events such as Harvey, Irma and Maria. The results of the performance assessment will be discussed in the context of uncertainty propagation. The type and degree of uncertainty in the system-level infrastructure recovery estimates as well as how the uncertainty propagates through the resilience methodology will be investigated in detail. Examples of the methodology with associated uncertainty estimates will be provided to assess the level of confidence in the results.

[1] D. Reed, S. Wang, K. Kapur and C. Zheng, “Systems-based approach to interdependent electric power delivery and telecommunications infrastructure resilience subject to weather-related hazards,” *Journal of Structural Engineering*,2015.

[2] D. Reed, C. J. Friedland, S. Wang and C. Massarra, “Multi-hazard system-level logit fragility functions,” *Engineering Structures*,2016.

[3] S. Wang and D. A. Reed, “Vulnerability and Robustness of Civil Infrastructure Systems to Hurricanes,” *Frontiers in Built Environment*,vol. 3, no. 60, 2017.

Efficient Reliability Analysis by Probability-Adaptive Kriging in N-Ball (PAK-Bn)

Wednesday, 19th June - 14:45: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1193

Mr. Jungho Kim (Seoul National University), Prof. Junho Song (Seoul National University)

As today's engineering systems are becoming more complex than ever, the computational demands required to analyze or design the structures have increased substantially. It is also noted that structural reliability analysis may entail large computational cost because existing methods generally repeat computational simulations to achieve accurate estimates on failure probability. Reducing the number of function evaluations, therefore, is essential for computational efficiency in reliability analysis. Adaptive Kriging methods have been widely adopted to facilitate such efforts because of its desirable properties and accuracy of the surrogate model. However, the assessment of reliability problem characterized with small failure probability and/or highly non-linear limit state function have remained challenging. In order to overcome these issues in reliability analysis, we recently developed a new adaptive Kriging method termed Probability-Adaptive Kriging method based on sampling in n-Ball (PAK-B^n). PAK-B^n improves the efficiency of reliability analysis by incorporating the probabilistic density in the random variable space into the adaptive procedure that identifies the surrogate limit-state surface. In addition, uniformly distributed samples inside the n-ball domain are used as the candidate set of points to enrich the experimental design, and the best simulation point is determined in terms of influence on the failure probability estimation. As a result, PAK-B^n can significantly reduce the number of calls of computationally demanding model by identifying relative important regions for accurate estimates of failure probability. Several benchmark problems are investigated to demonstrate the validity and efficiency of the proposed method.

Probabilistic Prediction of Nonlinear Hysteretic Responses under Stochastic Excitations by Deep Neural Network

Wednesday, 19th June - 15:00: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1208

Mr. Taeyong Kim (Seoul National University), Prof. Junho Song (Seoul National University), Prof. Oh-sung Kwon (University of Toronto)

A path-dependent relationship between force and displacement, i.e. hysteresis, is often observed in many engineering fields, such as shape memory alloy, isolated dampers and reinforced concrete elements. Assessment of such hysteretic behaviors subjected to a stochastic excitation is an important task for designing and maintaining the system. It is widely known that a nonlinear time history analysis is the most accurate way to estimate the responses of the hysteretic system, but the entailing computational cost may hamper the adoption of the analysis in a routine engineering practice. Recently, the authors developed a response prediction model based on deep neural network (DNN) as an alternative to the burdensome approach without compromising the accuracy. Although the DNN-based prediction shows superior accuracy compared to other simple regression-based equations, it cannot quantify the uncertain variabilities stemming from the input randomness, especially for the input details of the stochastic excitation. This assessment is important especially for the problems having a large randomness in the inputs and its impact on the outputs is significant. Thus, this paper aims to develop a new framework for probabilistic prediction of the responses, i.e. estimating mean and variance, given information regarding the hysteretic system and the feature set of stochastic excitations. The performance of the proposed method is demonstrated by applications to earthquake engineering, i.e. prediction of responses of nonlinear structures subjected to earthquake excitations. The results confirm that the method can accurately estimate the structural responses and the level of variabilities caused by uncertainties in the input ground motions.

A Bayesian Nonparametric Approach for the Stochastic Dynamic Analysis

Wednesday, 19th June - 15:15: MS92 - Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1317

Mr. Armin Tabandeh (University of Illinois at Urbana-Champaign), Prof. Paolo Gardoni (University of Illinois at Urbana-Champaign)

Stochastic differential equations (SDEs) that govern the response of general nonlinear dynamical systems are often complex and their analytical solutions are scarce. To address this restriction, we develop a hybrid approach that simplifies the governing SDE of the response of nonlinear systems using data from limited number of simulations and information available a priori. The main idea is to formulate a system identification problem whose objective is to identify a set of surrogate linear systems that sufficiently represent the original nonlinear system. Due to the limited number of simulations, we need to capture the epistemic uncertainty in the estimates of the number and parameters of the surrogate linear systems (i.e., unknown model parameters). To do so, we propose a Bayesian nonparametric approach, called a Dirichlet Process Mixture Model, that defines a probability distribution over an infinite number of potential surrogate linear systems. The number of surrogate linear systems can grow indefinitely (in a probabilistic sense) as the observed dynamics of the nonlinear system unveil new patterns. We also show that, under some mild conditions, the posterior distribution of the model parameters can concentrate as close as desired to the respective true, but unknown, probability distribution. We present a Gibbs sampling algorithm to estimate the unknown model parameters and introduce a Variational Bayesian inference to obtain an approximate closed-form expression for the posterior distribution. We then propagate the quantified uncertainty in the system identification, captured by the posterior distribution, into the estimates of nonlinear response statistics.

Innovative Modelling for Capturing Sloshing in TLCD

Wednesday, 19th June - 14:00: MS59 - Innovations and Advances in Passive Structural Control; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 504

Dr. Antonina Pirrotta (Università degli Studi di Palermo)

In application domain such as structural design, the notion of a "virtual experiment" is a valuable tool for checking and optimizing extensively complex designs before a realization is ever made. To aim at this, mathematical model and simulation should be consistent with the real behaviour for the analysis and design of complex systems, such as those for controlling vibrations. As regards, dealing with TLCD device for reducing vibrations, it has been demonstrated how correctly including the first linear liquid sloshing mode, through the equivalent mechanical analogy well established in literature, produces numerical results which highly match the corresponding experimental ones. Since the apparent effect of sloshing is the deviation of the natural frequency from the theoretical one, the authors propose a fractional differential equation of motion. The latter choice is supported by the fact that, introducing a fractional derivative of order α*, alters simultaneously both the resonant frequency and the degree of damping of the system. It will beshown, how such a proposed model may accurately describe liquid surface displacements.*

Numerical Analysis and Design Optimization of a Novel Eddy Current Damper

Wednesday, 19th June - 14:15: MS59 - Innovations and Advances in Passive Structural Control; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 747

Dr. Manuel Miranda (Hofstra University)

We present the design development of novel eddy current damper (ECD), which has already been shown to be effective in dissipating vibration energy. In an ECD, circular "eddy" currents are induced in an electrical conductor by the relative motion of the conductor within the magnetic field of an array of permanent magnets. These eddy currents cause a net damping force that is linearly proportional to the relative velocity between the magnets and the conductor. Ultimately, the energy of the vibrating system is dissipated through resistive heating of the conductor.

ECDs offer several advantages over traditional dampers: (a) they do not leak; (b) they do not require external power or electronic devices for their functionality; (c) their performance is constant over a wide range of ambient temperatures; (d) they do not degrade over time; and (e) their moving parts have minimal mechanical contact, so problems associated with friction and wear tend to be negligible. In summary, ECDs provide an entirely passive damping system that is highly effective and reliable.

At EMI 2008, the author presented a comprehensive set of experimental studies performed to validate the proposed ECD concept. In this follow-up work, we will present additional numerical studies as well as a design optimization effort. Preliminary results show that an optimized ECD design has the potential for achieving damping densities (damping coefficient per unit volume) comparable to those of silicone fluid-based viscous dampers. Real-world applications for the proposed design will also be discussed.

Evaluation of Energy and Power Flow in a Nonlinear Energy Sink Attached to a Linear Primary Dynamic System

Wednesday, 19th June - 14:30: MS59 - Innovations and Advances in Passive Structural Control; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 1024

Mr. Christian Silva (Purdue University), Prof. Shirley Dyke (Purdue University), Dr. Amin Maghareh (Purdue University), Dr. James Gibert (Purdue University)

The objective of this study is to understand, and quantify the energy transferred between a nonlinear energy sink and the primary system to which it is attached, as well as to evaluate the direction of such energetic activity. To extend the work done in previous studies, focused primarily in the characterization and performance evaluation of nonlinear energy sinks, as passive dampers for structures under different types of excitations, this study incorporates a methodology for determining and quantifying the energy transfer between NES and primary oscillator by means of considering the power flow of the primary oscillator. Several measures for evaluating the effectiveness of the NES to extract and dissipate energy irreversibly are considered through numerical simulation of different damping cases of the NES, each one providing a different dissipation scenario in the combined system, which is subjected to different types of base excitation signals.The methodology is further analyzed experimentally where impulse excitation is employed to identify the parameters of the physical NES device, and comparisons of the modeled versus measured responses are provided for different damping scenarios in the NES.

Preliminary Investigation of Seismic Isolation Systems with Geometric Nonlinearity for Important Equipment

Wednesday, 19th June - 14:45: MS59 - Innovations and Advances in Passive Structural Control; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 395

Dr. Chia-Ming Chang (National Taiwan University), Mr. Ting-Wei Hsu (National Taiwan University)

Earthquakes pose risks to sensitive equipment in a structure and sometimes can induce significantly economic loss. A widely utilized technique to mitigate seismic response is to install an isolation system underneath the equipment; however, excessive displacements along isolation layers may be found during severe earthquakes. Viscous dampers are recommended to be placed along the isolation layer. Still, this combination is only designed for a certain level of earthquakes and may not be effective in a small or moderate earthquake event. In this study, an isolation system with geometric nonlinearity of viscous dampers is proposed to enhance seismic performance. This configuration provides a better reduction in acceleration responses during small to moderate earthquakes, while the excessive displacement responses can be effectively reduced during severe earthquakes. To understand dynamic behavior of this system, a serious investigations are carried out. For dynamic characteristics, the restoring force surface is first generated in terms of displacement and velocity. The first derivatives of the restoring force surface represent the instantaneous stiffness and damping coefficient, while the second derivatives of this surface indicate the sensitivity of these two terms with respect to displacements and velocities.

Moreover, this isolation system under harmonic excitation is investigated to understand generalized frequency-domain performance. Control effectiveness of the proposed isolation system is also evaluated under nonperiodic excitation such as earthquakes and compared with the conventional isolation system. As found in the results, the viscous damper with geometric nonlinearity enhances seismic isolation performance to be effective in all levels of earthquakes.

Modeling, Characterizing, and Testing a Simple Negative-Stiffness Device to Achieve Apparent Weakening

Wednesday, 19th June - 15:00: MS59 - Innovations and Advances in Passive Structural Control; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 650

Mr. Thomas Cain (The University of Oklahoma), Prof. P. Scott Harvey (The University of Oklahoma), Prof. Kenneth Walsh (Ohio University)

Apparent weakening simulates yielding in an elastic structure in order to reduce peak deformations, accelerations, and base shears in the primary structure (PS). Apparent weakening can be achieved with negative-stiffness devices (NSDs) that use geometric nonlinearities to produce softening behavior in the coupled PS-NSD system. In this paper, a simple NSD consisting of gears and a single tension spring is analyzed. A nonlinear mathematical model of the force-displacement behavior of the device is derived. Then, the coupled PS-NSD system is nondimensionalized to facilitate a parametric study to determine the optimal geometry. A device based on the optimized geometry is fabricated and installed on an experimental small-scale structure for verification. The device is characterized both statically and dynamically. Static load-deflection tests serve to validate/calibrate the theoretical model. Dynamic tests include (a) swept-sine surveys of varying amplitude to characterize the backbone curve of the softening nonlinear system and (b) incremental dynamic analysis with nonstationary stochastic inputs (earthquake ground-motions). Peak responses (drifts and accelerations) in the coupled PS-NSD system are compared to those in the PS without the NSD installed to evaluate the advantages of the NSD. Experimentally measured peak responses (drifts and accelerations) are also compared to predictions from the calibrated numerical model for validation.

Seismic Retrofit of Buildings Using Inter-Story Drift-Dependent Stiffening and Supplemental Damping

Wednesday, 19th June - 15:15: MS59 - Innovations and Advances in Passive Structural Control; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 1381

Mr. Christopher Zaverdas (Rensselaer Polytechnic Institute), Dr. Michael Symans (Rensselaer Polytechnic Institute)

Increasing the seismic resilience of buildings using passive control dates back to the early twentieth century when a flexible or soft-first-story was proposed to protect the upper stories from damage. Previous earthquakes that caused large inter-story drift in soft-first-story structures led to global collapse of the structure. Base-isolation systems were developed using the concept of a flexible layer between the building foundation and the relatively rigid superstructure above. Base-isolation has been shown to be an effective passive control technique; however, it is not typically implemented as a retrofit due to constructability issues. This study presents a passive control technique for retrofitting existing structures that leverages the soft-first-story effect (similar to base isolation) while also preventing global collapse. The technique reduces the lateral stiffness of the first story by removing lateral force resisting elements to allow soft-first-story action while using the increased inter-story drifts to develop motion across a supplemental damping device, thereby limiting the inter-story drift of both the first story and the upper-stories. In addition, the retrofit includes an element that stiffens as the inter-story drift increases, thereby preventing global collapse of the structure. Numerical simulations demonstrate that the technique effectively limits inter-story drift in the upper-stories and prevents global collapse of an idealized structure. A consequence of this passive control technique could be that structures are more easily and effectively retrofitted, thereby increasing the resilience of seismically vulnerable structures.

Fire Engineering & Intelligent Smoke and Heat Evacuation

Wednesday, 19th June - 14:00: MS65+57 - Emerging Topics and New Developments in Structural Fire Engineering, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 990

Prof. Jean-Baptiste Schleich (EASE Engineering)

This contribution concerns two industrial halls, with 30m width, 60m length and 12m height, built in 1970/1974 and now retrofitted for social and cultural activities. The challenge consisted, notwithstanding budget limitations, of maintaining safety for people in the fire situation and ensuring fire resistance under natural fire conditions.

Design: Design under natural fire conditions was verified through the software “OZone” for local so-called creative quarters in which fire was confined by convenient compartmentation. These quarters were provided with passive smoke evacuation finally canalizing the heated smoke into the upper part of the industrial halls. From here smoke should be directed through natural smoke exhaust openings outside of the industrial halls.

The analysis of the complete smoke and heat circulation was performed through CFD – computational fluid dynamics – by applying the software “FDS “ from NIST. This was leading to a total of 1120 000 prismatic volumes of 0,25m · 0,25m ·0,25m and allowed to determine a.o. the speed of smoke and its temperature. Hence a logical set of air inlet sections and smoke exhaust openings was determined allowing to clearly decide whether fire resistance was sufficient or not. Fire protection materials were finally to be applied only locally on steel columns. In most areas the steel columns and steel trusses could be kept visible and not at all protected.

Conclusion: These industrial halls, erected 49 years ago, are to be classified highly sustainable, as their retrofitting could be achieved with low costs while saving the initial structural steel frame.

Microstructure of Post-fire Structural Steels

Wednesday, 19th June - 14:15: MS65+57 - Emerging Topics and New Developments in Structural Fire Engineering, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1051

Mr. Hizb Ullah Sajid (North Dakota State University), Dr. Ravi Yellavajjala (North Dakota State University)

It is now possible to predict the mechanical properties of post-fire structural steels as a function of temperature experienced during a fire accident. However, temperatures developed during a fire accident are seldom known. When the temperatures during a fire accident are unavailable, tracking post-fire microstructure of steels serves as an alternative method for quantifying the post-fire mechanical properties of structural steels. The current study aims to investigate the microstructural changes and their influence on post-fire mechanical properties of ASTM A36, A572, and A992 steels. Post-fire mechanical properties are obtained by conducting uniaxial tension tests on steel specimens that are air-cooled from temperatures up to 1000°C. A Microstructural analysis is conducted to determine the volume fractions of ferrite and pearlite phases, ferrite grain size and pearlite colony size corresponding to different target temperatures. It is observed that the increase in ferrite phase volume and ferrite grain size, in general, lead to a reduction in post-fire yield strength and tensile strength of structural steels. Ductility of post-fire specimens is observed to increase with an increase in ferrite grain size. Finally, multivariate regression equations are proposed that can be used to predict post-fire yield strength and tensile strength of structural steels as a function of volume fraction and average grain size of ferrite and average pearlite colony size. The results obtained in this study can be used by forensic structural engineers to evaluate the residual strength of fire affected steel structures.

Comparison of Simple and Advanced Methods of Analysis in AISC 360 for Fire Resistant Design

Wednesday, 19th June - 14:30: MS65+57 - Emerging Topics and New Developments in Structural Fire Engineering, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1061

Dr. Rachel Chicchi (University of Cincinnati)

Structural design for fire conditions in the United States has traditionally been conducted by architects or fire engineers using a prescriptive approach based on standard furnace testing of components and assemblies. Fire research and design has begun to move towards a performance-based approach that considers system-level response. With this shift, structural engineers are taking over the responsibility of fire-resistance design of the structure through conducting fire analyses.

Appendix4 of AISC 360-16 provides criteria to aid structural engineers in structural steel design for fire conditions. It includes an advanced method of analysis and a simple method of analysis. While the simple method is quite clear on how to determine member capacities at elevated temperatures, there is currently some ambiguity in how to incorporate demands due to temperatures (forces and deformations) on the structure. This work aims to minimize these gaps in knowledge and provide a comparison between the prescriptive, simple, and advanced methods of analysis.

A comparison of these methods will be articulated through analysis of a 10-story case study, office building. It is a steel structure with perimeter moment frames and a composite floor system that was designed for hazards in Chicago, IL. In order to conduct the advanced analyses, a three-dimensional (3D) finite element method building model was developed using Abaqus. This model can simulate inelastic deformations, instability failures, connection damage at elevated temperatures, and the effect of temperature on strength and stiffness of materials. Simple analyses were conducted using SAP2000, commercially availablestructural analysis and design software.

Eurocode 1 and NFPA 557: Is There a Conflict Between Using Standards and the Goal of Performance Based Fire Engineering?

Wednesday, 19th June - 14:45: MS65+57 - Emerging Topics and New Developments in Structural Fire Engineering, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1112

Dr. Luciana Balsamo (Thornton Tomasetti, Inc), Dr. Reyhaneh Abbasi (Thornton Tomasetti, Inc), Dr. Pierre Ghisbain (Thornton Tomasetti, Inc), Dr. Reza Imani (Thornton Tomasetti, Inc), Dr. Jenny Sideri (Thornton Tomasetti, Inc), Dr. Ali Ashrafi (Thornton Tomasetti, Inc)

Consideration of realistic fire scenarios is one of the driving factors for the use of Performance Based Fire Engineering (PBFE) over prescriptive approaches to design of fire protection of structural systems susceptible to fire hazards. The use of Eurocode 1 and NFPA 557 is the current standard approach available to the structural engineer in determining fire loads for design of structural fire protection. However, while NFPA 557 is the main standard used for the design of fire protection in the United States, the fire loads developed by the standard are based on structurally significant fires and, consequently, can be associated with unrealistically high values of the design fuel load density. In this study, we compare the baseline values of design fire loads obtained using the two standards and several realistic fire scenarios. By presenting the results of simulated fire scenarios, this study examines how factors such as heat release rate and plume temperature distribution are incorporated into the determination of the fire load. Additionally, the study demonstrates how the two standards treat localized and distributed(compartment) fire loads.

Accelerating Simulation of Wind Field with Time-Varying Correlation Based on Two-Dimensional Singular Value Decomposition

Wednesday, 19th June - 15:00: MS65+57 - Emerging Topics and New Developments in Structural Fire Engineering, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 441

Mr. Haifeng Wang (University at bu), Dr. Teng Wu (University at Buffalo)

Extreme wind events, which typically dominate the design wind load of structures, usually present nonstationary features characterized by the evolutionary energy spectrum. For large-size and long-span structures that are sensitive to wind loads, the time-varying spatial correlation also needs to be considered since it may have an important effect on the structural responses. The accurate and efficient simulation of nonstationary winds in the time domain is critical to effectively quantitatively analyze the extreme wind-induced linear/nonlinear structural responses. The simulation of correlated wind fields typically involves the decomposition of the correlation coefficient matrix. To consider the time-varying spatial correlation, the time-consuming decomposition needs to be performed for each time step, making the simulation computationally intensive. To address this issue, the two-dimensional singular value decomposition (2DSVD) is introduced to approximate the temporal behavior of the correlation matrix by a linear combination of several dominant modes. As a result, a significantly smaller number of decompositions on the dominant modes are needed as compared to that of simulation time steps. In this study, the 2DSVD is employed together with the Hilbert-wavelet-based scheme to simulate nonstationary wind fields with time-varying spatial correlation. The fidelity and efficiency of the proposed simulation scheme are validated by numerical examples.

Tensile Strength of Grade 10.9 Steel Bolts at Elevated Temperatures

Wednesday, 19th June - 15:15: MS65+57 - Emerging Topics and New Developments in Structural Fire Engineering, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1359

Dr. Abbas Rezaeian (Shahid Chamran University of Ahwaz), Dr. Mostafa Eskandari (Shahid Chamran University of Ahwaz), Dr. Mohammadreza Eslami (University of California, Berkeley), Prof. Khalid M. Mosalam (University of California Berkeley), Dr. Mahdi Shafiei (Virginia Commonwealth University)

Connections play a crucial role in transferring forces between structural steel members. Previous experimental studies reported the temperature-induced degradation of the mechanical properties of different grades of structural steel. The performance of bolted connections under fire conditions depends on the strength of the bolts. This paper presents results from experimental studies on the mechanical properties of Grade 10.9 high-strength bolts at elevated temperatures. Steady-state tension tests were carried out on Grade 10.9 bolt specimens at 20-800°C. The high-temperature mechanical properties including stress-strain response, yield and ultimate strengths are evaluated in broad temperature range. Data from the tests indicate that the bolts experience rapid reduction in strength at temperatures beyond 400°C, and this reduced strength reaches 40% and 5% of its original value when the bolts were heated to 600°C and 800°C, respectively. The use of the obtained reduction factor for strength of Grade 10.9 bolts can lead to better assessment of the capacity of bolted connections under fire conditions. The test data also indicate that the strength of Grade 10.9 steel bolts degrades faster than that of conventional carbon steel at elevated temperatures.

Simulation of Reinforced Concrete Structures via Lattice Discrete Particle Model (LDPM) Coarse Graining

Wednesday, 19th June - 14:00: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 83

Dr. Erol Lale (Istanbul Technical University), Dr. Roozbeh Rezakhani (École polytechnique fédérale de Lausanne), Prof. Mohammed Alnaggar (Rensselaer Polytechnic Institute), Prof. Gianluca Cusatis (Northwestern University)

In this study, a coarse-graining framework for discrete, fine-scale model is formulated on the basis of multiscale homogenization. The discrete model adopted in this study is the Lattice Discrete Particle Model (LDPM) which operates at the level of coarse aggregate pieces. LDPM is able to model most aspects of concrete behavior such as uniaxial, biaxial and triaxial responses. However, having a discrete model for analysing of real size structural elements leads to significant number of degrees of freedom and mostly it is not feasible with the currently available computational resources. In order to overcome this limitation, a coarse-grained model based on multi-scale homogenization procedure is proposed. The CG model is based on creating coarse model by scaling the actual size of the particles using a specific coarsening factor and optimization of the material parameters of the coarse grained model by best fitting macroscopic response of the coarse grained model to the corresponding fine scale one for different loading conditions. A Representative Volume Element (RVE) of LDPM is employed to obtain the macroscopic response of the fine scale and coarse grained models through a homogenization procedure. Accuracy and computational efficiency of the developed method are verified by comparing the responses of fine scale and coarse grained simulations of several reinforced concrete structural elements.

3D Discrete Element Contact Model for the Simulation of the Rheological Behavior of Concrete at Fresh State

Wednesday, 19th June - 14:15: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 1339

Mrs. Elham Ramyar (Northwestern University), Dr. Xinwei Zhou (Engineering and Software System Solutions (ES3), Inc.), Prof. Gianluca Cusatis (Northwestern University)

3D printing is poised to become a disruptive force in the construction industry. While more and more researchers are working on developing novel and appropriate concrete mixes as well as 3D printing technologies, only few and rather limited computational models are available in the literature. Nevertheless, engineers need simulation tools for the optimization of the construction process to obtain maximum energy, money and time-efficiency.
The main objective of this paper is the formulation of a contact model to simulate fresh concrete using discrete element method (DEM) in which the interaction among spherical particles is governed by a visco-plastic constitutive equation. Unlike conventional DEM, in which contact models are governed by force-displacement constitutive equations, the formulated DEM contact model is based on stress-strain constitutive equations by which the behavior of fresh concrete can be described by parameters of the same type as those used for modeling hardened concrete. In order to calibrate and validate the model against experimental data, a specific methodology for estimation of key input parameters of the model was formulated. This methodology included a series of sensitivity analysis and simulations to use experimental data such as aggregate volumetric fraction, density variation with pressure, bulk modulus at fresh state, and lateral pressure on the formworks. This presentation will discuss details of the performed analyses and the application of the formulated model to the simulation of concrete 3D printing.
*Keywords:*Discrete Element Method (DEM), Contact model, Fresh concrete, 3D printing

Modeling Early-Age Cracking in Concrete Using Phase-Field Model of Fracture

Wednesday, 19th June - 14:30: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 832

Mr. Vivek Kumar (Princeton University), Prof. Branko Glisic (Princeton University)

Early-age cracking in concrete is often detrimental to the service life of the structure, especially if it goes undetected. Such scenarios arise when cracks initialize inside the members without appearing on the surface. Correctly modeling the thermo-mechanical behavior of concrete during early stages combined with a fracture model to predict such failures is an important challenge for the design and later monitoring of the structures. In this work, a multi-physics model of early-age behavior of concrete is described which is combined with the phase-field model of fracture to predict crack initiation and propagation. Mathematical formulation of the problem followed by finite element formulation is presented. The described model is finally verified using 2D and 3D numerical examples and comparison with real-life structure is present as a model validation.

Multi-scale Homogenization Modeling of Ultra High Performance Concrete

Wednesday, 19th June - 14:45: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 1341

Mr. TATHAGATA BHADURI (Rensselaer Polytechnic Institute), Dr. Roozbeh Rezakhani (Swiss Federal Institute of Technology Lausanne (EPFL)), Prof. Mohammed Alnaggar (Rensselaer Polytechnic Institute)

Ultra-high-performance concrete (UHPC) is poised to be one of the major infrastructural materials thanks to its remarkable compressive strength (>150 MPa) and significant post-cracking ductility when mixed with fiber reinforcements. For numerical modeling of UHPC, macro-scale continuum models are unable to capture the effect of heterogeneity arising from the smeared fiber distribution and orientations accompanied by fiber-matrix interactions at lower scales. Recently, a mesoscale computational platform was developed known as lattice discrete particle model (LDPM) to simulate the damage and fracture behavior of regular concrete materials at a length scale of its coarse aggregate size. Further extension of LDPM for fiber reinforced concrete (LDPM-F) has served as an efficient computational tool which is able to capture different mesoscale phenomena associated with fiber debonding mechanics like micro-spalling, snubbing, slip hardening or slip softening etc. In addition to that, LDPM-F can incorporate the fiber orientation features quantitatively, which makes it suitable to probe into specimens having possible fiber alignments. Although LDPM and LDPM-F have been very successful, they become computationally more extensive for modeling ultra-high-performance concrete(UHPC) due to its exceptionally fine length scale of aggregates. Previously, an adaptive homogenization based LDPM was highly effective in reducing the computational cost while preserving the rich mesoscale mechanics of regular concrete. This homogenized version of LDPM is extended in the current study for LDPM-F framework to predict the behavior of UHPC. Simulations show the potential of homogenized LDPM-F (H-LDPM-F) in providing a good balance between computational expense and numerical predictions for UHPC specimens.

Comparison of Mechanical Performance Between Numerical Simulations and Analytically Idealized Spring Systems for Concrete Made with Recycled Aggregates

Wednesday, 19th June - 15:00: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 1350

Mr. Anuruddha Jayasuriya (New Jersery Institute of Technology), Dr. Matthew P. Adams (New Jersey Institute of Technology), Dr. Matthew J. Bandelt (New Jersey Institute of Technology)

Numerical modeling of concrete materials has been widely employed in understanding and predicting the mechanical behavior under different loading environments. However, such numerical modeling procedures can be extremely complex and computationally expensive depending on the component levels incorporated in the modeling phase. This paper presents an efficient method to estimate the mechanical properties of recycled concrete aggregate (RCA) systems by idealizing the material stiffnesses in the concrete geometry through a series of spring elements subjected to a compressive loading. Mechanical properties of the spring system are examined by performing a plane stress analysis of the same RCA geometry. Eight RCA systems consisting of 50 mm × 50 mm two-dimensional finite element simulations are numerically developed by considering three aggregate parameters for crushed particles including aggregate ratio, maximum aggregate size, and adhered old mortar content attached to the natural aggregate. Aggregates are generated randomly within the concrete boundary where the material phases are identified through an image analysis procedure. The overall elastic modulus of RCA numerical simulations is evaluated by adopting the stress-strain curve, and corresponding elastic modulus of the spring system is estimated by the equivalent spring stiffness. The peak displacement of stress-strain curve is adopted to evaluate the compressive strength of RCA spring system considering the linear-elastic behavior. Eventually, RCA mechanical properties of the numerical and analytical systems are analyzed, compared, and the feasibility of spring idealization is reported with respect to the numerical approach.

Effect of Strain Induced Crystallization on Fracture of Rubber-Like Materials

Wednesday, 19th June - 15:15: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 899

Mr. Prajwal Arunachala (Stanford University), Mr. Reza Rastak (Stanford University), Prof. Christian Linder (Stanford University)

The enhanced fracture resistance in rubber-like materials has often been attributed to the phenomenon of Strain Induced Crystallization. For this study, a multi-scale polymer network model of the phenomenon coupled with phase field fracture is proposed. At the microscopic scale, a new polymer chain model accounting for the thermodynamics of the polymer chain and its crystallization under stretch is presented along with a rate-dependent evolution law. This evolution law is constructed such that it ensures that the second law of thermodynamics is satisfied. The contribution of the deformation of the molecular bonds to the internal energy is also accounted for in this non-Gaussian statistical mechanics model. The recently developed maximal advanced path constraint in addition to the principle of minimum free energy is utilized to connect the deformation in the microscale to the macroscale, thus resulting in a non-affine model. At the macroscale, a continuous crystallinity distribution is considered which describes the crystallization along all polymeric orientations with only a few parameters. A chain scission criterion based on the internal energy contribution by the stretch of the atomic bonds is incorporated for fracture initiation. This model is then combined with a phase field approach to study the fracture behavior. The aspects of the model like stress response, crystallinity evolution and distribution, and fracture initiation and behavior have been validated by existing experimental results.

Addressing Near Incompressibility and Other Recent Developments in Meshfree and Coupled IGA-Meshfree Methods

Wednesday, 19th June - 14:00: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 538

Prof. Yuri Bazilevs (Brown University), Dr. Georgios Moutsanidis (Brown University), Mr. Jacob Koester (Sandia National Labs), Dr. Michael Tupek (Sandia National Labs), Prof. J. S. Chen (UC San Diego)

Nearly incompressible deformations approximated in a pure displacement framework suffer from volumetric locking. To address this issue, reduced/selective quadrature techniques, as well as more advanced B-bar and F-bar type formulations, were developed and popularized in the traditional FEM community. In Meshfree methods, however, emphasis is mainly placed on nodal integration, which is a form of uniformly reduced quadrature. As a result, volumetric locking is usually not observed. However, as in traditional FEM with reduced quadrature, the resulting formulation has zero-energy modes that need to be stabilized. The issue of volumetric locking, however, resurfaces for immersed formulations coupling Meshfree methods as the foreground, and FEM or IGA as the background, discretizations. In this work we develop a new class of formulations, inspired by B-bar and F-bar approaches, to handle traditional Meshfree methods as well as novel immersed IGA-Meshfree discretizations. Because the latter may be viewed as a new generation of material-point methods (MPMs), the proposed methodology also presents a solution for volumetric locking in MPM.

* Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

Numerical Convergence of State Based Peridynamic Models for Fracture

Wednesday, 19th June - 14:15: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 558

Prof. Robert Lipton (Louisiana State University, Baton Rouge, Louisiana), Dr. Prashant Jha (Louisiana State University)

Nonlinear peridynamic models are increasingly being used to study the dynamics of fracture in materials. The model treated here is a mathematically well posed regularized fracture model. Depending on initial and boundary conditions solutions are shown to lie the space of Hölder continuous functions or Sobolev spaces. These solutions converge to sharp sharp fracture evolutions when the peridynamic horizon goes to zero.The parameters in the model can be calibrated using the elastic properties of the material and its critical energy release rate and strength. We present numerical results which highlight key features of the model. We show a linear rate of convergence, with respect to the mesh size, of the finite difference approximation for the regularized crack propagation problem. The model is seen to capture the fracture energy accurately. We show numerically and theoretically that the fracture zone localizes as the non-local length scale is refined. Samples with notch and void show the nucleation of crack under different loading conditions. We conclude with our ongoing work on the coupling of local and non-local models.

Strong Form Meshfree Collocation Method for Nonlinear Problems in Solid Mechanics

Wednesday, 19th June - 14:30: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 691

Dr. Jeong-Hoon Song (University of Colorado Boulder), Mr. Ashkan Almasi (University of Colorado Boulder), Mr. Andrew Beel (University of Colorado Boulder), Mr. Peter Schaefferkoetter (University of Colorado Boulder)

We present a strong form meshfree collocation method with its recent applications to various types of nonlinear problems in solid mechanics, including material nonlinearity and thermo-mechanical contact. The method incorporates Taylor expansion with a moving least square approach to construct its interpolation and derivative operators at collocation points. By utilizing these pre-computed derivative operators, the method can directly discretize the governing partial differential equations while the global continuity in the solution and derivative fields are ensured. Since this strong form-based method requires resolving nonlinearities with the associated partial differential equations, it is necessary to devise new computational algorithms and approaches that can properly reflect various types of nonlinear constraint conditions to the governing partial differential equations. In this presentation, we will discuss new computational approaches that can model nonlinear constitutive behaviors and thermo-mechanical contact with the strong form collocation methods in terms of the double derivative and penalty approaches.

Implementation of Peridynamics Utilizing HPX – the C++ Standard Library for Parallelism and Concurrency

Wednesday, 19th June - 14:45: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 905

Dr. Patrick Diehl (Louisiana State University, Baton Rouge, Louisiana)

Peridynamics is a non-local generalization of continuum mechanics tailored to address discontinuous displacement fields arising in fracture mechanics. As many non-local approaches, peridynamics requires considerable computing resources to solve practical problems. Several implementations of peridynamics utilizing CUDA, OpenCL, and MPI were developed to address this important issue. On modern supercomputers, asynchronous many task systems are emerging to address the new architecture of computational nodes. This talk presents a peridynamics EMU nodal discretization implementation} with the C++ Standard Library for Concurrency and Parallelism (HPX), an open source asynchronous many task run time system. The code is designed for modular expandability, so as to simplify it to extend with new material models or discretizations. The code is convergent for implicit time integration and recovers theoretical solutions. Explicit time integration, convergence results are presented to showcase the agreement of results with theoretical claims in previous works. Two benchmark tests on code scalability are applied demonstrating agreement between this code's scalability and theoretical estimations.

Local-Peridynamic Coupling with the Splice Method

Wednesday, 19th June - 15:00: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 780

Dr. Stewart Silling (Sandia)

Meshless peridynamic simulation methods offer the capability to treat fracture and long-range forces within the basic field equations, without the need for supplemental equations that govern crack growth. However, because peridynamic methods are generally slower than local methods like finite elements, there is an incentive to develop coupled techniques that apply peridynamics only where needed within a larger local model. Many such coupling techniques have been proposed.

This talk will describe experience in coupling meshless peridynamics in the Emu code with a finite difference discretization using the splice method. In the splice method, the local and nonlocal grids overlap near their interface. The displacements are mapped in each direction where one grid extends into the other. Thus, no forces are exchanged explicitly between the two grids, avoiding additional complexity in the algorithm. The degree of accuracy and practicality of this coupling method will be demonstrated with examples of impact, fracture, and fragmentation, and wave propagation.

Enhanced Meshfree Approximation and Extrapolation with Application to Particle Methods

Wednesday, 19th June - 15:15: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 802

Prof. Francis Narcowich (Texas A&M University)

In this talk we will discuss enhancing meshfree approximation using localized bases constructed from thin-spline kernels. Let Ω be a bounded Lipschitz domain in $\mathbf{R}^d$, $f \ \varepsilon \ C^{M+1}(\Omega)$ and X be finite, quasi uniform subset of Ω. A typical approximation problem is this: Given f on X, approximate f in Ω. Standard meshfree approximation methods work well for points in the interior of Ω – i.e., points that are a distance ρ away from ∂Ω. However, for x within a distance ρ of ∂Ω the centers are no longer quasi-uniform in a ball about x, just in the half neighborhood of x that farthest from Ω, with only a few points coming from the half closest the boundary; this causes the approximation to degrade there. This problem comes up in connection with the meshfree particle methods described in the context of Babuska-Banerjee-Osborn (BBO) (t,k) regular systems. If a Sobolev extension is known, then the problem can be taken care. However, given function values *only* on X, such extensions are problematic, from a computational point of view. To ameliorate this problem, we introduce a novel meshfree extrapolation method that adds points to the exterior of Ω in such a way that Ω becomes the interior of a larger domain. This makes the rates of approximation in the vicinity of the boundary ∂Ω comparable to those in the interior, up to logarithmic factors.

Experimental Investigation of Shear Characteristics and Failure in Sandwich Beams with Cores Comprising Steel Hollow Sphere Assemblies

Wednesday, 19th June - 14:00: MS22 - Stability and Failure of Structures and Materials; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 293

Dr. Stylianos Yiatros (Cyprus University of Technology), Dr. Orestes Marangos (Cyprus University of Technology), Prof. Feargal Brennan (University of Strathclyde)

Metal foam sandwich components are novel metallic composites that can offer advantages in bucking mitigation and vibration damping at low weight. Assemblies of metallic hollow spheres, bonded together with thermosetting epoxy and acting as core material in sandwich components, can be easily fabricated and potentially work as multifunctional buckling stiffeners and passive dampers. The work herein presents experimental work undertaken during a Marie Curie Fellowship at Cranfield University in the UK and subsequent analysis undertaken at CUT in Cyprus to determine the shear characteristics of this versatile composite material. Two types of steel sphere cores were examined, based on the distribution of sphere sizes. SFS4 refers to assemblies comprising spheres of the same diameter in 3 layers, while SFSGRD refers to assemblies comprising two sizes of spheres, in three layers, where the smaller sphere sizes (and hence denser layers) were closer to the face plates. The specimens were primarily under monotonic 4-point testing while cyclic 4-point bending was also undertaken to capture the fatigue response of these assemblies as sandwich cores. Displacement fields, crack initiation and propagation were captured via a DIC system during the monotonic tests so that failure characteristics and post-failure residual stiffness and strength were identified, measured and recorded. Shear parameters were extracted via statistical analysis from the results, exhibiting good correlation between specimens of the same type as well as marking the distinct merits of each core stratification.

The Synergetic Thermo-Acoustic and Magneto-Acoustic Emitting from Free-standing Nano-Thin Film

Wednesday, 19th June - 14:15: MS22 - Stability and Failure of Structures and Materials; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 991

Mr. Yida MAO (Huazhong University of Science and Technology), Prof. CW Lim (City University of Hong Kong), Prof. Tianyun Li (Huazhong University of Science and Technology)

In this paper, the mixed thermo-acoustic and magneto-acoustic generations are synergistically discovered with respect to wave stability. Different from the thermo-acoustical nano-thin film devices, the present acoustical emitting device derives from both of the thermo-acoustical and the structural acoustical radiation. Moreover, the thermal and magnetic sounding production share the same voicing unit as well as the same simple harmonic current input. Due to the electric power excitation for thermo-acoustics and electro-magnetic loading for magneto-acoustics, the frequencies and wave stability response of the acoustic wave are apparently different as that in the steady magnetic field. The dynamic magnetic field with the same frequency as the electric current is introduced to correct the inharmonious frequency. As the thermo-acoustics and magneto-acoustics share the same velocity boundary condition, the two effects are partly coupled and affected. The characteristics of the mixed thermo-acoustics and magneto-acoustics are established and discussed. The sound pressure level is significantly improved compared with the single thermo-acoustical system.

Nonlinear Behaviors of Shallow Lattice Domes

Wednesday, 19th June - 14:30: MS22 - Stability and Failure of Structures and Materials; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 1256

Ms. Yue Guan (Duke University), Prof. Lawrie Virgin (Duke University), Mr. Daniel Helm (Duke University)

Shallow lattice domes, in similarity with arches, can exhibit highly nonlinear behaviors including multiple equilibrium paths, multi-stable configurations and ‘snap-throughs’. This is a classical instability problem, yet very few experiments have been carried out, especially for rigid-jointed domes and their complete post-buckling behaviors. In this study, we consider a number of 3D printed shallow domes with high-fidelity geometry and little pre-stress. Their experimental force-displacement relationship, including several sudden jumps from one equilibrium path to another, are tested by a load cell and proximity laser sensor. The corresponding simulations are achieved by finite element analysis using arc-length and branch switching method. The experimental data shows a close correlation with the numerical results. The loading and unloading paths are diverged as a result of the bifurcation phenomena and multiple equilibrium paths. The degree of asymmetry is also defined and presented both in experiment and in simulation, which reveals the significant influence of geometric sensitivity in the structure.
Multiple equilibrium configurations are also found at a fixed center deflection. The existence of dozens of equilibrium points gives us some insight into the complexity and the dynamical characteristics of the system. For a sparser dome, whose dynamical behaviors can be dominated by a few modes, these multiple equilibria would have a vital influence on the system’s transient trajectories. This phenomenon is verified by further experimental results.

The Influence of Distortional Buckling Mode on the Buckling and Postbuckling Behaviour of CFS Lip Channel Section Beam Under Pure Bending

Wednesday, 19th June - 14:45: MS22 - Stability and Failure of Structures and Materials; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 364

Ms. Monika Kamocka (Lodz University of Technology/Faculty of Mechanical Engineering/Department of Strength of Materials),
Prof. Zbigniew Kolakowski (Lodz University of Technology/Faculty of Mechanical Engineering/Department of Strength of Materials),
Mr. Filip Kazmierczyk (Lodz University of Technology/Faculty of Mechanical Engineering/Department of Strength of Materials),
Prof. Tomasz Kubiak (Lodz University of Technology/Faculty of Mechanical Engineering/Department of Strength of Materials)

Cold-formed steel beams are one of the most common structures used in the industry. Those thin-walled structures are designed not only with the restriction of strength but also stability issue. In thin walled beams both local and distortional buckling could occur. The problem of distortional buckling was analyzed by Kolakowski who indicated the influence of lateral-distortional buckling mode on the interactive buckling.

The aim of this investigation is to analyze numerically the influence of first and secondary distortional buckling mode on buckling and postbuckling response of lip channel section beam subjected to pure bending. In the nonlinear analysis initial geometric imperfection corresponds to primary and secondary local (w_0=0.1) and distortional (w_0=1) buckling modes were applied. Analysis on the effect of each individual buckling modes and also their interaction on the work of the structure was investigated. The signs of imperfection were chosen in the most unfavourable way (to obtain the lowest magnitude of load capacity). Results obtained from FEM were compared with those gained from SAM (Semi Analytical Method based on Koiter's asymptotic perturbation theory).

ACKNOWLEDGEMENTS: This study was financially supported with the Ministerial Research Project No. UMO-2017/25/B/ST8/00007 financed by the National Science Centre, Poland

Effect of Thickness on the Equilibrium Path of Axially Loaded Cylindrical Shells

Wednesday, 19th June - 15:00: MS22 - Stability and Failure of Structures and Materials; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 386

Mr. Ruben Adorno (Air Force Institute of Technology), Dr. Anthony Palazotto (Air Force Institute of Technology)

The behavior of circular cylindrical shells subjected to static and quasi-static loading has been largely studied, modeled and documented. The instability of these shells is typically characterized by the buckling failure mode under axial quasi-static loading, imperfection sensitivity, and boundary conditions. This study investigated the effects increasingly smaller thicknesses have on the instability of these shells, considering both material linearity and nonlinearity. It is shown that the path of equilibrium is driven by the shell thickness, considering thicknesses between 1E-3 to 1E-6 meters, while the post-collapse shape is driven by plasticity. Furthermore, a reduction in the yield onset can result in yielding before collapse, effectively changing the path of equilibrium and the post-collapse shape. Paths of equilibrium were found using finite element methods, where material nonlinearity was modeled using the Johnson-Cook constitutive relation.

Recent Developments in Experimental Path-Following

Wednesday, 19th June - 15:15: MS22 - Stability and Failure of Structures and Materials; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 458

Dr. Rainer Groh (University of Bristol), Dr. Robin Neville (University of Bristol), Dr. Jiajia Shen (University of Bristol), Dr. Alberto Pirrera (University of Bristol), Dr. Mark Schenk (University of Bristol)

The drive for lightweighting leads to thinner and thinner structures that are more prone to instabilities. Simultaneously, a renewed interest in structural instability revolves around purposefully embedding instabilities in structures to add functionality beyond structural load-carrying capability. By designing structures that behave predictably once an instability is triggered, our research aims to develop a new class of *well-behaved* nonlinear structures.

Advances in experimental testing of nonlinear structures are significantly lagging behind numerical methods. While numerical methods based on continuation principles such as path-following, calculation of bifurcations, branch-switching, and bifurcation tracking are now well established, nonlinear experimental methods have not advanced beyond simple displacement and force control. This means that the nonlinear response of even simple nonlinear structures cannot be fully characterised, as established techniques induce dynamic snaps at turning points and subcritical bifurcations.

We propose a testing method based on adding control points to a structure in order to: (i) stabilise otherwise unstable equilibria; (ii) control the shape of the structure; and (iii) provide information about the experimental "tangential" stiffness matrix. With this approach all the features of the numerical techniques mentioned above can (theoretically) be replicated.

The current testing method is intricately linked to a virtual testing environment that allows the experimenter to test the underlying algorithms, as well as the location and number of control points, *i.e.* to design the experiment. Here, we present the algorithms underlying experimental path-following, the use of virtual testing, and finally, experimental implementation on a shallow arch.

High-Resolution Remote Acoustic Sensing of Damage in Vibrating Plates

Wednesday, 19th June - 14:00: MS28 - Novel Methods in Imaging and Multiscale Characterization of Damage in Complex Materials (151 Crellin (50)) - Oral - Abstract ID: 1216

Mr. Tyler Flynn (University of Michigan, Ann Arbor, MI), Dr. David Dowling (University of Michigan, Ann Arbor, MI)

The presence of damage in a structure often changes its vibrational characteristics. For example, resonant frequencies and mode shapes may be changed in a damaged structure relative to a healthy counterpart. For structures immersed in a fluid medium, these changes result in alterations to radiated sound that, when recorded, can be examined to glean information about the damage. This use of radiated sound for structural health monitoring enjoys the benefit of being remote (*i.e.* non-contacting) such that sensors can be entirely independent from the system of interest, potentially making in situ measurements more feasible. However, such independence comes at the cost of introducing challenges associated with the acoustic environment and exogenous noise. In this presentation, we describe a remote acoustic technique for detecting and localizing damage in base-excited clamped plates in a reverberant environment. This is accomplished by measuring audible broadband sound (0.2-6 kHz) from 12”x12”x1/16” plates with and without damage in an ordinary laboratory using a remote array of microphones. Here, damage-free plates serve as baselines against which to compare potentially damaged plates. Both baseline- and damaged-plate recordings are processed using a high-resolution beamforming method (exploiting the relative signal phases between receivers) to determine locations where the *difference* in plate-radiated sound emanates, with these locations serving as estimates of true damage locations. Experimental results from various types of damage – including cuts, boundary-mounting failure, and delamination of composite plates – are presented and discussed. [Sponsored by NAVSEA through the NEEC and by the US DoD through an NDSEG Fellowship]

Elastic Waveform Tomography of Spent Nuclear Fuel Casks

Wednesday, 19th June - 14:15: MS28 - Novel Methods in Imaging and Multiscale Characterization of Damage in Complex Materials (151 Crellin (50)) - Oral - Abstract ID: 424

Mr. Othman Oudghiri-Idrissi (University of Minnesota), Prof. Bojan B. Guzina (University of Minnesota)

At the end of its service life, the nuclear fuel consumed by nuclear power plants is first cooled down in a spent fuel pool for a certain period of time, and then stored temporarily in spent nuclear fuel (SNF) casks. The latter is a cylindrical structure that encloses a sealed steel canister where the fuel assemblies (FAs) are arranged vertically via a holding basket. During insertion of an FA into the canister, the unit may be damaged or placed improperly with respect to its remaining nuclear capacity. In this setting, present research aims to develop an elastodynamic Non-Destructive Evaluation (NDE) technique that identifies and characterizes the FAs inside the sealed canister in order to evaluate their potential damage and misloading before transportation and permanent storage. The proposed NDE method is formulated as an inverse problem that models the steel canister and the FAs in terms of their condensed elastodynamic impedances that are linked by point-like contacts. By assuming a parallel arrangement of the FAs in response to dynamic excitation applied to the bottom of the canister base plate, the individual FA impedances are resolved using dynamic impedances of the (i) empty canister, and (ii) loaded canister as input data. In a second stage of the NDE technique, a comparison of the reconstructed FA impedances with their reference "stencils" furnishes information about potential misloading and damage of the FAs encapsulated by the canister. The presentation will include the theoretical framework as well as examples from numerical simulations and scaled laboratory experiments.

Monitoring of Cracks Using Transmission Eigenvalues with Artificial Backgrounds

Wednesday, 19th June - 14:30: MS28 - Novel Methods in Imaging and Multiscale Characterization of Damage in Complex Materials (151 Crellin (50)) - Oral - Abstract ID: 1228

Mr. Kevish Napal (Ecole Polytechnique, CMAP, Defi team), Prof. Houssem Haddar (Ecole Polytechnique, CMAP, Defi team), Dr. Laurenzo Audibert (EDF R&D, Department PRISME), Dr. Lucas Chesnel (Ecole Polytechnique, CMAP, Defi team)

This work is concerned with crack monitoring by employing acoustic waves. We localize sound hard cracks from far field data associated with incident plane waves. Recent developments on transmission eigenvalues (TEs) with artificial background are used to this end. The given far field operator F is modified into an operator F_m=F-F_0, where F_0 is computed numerically, which corresponds to an artificial sound soft obstacle Ω and whose associated TEs brings information on the position of cracks. Indeed if no crack intersects Ω, the TEs are the Dirichlet eigenvalues for the Laplace operator on Ω, otherwise the TEs are a perturbation of these. TEs corresponds to wave numbers k for which the far field equation cannot be solved and by this way can be determined by observing abnormal hight norms of solutions to the Tikhonov regularization of the far field equation with small penalty term. Cracks are localized with a scan of the probed medium by translations of Ω and determination of TEs using F_m. This procedure also allows one to detect and to quantify small cracks aggregates.

Bibliography:

L. Audibert, L. Chesnel, H. Haddar, Transmission eigenvalues with artificial background for explicit material index identification, 2017.

Evaluation of Damage in Rocks Through Ultrasonic Imaging and Digital Image Correlation

Wednesday, 19th June - 14:45: MS28 - Novel Methods in Imaging and Multiscale Characterization of Damage in Complex Materials (151 Crellin (50)) - Oral - Abstract ID: 1320

Dr. Reza Hedayat (Colorado School of Mines), Dr. Gabriel Walton (Colorado School of Mines), Mr. Deepanshu Shirole (Colorado School of Mines)

Ultrasonic imaging of rock fracturing and cracking at the laboratory scale has provided a very promising tool for detection of internal mechanisms in rocks typically not observable with common techniques. The failure process can generally be divided into five phases: (1) microcrack closure; (2) linear elastic deformation; (3) nucleation of microcracks at low stresses (crack initiation (CI)) and stable crack growth; (4) unstable crack propagation (crack damage (CD)) close to the ultimate strength; and (5) ultimate failure. Prismatic rock specimens were subjected to uniaxial compression and the induced damage in rock was monitored by the Digital Image Correlation technique as well and ultrasonic imaging technique. The amplitude, frequency and velocity of the transmitted ultrasonic waves exhibited significant changes as a result of the damage evolution in the rock specimen. Active ultrasonic waves provided evidence of damage inside a rock as the waveforms were very sensitive to the initiation and propagation of damage and a correlation was established between the changes in the signal attributes and the applied strain to the specimen. This talk also focuses on the non-destructive characterization of stress-induced damage progression in rocks through evaluation of non-linear response of the rocks. The non-linear ultrasonic testing procedure known as the Scaling Subtraction Method (SSM) is introduced and applied for testing rock specimens. This talk concludes that both linear and non-linear techniques are capable of detecting stress-induced damage in rocks.

Differential Imaging of Evolution in Elastic Backgrounds with Unknown Microstructure

Wednesday, 19th June - 15:00: MS28 - Novel Methods in Imaging and Multiscale Characterization of Damage in Complex Materials (151 Crellin (50)) - Oral - Abstract ID: 1153

Dr. Fatemeh Pourahmadian (University of Colorado Boulder), Mr. Hao Yue (University of Colorado Boulder)

Major components of nuclear power plants e.g., reactors, fuel cells and containment vessels are comprised of highly heterogeneous composites that **(a)** their topology and properties at micro- and meso- scales are uncertain or in most cases unknown, and **(b)** their deterioration due to various chemo-physical processes such as corrosion, irradiation, thermal cycling, etc are not yet fully understood. These processes are responsible for the continuous microstructural evolution, leading to an inevitable development of micro/macro cracks and other anomalies, that will gradually result in the loss of structural integrity and diminished functional performance such as radiation shielding.

This talk is focused on timely detection of degradation in such materials — i.e., anomalies at the microstructure scale, and active spatiotemporal tracking of their evolution. In this vein, a fast waveform tomography solution will be introduced for 3D reconstruction of evolving regions in a complex elastic background by way of ultrasonic waves. To this end, sequential sets of boundary measurements are leveraged within the framework of active sensing to carefully design a non-iterative indicator functional that is insensitive to the (unknown) stationary scatterers of the background domain e.g., its time-invariant interfaces and inhomogeneities. This differential imaging functional is rooted in the recently developed generalized linear sampling method whose affiliated cost functional is rigorously revised so that it's minimizer carries pertinent invariant properties. The performance of this new damage indicator will be illustrated through a set of numerical experiments.

Application of Variable-Order Fractional Operators to the Simulation of Nonlinear Oscillators

Wednesday, 19th June - 15:15: MS28 - Novel Methods in Imaging and Multiscale Characterization of Damage in Complex Materials (151 Crellin (50)) - Oral - Abstract ID: 119

Mr. Sansit Patnaik (Purdue University), Dr. Fabio Semperlotti (Purdue University)

Fractional derivatives and integrals are intrinsically multiscale operators that can act on both space and time dependent variables. Contrarily to their integer-order counterpart, fractional operators can have either fixed or variable order. For example, the order can be made function of either independent or state variables, hence yielding the so-called variable-order (VO) fractional operators. When using VO operators within the differential models describing the response of dynamical systems, the order can evolve as a function of the independent variables therefore allowing a natural and seamless transition between linear, nonlinear, and even discontinuous behaviors. In addition, the relation describing the variation of the order can be updated as a function of the system's response, hence making the governing equation completely evolutionary. In this talk, we present the possible application of VO operators to nonlinear lumped parameters models that have much practical relevance in mechanics and dynamics. Examples include hysteresis and impact problems for discrete oscillators. More specifically, we will discuss how the VO operators can be formulated in order to capture these phenomena. Despite using simplified lumped parameters nonlinear models to present the application of such operators to mechanics and dynamics, we will also provide a more qualitative discussion of the possible applications of this mathematical tool in the broader context of continuous multiscale systems.

Vibration Response, Rivulet Dynamics and Flow Structures of Rain-Wind Induced Vibrations of a Flexible Stay Cable

Wednesday, 19th June - 14:00: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 3 (103 Downs (50)) - Oral - Abstract ID: 485

Prof. Wen-Li Chen (Harbin Institute of Technology), Mr. Donglai Gao (School of Civil Engineering, Harbin Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

We successfully excited the multi-mode rain-wind induced vibrations (RWIVs) of a flexible stay cable in a wind tunnel by guiding water rivulets along the cable surface. The first, second and third mode RWIVs are excited respectively by increasing the incoming wind speed. The movements of upper rivulet during the first, second and third mode RWIVs are recorded with a high-speed camera. By employing a computer vision based recognition technique, the upper-rivulet dynamics of different modes of RWIVs are recognized and analyzed. The wake flow structures around the dry cable, the static cable with water rivulet running and the cable suffering from RWIVs are measured by using a particle image velocimetry (PIV) system. When the cable is suffering from RWIVs, the wake flow structures become more disordered, the vortex strength is increased, and the vortex formation length shrinks, due to the existence and oscillation of the upper rivulet. The von Kármán vortex shedding is alleviated and the small-scaled vortical structures become more present, with the formation and oscillation of upper rivulet.

Experimental and Numerical Simulation of Yopographic Effects over Idealized Three-Dimensional Hills Induced by Downburst Wind Flows

Wednesday, 19th June - 14:15: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 3 (103 Downs (50)) - Oral - Abstract ID: 925

Dr. Bowen Yan (Chongqing University), Ms. Chenyan Ma (Chongqing University), Mr. Kangkang Liu (Chongqing University), Prof. Qingshan Yang (Chongqing University), Prof. Xuhong Zhou (Chongqing University)

The highest wind speeds of downburst exist at low elevations, therefore, the topographic effects would play a dominant role in the distribution of the surface downburst winds. The main objective of this study is to clarify the topographic effects caused by the idealized three-dimensional hills on resultant downburst wind speeds. The impinging jet models, which have been proven appropriate for representing the flow structures of real downburst events, were experimentally and numerically simulated to investigate the topographic effects. In addition, the speed-up factors induced by the stationary and moving downbursts were experimentally measured over both parabolic and quadratic-shaped isolated hills, and the influences of hill size and slope were also studied. Meanwhile, the multi-point unsteady pressure measurements around and over the hill models were synchronously obtained for validation purposes. In addition, the downburst wind flows over three-dimensional isolated hills with various shapes (parabolic-, quadratic- and bell-shaped), sizes (Bottom diameter of hills D=100mm, 200mm, 300mm, 400mm and 500mm) and slopes (α=16^o, 20^o, 23^o and 26^o) were further numerically modelled using the Reynolds-averaged Navier-Stokes method (RANS), Detached-eddy simulation method (DES) and Large-eddy simulation method (LES). The parameters involved in the CFD model validations are the effects of grid size and turbulence models on the speed-up, flow separations and instantaneous flow turbulence structures. Finally, the comparison of topographic effects induced by downburst wind flows and atmospheric boundary layer (ABL) flows was made in regard to speed-up factors on different topographic features.

Performance of Tall-Wood Buildings Under Wind Loads

Wednesday, 19th June - 14:30: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 3 (103 Downs (50)) - Oral - Abstract ID: 546

Mr. Matiyas Bezabeh (Western University), Prof. Girma Bitsuamlak (Western University), Prof. Solomon Tesfamariam (University of British Columbia)

The past two decades have seen the continuing global recognition of engineered tall-wood buildings as energy efficient and sustainable option to address urban sprawl and densification. In this regard, recent design strategies are entertaining the use of wood for tall buildings. The use of timber panels to construct the lateral and gravity systems of the tall wood buildings makes them lightweight and less stiff than buildings made from conventional construction materials. As a result, frequent exposure to wind-induced oscillations can cause discomfort to occupants. With the increasing use of timber, the practicing structural engineers and researchers are continuously asking the question as to what height tall wood buildings can go. To answer this question from a wind engineering perspective, we conducted several aerodynamic and aeroelastic wind tunnel tests on case study tall-wood building models. The study buildings are the 18-story UBC Brock Commons, the 40-story Tall Timber Tower, and the 30-story FFTT building. Initially, aerodynamic wind tunnel tests are carried on rigid models of the case study buildings. To study the height effect, the Timber Tower project model was tested at various height, i.e., 10-, 15-, 20-, 30-, and 40-stories. Dynamic structural analyses are carried out to obtain peak floor acceleration and drift demands. To include the possible motion-induced effects, aeroelastic wind tunnel test is also carried out on the 40-story Timber Tower building model. Overall, the results indicate that tall-wood buildings exceeding the height of 90 meters either need supplemental damping or “Wind bracing” to satisfy the serviceability criteria.

Optimal Design of Tall Buildings Using Cyber-Physical Aeroelastic Wind Tunnel Experiments

Wednesday, 19th June - 14:45: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 3 (103 Downs (50)) - Oral - Abstract ID: 1094

Mr. Michael Whiteman (University of Maryland), Dr. Pedro Fernandez-Caban (University of Maryland), Prof. Brian Phillips (University of Maryland), Prof. Forrest Masters (University of Florida), Prof. Jennifer Bridge (University of Florida), Dr. Justin Davis (University of Florida)

This study explores a cyber-physical systems (CPS) approach to optimize the structural performance of tall buildings in a boundary layer wind tunnel (BLWT). The CPS approach couples BLWT testing with stochastic optimization algorithms to optimize user-specified objectives while satisfying performance requirements such as occupant comfort, inter-story drift, and overall building drift. Cyber-physical aeroelastic BLWT experiments were conducted at the University of Florida's Natural Hazard Engineering Research Infrastructure (NHERI) Experimental Facility. The building model consisted of a mechatronic aeroelastic specimen with physically adjustable dynamic properties to precisely control the natural frequencies and mode shapes of the building. The specimen was instrumented with accelerometers and displacement sensors to capture the along- and across- wind response. Cyber-physical optimization was conducted to minimize the overall building stiffness (i.e., natural frequency) while meeting design constraints; which typically indicates a lower in construction cost. The optimization was repeated for several hazard intensities (i.e., MRIs) to assess requirements for both occupant comfort and drift. Preliminary BLWT results suggest that the CPS framework can efficiently perform an exhaustive exploration of the design space and reliably reach optimal solutions that satisfy multiple constraints under different wind-hazard intensities. The use of mechatronic building models with physically adjustable properties (e.g., shape, stiffness, damping, etc.) enable optimal designs to be attained faster than conventional trial-and-error methods.

Downburst Simulations at The NHERI Wall of Wind Experimental Facility

Wednesday, 19th June - 15:00: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 3 (103 Downs (50)) - Oral - Abstract ID: 168

Prof. Amal Elawady (Florida International University), Mr. Alvaro Mejia (Florida International University), Prof. Peter Irwin (Florida International University), Prof. Arindam Chowdhury (Florida International University)

Downburst wind events are categorized among natural hazards due to their high wind speed, nonstationary, and spatial and temporal localization. The special nature of downburst events compared to synoptic winds results in significant differences of their wind actions on structures. In addition, the lack of design guidelines and research studies pertaining to the behavior and response of structures subjected to downbursts have resulted in several wind-related damage for civil infrastructure. Aiming at advancing the fundamental knowledge in this research area, the Wall of Wind (WOW) team is currently developing the incorporation of a downburst simulator in the WOW to expand its capabilities. The downburst simulator has been optimized in its size, location, the flow management technique so that it produces a two-dimensional development of the desired rolling vortex, localized wind speed time history showing the ramp-up and then the decay of the wind speed, and the nose-shape wind profile showing the maximum wind speed occurring near the ground. Using the small-scale downburst simulator, several rigid models representing high-rise structures have been tested to estimate wind pressure coefficients on their surfaces when subjected to downburst flow. In this study, flow field characterization of the produced downburst including a smoke visualization that shows the vortex ring formation, progression, and decay of the phenomenon, the time history of the wind speed at one point of the space, a validated velocity profile, and turbulence intensity is presented. Pressure coefficients for the tested model subjected to downburst winds at the small-scale WOW are then discussed.

3d Post-Flutter Analysis of a Long-Span Bridge Using Deep LSTM Networks

Wednesday, 19th June - 15:15: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 3 (103 Downs (50)) - Oral - Abstract ID: 498

Mr. Tao Li (Southeast University/University at Buffalo), Dr. Teng Wu (University at Buffalo)

The wind-induced effects on bridges are conventionally modeled according to the linear analysis framework. The semi-empirical, linear, unsteady model is actually a time-linearized method, where a steady-flow field (statically nonlinear) is first determined, and then a small perturbation (linear) is added on this base flow. While the linear schemes have been applied extensively both in research and design to investigate aerodynamic and aeroelastic behaviors of bridge decks under winds, the flow separation and hence nonlinear unsteady aerodynamics is prevalent as the fluid motion around the bridge deck cannot negotiate sudden changes in the deck profile (resulting in severe adverse pressure gradients). Recent advancements of performance-based wind design of long-span bridges have placed increasing importance on effectively modeling of the nonlinear post-flutter behaviors of long-span bridges. To this end, the deep long short-term memory (LSTM) networks are utilized in this study to develop a reduced-order model of the wind-bridge interaction system, where the model inputs are bridge deck motions and model outputs are motion-induced aerodynamics forces. The deep LSTM networks are first trained using the high-fidelity input-output aerodynamics datasets (e.g., based on the full-order computational fluid dynamics simulations). The trained LSTM networks are then integrated into the 3D finite element model (FEM) of a long-span bridge to explore the flutter and post-flutter behaviors. A non-dimensional post-flutter index is designed to quantitatively assess the effects of structural dynamics and aerodynamic properties (e.g., mechanical damping ratios, natural frequencies, and aerodynamic derivatives) on the bridge post-flutter performance.

The Role of Size on the Collapse of Granular Columns in Fluid

Wednesday, 19th June - 14:00: MS33 - Modeling Particle-Fluid Systems (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 1001

Dr. Krishna Kumar (University of Texas at Austin), Prof. Kenichi Soga (University of California, Berkeley), Prof. Jean-yves Delenne (INRA)

The run-out distance in dry granular column collapse is governed by the initial aspect ratio of the column. However, the underwater granular collapse is affected not just by the initial aspect ratio but also by the packing density, permeability, and the interaction between the soil and the surrounding fluid. The initial size (volume) of the granular column, and not just the aspect ratio, govern the collapse dynamics, due to the differences in the fluid inertia component. This paper investigates the effect of the size of the granular column on the run-out characteristics. A coupled Discrete Element Method (DEM) - Multiple-Relaxation-Time Lattice Boltzmann (LBM-MRT) is used to understand the evolution of submerged granular flows. In order to simulate interconnected pore space in 2D, a reduction in the radius of the grains (hydrodynamic radius) is assumed during LBM computations. The volume of the initial packing (size of the granular column) is varied to simulate different stress conditions while maintaining the same initial aspect ratio. The influence of the stress condition on the run-out behavior is studied for three different sizes of both a small and a tall column (aspect ratios of 0.8 and 4). The role of fluid-inertia is investigated by analyzing the effect of hydroplaning, water entrainment and viscous drag on the granular mass. The mechanism of energy dissipation, the shape of the flow front, the amount of water entrainment and evolution of packing density provides insight into the role of size and the effect of fluid-inertia on the collapse behavior.

DEM-SPH Coupling Algorithm with Dilated Polyhedral Elements

Wednesday, 19th June - 14:15: MS33 - Modeling Particle-Fluid Systems (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 356

Prof. Shunying Ji (Dalian University of Technology), Dr. Lu Liu (Dalian University of Technology)

Abstract: In the study of coupling problems between granular materials and fluid dynamics, the discrete element method (DEM) and the smoothed particle hydrodynamics (SPH) can be adopted to simulate the granular materials and fluid, respectively. In this study, the dilated polyhedron-based elements are constructed with the Minkowski sums theory. Meanwhile, the weakly compressible SPH is adopted to simulate the hydrodynamics. This approach avoids the huge amount of boundary particles in the boundary formation, and thus it is efficient for the complex boundary shape. Accordingly, the DEM-SPH coupling method is developed to simulate the interaction between granular materials and fluid. The dam break flow against a rectangular cylinder and the dynamic process of discrete blocks in dam breaking flow are simulated with the present DEM-SPH coupling model. The simulated results are compared well with the physical experiment and numerical simulation from the published literatures.

Dense-Phase Fluid-Particle Interaction in Varying Fracture Geometries and Particle Concentration Distributions

Wednesday, 19th June - 14:30: MS33 - Modeling Particle-Fluid Systems (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 1021

Mr. Brian Yamashiro (University of California, San Diego), Dr. Ingrid Tomac (University of California, San Diego)

This paper investigates the effects of varied fracture geometries and particle concentration distributions on particle-fluid slurry flow and transport. This research uses Discrete Element Method (DEM) coupled with computational fluid dynamics for studying effects from varying horizontal fracture orientation, non-uniform particle concentration distributions, and fracture surface roughness on proppant flow and transport. Proppant particle behavior is studied for dense-phase slurry flow and transport in rock fractures. The study is performed within a context of proppant used for hydraulic fracture productivity enhancement. Central to the success of proppant injection work is the ability to accurately predict proppant settling and tangential velocity behavior. A large portion of investigations into the behaviors of proppant injection have considered configurations in which the proppant is injected into idealized, smooth-walled, horizontal fractures. The idealized conditions are however non-reflective of in field fracture geometry that exhibits complex characteristics, including variance from horizontally level fracture alignment and roughened fracture surfaces with asperity variations, among other features. In addition, isotropic particle concentration distributions, considered in past studies, do not account for behavior variances that occur due to non-uniform concentration distributions that evolve during particle transport. Understanding of the variances' impacts on proppant flow and transport is essential for accurately predicting proppant behavior and improving design projects. This work provides an insight into the importance of fracture geometry and non-uniform concentration effects when considering proppant behavior in fractures. Specifically, the results provide greater understanding of the impact on particle settling and tangential, down fracture, particle velocity.

Coupled Three-Dimensional Discrete Element-Lattice Boltzmann Methods for Fluid-Solid Interaction with Polyhedral Particles

Wednesday, 19th June - 14:45: MS33 - Modeling Particle-Fluid Systems (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 230

Dr. Michael Gardner (NHERI SimCenter, University of California, Berkeley), Prof. Nicholas Sitar (University of California, Berkeley)

Interaction between solid particles and fluid is of fundamental interest to scientists and engineers in many different applications—cardiopulmonary flows, aircraft and automobile aerodynamics, wind loading on buildings to name a few. In granular media, particle shape significantly affects both particle-particle and particle-fluid interaction. Coupling the three-dimensional Discrete Element Method (DEM) with the Lattice Boltzmann Method (LBM) allows modeling of the interaction between polyhedral solid particles and fluid. The coupling between DEM and LBM is achieved through an algorithm based on a volume-fraction approach to consider three-dimensional convex polyhedral particles moving through fluid.The algorithm evaluates the interaction using linear programming and simplex integration, and is validated against experimental data. The results show that this approach to modeling the interaction between complex polyhedral particles and fluid is accurate for direct evaluation of hydrodynamic forces on the particles. This provides the capability to investigate sedimentation and particle transport where the polyhedral shape of particles influences the interaction between particles as well as the hydrodynamic loading. Additionally, the ability to capture the kinematic response of fractured rock based on particle shape, while also considering hydrodynamic loading, allows for analyses of many problems in rock mechanics and geomorphology.

Microscopic Analysis of Capillary Processes in Unsaturated Granular Media with X-Ray CT

Wednesday, 19th June - 15:00: MS33 - Modeling Particle-Fluid Systems (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 260

Dr. Marius Milatz (Hamburg University of Technology, Institute of Geotechnical Engineering and Construction Management), Prof. Jürgen Grabe (Hamburg University of Technology, Institute of Geotechnical Engineering and Construction Management)

Computed tomography (CT) has developed to an important tool in materials research for the visualization and analysis of matter. In geosciences research, CT can be used to investigate soil and rock composition, fracture, as well as hydro-mechanical processes such as soil deformation and the flow of water through porous media. In this constribution, CT is applied to investigate capillary phenomena in unsaturated packings of sand and glass beads on the microscale, i. e. resolving sub grain-scale dimensions. In this field, different macroscopic phenomena, such as the water retention behavior or unsaturated shear strength due to capillary cohesion are not yet fully understood because they originate from hydro-mechanical processes on the microscale. With the help of a miniature compression device, the microscopic changes of the air-water distribution and of capillary bridges during uniaxial compression and deformation of the grain skeleton can be monitored by CT. Furthermore, CT-imaging during drainage and imbibition of granular media can be applied to investigate the water retention behavior. The segmentation of the obtained image data allows to follow the liquid and air phase during compression or flow processes and to analyze processes on the microscale. The corresponding volumetric data of segmented pore air and pore water within the grain skeleton may serve for validation purposes or as input for numerical multi-phase simulations, e. g. using the Lattice Boltzmann Method coupled with the Discrete Element Method (LBM-DEM) or DEM in combination with bonded particle models (DEM-BPM), in numerical studies planned for the future.

Clever Mechanisms and Strategies Found in the Architecture of Some Naturally Occurring Materials

Wednesday, 19th June - 14:00: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1346

Prof. Pablo Zavattieri (Purdue Unviersity)

The focus of this talks is to discuss some interesting mechanics problems that we encountered as we studied the extraordinary damage tolerance of Bouligand Structures, a naturally-occurring architecture typically found in arthropods such as the smashing Mantis Shrimp. We carry out a combined analytical, computational and experimental investigation of the structure-function relationship of these structures Bouligand structure. Our results revealed different mechanisms that could be incorporated in the design of new impact resistant biomimetic composites at different scales. Our discussion will be focused on the material capability to delocalize damage, modulate mechanical properties and filter stress waves.

Thermal Strain and Cracking Analysis of Layered Composites Towards the Design of Solar Blinds

Wednesday, 19th June - 14:15: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 823

Mr. Yanchu Zhang (Columbia University), Prof. Huiming Yin (Columbia University)

Layered composites exhibit thermal stress and deformation when subjected to temperature change because of different thermal expansion coefficients between the layers. Particularly, in solar blinds design, the slate is made of glass-cell-Tedlar (GCT) layers or glass-cell-glass (GCG) layers bonded by ethylene-vinyl acetate (EVA). The two types of slates behave differently during temperature change: the GCT shows curling; whereas the GCG keeps straight due to the symmetry. There are two theories to model their thermomechanical behavior: a) Stoney's theory follows the assumption in classic beam theory and the shear stress across interface is neglected, so it does not work for GCT; and b) Yin-Prieto-Muñoz's theory assumes the layer keeps plane and addresses the stress transfer through interface well, but it cannot capture the behavior of GCT. Combining the two theories may better catches the physics. Therefore, a novel formulation is derived for both GCT and GCG, and two stress transfer mechanisms are investigated. Firstly, a partially bonded layered materials mechanism is established based on Bernoulli-Euler's beam theory, assuming the layers are only bonded at the endpoint at interface, from which the approximated deflection is obtained. Next, another mechanism is proposed based on Yin- Prieto-Muñoz's theory. However, the vertical displacement is revised to be a two-dimensional function by adding the deflection function obtained from the first mechanism, taking both Poisson's effect and curvature into consideration. The stationary principle of potential energy has been used to determine the parameter. Finally, the modeling results are verified with the experiments and simulation.

Numerical Simulation of Drained Piezocone Penetration Tests for Saturated Clayey Soils to Obtain Strength of Soils at Residual-Wet-Drained Condition

Wednesday, 19th June - 14:30: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 834

Prof. Chung Song (The University of Nebraska-Lincoln), Mr. Binyam Bekele (The University of Nebraska-Lincoln)

Soils of this area is overconsolidated and frequently contains approximately 10% expansive clay minerals. Due to this unique geotechnical condition, the shear strength of soils at slope failure is residual-wet-drained while the design shear strength of soils is typically determined by unconfined compression test, from which engineers take peak strength with unknown saturation and drainage conditions.

It is known that consolidated drained triaxial tests are required to obtain the residual-wet-drained strength. However, this technique may take several months to complete even one set of tests, which is impractical for design engineers. The authors proposed to use Piezocone Penetration Test device (PCPT) and Hydraulic Profiling Tool (HPT) to conduct so called “in situ residual-wet-drained strength test”. Once Piezocone advanced into the desired depth of the ground as in typical ground probing, then the penetration stops, and the system is pulled back 0.15 m so that the cone face will stay in a slightly enlarged hollow space formed by HPT body. Then water from HPT will be injected with low pressure so that the soils in a hole formed by Piezocone penetration may become fully wet. Then Piezocone penetration will resume through disturbed and wet soil surface. The penetration speed will be adjusted so that the pore pressure at the cone shoulder stays zero, providing the residual-wet-drained condition. This study presents the numerical simulation result based on Mohr-Coulomb yield criteria for above innovative test procedure with clayey soils in UNL campus. The result was also compared with the field test results.

Molecular Dynamics Modeling and Simulation of Bituminous Binder Chemical Aging Due to Variation of Oxidation Level and Molecular Group Fraction

Wednesday, 19th June - 14:45: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 879

Mr. Farshad Fallah (U. Nebraska), Dr. Fardin Khabaz (U. Texas at Austin), Prof. Yong-Rak Kim (U. Nebraska)

Bituminous binder's chemical aging process leads to significant changes in its mechanical and rheological properties. The two main outcomes of chemical aging are the oxidation of molecules and changes in the binder's molecular group fractions (i.e., saturate-aromatic-resin-asphaltene (SARA) fractions). The binder components' reaction to oxygen results in the formation of polar viscosity-building molecules, while changes in the SARA fractions disturbs the binder's balance, giving it brittle properties. As both of these factors affect the binder at the molecular level, molecular dynamics (MD) simulations can improve the fundamental understanding of binder aging. Therefore, nine MD models were built (one model that represents unaged binder and eight different aged binder models) in this study for two specific purposes: to compare the MD simulation results with the experimental results and to conduct a parametric analysis of the MD simulations to investigate the effect of each aging outcome on the properties of the binder. A comparison among binders with different aging levels showed that the MD simulations and experiments had the same rank order in viscosity values, but they had significantly different magnitudes, which may be partly attributed to the high shear rates used in the MD simulation. The parametric analysis indicated that the dominant aging mechanism in the laboratory aged binder was the disturbance of the SARA fractions, while the oxidation of the molecules appears to be a more dominant mechanism in the field aged binder.

Size Effects in Metals from MD Simulation to Strain Gradient Plasticity

Wednesday, 19th June - 15:00: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 992

Dr. George Voyiadjis (Louisiana State University, Baton Rouge), Dr. Yooseob Song (Louisiana State University, Baton Rouge, Louisiana), Dr. Mohammadreza Yaghoobi (University of Michigan)

The present work investigates the effects of grain boundary (GB) on the sources of size effects. Up to now, several studies have been conducted to address the role of GBs in size effects from the atomistic point of view. However, a study which addresses the effects of GB on different governing mechanisms of size effects as the sample length scale varies has not been presented yet. The results show that the main role of GB at larger length scale is to change the pattern of dislocation structure in a way that the dislocations are piled up near the GB which increases the hardness. Although MD is very powerful to model the size effects in nanoscale metallic thin films, it has both the size and time scale limitations. Another way to study the size effects is the strain gradient plasticity models. A coupled thermo-mechanical framework of higher-order strain gradient plasticity theory is used to investigate the behavior of small-scale metallic volumes in fast transient times.

Virtual Experiments of Phase Change Material Filled Concrete for Energy Efficient Buildings

Wednesday, 19th June - 15:15: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 728

Mr. Chunlin Wu (Columbia University), Dr. Zhenhua Wei (Columbia University)

The embedment of microencapsulated phase change materials (PCMs) is a promising means to improve the thermal inertia of concrete. However, PCMs are often soft inclusions with wide particle size distribution, which degrades mechanical properties and complicates the heat transfer behavior of the composite. This paper presents a novel numerical method to simulate the thermomechanical behavior of PCM filled concrete. Using the Green's functions, the material mismatch is simulated by eigen-fields, so that the composites can be considered as a homogeneous material with source fields on the particle domain, which is also called an equivalent inclusion. The boundary effect is taken into account by the boundary element method. The formulation is implemented in the in-house software package - iBEM (inclusion-based Boundary Element Method). The reliability of this model is validated by realistic experiments on thermal response of wall panels containing different volume fraction of PCMs. The iBEM model is further applied to develop a design rule for performance equivalence through parametric study, such that the energy efficiency of a building envelope can be maintained equivalent to that with R values required by building codes.

Dynamics of Unanchored Objects Considering Impact with Nearby Boundaries

Wednesday, 19th June - 14:00: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1123

Prof. Dimitrios Konstantinidis (University of California, Berkeley), Dr. Yu Bao (McMaster University)

An unanchored planar rigid block subjected to base excitation can rock, slide, slide-rock, and jump. Previous studies have focused on the dynamics of a rocking block assuming that the block does not interact with neighboring objects. However, there are many applications in which the block may interact with an adjacent boundary during its motion; e.g. a bookcase or cabinet colliding with a partition wall in an earthquake. This paper investigates the dynamics of a sliding-rocking block considering impact with an adjacent wall. The base and wall are assumed rigid, and impact is treated using the classical impulse and momentum principle. A model is developed and verified by comparing its predictions in numerical simulations against those of an existing general-purpose rigid body model in which impact is treated using a viscoelastic impact model. The developed model is used to investigate the effects of different parameters on the stability of a block subjected to analytical pulse excitations due to its high computational efficiency. It is found that among all parameters, the pulse direction has a dominant effect on the shape of the overturning spectra. While for other parameters, decreasing the friction coefficient, decreasing the wall distance and coefficient of restitution of the wall can generally enhance the stability of the block. Similar observations can also be made when evaluating the overturning probability of a block using floor accelerations computed from earthquake excitations.

A Robust Implementation of Rigid Contact Models for Slide-Rocking Bodies with Arbitrary Geometry

Wednesday, 19th June - 14:15: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 790

Mr. M. David Burton (University of Oxford), Prof. Manolis Chatzis (University of Oxford)

The dynamics of rocking systems have attracted the increasing interest of the engineering community. They can be encountered in several applications: from new designs of structural connections to unanchored equipment of significant importance in power facilities and hospitals. An application of special interest is that of museum exhibits. Such objects often have non-canonical geometries: A museum exhibit is rarely rectangular, may not have a flat base and could have multiple contact points. There are of course several other applications where the objects defy, the convenient in the literature, assumption of the rocking body being rectangular, as for example is also the case for precarious rocks. An additional challenge to such systems is that the presence of multiple contact points, does not allow to classify the system as slender or stocky, while it is possible to orient the body in such a way where pure sliding and pure rocking are possible for different orientations of the same body.

In this work an efficient implementation is suggested for handling the planar dynamics of rocking bodies with arbitrary geometries. This extends the Inverted Pendulum model and the slide-rocking-free-flight model of Shenton and Jones. An efficient implementation in Matlab allows working with geometries that may even have occurred from 3D scanning. A Newtonian formulations allows for obtaining the equations of motion, transitions between patterns and post impact velocities automatically. Suitable examples are chosen for demonstrating the implementation.

Computational Modeling of Hybrid Sliding-Rocking Bridge Columns Subjected to Multiaxial Loading

Wednesday, 19th June - 14:30: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 745

Mr. Mohammad Salehi Najafabadi (Texas A&M University), Dr. Petros Sideris (Texas A&M University), Dr. Abbie Liel (University of Colorado Boulder)

This presentation focuses on the three-dimensional (3D) computational modeling of hybrid sliding-rocking (HSR) bridge columns to allow their performance assessment under multidirectional earthquake excitation. The HSR columns are precast concrete segmental columns consisting of internal unbonded posttensioning, end rocking joints, and intermediate sliding-dominant (HSR) joints. The unbonded posttensioning and rocking joints provide these columns with significant self-centering, while joint sliding offers energy dissipation, thereby, reducing the seismically induced displacement demands. Compared to rocking-only columns, the joint sliding in HSR columns reduces rocking demands and the corresponding compressive damage at end joints, and reduces peak tendon strains. Joint sliding further alleviates torsion-induced shear damage by accommodating a portion of the column's torsional rotation demands from earthquakes.

This work significantly advances existing modeling capabilities to simulate the response of HSR columns under multiaxial loading by: (i) developing a 3D finite-length two-node HSR element formulation capable of simulating the sliding-rocking interactions and potential compressive damage at HSR joints (and their vicinity), (ii) introducing a *co-rotational 3D continuous multi-node truss element formulation* to simulate the response of unbonded tendons eliminating fictitious strain concentrations between closely spaced nodes that often lead to erroneous predictions of premature tendon fracture, and (iii) introducing a *3D co-rotational gap element* formulation that allows simulation of the duct-to-tendon interaction in the 3D space and in the deformed configuration. All formulations are implemented in the structural analysis software OpenSees. The proposed modeling strategy is used to simulate four half-scale HSR columns recently tested by the authors under various multi-axial loading conditions.

The Role of Supplemental Damping on the Rocking Response of Free-Standing Columns

Wednesday, 19th June - 14:45: MS102 - Recent Advances on the Dynamics of Unanchored Objects: Applications to Rocking and Sliding Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 318

Prof. Nikolaos Makris (Southern Methodist University), Dr. Mehrdad Aghagholizadeh (Southern Methodist University)

This paper investigates the nonlinear, rocking seismic response of slender, free-standing columns when equipped along their sides (or at their pivoting points) with vertical energy dissipation devices which offer either hysteretic or viscous (linear or nonlinear) dissipation. The paper first revisits the transverse response of the South Rangitikei Rail Bridge. The analysis shows that the 72m tall stepping bridge piers exhibits remarkable seismic performance even when excited with recorded ground motions that are much stronger than the known strong motions at the time of the design of the bridge. Subsequently, the paper proceeds by showing that there are isolated examples of earthquake excitations where the response of the rocking bridge pier when damped with either hysteretic or viscous dampers is more aggravated than the undamped response. This phenomenon may also manifest when idealized mathematical pulses are used. The paper concludes that the effectiveness of supplemental hysteretic or viscous damping in suppressing rocking response depends strongly on the local kinematic characteristics of the ground motion. Whenever the damped response exceeds the undamped response the exceedance is marginal and in most cases the damped response is lower than the undamped.

GPU-Accelerated Earthquake Simulations for Large Scale Urban Cities

Wednesday, 19th June - 14:00: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1166

Mr. Mert Uysal (Istanbul Technical University), Prof. Zeynep Tuna Deger (Istanbul Technical University), Prof. Gian Paolo Cimellaro (Politecnico di Torino)

After an earthquake occurs, large scale simulations of building damage can potentially reveal possible consequences that are important for disaster mitigation and managing rescue plans for saving as much lives as possible. Large scale non-linear time history analyses at the urban scale can be computationally intensive, therefore recent advances in computing has allowed to develop graphics processing unit (GPU)-accelerated earthquake simulations. In this study, an efficient GPU-based CuSP solver is developed and incorporated in OpenSees, an open source computational platform commonly used for structural and earthquake engineering simulations of buildings and civil infrastructures. To demonstrate the potential for a cost-effective and flexible computing paradigm for urban scale seismic simulation, the computational framework is applied to perform seismic simulation of a virtual city with around 23000 buildings. Compared to CPU-based solvers of OpenSees, the duration of the non-linear time history analysis has decreased significantly using the GPU-based solver. Consequently, according to the results of this study, CuSP solver can be used to prepare a rescue plan for urban communities.

Resilience-Based Building Safety Target Determination Framework

Wednesday, 19th June - 14:15: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1373

Mr. Vamshi Gudipati (University of Illinois at Urbana-Champaign), Prof. Eun Jeong Cha (University of Illinois at Urbana Champaign)

Concept of community resilience utilizes a holistic view of the impact from hazards and focuses on functionality and recovery of community as a whole. The idea of community resilience has attracted many sectors of risk management for its potential to guide risk management in various levels since it adds a dimension in the objective for risk management which often is aimed only at reducing the magnitude of consequence and probability of occurrence of hazardous events. A number of resilience guidance documents have been published in the past decade, including the SPUR Framework, the Oregon Resilience Plan, the Community Resilience Planning Guide, etc. Furthermore, various agencies including the National Institute of Standards and Technology, National Science Foundation and the Department of Homeland Security put forth efforts toward resilience. With all the efforts committed, it is reasonable to expect a growth of knowledge in community resilience research and community resilience goals.

This presentation introduces an approach to incorporate the concept of resilience into design practice. A framework to optimize building safety targets based on resilience of overall built-environment is developed. Target reliability index is used as a parameter to describe safety targets for buildings since its guiding role for specifications in prescriptive building codes. The design target reliability index optimization framework is equipped with high efficiency response approximation tool developed based on physics-based model and artificial neural network. The developed framework will be illustrated with seismic design target reliability index optimization for multiple types of building occupancy, including office and hospital buildings.

Quantifying the Resilience of Multi-Modal Transit Networks in Canada

Wednesday, 19th June - 14:30: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 912

Ms. Rasha Hassan (McMaster University), Dr. Mohamed Ezzeldin (McMaster University), Dr. Moataz Mohamed (McMaster University), Prof. Wael El-Dakhakhni (McMaster University)

Transportation networks are essential to provide high levels of accessibility and mobility services. For example, an efficient public transit network does not only promotes urban expansion, but also reduces car dependency and the associated traffic congestion and air pollution. Therefore, an efficient public transit network is a key building block for enhancing the quality of life.

In this study, we quantify the impact of multimodal transit networks in the reinforcement of the transportation system. The fundamentals of the Complex Network Theory are utilized to develop spatial indicators. These indicators in turn used to analyze the interaction between regional bus and light rail transit networks, while considering their dynamic behaviour.

The resilience of the transit networks is evaluated under normal conditions as well as under random and targeted failures that may be attributed to a station failure and the subsequent increase in the capacity of stations and routes due to the reassignment of traffic flow. The Spatiotemporal failure of the networks is studied based on the Dynamic Coupled Map Lattice (DCML) model. DCML model employs a discrete time variable and a continuous state that is represented by the chaotic logistic map. The Canadian Go multimodal transit network is utilized as a case study to validate our model.

This study is expected to provide sound contributions to decision makers with detailed indications for future development plans and mitigation strategies in an effort to avoid the cascading failure of multimodal transit systems when subjected to disruption events.

Finite Element Analysis of Resilience: A New Paradigm

Wednesday, 19th June - 14:45: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1386

Prof. Hussam Mahmoud (Colorado State University), Mr. Akshat Chulahwat (Colorado State University)

Mitigating the impact of disasters on communities requires not only a deep understanding of the essential features of infrastructure, social, and economical components that make a community resilient, but also the development of mathematical models that can seamlessly integrate these features. In this study, we present a new and novel theoretical dynamic model for quantifying community recovery from any extreme event. The model is founded on mathematically integrating infrastructural, social, and economic sectors of the community of interest. The underlying fundamentals of the proposed theory hinges on assuming the behavior of a community in response to a hazard is equivalent to the response of a vibrating mass of finite stiffness and damping. Using the concept of finite element analysis in which the community is divided into discrete girds, the model allows for the quantification of resilience both temporally and spatially. The integration of infrastructure, social and economic recovery in a finite element model model represents a new paradigm for how community resilience can be evaluated while representing a new hazard-agnostic definition of community resilience. The model is verified through logical tests conducted on a testbed city. Through various analysis and sensitivity studies, it is observed that the model can be used to identify vulnerable areas in a community as well as provide a spatial and temporal measure of community resilience for various types of hazards such as physical disruptions and even social disorder.

Bayesian Network Based Probabilistic Decision-Support Framework for Community Resilience Enhancement

Wednesday, 19th June - 15:00: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1018

Dr. Sabarethinam Kameshwar (Oregon State University), Prof. Daniel Cox (Oregon State University), Dr. Andre Barbosa (Oregon State University), Dr. Karim Farokhnia (Colorado State University), Dr. Hyoungsu Park (Oregon State University), Mr. Mohammad Alam (Oregon State University), Prof. John Van De Lindt (Colorado State University)

This study presents a probabilistic decision support framework that can be used to assess and improve the resilience of community level infrastructure systems following planning guidelines such as the Oregon Resilience Plan and the Community Resilience Planning Guideline by National Institute of Standards and Technology. The framework considers multiple hazards, several infrastructure systems, interdependence between infrastructure systems, and community's expectations on the performance of infrastructure systems. These expectations are expressed in terms of robustness and rapidity objectives which relate to the immediate post event performance and restoration time of infrastructure systems, respectively. To bridge the gap between the current and expected infrastructure performance, the framework also incorporates mitigation and response strategies. Next, the framework combines information on the built environment with hazard data for probabilistic simulations to determine damage, performance, restoration time, and losses while propagating uncertainties in capacity and restoration time estimates of infrastructure components. The framework uses these simulation results to inform a Bayesian network to quantify the resilience of infrastructure systems which is defined as the joint probability of achieving robustness and rapidity objectives. Furthermore, the Bayesian network is also used to quantify the effects of interdependence between infrastructure systems, and response and mitigation strategies on infrastructure resilience. The framework is demonstrated for Seaside, Oregon, considering building, transportation, water, and electric power infrastructure subjected to seismic and tsunami hazards emanating from the Cascadia Subduction Zone. The results highlight the effects of: community's expectations, interdependence between different systems, and response and mitigation measures on infrastructure resilience.

Integrating Decomposition Algorithm and Sampling Techniques for Reliability Analysis of Multi-State Infrastructures

Wednesday, 19th June - 15:15: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1240

Ms. Ji-Eun Byun (Seoul National University), Prof. Junho Song (Seoul National University)

Infrastructure systems consisting of multi-state components, e.g. transportation networks consisting of roads and bridges, or water distribution networks with multiple pipelines, are serving a critical role in urban communities. Majority of such systems are regarded as functional when a certain level of flow can be transmitted from source to terminal nodes. Flow analysis can be utilized to evaluate the reliability of those systems. However, as the event space grows exponentially as the number of components increases, there is a great limitation in the system size that analysis can handle, which makes approximate estimation inevitable. There are two alternative approaches to approximate the reliability – deterministic bounding and sampling. The deterministic bounding approach can exploit the characteristics of system events, but its extension to large-size systems is limited. On the other hand, sampling techniques are indirectly affected by the size issue as they try to estimate the whole event space through exploring only parts. However, it is not straightforward to incorporate the characteristics of system events into those techniques, despite its potential to improve their efficiency. In order to facilitate reliability analysis of large complex systems, we integrate the two approaches by partitioning the event space using deterministic decomposition algorithm designed from flow analysis theory, and then concluding the inference by sampling the space not addressed by the deterministic analysis. This paper demonstrates advantages of such integration in reliability analysis of multi-state structure. Numerical examples demonstrate and test the accuracy and efficiency of the proposed methodology.

Deciphering the Mechanical Function of the Bristles from Platynereis Dumerilii Larvae: A Kinematic Approach.

Wednesday, 19th June - 14:00: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 648

Mr. Luis Zelaya-Lainez (Vienna University of Technology), Dr. Giuseppe Balduzzi (Vienna University of Technology), Dr. Kyojiro Ikeda (University of Vienna), Prof. Florian Raible (University of Vienna), Prof. Christian Hellmich (Vienna University of Technology)

Bristle worms (polychaetae) belong to the most successful classes in the animal kingdom, spread across virtually all different habitats. What is equally interesting for biologists as well as for engineers, is their capability to process extremely well-tailored extracellular structures made of chitin (chaetae); with a very broad spectrum of morphologies, probably tuned for different performance criteria [1]. The chaetae, complex beam-liked-structures with complex hinges, may be seen as an extremely mature form of objects arising from “biologically mediated 3D-printing” – and this has motivated the cooperation of biologists and engineers forming the basis for this paper.
While the structure of chaetae has been investigated by several researchers, by techniques such as [2], the systematic exploration of their functions is at its very infancy. Their impressive design proposes obviously a mechanical function, which we aim at deciphering, through the following activities: Larvae of Platynereis Dumerilii are bred under laboratory conditions, and videos of their swimming patterns are recorded. It turns out that the swimming motion of larvae with an age of 3 days is driven by cilia mane prototroch, and not by the chaetae. The latter, being tightly attached to the animals’ bodies during acceleration and constant speed, are rather used for effective deceleration action – by stretching them apart from the body. We report how the recorded deceleration gives access to forces acting onto the chaetae, as an input for further multiscale structural mechanics analyses.

References

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[2] R.A. Merz and S.A. Woodin, Oph.Suppl.,5:615-623,1991.

Hierarchical Elastoplasticity of Bone

Wednesday, 19th June - 14:15: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 654

Mrs. Valentina Wittner (TU Wien - Vienna University of Technology), Dr. Claire Morin (Ecole de Mines de Saint Etienne), Prof. Christian Hellmich (TU Wien - Vienna University of Technology)

Bone is characterized by a hierarchically organized microstructure, exhibiting universal organizational patterns, whose „dosages", however, vary between different species, organs, and anatomical locations. This complex internal structure leads to a necessity of taking into account all hierarchical components - some of which behave plastic - in order to explain the overall elastoplastic response of bone.
A multiscale continuum micromechanics model is used to predict the resistance to failure under mechanical load - the bone strength - based on the mechanical properties and volume fractions of bone's three elementary constituents: mineral, collagen and water.

The hierarchical organization of bone is considered in terms of a micromechanical six-step homogenization scheme. Within this model, the sole source of elastoplasticity lies in mutual sliding between mineral phases. While the mineral is characterized by non-associated Mohr-Coulomb elastoplasticity, the collagen fails in a brittle manner, according to a Rankine-criterion. Upscaling of these processes from the nano to the macroscale was made possible by a novel iterative variant of the so-called return-map algorithm.
The model is able to accurately predict the experimentally determined strength of bone tested in uniaxial tension and compression. Furthermore, the sequence of plastic events and the stresses and strains can be determined across all hierarchical levels, illustrating the specimen specific influence of the different components – like bone porosity and mass density - on the overall mechanical behavior of bone.

Multi-functional Biomimetic Bioactive Biomaterials: Modular Rational Design with Tunable Properties

Wednesday, 19th June - 14:30: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 1225

Prof. Candan Tamerler (University of Kansas)

The need for biomaterials having unique biological functionalities is dramatically increasing over the coming decades with ageing populations all around the world. With the progress in biomaterials design, the emphasis on designing bioinert materials has already been shifted to search for bioactive materials. Rational design approaches have been increasingly explored to adapt specific, directional and dynamic interactions to the next generation materials to enable them with tunable properties. Biological systems has already mastered these desired properties, many of the biomolecule-materials interactions are intricate to achieve in purely synthetic systems. Molecular biomimetics, which offers solutions elicited from biochemical processes has gained considerable momentum in developing novel materials systems. Proteins play an essential role in biochemical processes with their molecular specificity and vast range of functionality leading to the formation of controlled structures and functions at all scales of dimensional hierarchy. Recognizing this, our group has been exploring peptides as the key fundamental building blocks to mimic biomolecular based self assembly in designing bioactive materials. We further incorporated experimentally integrated supervised iterative computational design approaches to tune multi-functional properties of these self-assembled peptides. Inspired by the linker sequences in multi-domain proteins, we explored spacer domains to tune multi-functionality in the self assembling peptide building blocks. Among variety of multifunctional peptides designed in our group, we recently combined antimicrobial, self assembly and mineralization properties into material design. We expanded modular design approach to developing bimodal imaging modalities where dynamic biological functions can be followed as an integral part of the system.

Bio-Inspired Cementitious Material: Effect of Biomolecules on Calcium-Silicate-Hydrate

Wednesday, 19th June - 14:45: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 781

Prof. Ali Ghahremaninezhad (University of Miami), Dr. Mahsa Kamali (University of Miami)

Nature has created nanocomposites, such as nacre of abalone shell, bones, and sea urchins, with intricate microstructure and superior mechanical and functional properties. Such properties are achieved in nature through certain biomolecules with specific structures and functionalities directing material formation, microstructure and macroscopic performance. Calcium-silicate-hydrate (C-S-H) is an inorganic nanostructured material, makes up a primary hydration product and is responsible for the mechanical and physical properties of cementitious materials. Use of biomolecules with a combination of functionalities provides an avenue to tune microstructure thereby controlling mechanical properties of C-S-H.

In this presentation, the interaction between biomolecules with varied functional groups and C-S-H is discussed. The effect of biomolecules on atomic structure and microstructure of C-S-H is studied using analytical techniques including X-ray diffraction (XRD) and Fourier infrared spectroscopy (FTIR), and the mechanical property is evaluated using nanoindentation. The effect of various functional groups including charged, hydrogen bond forming, and hydrophobic groups on the microstructure and elastic modulus of C-S-H is discussed.

Computational Modeling of Valve Interstitial Cells in a Three-Dimensional Environment

Wednesday, 19th June - 15:00: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 789

Dr. Emma Lejeune (University of Texas at Austin), Mr. Alex Khang (University of Texas at Austin), Dr. Michael Sacks (University of Texas at Austin)

Heart valve interstitial cells (VICs) reside within the leaflet tissue, where they play a major role in tissue maintenance. Despite their known importance, it is not well understood how specific changes in VIC behavior ultimately influence macroscale heart valve tissue, or how specific changes to macroscale valve loading conditions ultimately influence VICs. Herein we describe a first step towards a combined computational/experimental framework to address this challenge. We first use tools from spatial statistics to interpret experimental data on the geometric and mechanical properties of VICs in vitro. Unlike traditional statistical theory, spatial statistics does not assume that observations are independent. By computing these statistics, such as spatial autocorrelation of stiffness from Atomic Force Microscopy experiments, we are better able to interpret experimental results and translate representative information into the computational setting. Then, we describe the initial progress on a fully three-dimensional computational model of VICs in conjunction with experiments conducted on cells cultured in three-dimensional hydrogels. In this computational model, we include discrete sub-cellular components of VICs, and run simulations on suites of representative cells with heterogeneous geometries. From these simulations, we are better able to understand cell behavior across scales. Moving forward, we anticipate that this work will be meaningful for both straightforward analysis of experimental data, and for building a simulation framework to connect cellular scale behavior in vitro to macroscale changes in tissue properties in the demanding in vivo environment.

Human Stromal Cells to Form New Bone in a Bone-on-Chip

Wednesday, 19th June - 15:15: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 830

Ms. Nabila Gaci (Ecole Normale Superieure Paris Saclay), Ms. Samantha Sanders (Ecole Normale Superieure Paris Saclay), Dr. Bertrand Cinquin (Ecole Normale Superieure Paris Saclay), Dr. Patrick Tauc (Ecole Normale Superieure Paris Saclay), Dr. Morad Bensidhoum (Universite Paris Diderot), Prof. Hugues Portier (Universite Orleans), Prof. Elisa Budyn (Ecole Normale Superieure Paris Saclay)

Osteocytes orchestrate bone homeostasis, coordinate bone resorption by osteoclasts and bone formation by mesenchymal stromal cells (MSCs) differentiating into osteoblasts and osteocytes. Osteocytes morphology contributes to the detection of the mechanical environment but knowledge on the cell in situ mechanobiology is challenging to quantify in human.

A bone-on-chip containing one or multiple human bone samples provides the in situ 3D bone environment for MSCs to grow and form new bone. The biological responses of the cells to mechanical stimulations can be measured by coupling confocal microscopy and a multi-scale numerical model subjected to the experimental loading conditions such as stimulations mimicking human walk or run. The systems are cultured over long-term periods of time (over 8 months) to allow cell differentiation, new bone formation and bone samples reorganization. Changes in the cell morphology, gene expression, and secretome were characterized by 3D confocal imaging, PCR, immunohistochemistry and in situ immunofluorescence during their differentiation.The morphology of Stem Cell Derived Osteocytes exhibited long processes organized in a network at 19 months. The cell organized in layers of changing orientation up to 45^o. The mechanobiology of stromal bone cells showed a cytoplasmic calcium concentration adaptation to the expected in vivo mechanical load. The mineralized neo-formed bone displayed a strength nearly a quarter of native bone strength at 109 days. The newly-formed matrix further characterization by immuno-fluorescence under confocal microscopy at 547 days revealed the presence of E11 and sclerostin of which the amounts were correlated to exercise and local stresses.

Poromechanics of Unsaturated Materials with Capillarity and Adsorption and Generalization of BET Sorption Isotherm

Wednesday, 19th June - 14:00: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 2 (142 Keck (72)) - Oral - Abstract ID: 1107

Prof. Zdenek Bazant (Northwestern University), Mr. Hoang Nguyen (Nort), Mr. Saeed Rahimi-Aghdam (Nor)

Two recent advances in constitutive modeling and sorption isotherm formulation are presented. First, a new thermodynamic formulation of unsaturated poromechanics with capillarity and adsorption is developed. The Gibbs free energy of pore water is used to calculate the equivalent pore pressure and Biot coefficient. One application is the prediction of autogenous shrinkage, drying shrinkage and swelling of concrete. Good agreement with test results is achieved. Second, the effect of hindered adsorbed layers on the isotherm is calculated by molecular statistics. Hindered adsorbed layers completely filling the nanopores must be what causes significant deviations from the classical BET isotherm for multimolecular adsorption of vapor in porous solids. Since the point of transition from free to hindered adsorption moves into wider nanopores as the pore pressure increases, the area of adsorption layer exposed to vapor gets reduced by an area reduction factor that decreases with increasing adsorbed volume. The area reduction factor does not affect the local rates of direct evaporation and adsorption or condensation of adsorbent molecules, but imposes a constraint on the total area and volume of the free portion of the adsorption layer that is in direct contact with vapor. This leads to a modified isotherm expressed in terms of Jonquière functions. It deviates from the BET isotherm downwards, as observed experimentally, and gives close fits of published isotherms of hardened cement pastes, which are materials with a high content of hindered adsorbed water. Further comparisons are made with the semi-empirical GAB adsorption model.

Modelling Chemo-Mechanics of Reactive Granular Materials

Wednesday, 19th June - 14:15: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 2 (142 Keck (72)) - Oral - Abstract ID: 256

Mr. Parol Viswanath (Indian Institute of Technology Kanpur), Dr. Arghya Das (Indian Institute of Technology Kanpur)

Reactive geomaterials are prone to weathering induced degradation, which results in coupled chemo-mechanical creep. Despite knowing the grain scale mechanism of such process, which includes grain size reduction followed by grain rearrangement, development of constitutive framework is a challenging task. Earlier attempts, especially for the cemented geomaterials, mostly focused on augmenting the hardening law with a chemical state variable. However, such an approach is not sufficient for uncemented reactive granular geomaterials. In the present study, we analyze the problem from three different perspectives: laboratory scale experiment, numerical simulation via discrete element modelling (DEM), and formulation of constitutive framework. The experimental analysis involves dissolution of calcite granules within an oedometer setup under constant vertical stress with a steady flow of acetic acid solution. The results show with dissolution lateral stress initially reduces rapidly and finally returns to a constant value. It is noticed that such stress reduction increases with increasing acid concentration. DEM analysis confirms that the observed experimental response is a result of heterogeneous dissolution within the sample in which not all the reactive grains participate. During dissolution, the sample void ratio steadily increases though grain rearrangement leads to axial compression. Based on the experimental observation and DEM simulation we propose a simple constitutive model to mimic the coupled chemo-mechanical response of granular materials. The model suggests a reduction of stiffness due to the combined effects of grain size reduction and void ratio increase during grain dissolution is the prime ingredient behind lateral stress reduction rather than chemo-mechanically controlled hardening.

Poroelastic Solutions for the Nonlinear Productivity Index of Deformable Reservoir Rocks

Wednesday, 19th June - 14:30: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 2 (142 Keck (72)) - Oral - Abstract ID: 1305

Mr. Wei Zhang (The Pennsylvania State University), Dr. Amin Mehrabian (The Pennsylvania State University)

Productivity index is a measure of rock ability to deliver the pore fluids into a wellbore. The parameter is defined as the ratio of the wellbore influx rate to the wellbore pressure drawdown. The existing solutions fail to reflect on the combined imprint of the reservoir geomechanics and fluid flow on productivity index. Fluid flow in reservoirs alters the stress state of the subsurface which, in turn, results in changes in the pore volume and permeability of the reservoir rock. Consequently, the described coupling between the pore fluid pressure and rock stress will reversely affect the well productivity index.

A nonlinear analytical model accounting for the geomechanical effects on the productivity index of a well within a disk-shaped reservoir is presented. For this purpose, stress disturbances due to a center of dilatation in a semi-infinite elastic domain are integrated to obtain the redistribution of rock stress due to arbitrary distribution of the depleted reservoir pressure. The constitutive relations of poroelasticity are used to find the corresponding redistribution of the reservoir permeability. The obtained stress-dependent permeability function integrates within a set of nonlinear equations for Darcian fluid flow through the reservoir rock. The analytical solutions to these equations indicate that the rock permeability and well productivity index depend on the magnitude of the wellbore pressure drawdown. Higher fluid production rate enhances the permeability reduction throughout the reservoir, particularly, in the near-wellbore region. A sensitivity analysis of the solution results over the problem parameters including the rock poroelastic constants is conducted.

Fracture Propagation in Reactive Porous Media

Wednesday, 19th June - 14:45: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 2 (142 Keck (72)) - Oral - Abstract ID: 674

Dr. Igor Shovkun (The University of Texas at Austin), Prof. Nicolas Espinoza (The University of Texas at Austin)

Fluid-driven open-mode fractures in porous media are the result of multiple physical processes affected by the properties of the fluid, the porous media, the fracture geometry, and fluid injection parameters. This study focuses on the facilitation of fracture propagation by weakening of the rock at the fracture tip by injection of a reactive fluid that causes mineral dissolution. We explore this coupled problem through laboratory experiments and numerical simulation. We performed semicircular bending experiments on limestone samples pre- and post-acidizing. Semicircular bending experiments on acidized carbonate rock samples show that non-planar fractures follow high porosity regions and large pores, and that fracture toughness correlates well with local porosity. The numerical simulation work is based on a finite element method (FEM) formulation combined with the phase-field approach in order to solve equations for fluid flow, poroelasticity, linear elastic fracture mechanics, and reactive transport. The numerical results indicate a distinct behavior of fracture propagation and fracture breakdown pressure when injecting strongly reactive fluids. The results show that injection of acids lowers breakdown pressure and facilitates the evolution of fluid-driven fractures from toughness-dominated to viscosity-dominated propagation. The understanding of fracture propagation patterns and geometry manipulation is critical for safe and effective use of reactive fluids in the subsurface, such as in hydraulic fracturing and carbon geological sequestration applications.

Experimental Study and Modeling of Biogas Formation in Homogeneous Porous Media

Wednesday, 19th June - 15:00: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 2 (142 Keck (72)) - Oral - Abstract ID: 1076

Mr. Daehyun Kim (Arizona State University), Dr. Nariman Mahabadi (Arizona State University), Prof. Jaewon Jang (Hanyang University), Dr. Leon van Paassen (Arizona State University)

Biologically mediated processes are being developed as an alternative approach to traditional ground improvement techniques. Denitrification has been investigated as a potential ground improvement process towards liquefaction hazard mitigation. During denitrification, microorganisms reduce nitrate to dinitrogen gas and facilitate calcium carbonate precipitation as a by-product under adequate environmental conditions. The formation of dinitrogen gas desaturates soils and allows for potential pore pressures dampening during earthquake events. While, precipitation of calcium carbonate can improve the mechanical properties by filling the voids and cementing soil particles. As a result of small changes in gas and mineral phases, the mechanical properties of soils can be significantly affected. Prior research has primarily focused on quantitative analysis of overall residual calcium carbonate mineral and biogenic gas products in lab-scale porous media. However, the distribution of these products at the pore-scale has not been well-investigated. In this research, denitrification is activated in a microfluidic channel simulating a homogeneous pore structure. The denitrification process is monitored by sequential image capture, where changes in the gas and mineral phase are evaluated by image processing. The results from the experimental study are compared to the results of two-dimensional simulation model which involves the relevant biochemical reactions, diffusion, and convection.

CFD-DEM Modeling of Fluid-Driven Fracture Initiation

Wednesday, 19th June - 15:15: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 2 (142 Keck (72)) - Oral - Abstract ID: 677

Mr. Zhuang Sun (The University of Texas at Austin), Prof. Nicolas Espinoza (The University of Texas at Austin), Prof. Matthew Balhoff (The University of Texas at Austin)

Fluid-driven fracture processes are ubiquitous under subsurface conditions and have important scientific and practical impacts. For instance, fluid injection in the subsurface can induce fractures and presents risks to undesired migration of subsurface fluids. This work investigates the mechanisms of opening-mode fracture initiation based on grain-scale fluid-rock interactions. CFD-DEM numerical simulations involve coupling of the discrete element model (DEM) to solve for the mechanics of a solid granular medium and computational fluid dynamics (CFD) to model fluid flow and drag forces. We utilize the open source discrete element code LIGGGHTS and the CFD toolbox OpenFOAM in this work. The resolved CFD-DEM approach models the solid phase using the fictitious domain method and can capture the particle-particle/fluid interactions even at high particle concentrations. The study presents two benchmark problems validated with the corresponding analytical solutions in order to verify the resolved CFD-DEM approach: (1) seepage flow in a single column of spheres and (2) hydraulic fracture propagation in a regular packing of solid particles. Additional results show fracture initiation mechanisms in a random granular packing subjected to constant boundary stresses and a to fluid injection with localized source. Fracture initiation manifests through opening-mode particle displacement. Fracture initiates from the fluid injection point and propagates perpendicularly to the minimum principal stress. Sensitivity analyses help to explain the impact of physical properties and injection parameters including fluid viscosity, grain and cement micromechanical properties, principal stresses and injection velocity.

Prediction of Freezing and Thawing Depths Using Deep Learning Long Short-Term Memory

Wednesday, 19th June - 14:00: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1261

Ms. Aynaz Biniyaz (Michigan Technological University), Dr. Zhen Liu (Zhen Liu)

Accurate predictions of freezing and thawing depths could help set up an accurate time for Seasonal Load Restriction (SLR), a load limitation policy that transportation agencies apply to reduce road damages during spring-thaw seasons. Mechanistic or empirical models have been used for predicting the depths. However, these model-based approaches cannot well utilize the rapidly increasing data. This study attempts to apply the recurrent deep learning to develop a data-based approach for the prediction of freezing and thawing depths. For the purpose, one frequently used algorithm in multivariate time series predictions, i.e., Long Short-Term Memory (LSTM), is employed considering its ability to preserve the historical information and dependencies. An LSTM network was constructed and implemented using the Keras deep learning library in Python for multi-step predictions of freezing and thawing depths with weather information as the input. This new data-driven approach was tested at three road weather information sites in Michigan. Based on training and validations with different model parameters, the optimum LSTM architecture was obtained for the application. Results showed that the proposed method can obtain satisfactory predictions for three-step predictions of the freezing depth and one-step predictions of the thawing depth.

Scattering of In-Plane Shear Waves by Wedge-Shaped Irregularities: Integration of Elastodynamics and Machine Learning

Wednesday, 19th June - 14:15: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 840

Dr. Kami Mohammadi (California Institute of Technology), Mr. Peyman Ayoubi (California Institute of Technology), Dr. Utkarsh Mital (California Institute of Technology), Prof. Domniki Asimaki (California Institute of Technology)

Wedge models have been traditionally used as fundamental blocks of surface and subsurface irregularities due to their similarity with features like hills and mountain, continental margins, and crustal discontinuities. The scattering of seismic waves by elastic wedges has been a topic of interest in seismology and geophysics for many decades. Most of the studies, however, have focused on the incident SH wave due to the simple nature of governing scalar wave equation. The scattered wavefield resulted from an incident SV wave contains more complex phenomena like mode conversion, surface and interface waves of localized energy, and singular behavior near the critical angle. These features make the vector wedge problem analytically intractable as well as limit the generalization of numerical solutions. We here combine our expertise in elastodynamics with machine learning algorithms to develop a trained wave machine for the vector wedge problem, which can provide valuable insight to the understanding and parameterization of topographic amplification of seismic ground motion at significantly less computational cost. First, we use the finite volume method to calculate the surface response of elastic wedge under plane SV waves for a complete range of material properties and incident angles. Recorded time histories are then fed into a set of kernel-based regression models to predict amplification factor along the wedge surface. The trained wave machine has potential applications in seismic hazard analysis to predict the amplification pattern as well as in wave propagation in heterogeneous media to investigate the scattering of elastic waves by more complex features.

Reconstructing Granular Particles from X-Ray Computed Tomography Using the TWS Machine Learning Tool and the Level Set Method

Wednesday, 19th June - 14:30: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 393

Dr. Zhengshou Lai (Sun Yat-sen University), Prof. Qiushi Chen (Clemson University), Prof. Linchong Huang (Sun Yat-sen University)

X-ray computed tomography (CT) has emerged as the most prevalent technique to obtain three-dimension morphological information of granular geomaterials. A key challenge in using the X-ray CT technique is to faithfully reconstruct particle morphology based on the discretized pixel information of CT images. In this work, a novel framework based on the machine learning technique and the level set method is proposed to segment CT images and reconstruct particles of granular geomaterials. Within this framework, a feature-based machine learning technique termed Trainable Weka Segmentation (TWS) is utilized for CT image segmentation, i.e., to classify material phases and to segregate particles in contact. This is a fundamentally different approach in that it predicts segmentation results based on a trained classifier model that implicitly includes image features and regression functions. Subsequently, an edge-based level set method is applied to approach an accurate characterization of the particle shape. The proposed framework is applied to reconstruct three-dimension realistic particle shapes of the Mojave Mars Simulant. Quantitative accuracy analysis shows that the proposed framework exhibits superior performance over the conventional watershed-based method in terms of both the pixel-based classification accuracy and the particle-based segmentation accuracy. Using the reconstructed realistic particles, the particle size distribution is obtained and validated against experiment sieve analysis. Quantitative morphology analysis is also performed, showing promising potentials of the proposed framework in characterizing granular geomaterials.

Support Vector Machine-Based Statistical Evaluation of Slope Stability with Random Field Soil Properties

Wednesday, 19th June - 14:45: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 468

Prof. Linchong Huang (Sun Yat-sen University), Mr. Shuai Huang (Sun Yat-sen University), Dr. Zhengshou Lai (Sun Yat-sen University)

Soil properties are heterogeneous in nature, and the random field-based modeling of soil properties has gained distinct importance in slope stability analysis. To approach a statistical evaluation of slope stability, Monte-Carlo analysis with numerous realizations of soil properties are required, which leads to high computational expenses. This study proposed an efficient slope stability analysis method that incorporates the random field theory and support vector machine. In this method, a stochastic finite element model with soil properties modeled by random field theory is created for slope stability analysis. Particularly, an energy-based criterion is adopted to evaluate the factor of safety of a slope. With a set of sample calculations, the support vector machine is then adopted to approach a mapping between the random field soil properties and the factor of safety. The sample calculations are used as training set to tune the support vector machine. Instead of running the stochastic finite element simulations repeatedly, the trained support vector machine is used to estimate the factor of safety of the slope with other realizations of soil properties. The validity and efficiency of the proposed method are demonstrated with an example problem of a two-dimensional slope.

A Deep-Learning Framework for Inference in Geomechanics

Wednesday, 19th June - 15:00: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 967

Dr. Ehsan Haghighat (Massachusetts Institute of Technology), Prof. Ruben Juanes (Massachusetts Institute of Technology)

The solution of the inverse problem in geomechanical applications (like surface subsidence, slope stability, or fault slip) has traditionally relied on minimization procedures that involve many forward simulations of partial differential equations (PDEs) endowed with pre-defined constitutive relations. These approaches face well-known challenges: nonuniqueness for high-dimensional parameter spaces, and intractable computational complexity given the typical computational cost of forward simulations.

Over the past few years, the widespread availability and increased accuracy of geodetic data, whether through satellite imagery or GPS and positioning sensors, has transformed our ability to monitor ground deformation in space and time. The proliferation of geodetic data has facilitated a number of data-driven approaches towards identification of subsurface geomechanical processes. These approaches, however, are typically problem-specific and require enormous amount of data and significant retraining.

Recently, several studies have started to explore the possibility of merging the merits of both approaches, with the objective of developing physics-informed data-driven models, in which the governing PDEs impose constraints that reduce the demands on the amount of data necessary for model identification. In this study, we employ the framework of physics-informed neural networks to perform inference in geomechanical problems where the data is provided at the domain boundaries. This is particularly attractive for geological applications, where surface data can be available at high resolution, high accuracy, wide coverage and low cost, while subsurface data is often sparse, noisy, low-resolution and expensive.

Stability Analysis of Slopes with Deep Learning

Wednesday, 19th June - 15:15: MS39 - Machine Learning Enabled Geomechanics and Geotechnical Engineering; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1276

Mr. Behnam Azmoon (Michigan Technological University), Dr. Zhen Liu (Michigan Technological University)

As a classic geotechnical issue, slope stability has been traditionally analyzed with multiple limit equilibrium and strength reduction methods. This study is presented to employ the recent advances in deep learning as a new method for the stability analysis of slopes. First, 18000 images for slopes of different geometries were generated with random numbers as the input for deep learning. The slopes in the images were analyzed using a classic limit equilibrium method, i.e., simplified Bishop method. Images were labeled using their safety factors from 0.8 to 1.5. Therefore, nine categories of slope image data, each of which has a safety factor with a precision of one digit after the decimal, were generated. The code of the simplified Bishop method was validated against a commercial program, i.e., Slide2 in Rocscience, for its use. The labeled images were processed and grouped into two sets for training and cross-validation for training the deep neural network. After training, the trained model was used to predict the safety factor of slopes in another independent set of images; and the predictions were compared with safety factors obtained with the simplified Bishop method to measure the accuracy of the trained model. The results showed that it is possible to use deep learning to analyze image data of slopes directly to obtain their safety factors. The trained model successfully predicted the safety factor of most images. This indicates the high potential of applying deep learning to the safety analysis of geosystems like slopes.

Analytical Solutions for Rotations of Material Line and Plane in Triple-Slip, with Coupled Inverse Solutions for BCC Crystals Applied to a Finite-Deformation Experiment on Iron

Wednesday, 19th June - 14:00: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 153

Dr. Kerry Havner (North Carolina State University)

In Havner & Franciosi (2018, *Philos. Mag.* 98:31, 2797-2825, henceforth HF) general double-slip solutions of Havner (1979, *J. Mech. Phys. Solids* 27, 415-429; also see Havner, 1992, *Finite Plastic Deformation of Crystalline Solids*, Chap. 2) were applied to four experimental cases of measured finite deformations of bcc iron crystals from Franciosi et al. (2015, *Int. J. Plasticity*65, 226-249), two each in axial tension and axial compression. Rotations of both the load axis (material line or plane normal) and another edge line or plane normal were analyzed in HF for each case and compared with electron-back-scattering-diffraction rotation measurements. The two slips (either collinear or conjugate systems) were determined for each experiment to give the best match with rotation data. The results were good to very good in three cases; but in experiment C12 from Franciosi et al. (2015), neither slip-combination was fully satisfactory (HF, Sect. 6); and the possibility of significant slip on three systems was mentioned (HF, p. 2820). Here *triple*-slip analytical solutions for material line and plane, applicable to any crystal class, are derived. Coupled inverse analytical solutions considering both {110} and {112} slip-planes in bcc crystals are developed, to make use of experimental end-point data for both plane and line. These are applied to experiment C12 on iron to determine the respective slips and areal and length changes in the finite deformation. Such analyses can assist in assessment of relative hardening rates of the various slip systems.

Ultra High Thermal Expansion Metamaterials

Wednesday, 19th June - 14:15: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 961

Dr. Semih Taniker (California Institute of Technology (Caltech)), Dr. Paolo Celli (California Institute of Technology (Caltech)), Prof. Chiara Daraio (California Institute of Technology (Caltech))

In this work, we illustrate the possibility of creating ultra-high thermal expansion leveraging architected combinations of materials with different coefficients of thermal expansion (CTE). The low-CTE portion of the structure acts as a constraint for the high-CTE one; the latter is designed to display a displacement-amplification mechanism, that amplifies the low thermally-induced strains. In response to temperature increases of about 100 C, the size of our basic building block can be tripled along a single direction. We stack our building blocks to form lattices that can drastically change shape in-plane, or that can morph from two-dimensional into three-dimensional objects. While our proof-of-concept experiments are done with combinations of polymers and metals, we will discuss the possibility of extending this thermal shape-morphing paradigm to combinations of simultaneously-printed metals.

Topology Optimization of Lattices Considering Topology-Dependent Bonding

Wednesday, 19th June - 14:30: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 996

Mr. Hak Yong Lee (Johns Hopkins University), Prof. James Guest (Johns Hopkins University)

Micro-lattices have gained significant attention as a promising class of lightweight, multi-functional materials. This work will focus on lattices fabricated by 3D-weaving which offer a suite of unique and useful mechanical and thermal properties [1] that can be tailored through optimization of the lattice architecture (topology) [2]. As architecture is directly related to the insertion pattern of wires in the weaving loom, one has the ability to realize tailored pore structures within the lattice provided fundamental 3D-weaving manufacturing constraints are respected. This work will present topology optimization approaches for designing the architecture of 3D-woven lattices to achieve desired property sets [2-3]. A key advancement is the development of a novel bonding element that mimics the resulting bond structure when 3D woven materials are bonded by brazing. Past work has shown that this brazing process is remarkably conformal and necessary to achieve load-bearing in the lattice, but is also topology-dependent. The new bonding element introduces the bonding material with its own set of manufacturing constraints. The approach is demonstrated to design lattices with maximized elastic moduli and structures with tailored dynamic properties.

[1] Zhang et al. (2015). Fabrication and mechanical characterization of 3D woven Cu lattice materials. *Materials and Design* 85:743-751.

[2] Ha et al. (*press*).Topology Optimization of 3D Woven Materials using a Ground Structure Design Variable Representation. *ASME Journal of Mechanical Design*.

[3] Guest J.K. (2015). Optimizing Discrete Object Layouts in Structures and Materials: A Projection-Based Topology Optimization Approach. *Computer Methods in Applied Mechanics and Engineering* 283:330-351.

Omnidirectional Flexural Invisibility of Multiple Interacting Voids

Wednesday, 19th June - 14:45: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1209

Dr. Diego Misseroni (University of Trento), Prof. Davide Bigoni (University of Trento), Prof. Alexander Movchan (University of Liverpool)

The design of elastic metamaterials to shield objects from flexural vibrations, so to achieve their invisibility, is a thoroughly analyzed, but still unchallenged, mechanical problem. The 'cloaking transformation' concept, originally developed in electromagnetism and optics, is not directly applicable to elastic waves, which display a complex vectorial nature. As a consequence, all examples of elastic cloaking presented so far involve extremely complex design techniques with thick coating skins, often work only for problems of unidirectional propagation, confined to very narrow ranges of frequency, and excluding interaction between several objects to be made invisible. Here, a new method based on the concept of reinforcement, achieved via elastic stiffening and mass redistribution, is introduced to cloak multiple voids in an elastic plate. This simple technique produces invisibility of the voids to flexural waves within an extremely broad range of frequencies and thus surpassing in many aspects all existing cloaking techniques. The effectiveness of the proposed approach is demonstrated in an indisputable way both experimentally and numerically. The proposed design principle is applicable in mechanical problems ranging from the micro-scale to the scale of civil engineering. Just to provide an example of application, our results show how to design a perforated load-bearing building wall, vibrating during an earthquake exactly as the same wall, but unperforated, so that the voids will not decrease the mechanical performance of the wall, a new and fundamental finding for seismic protection.

Topology Optimization of Light Stiff Lattice Architectures with Length Scale and Complexity Control

Wednesday, 19th June - 15:00: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1237

Mr. Seyed Ardalan Nejat (University of Massachusetts Dartmouth), Dr. Mazdak Tootkaboni (University of Massachusetts Dartmouth), Dr. Alireza Asadpoure (University of Massachusetts Dartmouth)

We formulate design of lattice-like materials in the form of a discrete topology optimization problem, where free form manipulation of lattice micro-architecture is performed through the application of ground structure approach. The goal is to achieve lightweight architected materials with different combinations of relative axial and shear stiffness. The complexity and length scale of the optimized solution obtained using the ground structure approach depend on the initial lattice. A denser ground structure with more elements will typically result in lighter materials at the cost of more complex topologies with limited control on the size of the smallest elements in the final design. The emerging design could in fact possess hair-like elements with minimal effect on the stiffness which may not be practical from manufacturability viewpoint. This is particularly not desirable for situations where a much simpler material micro-architecture can be obtained with a slight increase in the weight. In this work, we propose approaches that not only allow for constraining the size of smallest elements in the optimized topology but also permit controlling the complexity of the final material micro-architecture. The final discrete topologies therefore require minimal post processing for manufacturability without significantly sacrificing their weight. We illustrate the efficiency of the proposed approaches by identifying micro-lattices that are significantly more efficient than well-known isotropic lattices and meet manufacturability constraints.

Periodic Cellular Materials with Temperature- and Stress-induced Phase Transformations

Wednesday, 19th June - 15:15: MS44 - Architected Materials: Advances in Modeling, Design, Fabrication, Characterization, and Applications; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1366

Ms. Yunlan Zhang (Purdue University), Prof. Mirian Velay-Lizancos (Purdue University), Mrs. Kristiaan Hector (Purdue University), Prof. David Restrepo (Purdue University), Dr. Nilesh Mankame (General Motors Research and Development), Prof. Pablo Zavattieri (Purdue Unviersity)

Phase transforming cellular materials (PXCMs) are architectured materials whose unit cells have multiple stable configurations. If designed correctly, these materials can absorb energy by allowing non-equlibrium release of stored energy through controlled elastic limit point transitions as the cells transform between different stable configurations. Most previous works on architecture materials with elastic limit point transitions have focused on material behavior under mechanical loading. The forward transformation in these materials always happens under an applied mechanical load, while the reverse transformation can be driven either by elastic energy stored in the material during the forward transformation (metastable PXCMs) or by an external force acting in the direction opposite to that of the force applied during the forward transformation. In this talk, we present a new PXCM design paradigm in which the forward transformation still happens under an external applied force but the reverse transformation is driven by a thermal stimulus. A family of bi-material PXCMs that exhibit this behavior will be discussed. We use FE simulations and experiments on 3D printed samples to explore the underlying mechanics.

Instadam: A Semi-Automated Tool for Rapid Pixel-Wise Annotation of Structural Cracks and Damage

Wednesday, 19th June - 16:00: MS87+92 - Advanced Deep Learning Based SHM with/without UAVs, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 213

Mr. Vedhus Hoskere (University of Illinois at Urbana-Champaign), Prof. Billie F. Spencer (University of Illinois at Urbana Champaign)

Deep learning methods have become very popular for a wide variety of computer vision applications over the past decade, including for the purpose of damage detection applications. The research on developing better models is progressing at a rapid pace in the computer vision community and thus most models developed specifically for damage identification can quickly become obsolete in a short span of 6-8 months. However, one thing that remains constant is the need for vast quantities of high-quality labeled data. As the ability of models improve, the complexity of data that can be handled also increases. Semantic segmentation algorithms have been successful in delineating the pixel-wise location of damage in images of structures. However, generating the ground truth for such images remains a tedious process. In this work, InstaDam - a semi-automated tool for fast pixel-wise annotation of damage is presented. InstaDam allows the user to choose from a variety of filters and image processing techniques to generate masks that speed the annotation process. The tool is developed in an object oriented framework and has cross-platform compatibility. The tool is evaluated for ease, speed and accuracy of damage annotation compared to existing general purpose semantic segmentation software.

Multiple Concrete Damage Detection using Mask R-CNN

Wednesday, 19th June - 16:15: MS87+92 - Advanced Deep Learning Based SHM with/without UAVs, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 241

Mr. Byunghyun Kim (University of Seoul), Prof. Soojin Cho (University of Seoul)

As the urbanization history of highly-developed countries is getting longer, the number of old structures is increasing rapidly. Although the number of aged structures is surging, damage detection of many structures still depends on visual inspection which potentially leads to subjective inspection result. Therefore, it is required develop a technology that can simultaneously detect various types of concrete damage to replace the subjective visual inspection with objective computer vision-based inspection. In this study, a novel concrete multi-damage detection technique is developed using a object detection deep learning model, Mask R-CNN. Mask R-CNN consists of three steps to detect location of object and segment shape of object. In the first step of Mask R-CNN, region proposal network detects location of target objects in the image. In the second step, classification layer of Mask R-CNN classifies the objects detected in the first step. In the third step, mask branch, a fully convolutional network, segments the shape of object and displays it in pixel units. Images of cracks, rebar exposure spalling and efflorescence are collected from the Internet and taken from real structures for the training data of Mask R-CNN. Performance of the trained Mask R-CNN is tested on the images taken from real structures. The trained Mask R-CNN successfully detected cracks, rebar exposure spalling and efflorescence on the surfaces of real concrete structures.

Using Deep Convolutional Neural Networks for Autonomous Detection of Bridge Deck Defects

Wednesday, 19th June - 16:30: MS87+92 - Advanced Deep Learning Based SHM with/without UAVs, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 176

Dr. Sattar Dorafshan (National Research Council (Turner-Fairbank Highway Research Center)), Ms. Sara Mohamadi (George Mason University), Dr. Hoda Azari (Federal Highway Administration (Turner-Fairbank Highway Research Center)), Dr. David Lattanzi (George Mason University)

Abstract: For several years, non-destructive evaluation (NDE) data of the nation's bridge decks have been collected through the Federal Highway Administration's Long-Term Bridge Performance (LTBP) program. Conventional use of NDE data, such as ground penetration radar (GPR), impact echo (IE), electrical resistivity (RE), and ultrasonic testing (UT), often requires an expert opinion for interpretation, which limits the use of these techniques in practice. Deep convolutional neural networks (DCNNs) have shown promising results for attaining human-like accuracy in the detection of surface structural defects in images. This study investigates the feasibility of using DCNNs to autonomously detect subsurface defects from NDE data, using LTBP data that has been categorized and annotated by NDE experts to generate training datasets. One and two dimensional DCNNs were tuned and trained on these datasets, and then were used to localize defects in a separate holdout testing dataset of LTBP NDE data. The accuracy of the network was then determined by comparing its results to the expert's decision on the testing dataset. This study presents the results of this effort, along with challenges and potentials of DCNNs for defect detection from NDE data. The creation and assessment of this annotated training dataset is an important first step towards automation in NDE applications for bridge deck evaluation and can be used for future benchmarking of the established deep learning architectures or for developing new ones.

Real-Time Damage Segmentation Using Advanced Deep Learning

Wednesday, 19th June - 16:45: MS87+92 - Advanced Deep Learning Based SHM with/without UAVs, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 758

Prof. Youngjin Cha (University of Manitoba), Mr. Wooram Choi (University of Manitoba)

The topic of deep learning-based damage detection is very popular in recent years. Most of the published works are focused on damage detection using bounding boxes within input images. Some of pixel level damage detection was also proposed. However, the method can detect damage only within monotonous background such as surface of pavements and concrete members. Therefore, this research develops a pixel level damage detection method that can consider various realistic backgrounds with real time processing. In order to achieve this, a new convolutional neural network is developed. The network was optimized to detect concrete crack by carefully arranging existing separable convolutions and advanced operators. The developed method shows quite accurate results with F1 score of 0.80, and the processing speed of the input image is 46 times faster than that of existing advanced network.

Autonomous UAV for SHM with Obstacle Avoidance

Wednesday, 19th June - 17:00: MS87+92 - Advanced Deep Learning Based SHM with/without UAVs, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 786

Mr. Dong Ho Kang (University of Manitoba), Prof. Youngjin Cha (University of Manitoba)

To date, many vision-based damage detection methods have been developed, and some of them used advanced deep learning methods with high performance to overcome image processing algorithms used for vision based methods. However, these approaches require many vision sensors to monitor large scale civil infrastructures. To overcome this drawback, the author developed autonomous UAV for structural health monitoring to expend spatial range of the monitoring using single camera mounted on the UAV. The autonomous UAV can navigate GPS-denied areas such as beneath a bridge deck etc. However, there is no research that addresses the issue of unexpected obstacles within the trajectory of the autonomous UAV. Therefore, this research proposes an autonomous navigation method of UAV for SHM that can avoid obstacles autonomously. The method is developed by using YOLO 3 which is one of the advanced deep learning for obstacle detection and avoidance.

Markov Chain Based Multiple Importance Sampling for Rare Failure Event Estimation

Wednesday, 19th June - 17:15: MS87+92 - Advanced Deep Learning Based SHM with/without UAVs, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 149

Dr. Jiaxin Zhang (Oak Ridge National Laboratory), Prof. Antwan Clark (Johns Hopkins University)

Rare failure events are events that happen infrequently with the potential to immobilize societal and economic functions due to their widespread disastrous impact. From a structural engineering standpoint, these failures can occur due to buckling instabilities, hurricanes, earthquakes, or a combination thereof. Hence, estimating the likelihood of these types of failures is an important topic within the structural reliability community. However, the challenge is devising algorithms that are accurate, efficient, and contain minimum computational overhead while considering multimodal and nonlinear failure domains. In this work, we introduce a Markov Chain based Multiple Importance Sampling (MC-MIS) methodology that estimates rare likelihood failure events with multiple and complex limit states. The novelty of this approach is that various multiple importance sampling (MIS) strategies, such as the standard MIS (*s*-MIS) and the deterministic mixture MIS (DM-MIS) schemas, are coupled with the cross-entropy (CE) method to automatically determine the best strategy for optimum performance. Therefore, only a few samples from the resulting probability density functions (PDFs) of each importance sampling (IS) method are needed to robustly identify each disjoint region of the failure domain. Next, an in-depth comparative assessment is performed against several popularly-cited benchmark problems which demonstrate the robustness of our proposed technique over multidimensional, nonlinear, and intermittent domains. The results of this work can help structural engineers and regional planners understand and predict what structures within a defined area are the most reliable, which ones are not, and the economic impacts of the entire area in terms of repairs and resources.

Uncertainty Quantification in Molecular Dynamics Simulations Using a Stochastic Reduced Order Basis

Wednesday, 19th June - 16:00: MS84 - Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 107

Dr. Haoran Wang (Duke University), Prof. Johann Guilleminot (Duke University), Prof. Christian Soize (Université Paris-Est Marne-la-Vall´ee)

Molecular Dynamics (MD) simulations are widely used in materials, mechanics and multiscale studies. In recent years, there has been a growing interest in the quantification and propagation of parametric uncertainties in MD simulations. The case of model-form uncertainties, generated by the a priori selection of functional forms for interatomic potentials, has received very little attention to date. In this talk, we present a probabilistic framework to assess, model and propagate model-form uncertainties in MD simulations. The approach is based on the proper randomization of a reduced-order basis, using a random matrix approach. The relevance of the framework is demonstrated by characterizing various types of modeling errors associated with MD simulations on a graphene sheet.

Performance Evaluation of Stochastic Finite Elements in Linear and Nonlinear Solid Mechanics

Wednesday, 19th June - 16:15: MS84 - Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 522

Mr. Nan Feng (University of Notre Dame), Mr. Guodong Zhang (University of Notre Dame), Prof. Kapil Khandelwal (University of Notre)

Recent years have seen a significant progress in the computational stochastic mechanics. Due to the inherent randomness in various systems, e.g. randomness in material properties, loading and boundary conditions, etc., deterministic approaches may not be able to satisfactorily characterize the system response. In such cases, stochastic approaches that can simulate various uncertainties has to be employed. In the past, a number of stochastic methods have been developed for uncertainty quantification, among which the perturbation methods, intrusive and non-intrusive polynomial chaos expansion (PCE) methods and stochastic collocation (SC) methods have received considerable attention. However, in solid mechanics, most of the applications of these methods are confined to relatively simple problems, and the applicability and performance of these methods to complex nonlinear mechanics problems is not clear. To this end, this study carried out a detailed investigation on the performance evaluation of different stochastic analysis methods to linear and nonlinear solid mechanics problems including linear elasticity, finite strain hyperelasticity, elasto-plasticity and nonlocal coupled damage-elasto-plasticity. Specifically, the convergence properties of various methods are compared to the reference solutions obtained via Monte Carlo method. As revealed from numerical studies, the non-intrusive PCE and SC methods are superior in terms of accuracy among other methods, while having comparable computational expense.

Uncovering Exploitable Insight from Microstructures Using Machine Learning Algorithms

Wednesday, 19th June - 16:30: MS84 - Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 534

Dr. Audrey Olivier (Johns Hopkins University), Prof. Michael Shields (Johns Hopkins University), Prof. Lori Graham-Brady (Johns Hopkins University)

Design of advanced materials finds applications in many industries; however, it can take many years for new materials to go from design to market. In an effort to accelerate the pace of discovery and deployment of new materials, the Materials Genome Initiative has embraced the idea of data-assisted materials design. The idea is to make use of data gathered through experiments or high-fidelity simulations in conjunction with machine learning techniques to obtain a better understanding of structure-property-performance linkages. This could find applications with respect to both forward modeling (property prediction) and inverse modeling (materials discovery). Utilization of machine learning algorithms in the fields of materials science presents its own challenges, for instance the need of learning schemes that can learn from small amounts of data and accurately quantify uncertainties. An interesting area of study regards characterization and reconstruction of materials microstructures. In this work, we show that deep learning algorithms such as deep convolutional neural networks can be leveraged to characterize microstructures from image data. Making use of the idea of transfer learning, i.e., transferring knowledge from a pre-trained neural network to the task of interest, enables to circumvent the need for large data sets. Such a pre-trained network can then be used to uncover features from the data that help characterize the microstructure, and build efficient linkages between the microstructures and homogenized properties such as nonlinear stress/strain laws of the representative element.

Computational Generation and Stochastic Upscaling of Concrete Microstructure

Wednesday, 19th June - 16:45: MS84 - Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 951

Mr. Vasav Dubey (Texas A&M University, College Station), Ms. Christa E. Torrence (Texas A&M University, College Station), Prof. Yang Lu (Boise State University), Dr. Edward Garboczi (National Institute of Standards and Technology), Dr. Zachary Grasley (Texas A&M University, College Station), Dr. Arash Noshadravan (Texas A&M University, College Station)

The mechanical behavior of concrete is strongly influenced by the characteristics of its highly heterogeneous microstructure. The mesoscale structure of concrete can be described as a composite with aggregates (inclusions) embedded in mortar (matrix). There is inherent randomness in composition and mechanical properties of these constituents, which in turn causes spatial heterogeneity in the local material behavior. The randomness in the morphological features includes size, shape, local volume fraction, spatial distribution of aggregates, and mechanical properties of different phases. In order to improve the microstructural representation, a spherical harmonic expansion is used to recreate the irregular geometry of real aggregates. A custom meshing framework is also utilized to produce periodic finite element model of these microstructures. In this research, we use a nonparametric stochastic model describing the mesoscale mechanical behavior of concrete microstructure, which relies on the theory of micromechanics, random matrix theory and maximum entropy principle. Sensitivity analysis is conducted to determine the link between the uncertainty of model output and the uncertainty of the model input parameter. The proposed model provides a stochastic mesoscale material description exhibiting random fluctuations that are connected to the subscale microstructural randomness. We calibrated the model using a calibration process based on the numerical homogenization of digitally generated random microstructures. This upscaling model provides a computationally efficient material description that can be used for macroscale simulation taking into account local fluctuations in material properties that can influence the mechanical behavior of structures.

Predicting the Residual Velocities for Continuum Plain-Weave Composite Plate Model Under Projectile Impact

Wednesday, 19th June - 17:00: MS84 - Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 985

Mr. Anindya Bhaduri (Johns Hopkins University), Prof. Lori Graham-Brady (Joh), Prof. Michael Shields (Johns Hopkins University), Mr. Christopher Meyer (University of Delaware), Dr. Bazle Haque (University of Delaware), Prof. John Gillespie (University of Delaware)

A plain-weave S2/SC15 continuum composite plate model under impact by a steel projectile is considered. The strength parameters of the composite plate, namely, the longitudinal strength and the punch shear strength, are considered to be homogeneous throughout the plate but considered to vary in an uniformly random manner within a specified range. The impact velocity of the projectile is also assumed to be uniformly random within a specific range. The residual velocity of the projectile after impact is the quantity of interest. The challenge here is to build a response surface of the residual velocity with respect to the input random parameters efficiently with as few model runs as possible. An accurate estimation of the response surface will not only help in predicting residual velocities for new input parameters but also helps in better understanding the sensitivities of the input parameters with respect to the residual velocity. On top of that, V_0- V_{100}curves can also be efficiently developed for the composite plate model from the generated response surface.

Multi-Model Bayesian Material Model Calibration for Probabilistic Thermo-Viscoplastic Structural Analysis

Wednesday, 19th June - 17:15: MS84 - Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 1033

Mr. Aakash Bangalore Satish (Johns Hopkins University), Prof. Michael Shields (Johns Hopkins University)

Structure-scale response is typically estimated from macro-scale finite elements where the material behavior is represented in terms of models calibrated to replicate material response from mechanical experiments. Predictions of structural safety therefore depend on the uncertainties in the form and parameters of the material model at the element level. We present an approach where Bayesian material model calibration is performed accounting for discrepancy between the model predictions and the experimental data. An ensemble of several candidate calibrated models are probabilistically integrated to obtain better estimates of structural safety. Material models employing damage-based plasticity formulations along with those expressed as explicit analytical expressions (e.g. Johnson-Cook) are considered in this study. Bayesian model calibration from experimental stress-strain data under differing triaxiality conditions and temperatures is assisted by a Gaussian process regression interpolation of the yield surface (for plasticity models) and of the model parameters (for explicit models). The approach developed in the study is applied to analyze an aluminum structural component subjected to mechanical and fire loads. A thermomechanical analysis of the component is performed using finite elements to evaluate the performance of this component and its sensitivity to material model form and parameter uncertainties.

Impedance-Based Spatial Damage Sensing in Concrete Materials and Structural Members

Wednesday, 19th June - 16:00: MS95 - Nondestructive Evaluation and Sensing Technologies for Characterization of Concrete Materials (Kerckhoff 119 (174)) - Oral - Abstract ID: 1227

Dr. Mo Li (University of California, Irvine)

Concrete is susceptible to cracking and deterioration under service conditions and damage under extreme hazard events. Conventional structural health monitoring approaches mainly depend on point-based sensors that provide local measurements and cannot spatially locate or quantify damage such as cracking. To address this challenge, this work focuses on a new direct, spatial sensing approach based on multifunctional cementitious materials that are encoded with damage tolerance and damage self-sensing capacity. The tailored electromechanical behaviour of the material enables strain and damage sensing during elastic and post-cracking stages. Through advances in tomography methods, spatial mapping offering a visual depiction and quantification of damage in concrete members is achieved through boundary electrical probing.

Thermal Modulation of Nonlinear Coda Wave Using Ambient Temperature Change for Concrete Damage Evaluation

Wednesday, 19th June - 16:15: MS95 - Nondestructive Evaluation and Sensing Technologies for Characterization of Concrete Materials (Kerckhoff 119 (174)) - Oral - Abstract ID: 731

Mr. Hongbin Sun (The University of Nebraska-Lincoln), Prof. Jinying Zhu (The University of Nebraska-Lincoln)

Nonlinear ultrasonic methods such as nonlinear resonance acoustic spectroscopy (NRAS) and nonlinear wave modulation spectroscopy (NWMS) show higher sensitivity to microcracking damage in concrete than the conventional linear ultrasonic testing methods. However, the NRAS method is only applicable to small specimens, and the NRAS method needs complicate test setup and expensive equipment. In this work a modified NWMS method is proposed using temperature changes as the wave modulation instead of low frequency pump or hammer impact, which is denoted as thermal modulation. Coda wave is used to examine the relative velocity change of the high frequency elastic wave instead of calculating the sideband energy wave. Ambient temperature change modulates the ultrasonic waves and excites the nonlinear behavior of concrete with microcracks. Coda wave interferometry is used to analyze the relative velocity change with temperature that is defined as thermal-modulation coefficient. Experiments were performed on four concrete prisms made from the same batch while three have different thermal damage levels and the other one was used as the control sample. Results indicate that the concrete samples with higher damage level demonstrate higher relative velocity change to temperature variation. Nonlinear parameter was also tested using the NRAS method on the four prisms. The thermal-modulation coefficients agree well with the measured nonlinear parameters α. Therefore, the thermal-modulation coefficient can be used as a nonlinear parameter for concrete damage characterization. The proposed method has potential applications to in-situ evaluation and health monitoring of concrete structure.

NDT of 3D Printed Concrete Interlayer Bonds

Wednesday, 19th June - 16:30: MS95 - Nondestructive Evaluation and Sensing Technologies for Characterization of Concrete Materials (Kerckhoff 119 (174)) - Oral - Abstract ID: 422

Ms. Michelle Helsel (University of Illinois at Urbana-Champaign), Dr. John Popovics (University of Illinois at Urbana-Champaign), Dr. Peter Stynoski (U.S. Army Engineer Research and Development Center), Mr. Eric Kreiger (U.S. Army Engineer Research and Development Center)

3D printing in the construction industry involves extruding layer upon layer of concrete to create a desired structure. Layer interfaces can form cold joints, or bond weaknesses, that could compromise structural integrity. Furthermore, the unique geometric constraints posed in 3D printed concrete render traditional inspection methods to characterize material quality useless. This research examines nondestructive testing (NDT) techniques that characterize the interlayer bond quality of 3D printed concrete with the aim of determining overall condition of 3D printed wall structures. An experimental study applied four NDT methods (multi-array ultrasonics, ultrasonic pulse velocity, vibration resonance, and x-ray radiography) to idealized, layered concrete specimens. The bond quality was qualitatively estimated based on the NDT results and confirmed with mechanical testing. Two of those NDT methods were adapted and applied to full-scale 3D printed concrete walls. The combined results from multi-array ultrasonics and ultrasonic pulse velocity measurements successfully identified existing and potential interlayer delaminations.

Determining Dynamic Elastic Modulus and Poisson's Ratio of Rectangular Timoshenko Beams

Wednesday, 19th June - 16:45: MS95 - Nondestructive Evaluation and Sensing Technologies for Characterization of Concrete Materials (Kerckhoff 119 (174)) - Oral - Abstract ID: 1396

Thursday, 20th June - 14:00: MS107 - Advances in Computational Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 1396

Prof. Roger Chen (West Virginia University), Mr. Guadalupe Leon (West Virginia University)

\textbf{Determining Dynamic Elastic Modulus and Poisson's Ratio of Rectangular Timoshenko Beams} Hung-Liang (Roger) Chen~and Guadalupe Leon West Virginia University, Morgantown, WV 26506 In this study, direct determination of the dynamic elastic modulus and the Poisson's ratio using a simple vibration testing is presented. First, the exact solution of the Timoshenko beam vibration frequency equation under free-free boundary condition is determined with an accurate shear shape factor. The exact solution is compared with a 3-D finite element calculation using ABAQUS program, and the difference between the exact solution and the 3-D FEM are within 0.05\% for both the transverse and torsional modes. Based on the exact solution, a relationship between the resonance frequencies and the Poisson's ratio was proposed which can directly determine the elastic modulus and the Poisson's ratio simultaneously, without the need for iteration, unlike the equations provided by ASTM C215. Using this relationship, the frequency ratio between the first bending mode and the first torsional mode for different combination of specimen dimensions can be determined directly.~ Rectangular concrete beam specimens produced using three different mix designs were tested, and the transverse and torsional frequencies of these beams were measured.~ Results show that using the equations proposed in this study, the Young's modulus and Poisson's ratio of the concrete beams can be determined more directly than those obtained from the ASTM C215 and with better accuracy.~~\\

Dynamics-Based Testing to Localize Macro Cracking Due to Alkali-Silica Reaction in Concrete

Wednesday, 19th June - 17:00: MS95 - Nondestructive Evaluation and Sensing Technologies for Characterization of Concrete Materials (Kerckhoff 119 (174)) - Oral - Abstract ID: 891

Ms. Sarah Miele (Vanderbilt University), Dr. Pranav Karve (Vanderbilt University), Prof. Sankaran Mahadevan (Vanderbilt University), Dr. Vivek Agarwal (Idaho National Laboratory), Dr. Eric Giannini (R. J. Lee Group Inc.), Prof. Jinying Zhu (The University of Nebraska-Lincoln)

Alkali-silica reaction (ASR) is a concerning degradation mechanism for aging concrete infrastructure. Reliable methodologies to detect, localize, and/or track the growth of ASR-induced diffused macro/micro-cracking are vital to ensure satisfactory performance of concrete structures over the intended lifespan. In this work, we investigate the suitability of a novel vibro-acoustic-modulation-based (VAM-based) method for ASR damage diagnosis. In a VAM test, the structural component is excited using two frequencies. When the structural component is cracked, the geometric nonlinearity at the crack results in frequency modulation. In the neighborhood of the damage, the frequency modulation appears as sidebands around the higher frequency in the linear spectrum of the measured response. A map of the magnitude of sidebands can be used to detect and localize the damage. Previously, VAM has successfully been used for detection and localization of near-surface delamination in thin composite plates. We perform numerical and laboratory experiments to investigate VAM-based damage diagnosis in thick concrete components. We conduct laboratory testing on reinforced and unreinforced concrete slabs and blocks containing non-reactive aggregate and blocks with reactive aggregate. We propose a damage index based on statistics of sideband-magnitudes at different sensor locations to identify damaged areas. We also demonstrate Bayesian information fusion for VAM test data to assimilate the information gained from VAM tests performed using different test parameters (probe frequencies, amplitudes, etc.). Our experiments show that VAM-based testing with optimized test parameters and suitable sensor density can potentially be used to detect and localize cracks in thick concrete structures.

Rapid Global Damage Assessment of Concrete Samples by Air-Coupled Non-Linear Signal Impact Resonance Acoustic Spectroscopy

Wednesday, 19th June - 17:15: MS95 - Nondestructive Evaluation and Sensing Technologies for Characterization of Concrete Materials (Kerckhoff 119 (174)) - Oral - Abstract ID: 910

Dr. Shukui Liu (School of Mechanics and Civil Engineering, China University of Mining and Technology), Prof. Hongwen Jing (State Key Laboratory for GeoMechanics and Deep Underground Engineering,China University of Mining and Technology), Prof. Jinying Zhu (The University of Nebraska-Lincoln), Dr. Qi-ang Wang (School of Mechanics and Civil Engineering, China University of Mining and Technology)

Non-linear impact resonance methods have shown great potential for the micro-damage identification in inhomogeneous materials such as concrete. However, the application of these methods for cement-based materials and structures is severely limited by the physical coupling between sensors and concrete surface, which reduces testing efficiency. In this study, the air-coupled sensing technique is proposed as a solution to improve the efficiency of non-linear impact resonance testing. Specially, air-coupled non-linear signal impact resonance acoustic spectroscopy, is proposed and used to characterize the global damage in concrete samples in this study.

Concrete damage in this study was induced by step compressional loading, and instead of contact sensor, air-coupled non-contact sensor was used for signal acquisition. Spectral distribution of signals obtained from both contact and non-contact sensors, were compared at the very beginning. Specially, the non-classical non-linear parameter, which is nonlinear resonance shift in this study, was extracted using only one signal through a short-time Fourier transform based approach, and then the nonlinear resonance frequency shift was used as an indicator to track the damage process of the concrete samples. For comparison purposes, two linear damage indicators, compressive wave velocity and linear resonance frequency, were measured parallel to the nonlinear damage indicator during the tests. The results from the experimental tests show that air-coupled sensor could catch the leaky resonant waves effectively and the nonlinear damage indicator shows high sensitivity to internal global damage in concrete samples.

Semi-Active Control of Spar Floating Offshore Wind Turbines Subjected to Wind-Wave and Current Loading

Wednesday, 19th June - 16:00: MS62 - Complex Dynamics and Vibration Control of Structures under Single/Multiple Hazards (Firestone 384 (76)) - Oral - Abstract ID: 443

Mr. Vahid Jahangiri (Louisiana State University), Dr. Chao Sun (Louisiana State University)

Offshore floating wind turbines subjected to combined wind, wave and current loading experience excessive vibrations which will increase the fatigue loading on the superstructure and mooring cables. In the present paper, dual semi-active tuned mass dampers with tunable damping ratio and natural frequency is introduced to mitigate the bi-directional response of the floating wind turbine. A new coupled three dimensional analytical model of the spar floating wind turbine is established using Euler-Lagrangian equation. The aerodynamic loading is computed using Blade Element Momentum method and the wave loading is calculated using Morison's equation. The wave-current interactions are considered in mooring model using an open source software OpenMOOR. The NREL 5MW OC3-Hywind spar-type wind turbine is used to examine the performance of the dual linear semi-active tuned mass dampers in reducing the vibrations of the spar floating wind turbine. Dual linear passive tuned mass dampers are utilized for comparison. With damage presence in the mooring cables and the tower, the natural frequency of the floating wind turbine changes and the passive tuned mass damper with fixed parameters becomes off-tuned and loses its effectiveness. In comparison, the semi-active tuned mass damper retuned in real time can provide consistently effective reduction of the vibrations of the floating wind turbine. Therefore, the dual semi-active tuned mass dampers outperform their linear passive counterparts and are more preferable in presence of system variations and structural damages.

Comparative Real-Time Hybrid Simulation Study of Controllable Damping Strategies for a Base-Isolated Benchmark Structure

Wednesday, 19th June - 16:15: MS62 - Complex Dynamics and Vibration Control of Structures under Single/Multiple Hazards (Firestone 384 (76)) - Oral - Abstract ID: 980

Ms. Qian Fang (University of Southern California), Prof. Erik Johnson (University of Southern California), Prof. Richard Christenson (University of Connecticut), Prof. Hideo Fujitani (Kobe University), Prof. Yoichi Mukai (Kobe University), Prof. Mai Ito (Kobe University)

Experimental testing is necessary to verify innovative concepts in structural control. Experiments in civil engineering usually involve large-scale structures, which are sometimes difficult to conduct due to cost, convenience and sustainability. Thus, real-time hybrid simulation (RTHS) is now an effective experimental method in which physical experiments of large-scale structural components are subjected to real-time loading while the remaining structure is simulated numerically.

This paper presents comparative studies of the performance of several semiactive control strategies used in a RTHS to mitigate the responses of a well-defined numerically-simulated base-isolated benchmark building with one experimentally tested magnetorheological (MR) damper. The benchmark structure posed herein is based on a Kobe University base-isolated three-story superstructure with an MR damper. In particular, the performance of two algorithms for commanding controllable damping devices is investigated: the clipped LQR (CLQR) and the first two authors' proposed optimal clipped linear control (OCLC), subjected to three scaled historical earthquake excitations: 1940 El Centro, 1995 Kobe and 1968 Hachinohe. Two structural models are used for the control design, a reduced-order single-degree-of-freedom (SDOF) model and the full four-degree-of-freedom (4DOF) model. Then, the full 4DOF model is numerically simulated while the MR damper, commanded by one of the control algorithms, is physically tested in a RTHS. The effectiveness of OCLC is demonstrated via comparative studies by reducing the mean square base drift, total absolute accelerations and control forces through both numerical simulation and RTHS. The experimental results are also compared to pure simulation results to demonstrate the accuracy of RTHS tests.

Regularized Model-Free Adaptive Control of Base Isolated Buildings

Wednesday, 19th June - 16:30: MS62 - Complex Dynamics and Vibration Control of Structures under Single/Multiple Hazards (Firestone 384 (76)) - Oral - Abstract ID: 403

Mr. Alvaro Javier Flórez Martínez (University of los Andes), Prof. Luis Felipe Giraldo (University of los Andes), Prof. Mariantonieta Gutierrez Soto (University of Kentucky)

Base isolation is a widely-used technique to minimize damages in civil structures subjected to earthquake loading. A building that implements this type of technology has a superstructure separated from the base by introducing a suspension system between the base and the main structure. Due to the lack of real-time adaptability of this system, hybrid control strategies that involve active and semi-active actuators are currently investigated to minimize the effect of near-fault earthquakes were traditional base isolation systems are less effective. The strategies that are used to control these active and semi-active components are typically based on models of the system that are known a priori. Although these models describe some of the most important dynamics of the elements involved in the system, the uncertainty in the behavior of a structure subjected to earthquake loading is very difficult to be characterized using a fixed model. This work presents a strategy that deals with this issue: the input that controls the base isolation system results from the compound action of a controller that relies on a model of the system that is known a priori, and online data-driven inferences on the behavior of the system. In this way, the control design process integrates both prior information of the system and unknowns of the system such as non-modeled parameters, nonlinear behaviors in the materials and actuators, unbalanced loads at each story, and the dynamics caused by human-induced vibrations, among others. The performance of the proposed methodology is evaluated through numerical simulations.

Nonlinear Dynamics of Short-Space Electrical Conductors Under Uniaxial Periodic Excitation

Wednesday, 19th June - 16:45: MS62 - Complex Dynamics and Vibration Control of Structures under Single/Multiple Hazards (Firestone 384 (76)) - Oral - Abstract ID: 214

Ms. Yushan Fu (University at Buffalo), Prof. Mettupalayam Sivaselvan (University at Buffalo)

Flexible bus conductors are commonly used in electrical substations to connect different types of equipment, such as circuit breakers, transformers, surge arresters, etc. In terms of seismic safety, IEEE standards recommend providing significant slack between interconnected equipment, so that the flexibility of conductors is ensured and the effect of interconnection is minimized. However, it has revealed by many researchers that such effect of interconnection is more likely due to conductor nonlinear dynamics. This research specifically seeks to quantify the effects of interconnection resulting from nonlinear dynamics of short-span flexible bus conductors, so that less conservative and more practical measures can be taken. Four types of flexible bus conductors having different slack levels were subjected to a series of sinusoidal excitation with multiple combinations of frequencies and amplitudes. It was observed that these conductors exhibited a variety of sub-harmonic resonances. Maximum conductor axial forces were also obtained and compared in terms of conductor types, slack levels, excitation frequencies and amplitudes. For a better understanding of these dynamic behaviors, a simplified cable model having only in-plane rotational and out-of-plane rotational degrees-of-freedom was developed to capture the mode coupling effect due to the 2-to-1 resonance. Derived governing equations for this model were solved theoretically using perturbation method, and numerically using continuation software AUTO-07P and MATLAB. This model is found to be able to qualitatively predict the occurrence of nonlinear dynamic responses of short-space electrical conductors observed from experiments.

Modeling Human Bouncing on a Flexible Structure Using Control Models

Wednesday, 19th June - 17:00: MS62 - Complex Dynamics and Vibration Control of Structures under Single/Multiple Hazards (Firestone 384 (76)) - Oral - Abstract ID: 1310

Mr. Ahmed Alzubaidi (University of South Carolina), Dr. Juan Caicedo (University of South Carolina)

Live loads on structures such as dance halls, fitness centers, and malls can generate excessive vibrations causing serviceability problems. Classical methods to study this human-structure interaction (HSI) model the human as a mass-spring-damper system (MSD). While these models area able to represent the dynamics of the system in some cases, the human body is a more complex dynamic system. For example, MSD systems are not capable of adding energy to the overall human-structure system and therefore do not allow to use of excitations provided by the human. This paper expands a prior model of human standing on flexible structure using control theory to a model that consider sound as the excitation to the human-structure system. Energy is added to the system when a person bounce or performing short movement up and down by bending their knees at the bit of a metronome. Here, the sound created by the metronome is used as input to overall system.

A flexible cantilever structure, idealized as single degree of freedom system, is used to develop and validate the proposed model. The force exerted by people bouncing as well as the acceleration records are used to determine the probability distribution functions of the model parameters. The model is validated by comparing model predictions with additional experimental records.

Bayesian Approach to Develop Business Recovery Models After Disaster Events: Application Study for the Community of Lumberton, NC Following Hurricane Matthew

Wednesday, 19th June - 16:00: MS57 - Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 142

Mr. Mohammad Aghababaei (Texas A&M University), Dr. Maria Koliou (Texas A&M University), Ms. Maria Watson (Texas A&M University), Dr. Yu Xiao (Portland State University)

Businesses are an integral part of the community and their recovery is vital to overall community recovery following natural disasters. This study introduces a modeling approach to quantify and predict business recovery using Bayesian linear regression. The proposed approach comprises three main steps, namely, data collection, development of model forms, and model selection. The modeling approach starts with collecting a comprehensive dataset, containing six main categories of information needed to predict business recovery, using previously conducted reconnaissance studies. Then procedure Bayesian linear regression candidate model forms are developed based on the collected information from the first step. Finally, the most appropriate model is selected in the third step through rigorous evaluation and elimination steps. Four complementary measurements of business recovery (business cease operation days, revenue recovery, customer retention, and employee retention) are considered in this study to comprehensively describe the post-disaster business recovery. One of the advantages of this modeling approach is accounting for the interplay between businesses and households in a community during the recovery process. As an application of this modeling approach, a dataset collected through a longitudinal field study conducted by the NIST-funded Center of Excellence for Risk-Based Community Resilience Planning in Lumberton, NC, after the 2016 Hurricane Matthew is employed to develop predictive models. The developed models are applicable in risk-based resilience assessment of communities after disasters; while the specific findings based on the Lumberton dataset may be further used for predicting business recovery in communities with similar socioeconomic characteristics and exposure to comparable hazards.

An Efficient Reliability Assessment Framework for the Performance-Based Wind Design of Inelastic Structural Systems

Wednesday, 19th June - 16:15: MS57 - Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 939

Ms. Wei-chu Chuang (University of Michigan), Dr. Seymour Spence (University of Michigan)

Wind engineering is rapidly adopting the principles of performance-based design. This has led to the need to estimate the inelastic reliability of the main wind force resisting system (MWFRS). This paper introduces a framework to this end that is based on describing performance through a system-level limit state that allows yielding of the MWFRS. Safety against collapse is described through limits on inelastic responses (e.g. inter-story drifts and residual deformations) as well as the attainment of the state of dynamic shakedown (i.e. safety against low-cycle fatigue and/or ratcheting). To assess whether a system subject to a given stochastic wind load history and set of uncertain parameters (e.g. material strength, damping levels) satisfies the system-level limit state, a distributed plasticity model is introduced based describing inelasticity through elastic perfectly plastic material models at the level of the generalized forces. Through the Haar–Karman condition, a model based on solving a sequence of quadratic programming problems is proposed for estimating whether a state of dynamic shakedown and the associated inelastic responses. The efficiency of the proposed model allows stochastic simulation to be used to estimate the reliability of the MWFRS with respect to the aforementioned system-level inelastic limit state function. A full-scale 260 m tall concrete core structure subject to a directional wind climate, wind tunnel informed stochastic wind loads, and full set of parameter uncertainties is presented in order to illustrate the both the potential of the proposed framework as well as the advantages of inelastic design of the MWFRS.

Pounding Tuned Mass Damper for Vibration Control of Off-Shore Wind Turbine Subject to Combined Wind and Wave Excitation

Wednesday, 19th June - 16:30: MS57 - Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 629

Dr. Fan Kong (Wuhan University of Technology), Dr. Chao Sun (Louisiana State University), Mr. xia hongbing (Wuhan University of Technology)

A Pounding Tuned Mass Damper (PTMD) for reducing vibration of a wind turbine subject to combined wind and wave excitation is presented in this paper. For this purpose, the equation of motion of the uncontrol/controlled wind turbine system is derived using the Lagrangian equation. The dynamic response of the PTMD-controlled wind turbine is calculated and compared to the uncontrolled and TMD-controlled responses. A 5MW monopile offshore wind turbine developed by the National Renewable Energy Laboratory (NREL) is used as an example to demonstrate the effectiveness and superority of the PTMD in reducing the wind turbine response. Pertinent numerical results show that the non-linear pounding mechanism greatly improves the robustness of the TMD under the detuned conditions and reduces significantly the TMD stroke.

Performance Assessment of Friction Pendulum Systems Under Near-Fault and Long-Period Ground Motions

Wednesday, 19th June - 16:45: MS57 - Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1324

Dr. Nicholas Oliveto (University of Catania)

Seismic isolation is a widely adopted technology for the protection of building infrastructure from earthquakes. Single (FP), double (DFP) and triple friction pendulum (TFP) systems have been studied extensively in the last few decades and are nowadays widely used around the world. However, due to their relatively recent adoption for the seismic isolation of buildings and bridges, critical aspects of their behavior and possible causes for their malfunctioning are still being investigated. Among these are the dependence of the friction coefficient on contact pressure, sliding velocity and temperature. Other relevant issues concern the effects of vertical ground acceleration, uplift, impact and residual displacements. After recent severe earthquakes, such as Kobe (1995) and Tohoku (2011), considerable attention has been devoted to the effects of near-fault and long-period earthquakes, with specific reference to tall buildings. However, no mention has been made in the literature of the resonant effects of nearly periodic ground motions on friction pendulum systems. The "small displacement" assumption currently used in the analysis of the behavior of such systems leads to an unbounded resonant response for the low friction coefficient values used for seismic isolation. In this work, it is shown that even the exact "large displacement" theory leads to displacement demands that determine failure of the devices. Using the large displacement theory, the performance of friction pendulum systems is assessed under a number of recorded near-fault and long-period ground motions. The results are presented in the form of displacement response spectra for different values of the friction coefficient.

Performance-Based Loss Estimation for Tall Buildings Under Ordinary and Hurricane Winds

Wednesday, 19th June - 17:00: MS57 - Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1348

Prof. Michele Barbato (University of California, Davis), Dr. Francesco Petrini (Sapienza University of Rome)

The performance of high-rise buildings under wind actions is crucial in driving the design; thus, a probabilistic risk assessment analysis becomes necessary to ensure appropriate serviceability and safety in combination with an economic design. A Performance-Based Engineering approach can provide a coherent and rigorous evaluation of performance in monetary terms to inform the optimal design of structural systems that maintain an acceptable performance during their whole life cycle. The Performance-Based Wind Engineering (PBWE) and Performance-Based Hurricane Engineering (PBHE) frameworks were inspired by the existing Performance-Based Earthquake Engineering (PBEE) approach developed by the Pacific Earthquake Engineering Research Center (PEER) to extend the advantages of PBE to the wind and hurricane engineering fields, respectively. In particular, the PBHE framework considers the multi-hazard nature of hurricane events, the interaction of different hazard sources, and the possible sequential effects of these distinct hazards.

In this paper, the PBHE framework is used for the risk assessment of tall buildings subjected to both hurricane and non-hurricane wind hazards. A story-based loss estimation method is used for the loss analysis in conjunction with damage and loss functions taken from HAZUS®. An application example consisting of a 74-story building located in Miami County, Florida, is presented to illustrate the framework. The expected losses for the target building for different limit states are calculated considering structural losses, non-structural losses, and serviceability losses. The effects of designing structures to remain elastic under wind loads are also discussed.

Performance-Based Assessment of 20-Story SAC Building under Wind Hazards through Collapse

Wednesday, 19th June - 17:15: MS57 - Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 695

Ms. Azin Ghaffary (University of Nevada, Reno), Dr. Mohamed Moustafa (University of Nevada, Reno)

Frequent occurrence of recent intense wind events, along with the growing interest in performance-based wind engineering, sets the need for better understanding of collapse response of our structures. In particular, studying the inelastic nonlinear response of buildings through collapse under wind hazards can lead to safer structures, but also informs future economic designs. The objective of this presentation is to investigate the performance of a typical steel building through a set of nonlinear wind response history analyses for different wind speeds. A 20-story moment resistant steel frame from the SAC project is used for this purpose. It is shown that for wind hazards much higher than the code design wind speed, the building is capable of providing the required structural capacity and withstand shear deformations on the cladding in a conservative way, while slightly exceeding the motion comfort limit state. Additionally, wind history analysis of the structure with cumulatively increasing wind speeds is performed. It is observed that structural collapse occurs at unrealistically large hazard levels. These observations, along with an overview of four other studies from the literature that conducted performance-based wind assessment, suggest that designing wind-dominated steel structures to go nonlinear under very rare events can lead to more economic designs and is worthy of further investigations.

A Sequential Non-Iterative Approach for Modeling Multi-Ionic Species Reactive Transport During Localized Corrosion

Wednesday, 19th June - 16:00: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 3 (107 Downs (71)) - Oral - Abstract ID: 535

Mr. Xiangming Sun (Vanderbilt University), Dr. Ravindra Duddu (Vanderbilt University)

Structural damage driven by localized corrosion is a slow degradation process, but can lead to catastrophic failures. Complementary to experimental studies, we need to modeling studies to understand the mechanisms of localized corrosion and to predict service life of structures. Localized corrosion is a complex electrochemical process involving a moving electrode-electrolyte interface and is significantly influenced by the chemistry of the electrolyte environment. The presence of numerous chemical species and their products in the electrolyte along with the electro-diffusion of ionic species poses significant challenges for numerical modeling. Consequently, existing approaches in the literature for modeling localized corrosion encounter numerical issues while handling the reactive-mass transport and chemical reactions of multiple chemical species. To alleviate these issues, we present a sequential non-iterative approach (SNIA) for modeling localized corrosion in idealized carbon steel microstructures. We use the Nernst-Planck equations and chemical equilibrium equations to describe concentrations of ionic species and the electrical potential in the electrolyte domain. The concept of total solute concentration is used to de-couple equations, leading to a two-step staggered numerical method. At each time step, we first compute the uncorrected concentrations based on mass transport and then correct them considering local chemical equilibrium. The resulting nonlinear equations are linearized using the Newton-Raphson method and solved using the finite element method in the open-source software FEniCS. We compare the accuracy of the SNIA against existing numerical solutions, and validate the results with experimental data of crevice corrosion of Fe-Cr binary alloys.

A Return-Free Integration for Viscoelastoplastic Models

Wednesday, 19th June - 16:15: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 3 (107 Downs (71)) - Oral - Abstract ID: 641

Prof. Li-Wei Liu (National Cheng Kung University)

The return-free integration for elastoplastic models has be proposed in [Chein-Shan Liu, Li-Wei Liu, and Hong-Ki Hong, A scheme of automatic stress-updating on yield surfaces for a class of elastoplastic models, International Journal of Non- Linear Mechanics, Vol. 85, pp. 6-22, 2016.]. The theory of Lie group and Lie algebra support this integration to update the stress point on the yield surfaces automatically without any the so-called predict-correct return mapping. This implicit integration shows explicit-like process and high accuracy for solving problems of elastoplastic material. In the present paper, we extend the return-free integration to models of viscoelastoplasticity and exhibit the performance. Theoretical derivation of development of return-free integration is exhibited and numerical demonstration is shown. The stress points of viscoelsatoplastic models are updated on the yield surfaces automatically and exactly within the machinery round-off error.

Modelling the Tension – Torsion Asymmetric Yield Behavior of Nitronic 40 Steel

Wednesday, 19th June - 16:30: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 3 (107 Downs (71)) - Oral - Abstract ID: 396

Dr. Jinyuan Zhai (Purdue University Northwest), Prof. Xiaosheng Gao (The University of Akron), Prof. Jiliang Li (Purdue University Northwest), Prof. Stephen M. Graham (United States Naval Academy)

Steel Nitronic 40 is used in industry applications due to adequate strength, ductility and resistance to radiation damage. Recent modeling efforts have focused on improvements to the predicted elastic–plastic response in this material. This study develops a pressure-insensitive, continuum plasticity model, dependent on the second and third invariants of the stress deviator (J_2 and J_3), to describe the tension–torsion asymmetry of a steel Nitronic 40. The proposed plasticity model has been calibrated and validated using measured results from an experimental test program. Results show that the proposed model captures the complex elastic–plastic response observed in measured load–displacement and torque–rotation curves over a range of triaxiality and Lode parameter values.

Nonlinear Beam Element with a 3D Response

Wednesday, 19th June - 16:45: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 3 (107 Downs (71)) - Oral - Abstract ID: 871

Prof. Mauro Schulz (Fluminense Federal University)

Classical beam formulations do not precisely represent the actual three-dimensional state of stresses and strains. Fiber beam elements do not consider the coupling between normal and shear forces. Nonlinear analysis of beams requires 3D evaluation of stresses and strains.

Reference [1] presents a beam formulation for which the cross section remains neither plane nor orthogonal to the beam axis. The arbitrary geometry of the cross-section is modeled by 2D finite elements. Kinematics is defined by the gradient functions of the averaged movements of the cross-sections and corresponding displacement shapes.

A weighting matrix yields the averaged movements of the displacement shapes, whichs are obtained by minimizing the potential energy of a beam slice submitted to the compatibility constraints of a kinematics framework. The energy methodology proposed in [2] is augmented with constraints that ensure compatibility between the displacement fields.

The first-order approach of this formulation is extended to nonlinear materials. The mechanical model is validated through examples. The material behavior is defined by nonlinear hyperelastic stress-strain relationships that assume coaxiality between principal stresses and strains. The numerical procedure requires few iterations to achieve convergence. The 3d response of nonlinear beam models corresponds well to displacements, stresses and strains that are obtained from nonlinear solid models made of isoparametric hexahedral brick elements.

References

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[2] Kazic, M., and Dong, S. B. (1990). “Analysis of restrained torsion.” *J. Eng. Mech. - ASCE*, 116(4), 870-891.

Modeling, Design, and Control of Tensegrity Structures Incorporating Active Materials

Wednesday, 19th June - 17:00: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 3 (107 Downs (71)) - Oral - Abstract ID: 1050

Mr. Gavin Butler (University of California, Irvine), Prof. Edwin Peraza Hernandez (UC Irvine)

Tensegrity structures, which are pre-stressable networks of one-dimensional members, are being widely studied in many engineering fields due to their potential transformative applications as lightweight structural solutions. This talk presents a novel model for tensegrity structures comprised of arbitrary materials. The model is applicable to tensegrity structures that morph due to external forces and/or intrinsic material actuation. An implicit numerical implementation of the model is also addressed, allowing to preserve numerical accuracy and permitting large loading/time steps, unlike conventional explicit implementations. The model readily allows for the incorporation of heat transfer effects and control algorithms. Comprised of one-dimensional members, tensegrity structures can also be naturally integrated with shape memory alloy (SMA) wires, which are widely commercially available. We perform studies that demonstrate the feasibility of employing tensegrity topologies to create new morphing structures or energy dissipative devices by respectively exploiting the SMA's shape memory and superelastic effects.

A Harmonic-Enriched Reproducing Kernel Approximation for Highly Oscillatory Differential Equations

Wednesday, 19th June - 16:00: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 934

Prof. Sheng-Wei Chi (University of Illinois at Chicago), Dr. Ashkan Mahdavi (University of Illinois at Chicago)

The harmonic-enriched reproducing kernel (HRK) approximation together with collocation method is introduced to circumvent the discretization restriction for highly oscillatory PDEs. It is first shown that to embed the harmonic function with a desired frequency in the HRK, both sin and cos with the same frequency should be included in the basis vector for construction of HRK approximation. The HRK and its implicit derivatives are then used in the collocation method to effectively obtain solutions of oscillatory PDEs. The standard monomials can be included together with harmonic functions in the HRK and the reproducing conditions can be exactly satisfied with a complete set of basis functions. For PDEs with semi-harmonic solutions, the present method yields more accurate results compared to the standard RK when a coarse discretization is used. On the other hand, when the discretization is refined, the HRK exhibits a similar convergence behavior as the standard RK. The effectiveness of the present method is demonstrated using highly oscillatory 2nd order and 4th order PDEs. The accuracy and performance of this method are compared with standard RK with collocation method as well as finite element method.

Anisotropy in Two-Dimensional and Planar Elasticity Bond-Based Peridynamics

Wednesday, 19th June - 16:15: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 754

Dr. Pablo Seleson (Oak Ridge National Laboratory), Dr. Jeremy Trageser (Oak Ridge National Laboratory)

The peridynamic theory of solid mechanics is a nonlocal reformulation of classical continuum mechanics suitable for material failure and damage simulation. As opposed to the classical theory, constitutive models in peridynamics do not require spatial differentiability of displacements, which allows for a natural representation of material discontinuities, such as cracks. Applications in peridynamics to date cover a wide range of engineering problems; however, the majority of those applications employ isotropic material models. In this presentation, we will present recent advances in modeling anisotropic media in bond-based peridynamics with a specialization to two-dimensional and planar elasticity problems.

Data Transfer and Coupling of Native Fields with the Compadre Toolkit

Wednesday, 19th June - 16:30: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 98

Dr. Paul Kuberry (Sandia National Laboratories), Dr. Mauro Perego (Sandia National Laboratories), Dr. Nathaniel Trask (Sandia National Laboratories), Dr. Pavel Bochev (Sandia National Laboratories)

Simulating earth system models requires coupling specialized subdomain codes for ocean and atmosphere, as well as land, land ice, and sea ice. Each of these domains are meshed independently and contain a large variety of different discretizations, sometimes referred to as a discretization 'zoo'. Transferring information between subdomain codes requires one to be able to deal with the data contained in these fields, which may not be something as simple as point-wise evaluations of some function.
In the case of Raviart-Thomas elements being used to discretize a subdomain problem, the degrees of freedom for the solution represent integral quantities on faces. In this presentation, we will describe and demonstrate how to use the Generalized Moving Least Squares method with a particular choice of sampling functional, reconstruction space, and target functional, in order to accurately reconstruct and transfer the vector field represented as a linear combination of the Raviart-Thomas elements into a pointwise evaluation on some target grid.
A description of the Compadre Toolkit along with code snippets elucidating how one can apply it to the above stated problem will be presented, along with numerical experiments demonstrating its speed and accuracy.

An Immersed Volumetric Nitsche's Approach for Meshfree Analysis of Composites

Wednesday, 19th June - 16:45: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 152

Prof. Mike Hillman (Penn State), Dr. Guohua Zhou (Optimal Inc.)

It is difficult to generate body fitting discretizations for interface problems such as modeling inclusions in solid mechanics. Among the methods available, immersed boundary methods that discretize bodies independently provide potential for tackling these type of problems since a matching discretization is not needed. However, for meshfree methods the associated strong enforcement of kinematic conditions on boundaries is non-trivial [1], particularly for arbitrary interior interfaces [2]. Volumetric approaches are available such as the Lagrange multiplier and penalty methods which can circumvent this issue [3], yet have the well-known inherent shortcomings of LBB instability and sensitivity to tunable parameters, respectively.

In this work, an immersed framework is proposed that imposes interface continuity with a volumetric Nitsche's approach, which precludes the issues of imposing boundary constraints, and avoids the issues with penalty- or Lagrange multiplier-based volumetric approaches. The higher-order continuity required in the method is easily attained using the flexibility of meshfree approximations. The effectiveness of this method is examined by solving composite benchmark problems, where high accuracy and optimal convergence are obtained.

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[3] P.J. Blanco, R.A. Feijóo, E.A. Dari, "A variational framework for fluid-solid interaction problems based on immersed domains: Theoretical bases," Comput. Methods Appl. Mech. Eng. (197) 25–28, 2353–2371, 2008.

Granular Flows vs. Fluid Flows: A Look of at the Similarities and Differences

Wednesday, 19th June - 17:00: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 757

Mr. Milad Rakhsha (University of Wisconsin – Madison), Mr. Conlain Kelly (University of Wisconsin – Madison), Mr. Nicholas Olsen (University of Wisconsin – Madison), Dr. Radu Serban (University of Wisconsin – Madison), Prof. Dan Negrut (University of Wisconsin – Madison)

Granular media can demonstrate distinctively different behaviors under various local stress conditions. Among these behaviors, we are particularly interested in the fluid-like evolution of granular materials that happens when rapidly sheared. In such cases, (i) shear stress in granular material shows strain-rate dependency, which is a characteristic of fluids and, (II) there exists a threshold value (yield criterion), under which the grains do not flow, a characteristic of solid materials. These features point out a visco-plastic behavior in granular materials which is an attribute of non-Newtonian fluids such as Bingham liquids. However, flow of granular materials is governed by the Newton-Euler equations whereas the momentum balance in fluids is captured via the Navier-Stokes equation. More specifically, pressure and viscous forces arise respectively from the normal and shear stresses in fluids. In granular media in contrast, frictional forces depend on the normal forces, i.e. shear stresses correlate with normal stresses. We hypothesize that despite having different governing physics, the fluid and the granular media may behave similarly in certain flow regimes. In this study we compare the behavior of inviscid fluid with frictionless granular material flows in standard fluid mechanics problems. Finally, we highlight the similarities and differences between the two physics for a few experiments such as a static bucket of material, the dam break problem, and the interacting force of dam break problem with an obstacle. We show that the granular material resembles certain bulk characteristics of fluid flow for the aforementioned experiments.

A Peridynamic Strain Tensor

Wednesday, 19th June - 17:15: MS17 - Meshfree, Peridynamics, and Particle Methods: Contemporary Methods and Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 217

Dr. Hailong Chen (University of Kentucky)

The peridynamics is a framework for continuum mechanics based on the idea that pairs of particles exert forces on each other across a finite distance. The horizon size defines this interaction range. The equation of motion in the peridynamics is an integro-differential equation, thus peridynamics avoid issues with spatial singularities such as cracking otherwise exists in continuum mechanics. In this paper, a notion of a peridynamic strain tensor derived from pairwise stretch is defined. At any point in the body, this strain tensor is obtained from the stretch within peridynamic bonds that geometrically go through the point. The content of this presentation will be organized as follows: we will first briefly review the deformation gradient approximation in the non-ordinary state-based peridynamic model. Following this, a new peridynamic strain tensor based on the bond stretch will be presented. After that, numerical examples of both homogeneous and inhomogeneous deformations will be used to verify the derived strain tensor. Comparison between the derived strain tensor and that based on deformation gradient will be studied. Discussions and conclusions are drawn based on current study.

A Gradient Damage Theory for Fracture of Quasi-Brittle Materials

Wednesday, 19th June - 16:00: MS24 - Advances in Experimental, Theoretical and Computational Fracture Mechanics (Lees-Kubota (118)) - Oral - Abstract ID: 673

Prof. Lallit Anand (Massachusetts Institute of Technology), Mr. Sooraj Narayan (MIT)

Phase-field modeling of brittle fracture of linear elastic solids has been the subject of several studies in the past 25 years. An attractive feature of this approach to model fracture is its seamless ability to simulate the complicated fracture processes of nucleation, propagation, branching and merging of cracks in arbitrary geometries. While most existing models have focussed on fracture of “ideal brittle” materials, we consider fracture of “quasi-brittle” materials. The material is considered to be quasi-brittle in the sense that it does not lose its entire load-carrying capacity at the onset of damage. Instead there is a gradual degradation of the strength of the material, which is the result of microscale decohesion/damage micromechanisms.

In this talk we shall discuss the formulation of our gradient-damage theory for quasi-brittle fracture using the virtual-power method. The macro- and microforce balances, obtained from the virtual power approach, together with a standard free-energy imbalance law under isothermal conditions, when supplemented with a set of thermodynamically-consistent constitutive equations will provide the governing equations for our theory. We have specialized our general theory to formulate a simple continuum model for fracture of concrete — a quasi-brittle material of vast importance. We have numerically implemented our theory in a finite element program, and we will present representative numerical examples which show the ability of the simulation capability to reproduce the macroscopic characteristics of the failure of concrete in several technically relevant geometries reported in the literature.

A Phase Field Method for Modeling Fracture of Bones

Wednesday, 19th June - 16:15: MS24 - Advances in Experimental, Theoretical and Computational Fracture Mechanics (Lees-Kubota (118)) - Oral - Abstract ID: 338

Mr. Rilin Shen (Columbia University), Prof. Haim Waisman (Columbia University), Prof. Zohar Yosibash (Tel Aviv University), Ms. Gal Dahan (Tel Aviv University)

A proximal humerus fracture is an injury to the shoulder joint that necessitates medical attention. While it is one of the most common fracture injuries impacting elder communities and those who suffer from traumatic falls or forceful collisions, there are almost no validated computational methods that can accurately model these fractures. This might be due to the complex, inhomogeneous bone microstructure, complex geometries and the limitation of current fracture mechanics methods.

In this presentation, I will present a new phase field method to investigate the proximal humerus fracture. The method is validated by an in vitro experiment, in which a human humerus is constrained on both ends while subjected to compressive loads in the longitudinal direction of the bone that lead to fracture of the anatomical neck. CT-scans are employed to obtain geometry and material properties for the bone . Herein, we propose a power law relationship between the inhomogeneous Young modulus and critical fracture energy, together with a volumetric-deviatoric split of the elastic energy that drives the fracture evolution.

The method is implemented in a high performance computing environment, is used to successfully predict the complex 3D brittle fracture response of the bone, and is shown to be in good agreement with experimental data.

Size Effect Law for Microscopic Scratch Testing

Wednesday, 19th June - 16:30: MS24 - Advances in Experimental, Theoretical and Computational Fracture Mechanics (Lees-Kubota (118)) - Oral - Abstract ID: 344

Dr. Ange Therese Akono (Northwestern University)

Scratch tests consist in pulling a spheroconical probe across a weaker material while monitoring the resulting forces and penetration depth. Scratch tests are applied in many fields of science and engineering to assess the wear and damage of metals and polymers, characterize the adhesion and cohesion of hard films and coatings, and quantify the strength of ceramics and rocks. A recently proposed application of scratch testing is to measure the fracture toughness of materials. In our study, we apply the size effect law to microscopic scratch testing to capture the transition from strength to brittle fracture in nonlinear fracture cases. A theoretical model is articulated first in the case of scratch testing using a conical probe, and second in the general case of an axisymmetric probe. Our theoretical model is validated using scratch tests on organic-rich shale. A ductile-to-brittle failure mode is observed that is driven by the penetration depth. In particular, organic-rich shale exhibits an anisotropic behavior with the fracture characteristics being dependent on the orientation: arrester, divider, and short transverse. Furthermore, several fracture micro-mechanisms are observed at different length-scales. Moreover, a negative correlation is found between the quartz-feldspar-pyrite fraction and the fracture toughness. Meanwhile, a positive correlation is found between the combined total organic content, clay content, and calcite content and the fracture toughness. These novel results suggests that gas shale formations with rich in clay and kerogen are more likely to be equally tough. Nevertheless, scratch testing yields a deeper understanding of the fracture at the mesoscale.

Sub-Rayleigh and Supershear Rupture Characteristics Inferred from Dynamic Digital Image Correlation Measurements

Wednesday, 19th June - 16:45: MS24 - Advances in Experimental, Theoretical and Computational Fracture Mechanics (Lees-Kubota (118)) - Oral - Abstract ID: 862

Dr. Vito Rubino (California Institute of Technology (Caltech)), Prof. Ares Rosakis (California Institute of Technology), Prof. Nadia Lapusta (California Institute of Technology)

The vast majority of earthquakes propagate at sub-Rayleigh speeds. On the other hand, earthquakes propagating at supershear speeds, though less common, are by far more destructive. Hence, it is important to quantify the characteristics associated with both sub-Rayleigh and supershear earthquakes. Here we report on the spatiotemporal properties of dynamic ruptures measured in our laboratory experiments using the dynamic digital image correlation (DIC) technique. Earthquakes are mimicked in our lab by the frictional rupture propagating along the interface of two Homalite plates. Digital images of the propagating ruptures are captured by an ultrahigh-speed camera and are processed with DIC in order to produce sequences of evolving displacement and velocity maps. Our measurements reveal the full-field structures of the velocity components and help to explain previous point-wise velocimeter time histories, only available at 2-3 locations. Supershear ruptures are characterized by a more pronounced motion in the fault-parallel direction, while sub-Rayleigh ruptures in the fault-normal direction, as shown by previous studies. This study clarifies how the velocity signatures gradually evolve moving from the fault to the bulk, bridging the gap between previous spatially sparse velocimeter measurements. The full-field maps also allow us to quantify the attenuation characteristics. For sub-Rayleigh ruptures, the amplitude decay of fault-normal velocity jump is consistent with the inverse square root of the distance from the fault. This work contributes to enhance our understanding of ground shaking associated with dynamic ruptures with important implications for earthquake hazard assessment.

Fracture Mechanics Analysis of Cracked Structures with Residual Stress Fields Using the Hypercomplex-Variable Finite Element Method

Wednesday, 19th June - 17:00: MS24 - Advances in Experimental, Theoretical and Computational Fracture Mechanics (Lees-Kubota (118)) - Oral - Abstract ID: 863

Dr. Arturo Montoya (The University of Texas at San Antonio), Mr. Daniel Ramirez (The University of Texas at San Antonio), Mr. Ernest Ytuarte (The University of Texas at San Antonio), Dr. Harry Millwater (The University of Texas at San Antonio)

Residual stresses may retard or accelerate the propagation of cracks in structures. Hence, structural integrity assessments must account for the effects of residual stresses in order to determine the load carrying capacity and crack propagation paths of defective structures. The state of the art approach is to use a modified J-integral that eliminates path dependency and numerical issues arising from the presence of residual stresses in the standard J-integral. In this work, we demonstrate the applicability of the virtual crack extension (VCE) approach for computing the energy release rate under the presence of residual stresses. The method consists of performing a numerical derivative of the potential energy with respect to a crack extension by implementing the complex Taylor series expansion method (CTSE) within the hypercomplex variable finite element method, ZFEM. The residual stresses are introduced by inputting the strain vector resulting from a residual stress inducing process as an initial strain field in the fracture mechanics analysis. ZFEM does not depend on the existence of a strain energy density and does not require contour or domain integrals; hence, no modifications are required for this application. ZFEM capability is demonstrated on a thick-walled sphere with a residual stress field induced during an autofretagge process. The results are compared against the modified J-integral results available in Abaqus, showing the robustness and accuracy of the ZFEM approach.

Statistical Analysis of Relation Between Texture and Fracture Properties in Porous Materials

Wednesday, 19th June - 17:15: MS24 - Advances in Experimental, Theoretical and Computational Fracture Mechanics (Lees-Kubota (118)) - Oral - Abstract ID: 315

Ms. Xuejing Wang (University of Massachusetts Dartmouth), Dr. Mazdak Tootkaboni (University of Massachusetts Dartmouth), Dr. Arghavan Louhghalam (University of Massachusetts Dartmouth)

The impact of porosity on elastic and fracture properties of porous materials has been studied in literature. However, impact of texture and porosity disorder is not yet well understood. Since most construction materials are porous at some scale, it is crucial to study how porosity disorder affects crack nucleation and propagation in microscale and changes the macroscopic fracture properties of those material.

In this presentation we study the impact of porosity and micro-texture of porous materials on their fracture properties. To this end, we use standard deviation of local porosity as a metric to quantify porosity disorder. Realizations of porous materials with various porosities and different levels of disorder are generated via Monte-Carlo simulations. The samples are analyzed with the Lattice Element Method (LEM) and by considering a potential of mean force approach. Stress transmission patterns within the material, energy release rate as well as crack nucleation and propagation are monitored until the complete rupture of sample is observed. The statistical analysis of more than 800 samples reveals the inverse relationships between porosity and disorder with energy release rate and the total crack length. Furthermore, we observe different crack propagation patterns for material with high porosity. More specifically in highly disordered materials initial micro-cracks are highly scattered within the entire sample before a dominant crack propagates and ruptures the entire sample.

On the Use of Tuned Mass Dampers and Self-Centering Systems to Control Hurricane-Induced Cumulative Damage Demands of Tall Buildings

Wednesday, 19th June - 16:00: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 4 (103 Downs (50)) - Oral - Abstract ID: 544

Mr. Matiyas Bezabeh (Western University), Prof. Girma Bitsuamlak (Western University), Prof. Solomon Tesfamariam (University of British Columbia)

Building codes and standards in many parts of the world, including regions with a high risk of tropical cyclones, recognize the first significant yielding point as an ultimate limit state. The main argument used in favor of linear-elastic design approach is its presumed ability to avoid asymmetric yielding and the subsequent damage accumulation. However, this design philosophy ignores the ductile capacity of materials and structural systems, resulting in uneconomical and brittle buildings. In general, the current state of knowledge regarding the nonlinear-inelastic response of structures under wind loads is limited. Therefore, in this paper, we re-examined the classical linear-elastic design philosophy with consideration of performance-based design principles, innovative technologies, and materials. We propose the use of tuned mass dampers (TMDs) and self-centering systems to control the cumulative damage demands of structures subjected to tropical cyclones. Nonlinear dynamic analyses of a simplified TMD-structure and self-centering systems are conducted. In the analyses, hurricane wind speed records collected by the Florida Coastal Monitoring Program are used. Results of the analyses reveal that TMDs are effective in controlling the frequency of excursions into the nonlinear range for moderate levels of excitation. However, when the excitation level significantly exceeds the yield capacity, "de-tuning" of TMDs is observed. On the other hand, self-centering systems controlled permanent damage accumulation by a complete re-centering at the end of excitation. Hence, with the use of self-centering systems, ductility-based design approaches can be effectively used to design economic structures in regions with a high risk of tropical cyclones.

Identification of Aerodynamic Load Parameters to Predict Dry/Ice Galloping and Buffeting Response of Power Transmission Lines

Wednesday, 19th June - 16:15: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 4 (103 Downs (50)) - Oral - Abstract ID: 860

Mr. Mohammad Jafari (Iowa State University), Prof. Partha P. Sarkar (Iowa State University)

Dry and ice galloping of power transmission lines (conductors) that occurs at moderate to large wind speeds causes large-amplitude motion of these long-suspended cables. This phenomenon can cause catastrophic damages such as flashover, wire burning, tripping, transmission-line tower collapse, accident, interphase short circuit, and fatigue failure of the tower and conductor. Many studies have investigated the mechanisms causing different types of flow-induced vibrations in cables such as rain-wind induced vibration (RWIV), vortex-induced vibration (VIV), ice galloping, wake/dry galloping that have improved the understanding of these vibration mechanisms. In this study on prediction of dry/ice galloping of conductors, the parameters governing the turbulence-induced (buffeting) and motion-induced (self-excited) wind loads on bare conductors and conductors with ice formation were identified in normal and yawed wind using wind tunnel section models. The AABL Wind and Gust Tunnel located in the Department of Aerospace Engineering at Iowa State University was used for this study. Aerodynamic surface pressure measurements and force measurements on stationary section models of non-yawed/yawed conductors in smooth wind and sinusoidal-oscillating wind and response measurements of one-degree-of-freedom dynamic section models of these conductors resulted in identification of Strouhal number *aerodynamic load coefficients, aerodynamic damping/stiffness (flutter derivatives) and buffeting indicial derivative functions of the conductors for yaw angles ranging from 0º to 45º. The load parameters identified here can be used to calculate the response of dry/iced conductors in turbulent wind, critical wind speed for galloping of conductors, and minimum damping required to prevent galloping below their design wind speeds.*

Large Eddy Simulation of Atmospheric Flow Around a Simple Rectangular Building Using Thermal Perturbation and Synthetic Eddy Turbulence Generators

Wednesday, 19th June - 16:30: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 4 (103 Downs (50)) - Oral - Abstract ID: 515

Dr. Goncalo Pedro (RWDI), Prof. Amir Aliabadi (University of Guelph)

A thermal perturbation method is used to generate inflow conditions for a large eddy simulation (LES) of a neutral atmospheric boundary layer. Using this inlet condition, the wind loading of a standard tall building, Commonwealth Advisory Aeronautical Council (CAARC) is investigated. The results are compared with wind tunnel measurements and another LES model that uses a synthetic eddy method to generate turbulence at the inlet. Initial results show that the thermal perturbation method can be optimized to provide turbulent inflow conditions which closely approximate the expected transport phenomena in the neutral atmospheric boundary layer.

Data-Driven Modeling of Linear and Nonlinear Systems Using LSTM Networks

Wednesday, 19th June - 16:45: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 4 (103 Downs (50)) - Oral - Abstract ID: 446

Dr. Ruilin Chen (Harbin Institute of Technology), Dr. Xiaowei Jin (Harbin Institute of Technology), Prof. Shujin Laima (Harbin Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

A data-drivenapproach is proposed for modeling linear and nonlinear dynamical systems usingLong Short-term Memory (LSTM) networks. The LSTM network has output recursiveconnection in the time direction, namely simultaneously accepts the previouspredicted output and the current external excitation (if any) as the inputs ofnetwork at the current time step, which has the effect of constraining thenetwork itself. Several classical dynamic problems, including the buffeting of alinear system under turbulent wind, the trajectories tracking of three Van derPol oscillators with different degrees of nonlinearity and a Lorenz system, aretaken as applications. The models are performed by feeding the external load sequenceand the initial conditions (initial displacement and initial velocity) into theLSTM network to predict the corresponding responses of the system. The datasetsfor training the LSTM network are obtained by numerical simulations. Adam(adaptive moment estimation) is employed to optimize the network, and the MeanSquare Error (MSE) function is defined to measure the prediction results. Theprediction results show that the LSTM network with output recursive connectionis an effective modeling method for dynamical systems, which is applicative forboth linear and nonlinear systems. Moreover, the output recursive connectionwithin the LSTM network effectively maintain the long-term robustness of the network.In addition, the LSTM network is also an alternative method for trajectorytracking.

A Modified Hybrid Model for Dynamic Response of a Spar-Type Floating Wind Turbine Under a Hurricane Event

Wednesday, 19th June - 17:00: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 4 (103 Downs (50)) - Oral - Abstract ID: 489

Mr. Shaopeng Li (University at Buffalo), Dr. Teng Wu (University at Buffalo)

Floating wind turbines are sensitive to winds and waves during extreme weather events such as hurricanes. Compared to the hydrodynamic loads, the aerodynamic loads are relatively easy to consider because the turbine rotors are parked and the blades are feathered. In large-amplitude hurricane waves, severe flow separation occurs and hence viscous force becomes important, indicating the loads calculated by linear potential theory are inaccurate. Although the semi-empirical Morison equation could take the viscous force into account, the fluid-memory effects are ignored. The so-called hybrid model simply adds the viscous drag term in Morison equation to the linear potential theory-based formula, and hence includes both viscous force and fluid-memory effects. However, the inertia force is still calculated by linear potential theory assuming no flow separation. In this study, a modified hybrid model is proposed to better model the extreme wave load. More specifically, the linear unsteady inertia force in the hybrid model is modified using available mass coefficients of Morison equation to consider flow separation effects. In addition, the third-order nonlinear inertia force with respect to the wave amplitude is introduced to account for large-amplitude waves in hurricanes. The dynamic response of a spar-type floating wind turbine under a hurricane event is calculated using the proposed model and the results are compared with those from the conventional approaches.

CFD-Based Design of Experiments for Validation of Natural Ventilation Models in Stanford's Y2E2 Building

Wednesday, 19th June - 17:15: MS32 - Computational and Experimental Methods for Assessing Wind Effects on the Built Environment; Part 4 (103 Downs (50)) - Oral - Abstract ID: 433

Ms. Chen Chen (Stanford University), Prof. Catherine Gorle (Stanford University)

Natural ventilation can significantly reduce building energy consumption, but robust design is challenging due to the complexity of the flow and heat transfer phenomena, and the uncertainties in a future building's operating conditions. The overall goal of this research is to establish predictive computational models to support robust design of natural ventilation systems, hence promoting their widespread implementation. In a previous study, we presented a computational framework using an integral model, a computational fluid dynamics (CFD) model, and uncertainty quantification (UQ) to predict the volume-averaged indoor air temperature during night-time ventilation in Stanford's Y2E2 building. The predictions exhibited a slightly higher cooling rate than building measurements. Initial analysis of the CFD results indicated that this discrepancy could be related to spatial variability in the temperature field, which introduces a discrepancy between point-wise measurements from the building sensors and the volume-averaged temperature predicted by the integral model. The objective of the present study is to use CFD simulations to design an experiment that will support a more accurate and detailed validation of the proposed model. The locations of temperature sensors will be optimized to obtain measurements that: (1) are representative of the volume-averaged temperature in the building for validation of the integral model prediction, and (2) enable to validate CFD predictions of the spatial variability in the temperature field. Initial experimental results will be presented together with a comparison to the model predictions.

X-Ray Micro-CT Observation of Methane Hydrate Growth and Dissociation in Sandy Sediments

Wednesday, 19th June - 16:00: MS31 - Gas Hydrate-Bearing Sediments Behavior: Phase Change and Multiphase Flow (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 865

Prof. Nicolas Espinoza (The University of Texas at Austin), Dr. Xiongyu Chen (The University of Texas at Austin), Mr. Jeffery Luo (The University of Texas at Austin), Prof. Nicola Tisato (The University of Texas at Austin), Prof. Peter Flemings (The University of Texas at Austin)

We use X-ray computed micro-tomography (μCT) to perform time-lapse monitoring of methane hydrate formation and dissociation in sand partially saturated with potassium iodide brine under excess-gas and excess-water conditions. The experiments show pore-scale coexistence of gas, brine and hydrate with unambiguous phase segmentation. Furthermore, the calibration of CT number with salinity allows us to quantify ion exclusion from brine-hydrate mixtures and brine freshening during dissociation. Porous hydrate and brine are mixed together during initial phases of formation. However, they evolve into separate phases as brine salinity increases and hydrate growth continues. The system evolves toward three-phase equilibrium of gas, hydrate and brine, resulting in very heterogeneous hydrate distribution, even in homogenous sand-packs. Upon depressurization, hydrate located next to large gas-filled pores and next to the vessel walls dissociate first. At late stages of dissociation, the water from hydrate mixes with concentrated brine and forms a connected brine phase with gas and hydrate pockets. The μCT images show a very distinct hydrate/brine/gas habit after dissociation depending on initial hydrate saturation. The results show new pore-scale observations during hydrate formation and dissociation that help to understand the in-situ conditions of natural sedimentary systems and evolution upon gas production.

Numerical Modeling of Gas Hydrate-Bearing Sediments Behavior Under Isotropic Consolidation with Gas Hydrate Dissociation

Wednesday, 19th June - 16:15: MS31 - Gas Hydrate-Bearing Sediments Behavior: Phase Change and Multiphase Flow (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 669

Dr. Xuerui Gai (National Energy Technology Laboratory), Dr. Shun Uchida (Rensselaer Polytechnic Institute), Dr. Evgeniy Myshakin (National Energy Technology Laboratory), Dr. Jeenshang Lin (University of Pittsburgh), Dr. Liang Lei (National Energy Technology Laboratory), Dr. Yongkoo Seol (National Energy Technology Laboratory)

Gas hydrate-bearing sediments (GHBS) are natural sediments that formed in permafrost and sub-marine settings where the temperature and pressure conditions maintain the stability of gas hydrate. Gas hydrate has been recognized as possible future energy resources and it also closely related with many engineering and environment problems. Gas production from gas hydrate bearing sediments is accompanied with coupled Thermo-Hydro-Chemo-Mechanical (THCM) processes that involve endothermic gas hydrate dissociation, multiphase flow and heat fluxes in porous media, and mechanical deformation of the sediments. This study presents a THCM coupled code developed by National Energy Technology Laboratory's group. The code couples flow and geomechanical components through a sequential technique. The technique provides a possibility of a two-way coupling, at which porosity is updated with effective stress change induced by gas hydrate decomposition and pore pressure changes. A case study of a gas hydrate-bearing sample under isotropic consolidation condition and gas hydrate dissociation shows the capabilities of the developed code.

Numerical study of CO2-CH4 hydrate exchange within gas hydrate-bearing sediments

Wednesday, 19th June - 16:30: MS31 - Gas Hydrate-Bearing Sediments Behavior: Phase Change and Multiphase Flow (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 194

Ms. Shuman Yu (Rensselaer Polytechnic Institute), Dr. Shun Uchida (Rensselaer Polytechnic Institute)

Carbon dioxide (CO_2) injection into methane (CH_4) hydrate-bearing sediments is deemed to facilitate a carbon-neutral and geomechanical stability-favored energy production. When the temperature is lower than approximately 281 K, CO_2 hydrate is more stable than CH_4 hydrate, leading to replacement of CH_4 hydrates with CO_2 hydrates as a result of the phase changes of CH_4 from hydrates to gaseous and CO_2 from gaseous to hydrates. This results in sequestration of CO_2 gas with a little change in the state of the hydrate-bearing sediments and thus may achieve carbon neutrality and geomechanical stability. Due to the complexities involved such as generation of gas mixtures and hydrate mixtures, however, it still remains a challenge to develop a comprehensive analytical model to capture the CO_2-CH_4 hydrate replacement process. This work presents a coupled thermo-hydro-chemo-mechanical formulation including the equations of state for gas mixtures and the phase pressure evolution model for hydrate mixtures and its applicability to the existing laboratory experiments. Good agreements between numerical and experimental results imply that the proposed formulation can provide production assessment of CO_2 injection and reliable prediction of production-related response of gas hydrate-bearing sediments.

Crustal fingering facilitates free gas migration through the hydrate stability zone

Wednesday, 19th June - 16:45: MS31 - Gas Hydrate-Bearing Sediments Behavior: Phase Change and Multiphase Flow (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 1200

Dr. Xiaojing Fu (University of California, Berkeley), Prof. Joaquin Jimenez-Martinez (Swiss Federal Institute of Aquatic Science and Technology), Dr. William Carey (Los Alamos National Laboratory), Dr. Hari Viswanathan (Los Alamos National Laboratory), Prof. Luis Cueto-Felgueroso (Technical University of Madrid), Prof. Ruben Juanes (Massachusetts Institute of Technology)

Widespread methane seepage at deep seafloors suggests free gas can migrate through hydrate-stable regions of the marine sediments. Such observations, however, contradict with hydrate equilibrium thermodynamics, which predicts that three-phase coexistence of free gas, water and hydrates are rare. Thus, a long standing question in gas hydrates community has been to address mechanisms with which free gas can bypass hydrate stability zones. In this work, I will describe how the spontaneous formation of a solid hydrate crust on a moving gas-liquid interface gives rise to a new type of flow instability we term crustal fingering. We demonstrate crustal fingering with analog microfluidic experiments and describe the key physical processes using phase-field modeling and high-resolution simulations. I will further show that this solid-modulated gas percolation mechanism is crucial to our understanding of methane venting in the world's oceans, gas hydrate dissociation as a trigger to landslides, and energy extraction from gas hydrate deposits.

A Virtual Database of Relative Water and Gas Permeability for Hydrate-Bearing Sediments

Wednesday, 19th June - 17:00: MS31 - Gas Hydrate-Bearing Sediments Behavior: Phase Change and Multiphase Flow (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 1361

Dr. Nariman Mahabadi (Arizona State University)

Relative water and gas permeability equations are critical for estimating gas and water production from hydrate-bearing sediments. However, experimental or numerical studies to determine the fitting parameters of these equations are limited, or specific to a unique type of sediment. In addition, multiphase flow behavior of hydrate-bearing sediments are significantly affected by the pore-scale characteristics of the porous media such as pore size distribution, coordination number, and hydrate pore habit. This study utilized micro-focus X-ray computed tomography to extract a 3D pore-network model from a recovered hydrate sediment. The pore-scale properties of the extracted network have been repeatedly tuned to generate a virtual database of pore-networks for a wide-range of hydrate-bearing sediments. The processes of gas invasion, hydrate dissociation, gas expansion, and water and gas permeability have been simulated for the generated database. Based on the simulation results, the fitting parameters of relative water and gas permeability equations have been suggested for a full range of hydrate-bearing sediments.

Geomechanical Characteristics of Hydrate-bearing Sands

Wednesday, 19th June - 17:15: MS31 - Gas Hydrate-Bearing Sediments Behavior: Phase Change and Multiphase Flow (Gates-Thomas Room 115 (44)) - Oral - Abstract ID: 1344

Prof. Jeffrey Priest (University of Calgary), Mr. Mohammad Abbas (University of calagry.ca), Prof. Jocelyn Hayley (University of Calgary)

The production of methane gas from sand dominated hydrate reservoirs has moved a step nearer to reality over the last few years. However, robust evaluation of the economic potential and environmental risks associated with hydrate production requires a detailed understanding of the geomechanical response of the hydrate-bearing sand (HBS) during long term gas production. The limited number of intact natural HBS available for testing is such that laboratory testing of synthesized HBS is the norm. It has been shown that inclusion of ice-like hydrate within the sand can lead to significant increases in stiffness and strength (with corresponding reduction in permeability), which can be lost upon dissociation. In addition, the formation technique adopted can also influence the observed geomechanical behavior.

Herein, we present the results of an experimental study on the geomechanical characteristics of laboratory-synthesized methane hydrate-bearing sand using an advanced triaxial/resonant column apparatus. Sand was tested in four different states, namely, base sand (BS), frozen sand (FS), gas-saturated hydrate bearing sand (HS), and water-saturated hydrate bearing sand (WHS). Test specimens were evaluated for permeability, stiffness and strength. Hydrate formation increased the stiffness of the sand. However, stiffness was significantly reduced when the BS was subsequently saturated with water to form WHS; likely resulting from minor hydrate dissociation. The inclusion of hydrate and ice increased peak strength of the sand, with increasing strain-softening behavior being observed. HS had the largest increase in peak strength, with WHS the lowest. However, the WHS still exhibited inter-significant inter-granular cementation.

Multiscale modeling of soil thermal collapse

Wednesday, 19th June - 16:00: MS78 - Multiphysics Analysis of Geo-Energy Problems involving Non-Isothermal Processes (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 624

Prof. Alessandro F. Rotta Loria (Northwestern University), Dr. Jibril B. Coulibaly (Northwestern University)

Understanding the mechanical response of soils under non-isothermal conditions is paramount for the analysis and design of shallow and deep geothermal systems, nuclear waste repositories and other applications. Soils subjected to heating-cooling cycles can exhibit a reversible (i.e., thermo-elastic behavior) and/or an irreversible (i.e., thermo-plastic) behavior depending on the stress state and stress history characterizing the material structure. The so-called thermal collapse phenomenon is associated with the irreversible behavior of soils that is observed in the latter situations and causes a shrinkage of the material structure under a temperature increase. Such a behavior is common to materials like rubber where it stems from entropic changes in the configurations of polymer chains, while it is atypical in general for any material. Prior to this study, various constitutive models at the continuum scale have been made available to interpret the thermal collapse phenomenon for soils. However, a sound theoretical understanding of the fundamental physical variables and processes that govern the thermal collapse has been missing. Looking at this challenge, the present work investigates the micromechanics of the thermal collapse of soils by unraveling the origins of such a phenomenon through space-resolved numerical simulations at the particle length scale. The considered approach provides microscopic explanations regarding the role of topological reorganization of the material structure in thermal shrinkage, and contributes to the development of novel methods for engineered stabilization of soil masses, for example.

Coupled THM Modeling of a Large Scale Barrier Experiment Mimicking High-Level Radioactive Waste Disposal Conditions

Wednesday, 19th June - 16:15: MS78 - Multiphysics Analysis of Geo-Energy Problems involving Non-Isothermal Processes (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 940

Prof. Marcelo Sánchez (Texas A&M University), Dr. Beatrice Pomaro (University of Padova), Prof. Antonio Gens (Universitat Politècnica de Catalunya)

Large-scale in-situ tests have been instrumental to examine the behavior of barrier systems for the disposal of high level radioactive waste (HLRW) at full scale and under actual operational conditions. The FEBEX experiment was based on the disposal concept proposed by ENRESA (i.e. the Spanish agency for radioactive waste disposal), which envisages the canisters (enclosing the nuclear waste) placed in horizontal drifts excavated in a granite and surrounded by a clay barrier made up of highly compacted bentonite blocks. The thermal effect of the HLWR is simulated by means of two cylindrical heaters that maintain a maximum constant temperature of 100°C at the contact between the clay and the heater. The behavior of the barrier system is highly complex, since it involves coupled thermo-hydro mechanical (THM) phenomena triggered by the simultaneous heating and hydration under confined conditions that take place during the repository time life. A fully coupled THM approach is adopted in this work to model the FEBEX experiment. The numerical analysis starts with the initial hydration and heating of the in-situ test and ends with its final dismantling around 18 years later. The model parameters for the hydraulic, mechanical and thermal constitutive models are obtained from independent experiments conducted at the beginning of the operational stage of the FEBEX experiment. This paper discusses in detail the main comparisons between the model predictions and the experimental observations. A very satisfactory performance of the model was obtained in terms of temperature, relative humidity, stresses, clay barrier moisture and density.

Effect of Heat Transfer Mechanisms on Thermal Response of Horizontal Heat Exchangers

Wednesday, 19th June - 16:30: MS78 - Multiphysics Analysis of Geo-Energy Problems involving Non-Isothermal Processes (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1191

Mr. Matthew Hayes (University of Illinois at Urbana-Champaign), Dr. Tugce Baser (University of Illinois at Urbana-Champaign), Dr. Ayse Ozdogan Dolcek (Balikesir University)

This paper focuses on the characterization of transient thermal response of horizontal heat exchange system installed in unsaturated soils. Horizontal heat exchange systems are relatively cost-effective compared to vertical heat exchange systems when there is sufficient space available due to ease of installation in trenches and maintenance. Because these systems are installed very close to the surface (i.e. up to 5 m), there are numbers off actors affecting heat transfer such as ambient air temperature penetration into the ground and coupled heat transfer and water flow. Extensive heat transfer analyses have been developed to evaluate the vertical heat exchange systems, but fewer focus on the transient thermal response of horizontal heat exchangers. To investigate the effect of different heat transfer mechanisms in the subsurface, a three-dimensional (3D), transient finite element model was built in COMSOL to investigate the effect of transient weather and thermal loading conditions as well as coupled heat transfer and water flow processes in the unsaturated soil within a horizontal heat exchange system. The actual ambient air data and operational inlet fluid temperatures as well as coupled thermo-hydraulic soil properties were used in the analysis to assess the effect of different heat transfer mechanisms and outlet pipe temperatures were compared.

Coupled thermo-hydro-mechanical analysis of unsaturated subgrade soils under freeze-thaw cycles

Wednesday, 19th June - 16:45: MS78 - Multiphysics Analysis of Geo-Energy Problems involving Non-Isothermal Processes (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 381

Mr. Zhuang Zhuo (Rowan University), Dr. Ayman Ali (Rowan University), Dr. Yusuf Mehta (Rowan University), Dr. Cheng Zhu (Rowan University)

Cyclic freezing and thawing effects on subgrade soils cause substantial damage to the overlying pavement in cold regions. With each freeze-thaw cycle, soils are subjected to complex thermos-hydro-mechanical (THM) couplings. Many multiphysical models have been developed to simulate THM effects on geomaterials. However, these models generally ignore the phase change in water and the interaction of multiple phases in unsaturated soil (i.e. water, ice, air, and soil particle), which are the underlying mechanisms responsible for frost heaving and thawing weakening in pavements. This study aims to develop and validate a theoretical framework incorporated with phase change in water to capture the deformation and stress evolution in subgrade soils. The theoretical THM framework developed for porous materials accounts for time-dependent multi-physics processes in soils under freezing and thawing. Numerical implementation of the framework into a Finite Element Program is carried out to assess the performance of the overall pavement structure. We configure a three-dimensional model and calibrate the model with published experimental data. Parametric analyses are performed to better understand the dependence of the behavior of subgrade and pavement layers on soil properties under cyclic temperature variations. Simulation results show the distribution of fluid pressure and stress fields in soils under heating and cooling, with more differences observed if phase change or phase interaction is considered. This study is expected to bring new insights into the improved design of pavements in cold regions.

Heat Transfer from Spherical Heat Sources to an Infinite Bi-Material Toward Geothermal Energy Applications

Wednesday, 19th June - 17:00: MS78 - Multiphysics Analysis of Geo-Energy Problems involving Non-Isothermal Processes (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 729

Mr. Tengxiang Wang (Columbia University), Prof. Huiming Yin (Columbia University)

This paper derives the Green's function for heat transfer in an infinite three-dimensional (3D) domain consisted of two semi-infinite domains with different material properties, which is subjected to a steady-state or sinusoidal point heat source. Using Eshelby's equivalent inclusion method (EIM), the Green's function has been applied to determine the temperature field of a spherical particle filled in an infinite bi-material. When one material has zero or infinite thermal conductivities, the above solution can be used for a semi-infinite domain containing a heat source with heat insulation or constant temperature on the boundary, respectively. The formulation is used to simulate a spherical heat source of a phase change material (PCM) embedded in a semi-infinite domain. Different models of PCM simulation are established and results are compared to validate each model. The method can be used for geothermal energy applications.

Microstructural-Nanomechanical-Chemical Mapping to Examine Material-Specific Characteristics of Cementitious Interphase Regions

Wednesday, 19th June - 16:00: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 3 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1056

Ms. Mahdieh Khedmati (U. Nebraska), Prof. Yong-Rak Kim (U. Nebraska), Prof. Joseph Turner (U. Nebraska)

Effective properties and structural performance of cementitious mixtures are substantially governed by the quality of the interphase region because it acts as a bridge transferring forces between aggregates and a binding matrix and is generally susceptible to damage. As alternative binding agents like alkali-activated precursors and recycled materials have obtained substantial attention in recent years, there is a growing need for fundamental knowledge to uncover interphase formation mechanisms. In this paper, two different types of binding materials (i.e., fly ash-based geopolymer and ordinary portland cement) were mixed with three different aggregates (i.e., limestone, quartz, and recycled concrete aggregate) to examine and compare the microstructures and nanomechanical-chemical characteristics of interphase region. To this end, microstructural characteristics using scanning microscopies, nanomechanical properties by nanoindentation tests, and spatial mapping of chemical contents based on the energy dispersive spectroscopy were integrated to identify and investigate the interphase region formed by the case-specific interactions between the binding matrix and aggregate. The microstructural-nanomechanical-chemical mapping was effective to better understand links between material-specific properties of cementing phases. More specifically, the fly ash-based geopolymer paste was usually well bonded to the aggregate surface with a rich formation of N-A-S-H gel, while interfacial debonding was often observed between aggregate surface and paste in ordinary portland cement concrete. In addition, geopolymeric materials can reach the pre-existing incomplete interphase within recycled concrete aggregate and create hydration-geopolymerization products that combine calcium-silicate-hydrate (C-S-H) and sodium aluminosilicate hydrate (N-A-S-H) gel.

PRISMS-Plasticity Crystal Plasticity Finite Element Software

Wednesday, 19th June - 16:15: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 3 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1144

Dr. Mohammadreza Yaghoobi (University of Michigan, Ann Arbor, MI), Dr. Sriram Ganesan (University of Michigan, Ann Arbor, MI), Mr. Srihari Sundar (University of Michigan, Ann Arbor, MI), Mr. Aaditya Lakshmanan (University of Michigan, Ann Arbor, MI), Prof. John Allison (University of Michigan, Ann Arbor, MI), Prof. Veera Sundararaghavan (University of Michigan, Ann Arbor, MI)

An open source parallel 3-D crystal plasticity finite element (CPFE) software package PRISMS-Plasticity is presented here as a part of PRISMS integrated computational materials engineering (ICME) framework. A highly efficient rate-independent crystal plasticity algorithm is implemented along with developing a new algorithmic tangent modulus. Additionally, a twin activation mechanism is incorporated into the framework based on a Gauss integration point sensitive scheme. Next, the integration of the software as a part of the ICME framework is demonstrated. To do so, the integration of the PRISMS-Plasticity software with experimental characterization techniques such as electron backscatter diffraction (EBSD) and synchrotron X-ray diffraction using available open source software packages of DREAM.3D and Neper is elaborated. The integration of the PRISMS-Plasticity software with the information repository of Materials Commons is also presented. The parallel performance of the software is investigated in the next step which demonstrates it can satisfactory scale for large-scale problems running on hundreds of processors. Various examples of polycrystalline metals with different crystal structures of face-centered cubic (FCC), body-centered cubic (BCC), and hexagonal close packed (HCP) are presented to show the capability of the software to efficiently handle the corresponding problems in addition to integration with preprocessing and postprocessing tools.

A fully coupled periporomechanics model for modelings multiphysics behaviour of unsaturated porous media with chemical effect

Wednesday, 19th June - 16:30: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 3 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 563

Prof. Xiaoyu Song (University of Florida), Mr. Shashank Menon (University of Florida)

We develop a fully coupled periporomechanics model for simulating localized failure in unsaturated porous media with chemical effect. The novelty of the new formulation is twofold. First, the field equations are integral equations with no assumptions on the continuity of solid displacement and pore pressures which are long-sought features for modeling discontinuities of multiphysics fields of unsaturated porous media. Second, the formulation includes an intrinsic length scale in the field equations which can be adapted to characterize the size dependence of the mechanical behavior of unsaturated porous media. In this framework, the deformation of the solid skeleton is modeled by a chemo-plastic constitutive model through the correspondence principle. The meshfree numerical implementation is validated against classical closed-form solutions. We then run numerical simulations of strain localization in unsaturated porous media with chemical effect. The numerical results demonstrate that the proposed periporomechanics model is robust in simulating the inception of strain localization and capturing the thickness of shear bands in unsaturated porous media with chemical effect.

Design and Simulation of a Novel Wave Energy Converter for High Energy Harvesting Efficiency

Wednesday, 19th June - 16:45: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 3 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 735

Mr. Tengxiang Wang (Colum), Dr. Junhui Lou (Columbia University)

This paper presents a numerical method to predict the energy harvesting of a novel wave energy converter (WEC) under ocean/irregular waves. As the waves pass by, the oscillating water pressure on the flexible surface of the WEC moves the pistons of the power take-off (PTO) system, in such a way the wave energy is converted into electricity. In the numerical model, the interaction between the WEC body and waves is considered using a boundary element method, where the hydrodynamic parameters of added mass and radiation damping are calculated at each wave frequency. Then the response of the WEC under irregular waves is calculated in the time domain, where wave forces are calculated based on linear assumption. The results show that the WEC can reach a high energy conversion rate through system optimization (adjusting the stiffness and mass of the PTO system).

Additive Manufacturing of Self-Healing Elastomers

Wednesday, 19th June - 17:00: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 3 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 956

Mr. KUN-HAO YU (University of Southern California), Prof. Qiming Wang (University of Southern California)

Nature excels in both self-healing and 3D shaping; for example, self-healable human organs feature functional geometries and microstructures. However, tailoring man-made self-healing materials into complex structures faces substantial challenges. Here, we report a paradigm of photopolymerization-based additive manufacturing of self-healable elastomer structures with free-form architectures. The paradigm relies on a molecularly designed photoelastomer ink with both thiol and disulfide groups, where the former facilitates a thiol-ene photopolymerization during the additive manufacturing process and the latter enables a disulfide metathesis reaction during the self-healing process.We find that the competition between the thiol and disulfide groups governs the photocuring rate and self-healing efficiency of the photoelastomer. The self-healing behavior of the photoelastomer is understood with a theoretical model that agrees well with the experimental results. With projection microstereolithography systems, we demonstrate rapid additive manufacturing of single- and multimaterial self-healable structures for 3D soft actuators, multiphase composites, and architected electronics.Compatible with various photopolymerization-based additive manufacturing systems, the photoelastomer is expected to open promising avenues for fabricating structures where free-form architectures and efficient self-healing are both desirable.

Multiscale Modeling of Cracking in Heterogeneous Materials Using an Adaptive Element Elimination Method

Wednesday, 19th June - 17:15: MS74 - 4th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures; Part 3 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 867

Mr. Keyvan Zare-rami (U. Nebraska), Prof. Yong-Rak Kim (U. Nebraska)

Two-way linked multiscale simulation is an effective approach to simulate progressive damage of heterogeneous materials. A new approach is developed and implemented in the finite element framework to simulate cracking in heterogeneous materials using two-way linked multiscale method. In this approach, the averaged properties at the larger length scale are obtained from homogenizing the response of representative volume elements (RVEs) which represent the heterogeneity at the smaller length scale. Damage development within the RVE is simulated as the formation of microcracks using a nonlinear cohesive zone method. It is assumed that failure of RVE corresponds to location-specific global-scale fracture (i.e., crack propagation). Toward that end, the current study includes two major efforts: to assess the failure of RVEs and to link RVE's failure to the crack propagation at the larger length scale. The stress analysis and the bifurcation analysis methods were implemented to assess the failure of RVEs. Also, the crack propagation at the larger length scale was simulated using an adaptive element elimination method. The whole framework was verified by simulating the three-point bending beam specimens where potential fracture zone was linked to corresponding RVEs.

Quantification of Resourcefulness for community Resilience framework

Wednesday, 19th June - 16:00: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1168

Mr. Alessandro Zona (Politecnico di Torino), Mr. Omar Kammouh (Politecnico di Torino), Prof. Gian Paolo Cimellaro (Politecnico di Torino)

MCEER's "4-R" approach to Resilience put a question about the quantification of Resourcefulness, which is capacity to identify problems, establish priorities, allocate and mobilize resources before, during and after an event that threaten to disrupt some element, system, or other unit of analysis. Since there are no attempts in literature to quantify this dimension, the paper goal is to develop a resourcefulness index, reasoning on the theoretical framework and relevant indicators, which include issues apparently impossible to evaluate, as heterogeneity of economic sectors, government fragility, trust and creativity.

After having explored the state of the art about the construction of composite indicators, we have selected the most proper methods to input missing data, normalize, assign weights and finally aggregate indicators to calculate the Resourcefulness index.

The methodology has been applied using as case study the entire United States, computing its Resourcefulness index and, above all, checking the consistency between the results and the theoretical framework.

Encouraging results shown by the methodology pave the way for its implementation in communities' resilience frameworks to point out weaknesses of communities which display low resilience and to guide policymakers.

Probabilistic Resilience Distance Measures and Application for Rural Power Distribution Systems

Wednesday, 19th June - 16:15: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 505

Mrs. Prativa Sharma (University of Missouri Kansas City), Dr. Zhiqiang Chen (University of Missouri Kansas City)

For over a decade now, the research community has been doing an extensive study for quantifying the resilience of infrastructure systems to natural or man made disruptions. Several quantitative resilience measures or ambiguously termed metrics are found, most of which are based on the calculation of the geometric area under a select recovery function. However,objective decisions based on such measurements are not ready to make. One ingrained drawback of such measurements is its lack of theoretical basis in discriminating relatively that how a parametric infrastructure system is more resilient than a different one or the same one subject to some changed conditions. In short, besides measuring resilience, theoretic measures of resilience distances (RD) are essentially entailed. Such RD measures can be defined between two different systems (inter-system RDs) or the same systems indifferent states (intra-system RDs). This paper has a two-fold purpose. First,a probabilistic framework for resilience-distance measures is proposed and formulated, and several statistical or information-theoretic resilience-distance measures and strictly defined mathematical metrics are proposed. Second, with the witnessed high vulnerability and the low resilience of rural power distribution systems in recent extreme hurricane events, the proposed RD measures are applied to evaluate and compare their relative resilience. The experimental evaluation in this paper proves the effectiveness of the proposed resilience distance measures, making the proposed probabilistic resilience-distance measurement framework a possible objective decision-making tool.

RELIABILITY ASSESSMENT MODELLING OF DETERIORATING CAST IRON WATER MAINS SUBJECTED TO MOISTURE INDUCED SOIL EXPANSION

Wednesday, 19th June - 16:30: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1296

Mr. Piyius Raj Singh (University of Waterloo), Prof. Amit Kanvinde (University of California, Davis), Prof. Sriram Narasimhan (Univeristy of Waterloo)

As of 2018, approximately 82% cast iron water pipes in US and Canada are over 50 years old and have experienced a 43% increase in break rate. Following the current replacement rate, this would mean a 125-year replacement schedule. A preliminary investigation on the probable causes of fracture of deteriorated cast iron water mains reveals flexural failure due to differential soil expansion as the primary one. The present work combines a physics based mechanical model with risk-based probabilistic assessment to quantify deterioration and remaining life of cast iron water pipes. A simplified analytical model supported by a sophisticated finite element model is developed to simulate pipe stresses caused by moisture induced differential soil heave/settlement. This analytical model accounts for soil non-linearity and can be calibrated with experimental or field measurements if available. The analytical model formulates the expression for strength demand of pipe and the strength capacity is computed using the American Water Works Association model for external corrosion and fracture mechanics to construct a limit state function, expressing the boundary between failure and non-failure states. The probability of failure is then evaluated using structural reliability analysis and consequently remaining life of aging pipes. Finally, the applicability of the proposed system is illustrated by forecasting the failure probability of cast iron water pipes in the City of Sacramento, California, US.

MULTISCALE RESILIENCE ASSESSMENT OF INTERDEPENDENT LIFELINE SYSTEMS SUBJECTED TO A SERIES OF EARTHQUAKES

Wednesday, 19th June - 16:45: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 519

. Szu-Yun Lin (University of Michigan, Ann Arbor, MI), Prof. Sherif El-Tawil (University of Michigan, Ann Arbor, MI)

Modeling disasters and the subsequent recovery effort is complicated by the vastly differing time scales for both phases of the process, i.e., seconds or minutes as the hazard unfolds versus days or months as the recovery process takes place. It is also challenging to model the varying spatial scales, e.g., component (meters) versus system level (kilometers) within an integrated framework. A distributed computational platform is proposed to address this challenge. The simulation breaks down the hazard and recovery efforts into a set of simulators, each of which handles a specific part of the overall process. Simulators are considered black boxes that interact together through a publish-subscribe data transmission pattern. The framework's highly decentralized nature permits handling the varying spatial and time scales in a natural and convenient manner. A case study, representing an existing community with interdependent lifeline systems subjected to two subsequent seismic shocks, is presented to highlight the capabilities of the proposed system. Multiscale interdependency within the community is considered and various recovery resource allocation strategies are examined.

Optimal Adaptive Monitoring of Redundant Systems of Binary Components

Wednesday, 19th June - 17:00: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1097

Mr. Chaochao Lin (Carnegie Mellon University), Prof. Matteo Pozzi (Carnegie Mellon University)

Many infrastructure systems can be modeled as networks of components with binary states. Information about the components' conditions, collected by sensors or inspectors, can enhance the maintenance process at the system level. However, it is often impractical to monitor all components, due to budget constraints. Hence, it is crucial to assign appropriate priority among component inspections.

Previous research shows that, for a one-shot maintenance problem of redundant systems such as parallel networks, the inspection of the most reliable component has the highest Value of Information and, thus that component should receive the highest priority. This result is counter-intuitive and seems to be inconsistent with reasonable inspection planning.

This paper investigates the long-term adaptive monitoring process of redundant systems, using a sequential decision-making framework. At each time step, the agent can select a subset of components to be inspected, with the goal of minimizing long-term maintenance costs. In this context, the highest priority can be assigned even to the most vulnerable component, depending on the discount factor modeling the time value of money related to future costs. We investigate the optimal monitoring planning and maintenance process as a function of parameters such as: the ratio of component repair and system failure cost, the system deterioration model, the current failure probability for the components, and we compare the results with the one-shot inspection plans.

Periodic barriers for seismic hazard mitigation of civil infrastructures

Wednesday, 19th June - 17:15: MS100 - Risk and Resilience Assessment of Civil Infrastructure Systems; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 687

Ms. Hsuan Wen Huang (University of Houston), Dr. Kalyana B.Nakshatrala (University of Houston), Ms. Claryssa Merino (University of Houston), Ms. Kimberly Ruiz (University of Houston), Prof. Y. L. Mo (University of Houston)

Periodic (phononic) metamaterials possess a unique characteristic to filter out the waves within its frequency bandgap, and one can utilize such a feature as a waveguide in various engineering applications. In civil engineering, periodic metamaterials can be used to mitigate the damage to civilian infrastructures caused by earthquakes. In this study, we focus on utilizing periodic metamaterials as effective seismic isolators. Previous studies have shown that a periodic foundation, essentially a foundation composed of periodic metamaterial, can successfully attenuate the disturbances caused by body waves (P and S waves) that have the frequencies within its frequency bandgap. We now take the next logical step to demonstrate that one can also use periodic metamaterials for filtering the surface waves. A trench-type wave barrier, developed for blocking high-frequency human-made surface waves, was found to be useful especially when the trench is empty. However, it is quite challenging to maintain an empty trench and avoid it from collapsing. On the other hand, periodic barrier, which is the trench-type wave barrier filled with periodic metamaterials, is expected to filter the seismic waves and it will be easier to maintain. Our study includes modeling both the empty trench wave barrier and periodic barrier based on ABAQUS simulations. We will also briefly describe the large-scale field testing that we are planning to implement soon, which will be used eventually to validate the finite element simulations.

Multiscale material modeling for improved phenotyping of oat stalk strength

Wednesday, 19th June - 16:00: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 3 (147 Noyes (84)) - Oral - Abstract ID: 841

Mr. Tarun Gangwar (University of Minnesota), Dr. Jo Heuschele (University of Minnesota), Prof. Kevin Smith (University of Minnesota), Prof. Alex Fok (University of Minnesota), Prof. Dominik Schillinger (University of Minnesota)

In this talk, we investigate material and morphological factors to develop a better understanding of oat stalk strength. In the first part, we focus on a micromechanics approach that derives a hierarchical microstructure driven model of macroscopic stiffness and strength properties of oats. As model input, it requires mechanical properties of the base constituents such as cellulose and lignin as well as morphology and volume fractions of all heterogeneous components at each hierarchical level. The latter are retrieved from chemical analysis and imaging data at different length scales, obtained from scanning electron microscopy, transmission electron microscopy and light microscopy. We validate our model against standard bending experiments that we conducted in our lab with oat stem samples. Our results demonstrate that the micromechanics model provides excellent accuracy without any further phenomenological calibration. In the second part, we employ our material model in macroscale finite element analysis of oat stems to predict their strength and failure behavior. Our simulation results predict the major failure modes observed in both a laboratory setting and in the field and enables a better physics-based understanding of the stalk strength. We finally discuss how our results will support the exploration of suitable phenotypes for oat varieties with improved lodging resistance.

Experimental and Numerical Investigation of the Mechanical and Fracture Properties of Rat Bone Based on a 3D-Multiscale Modeling Framework

Wednesday, 19th June - 16:15: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 3 (147 Noyes (84)) - Oral - Abstract ID: 868

Mr. Santosh Reddy Kommidi (U. Nebraska), Prof. Yong-Rak Kim (U. Nebraska), Prof. Do-gyoon Kim (The Ohio State University)

Alterations in the bone microstructure due to remodeling, growth and disease such as osteoporosis can significantly change the overall global behavior of the bone and its ability to resist fracture. The current study is aimed at capturing the viscoelastic behavior of bone and its viscoelastic-plastic fracture properties using a multiscale experimental-computational approach. The framework used to model the behavior and simulate fracture process zones utilizes a two-way coupled modeling where the homogenized global scale is linked to a site or location specific heterogeneous local scale. Such an analysis will provide a better understanding of detailed mechanisms responsible for inelastic deformation and fracture initiation at the global and local scale. In doing so one can identify critical factors such as remodeling or restructuring of bone segments due to aging, osteoporosis and its related changes in bone mineral density (changes in local scale-material properties) that are responsible for deterioration of fracture resistance properties in bone. The osteoporotic effects were simulated by using two rat models (rats received a bilateral ovariectomy operation and other rats received a sham operation) where the mechanical and fracture properties were evaluated by performing cyclic three-point bending test followed by monotonic fracture test. It was observed that the 3D-multiscale modeling framework could effectively capture the viscoelastic-fracture behavior of the case-specific rat models. Also, the model showed that the morphological changes in the local-scale due to osteoporotic effects played a critical role in crack initiation and propagation at the global scale.

Mechanical Modelling of Bio-Cemented Soils

Wednesday, 19th June - 16:30: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 3 (147 Noyes (84)) - Oral - Abstract ID: 947

Dr. Xuerui Gai (Texas A&M University, College Station), Prof. Marcelo Sánchez (Texas A&M University)

Microbially induced calcite precipitation (MICP) is an innovative bio-mediated soil improvement technique that develops cementation within originally loose and potentially collapsible soils. This method utilizes biogeochemical processes with microbes and it has the advantage of being friendly to the environment and sustainable. In spite of the considerable current interest in MICP technique, the mechanical modeling of MICP treated soils behavior is yet limited. In this paper, a constitutive model for MICP treated sands is presented. The core components of the approach include a critical state yield surface, sub-loading concepts, a mechanism to account for the MICP induced cementation enhancement, and an evolution law to consider bonding degradation effects during shearing. The mathematical framework is presented in detail. The model is then applied to analyze recent published experiments involving MICP treated samples, with different calcite contents and tested under different conditions (i.e. various confining pressure and loading paths). The model was able to properly capture the main features of MICP treated sands behavior, and it also assisted to the interpretation of this type of soil responses under different loading conditions

Heterogenous Material Mapping Method Affects the Accuracy of Patient-specific Finite Element Models for Pelvic Reconstruction

Wednesday, 19th June - 16:45: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 3 (147 Noyes (84)) - Oral - Abstract ID: 973

Dr. Ata Babazadeh-Naseri (Rice University), Dr. Nicholas Dunbar (Rice University), Mr. Andrew Baines (Rice University), Dr. John Akin (Rice University), Dr. C. Fred Higgs Iii (Rice University), Dr. Benjamin Fregly (Rice University)

Long-term fixation of implant in individuals with pelvic sarcoma can be significantly improved by stimulating bone in-growth and avoiding stress shielding at the bone-implant interface. It is thus crucial for the long-term stability of pelvic implants to accurately predict bone stresses. Bone's heterogeneous material properties can be extracted from a patient's computed-tomography (CT) images to create a patient-specific finite element (FE) model. However, assigning these CT-derived material properties to the FE model requires a mapping step for which different node- and element-based methods have been proposed. In this research, CT images from pelvic bone of three individuals with osteosarcoma are used to extract material properties of trabecular bone. In addition, artificial heterogeneous materials, which resemble the cancellous bone, are generated using random fields. FE analyses are performed to evaluate the sensitivity of the stress and strain distributions within the bone to the choice of MMM. Different methods for assigning CT-derived material properties to FE model are tried. The models are subjected to different loading conditions for which stress and strain energy density values are extracted, and error measures are calculated. In addition, the sensitivity of each MMM to the FE mesh-size is evaluated by varying the FE mesh from a coarser to a finer mesh. Overall, node-based MMMs demonstrated a superior performance to element-based MMMs by achieving higher accuracy and requiring lower preprocessing. Mesh sensitivity analyses also showed that node-based methods offered stable convergence, whereas element-based methods exhibited a considerable variation in the accuracy as mesh size varied.

Naturally motivated concrete healing

Wednesday, 19th June - 17:00: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 3 (147 Noyes (84)) - Oral - Abstract ID: 1160

Ms. Jessica Rosewitz (Worcester Polytechnic Institute), Prof. Suzanne Scarlata (Worcester Polytechnic Institute), Prof. Nima Rahbar (Worcester Polytechnic Institute)

Concrete is the most built construction material worldwide. Its brittle nature leads to frequent repair or replacement at both economic and environmental cost. Traditional repair is a lengthy exothermic process requiring mortar and epoxies, emerging in a less resilient state than original. Novel SOTA methods employ microbes resulting in structures with reduced strength and reliability. Our preferred method is to use trace amounts of the ubiquitous enzyme *Carbonic anhydrase*(CA) to facilitate rapid concrete repair, laying the groundwork for a new class of self-healing materials. The CA enzyme catalyzes carbon dioxide and calcium ions to create calcium carbonate, which self-assembles to repair concrete. The strengths of CA-catalyzed concrete healing are consumption of CO_2, low heat generation, and avoidance of unhealthy reagents. Testing for strength and water-permeability of the CA-catalyzed repair shows regains in material properties as compared to intact samples, and improved over a simple mortar repair. This concrete healing method is inexpensive, safe, and efficient.

Mechanics as a New Marker for Cancer Metastasis to Bone

Wednesday, 19th June - 17:15: MS1 - 18th Symposium on Biological and Biologically Inspired Materials and Structures; Part 3 (147 Noyes (84)) - Oral - Abstract ID: 726

Prof. Kalpana Katti (North Dakota State University), Dr. Md. Shahjahan Molla (North Dakota State University), Mr. Sumanta Kar (North Dakota State University), Prof. Dinesh Katti (North Dakota State University)

Prostate and breast cancer both exhibit a strong propensity to metastasize to bone at which point the prognosis for patients is poor. Cancer when diagnosed at the primary site is treatable. However, more than 90% of cancer-related deaths result from metastasis. Current *in vivo* studies modeling prostate and breast cancer metastasis to bone have failed because the animals die before the metastasis to bone occurs. Human samples at bone metastasis are difficult to obtain as patients are under hospice care. We report the development of a humanoid testbed for cancer metastasis to bone. A bone mimetic nanocomposite comprising of amino acid intercalated nanoclays, biomineralized hydroxyapatite and polycaprolactone is used for fabrication of scaffolds that enable human mesenchymal cells to differentiate and form human like bone tissue. After generation of the extracellular matrix, scaffolds are seeded with human prostate cells and breast cancer cells. The testbed enables development of early stage of osteoblastic cancer colonization by developing tight junction tumoroids and inducing mesenchymal to epithelial transition or late stage metastasis. During bone metastasis, cancer cells exhibit complex biochemical, morphological, pathophysiological, and genetic changes. We report here that these changes are effectively captured by evaluating nanomechanical properties of cancer cells during metastasis. Immunocytochemistry and qRT-PCR experiments illustrate correlation between changes to cytoskeleton and nanomechanical changes of prostate cancer cells. As metastasis progresses, we observe significant softening of prostate cancer cells. For the first time, the evolution of mechanics at metastasis, providing a mechanobiological pathway of cancer progression during metastasis is reported.

Numerical simulations of viscoplastic Cosserat continua with thermo-chemical couplings

Wednesday, 19th June - 16:00: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 3 (142 Keck (72)) - Oral - Abstract ID: 1136

Dr. Hadrien Rattez (Duke University), Prof. Manolis Veveakis (Duke University)

Most of earthquakes are nucleated in the brittle part of the lithosphere along preexisting faults. Observations from drilling or outcrops have shown a localization of the deformations in seismogenic faults in a very thin zone called the principal slip zone that accommodates most of the slip. This phenomenon is also observed experimentally and is also related to the different physical couplings occurring in a fault. The size of this zone plays a major role as it affects the energy budget of the system and its stability.

Strain localization can be captured correctly using visco-plasticity and Cosserat continuum theories together with thermo-chemo-mechanical couplings. In this study, the fault core is modelled as a saturated infinite sheared layer under multi-physical couplings. An inverse analysis of the laboratory derived stress-strain curves is conducted in light of the microstructural information obtained from DIC analysis of the CT-scan images, with the aim of finding the best constitutive parameters that enable to fit the macroscopic response of the system and the kinematics fields. The simulations enable us to understand the role of various phenomena on the behavior of a fault, such as endothermic reactions, flash heating, the size of the microstructure and grain breakage, among others, on the thickness of the band but also on the mechanical response of the system.

Identification of deformation instabilities caused by fluid injection in unsaturated porous media

Wednesday, 19th June - 16:15: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 3 (142 Keck (72)) - Oral - Abstract ID: 986

Ms. Yanni Chen (Northwestern University), Prof. Giuseppe Buscarnera (Nothwestern University)

Evidence shows that fluid-infiltrated inelastic porous media are vulnerable to fluid injection and may exhibit instabilities marked by sharp suction loss and rapid deformation. In this work, the field equations that govern coupled flow-deformation processes in unsaturated deformable solids are investigated from an analytical standpoint, with the purpose to link the ill-posedness of the governing equations and the violation of material stability. It is shown that for elasto-plastic materials the singularity of the constitutive operator is linked to a loss of definition of the diffusion coefficient, therefore linking the mathematical ill-posedness of the field equation to the lack of uniqueness of the underlying hydro-mechanical constitutive response. Conversely, it is shown that the use of an elasto-viscoplastic constitutive law is an efficient countermeasure to suppresses such form of instability by allowing more robust numerical analyses of coupled hydro-mechanical problems in the vicinity of unstable conditions. To validate the results, a simple 1D finite element program is developed to simulate infiltration tests for both elasto-plastic and elasto-viscoplastic materials. The analyses reveal that, although the loss of elasto-viscoplastic stability (i.e., sharp acceleration of the system response) is located in the proximity of the unstable states predicted by the rate-independent model, the presence of viscosity delays the onset of failure and enables post-peak simulations, thus offering a useful diagnostic tool to study runaway failures triggered by fluid injection.

Geochemical alternation of the mechanical properties in sandstone formations

Wednesday, 19th June - 16:30: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 3 (142 Keck (72)) - Oral - Abstract ID: 423

Dr. Marta Miletic (Auburn University), Dr. Lauren Beckingham (Auburn University)

The rapid industrialization associated with human activities has caused an unprecedented increase in the emission of greenhouse gases, especially carbon dioxide (CO_2), to the atmosphere. Geological sequestration of CO_2 in deep underground formations is a promising means of reducing atmospheric CO_2 emissions. Once injected, CO_2 dissolves into formation brine, lowering pH and creating conditions favorable for mineral dissolution. Cations released from dissolving minerals may create conditions favorable for secondary mineral precipitation which can result in the long-term mineralogical trapping of injected CO_2. These reactions may alter the natural rock mechanical properties, which can affect the safety and efficiency of geological sequestration.

This work aims to investigate the impact of CO_2 on the mechanical properties of sandstone formations. In this study, laboratory experiments are coupled with numerical simulations to evaluate the mechanical response of un-reacted and acid-reacted rocks. Sandstone samples were exposed to synthetic acidified formation brine, then tested to determine their altered mechanical properties. The mechanical properties of the rock samples were analyzed using the unconfined compression and indirect tensile tests. A constitutive model was then developed based on the chemo-plasticity framework and compared with the experimental data. The experimental and numerical results showed that exposure of rock samples to acid significantly degraded mechanical properties of the carbonate rocks due to the mineral structure breakdown, with important practical consequences for geological sequestration of CO_2.

Prediction of tertiary creep in soils with varying degree of water saturation

Wednesday, 19th June - 16:45: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 3 (142 Keck (72)) - Oral - Abstract ID: 1403

Prof. Giuseppe Buscarnera (XXX), Ms. Yanni Chen (Northwestern University), Dr. Ferdinando Marinelli (Plaxis bv)

The delayed deformation of fluid-saturated ground is a major source of infrastructure deterioration. Although such deformations often occur at slow rate and require long time to cause damage, in some circumstances they can involve major accelerations by turning slow creep into catastrophic runaway failure. Such transitions from stable to unstable creep are often controlled by pore fluid intake, in that pore water pressure and degree of saturation play a crucial role in the resulting rate of ground movement. In this contribution the phenomenon of soil creep is investigated from an analytical standpoint. First,the mathematical conditions controlling the passage from primary (i.e.,decelerating) to tertiary (i.e., accelerating) creep are derived by using overstress viscoplasticity as reference constitutive framework. It is shown that the onset of accelerating behavior can be naturally connected with the indices that govern the stability of the underlying rate-independent plastic behavior. Most importantly, it was found the transition from stable to unstable creep is primarily controlled by drainage conditions, degree of saturation and constitutive properties. Based on these results, it was possible to identify different regimes of creep behavior as a function of capillary pressure, stress conditions and soil viscosity. These findings provide a useful platform to study the interplay between hydrologic processes and hazards for property and human life and can be used to assess patterns of evolving risk for future scenarios.

Contact Phase-Field Modeling for Materials with Spatial Irregularities

Wednesday, 19th June - 17:00: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 3 (142 Keck (72)) - Oral - Abstract ID: 849

Mr. Alexandre Guevel (Duke University), Prof. Manolis Veveakis (Duke University), Dr. Hadrien Rattez (Duke University)

As phase-field modeling is booming across various disciplines and has been proven fitted for numerically modeling interfacial problems, we aim at taking a step back and look at the fundamental hypotheses behind the model, especially with regard to the non-equilibrium implicit assumption. Starting from the two main postulates of phase-field modeling, non-equilibrium thermodynamics and maximum dissipation principle, along with the micro-momentum balance, the gradient flow equation usually obtained from a variational formulation can be extended from generalized relaxation equations to a strong form. To that end, a general contact thermodynamic framework is naturally derived from contact geometry, thus expanding Gibbs' seminal geometrical representation of thermostatics. This procedure extends the usual phase-field equations by allowing both the normal variations of the interface and the curvature variations introduced here to be fully dissipative. The curvature variations term, which has the form of a Laplacian rate, represents a secondary complementary leverage, consisting of an inhibition or viscosity effect balancing the already existing initiation effect. It is of key importance for modeling structures with spatial irregularities like geomaterials. Our objective is to try and show the role of this term in various applications, including mechanical loading of porous micro-structures and capillarity effects. For instance, the phase-field viscosity provides control over the coupling between the phase changes and the mechanical loading at the microstructural level of granular materials, hence in particular over the material's mechanical softening. The particular example of pressure solution will be discussed.

An implicit gradient model for the numerical modeling of strain localization in geomaterials

Wednesday, 19th June - 17:15: MS41 - Coupled Processes in Porous Materials: Characterization and Modeling; Part 3 (142 Keck (72)) - Oral - Abstract ID: 357

Mr. Dawei Xue (Tongji University), Prof. Xilin Lu (Tongji University), Dr. Keng-wit Lim (Simpson Gumpertz & Heger Inc.)

For the purpose of regularizing ill-posed boundary value problems caused by strain softening, an implicit gradient plasticity model and its numerical implementation are presented. According to the micromorphic approach, the thermodynamic consistency can be met and pressure-dependency in geomaterials is considered. A micro-variable corresponding to the scalar effective plastic strain is introduced to consider the effects of material heterogeneity at the microscopic level. The classical balance of momentum equation and a micro-force balance containing generalized stresses are derived based on the method of virtual power; the micro-force balance is converted into a coupled Helmholtz equation. Numerically, a finite element method coupling both the scalar effective plastic strain and the micro-variable was implemented. The applicability of the proposed method in capturing strain-softening response accompanied by localized shear bands is verified using biaxial test simulations; the obtained results are mesh-independent. The proposed method is used to study the bearing behavior and failure of a shield tunnel face in softening soil. By comparing with numerical results obtained from elastoplasticity, the influence of soil weakening on the failure mechanism of the foundation and tunnel face is clearly shown.

Semi-analytical Method for Tracking the Evolution of Borehole Breakouts

Wednesday, 19th June - 16:00: MS38 - Advances in Analytical/Numerical Modeling of Petroleum Geomechanics Problems (Baxter Lecture Hall (296)) - Oral - Abstract ID: 551

Mr. N. Beni Setiawan (Imperial College London), Prof. Robert Zimmerman (Imperial College London)

In response to the high-stress concentration, rocks at the wellbore wall will collapse if the shear failure limit is exceeded. At this stage, breakouts occur, and the shape of the wellbore enlarges from circular to roughly elliptical, and then dog-eared. The standard stress calculation method is limited to a wellbore with a circular cross-section, and hence can no longer be used. Yet, various purposes, such as post-drill open hole stability assessment, may still require information about the near-wellbore stress state after the wellbore has been damaged.

We present a semi-analytical solution for the calculation of the stresses around a wellbore having an essentially arbitrary cross-sectional shape. For a given stress state, the zone of potential hole enlargement around a wellbore is first calculated, based on some assumed failure criterion. The damaged hole contour is then captured, and the method of conformal mapping and complex elasticity potentials is used to compute the stresses around this new contour.

We find that the stress concentration around the tip of the elongated section of the borehole increases as breakout proceeds, Eventually, the iterative process continues until a shape is obtained for which the breakout will not progress further, at which point a stable state is reached. Our modeling shows that stresses around the flank of the breakout evolve so as to reduce the propensity for shear failure, which helps to explain why the breakout width (i.e., angular extent) remains relatively constant throughout the process, even as the breakout region deepens radially.

Kerogen Cracking as a Chemomechanical Approach to Hydraulic Fracturing in Organic-Rich Shales

Wednesday, 19th June - 16:15: MS38 - Advances in Analytical/Numerical Modeling of Petroleum Geomechanics Problems (Baxter Lecture Hall (296)) - Oral - Abstract ID: 646

Dr. Katherine Hull (Aramco Research Center), Prof. Younane Abousleiman (The University of Oklahoma), Mr. David Jacobi (Aramco Research Center)

Hydraulic fracturing in unconventional source rock formations has proven challenging due to the presence of the ductile hydrocarbon source material kerogen. This organic matter is dispersed among silicate, aluminosilicate and other minerals as fine laminae that compose the rock fabric. To mitigate the effects of kerogen on the hydraulic fracturing operation and enhance subsequent overall fracture conductivity, a new type of reactive fracturing fluid composed of strong oxidizers was developed. High resolution SEM imaging of shale samples before and after fluid treatment demonstrate porosity and permeability enhancement on the fractured faces of kerogen-rich shales. Reactivities were demonstrated to scale with organic matter maturity and chemical composition. The stability of the new formulation at high temperatures and the results shows promise of its use in downhole applications to improve oil and gas recovery from hydraulic fracturing in unconventional reservoirs.

Generalized Solution to the Anisotropic Mandel's Problem

Wednesday, 19th June - 16:30: MS38 - Advances in Analytical/Numerical Modeling of Petroleum Geomechanics Problems (Baxter Lecture Hall (296)) - Oral - Abstract ID: 803

Dr. Chao Liu (Aramco Services Company: Aramco Research Center-Houston), Prof. Younane Abousleiman (The University of Oklahoma)

To this day, the analytical solution for the Mandel's problem in regard to material anisotropy was the one derived by Abousleiman et al. (1996). In their solution, the response of material transverse isotropy to stress and pressure perturbation was studied and two loading orientations were considered, i.e., the load was either in parallel with or perpendicular to the axis of the material's rotational symmetry. In this work, the analytical solutions for Mandel's anisotropic poroelastic problem is derived. An arbitrary loading direction with respect to material symmetry is accounted for. This solution is a generalized one which is capable of reproducing the existing solutions as special cases of the loading orientations.

This newly-derived analytical solution is shown to serve as a benchmark for the study of saturated porous material anisotropy. It captures the effects of material anisotropy, vis-à-vis the loading orientation, on the responses of pore pressure, stress, and displacement, and can be utilized to validate numerical schemes. The solution can also be applied to simulate and analyze experiments on various porous materials including rocks such as shale, and bio-materials such as cartilage, cortical bone, and meniscus. It can be used to match, calibrate, and simulate experimental results to estimate anisotropic poromechanical parameters such as stiffness coefficients and permeabilities in any desired direction.

Poroelastic Solution to the Generalized Brazilian Test

Wednesday, 19th June - 16:45: MS38 - Advances in Analytical/Numerical Modeling of Petroleum Geomechanics Problems (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1424

Dr. Amin Mehrabian (Pennsylvania State University), Prof. Younane Abousleiman (The University of Oklahoma)

The Brazilian test, also known as the indirect tensile strength test, is a standardized laboratory method for measuring the tensile strength of brittle solids including rocks (ASTM D 3967-08; ISRM 1978). The procedure involves diametral compression of a disk-shaped specimen of the tested material until failure. The failure is expected and often observed to occur through tensile crack development along the loading line. The tensile strength of the sample is estimated from the elastic solution to the geometry and loading configuration of the Brazilian test (Hondros 1959).

This classical solution is revisited to develop the fully-coupled, poroelastic solution for the time-dependent stress and pore fluid pressure of hollow or solid, disk-shaped specimens of porous, fluid-saturated rock undergoing the diametral compression test. It is shown that the long-time asymptote of the poroelastic solution for the case of solid specimen recovers the related elastic solution of (Hondros 1959). Findings reveal the nontrivial and substantial effect of the evolving pore fluid pressure disturbances on the rock effective stress which is predicted to cause instantaneous or delayed failure of the tested specimen.

Coupled CFD-DEM-LAG Framework to Investigate Leakage of CO2 after Nanoparticle Injection in Geological Carbon Storage

Wednesday, 19th June - 17:00: MS38 - Advances in Analytical/Numerical Modeling of Petroleum Geomechanics Problems (Baxter Lecture Hall (296)) - Oral - Abstract ID: 604

Mr. Bang He (University of Utah), Prof. Pania Newell (University of Utah)

As an effective approach to reconcile the conflicts between the consumption of fossil energy and the associated greenhouse gas effect on the environment, geological CO2 sequestration technology has been extensively studied and evaluated. However, one big potential risk in CO2 sequestration is the leakage of carbon dioxide, which may result in contamination of underground water resources, which is harmful to the existing ecosystems. One of the common leakage pathways is the pre-existing fractures or discontinuities within cement in the wellbore, incurred by the environmental conditions imposed to the cement, including pressure and temperature change during field operations, cement shrinkage during hydration, mechanical shock from pipe tripping, etc. To repair existing cracks, a variety of mitigation technologies have been developed in the past. One of the most recently proposed mitigation plans is to heal the existing cracks by injecting nanoparticles to prevent them from further propagation. However, one of the big challenges in this proposed solution is to demonstrate the feasibility and long-term effectiveness of this technology, which is difficult to evaluate with laboratory experiments. To address this issue, in this study, we proposed a coupled CFD (Computational Fluid Dynamics)-DEM (Discrete Element Method)-LAG (Lagrangian) modeling strategy using LS-Dyna. Within this simulation framework, we investigated the coupling interaction among the CO2 fluid flow, nanoparticle, and cracks within the cement. The injected nanoparticles can reduce the pressure imposed on the crack surface, thus the fracture propagation can be mitigated as pressurized by fluid flow, ensuring the long-term effectiveness of proposed nanoparticle injection technology.

Hydromechanical coupled hydraulic fracture simulation by using discretized virtual internal bonds

Wednesday, 19th June - 17:15: MS38 - Advances in Analytical/Numerical Modeling of Petroleum Geomechanics Problems (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1253

Prof. Zhennan Zhang (Shanghai Jiao Tong University), Mr. Yujie Wang (Shanghai Jiao Tong University)

The discretized virtual internal bond(DVIB) is a discrete lattice model, which was originally developed for the dynamic fracture simulation. It considers a rock to consist of lattice bond cells. Each cell can take any geometry with any number of bonds. The bond is characterized by a hyperelastic potential, which intrinsically contains the micro fracture mechanism. This makes the DVIB free of the separate fracture criterion in fracture simulation. From another standpoint of view, the bond can be considered as the micro fluid channel. The bond network constructs the fluid channel network in a rock matrix. Thus, the DVIB can be used to simulate the seepage process in a rock. By this means, both the 3D mechanical and seepage field are reduced to the 1D problem. The micro bond parameters are associated with the macro mechanical and seepage parameters via the ideal cell approach. The seepage and mechanical process are naturally unified together on the micro bond level, which highly simplifies the simulation of the hydromechanical process. The mechanical and hydraulic process are assumed to be coupled only in the fracture, which is represented by the array of broken cells. The fully hydromechanical coupled equation for the broken bond cell is derived. This method is used to simulate the hydraulic fracture initiation, propagation and branching.

Origami Based Prestressed Compliant Mechanisms

Wednesday, 19th June - 16:00: MS46 - Origami/Kirigami Inspired Structures and Metamaterials (153 Noyes (134)) - Oral - Abstract ID: 326

Dr. Yang Li (California Institute of Technology), Prof. Sergio Pellegrino (California Institute of Technology)

Cutting closely spaced, parallel slots in a thin plate reduces its bending stiffness in the direction perpendicular to the slots, forming a compliant region that macroscopically behaves similarly to an elastic torsional hinge. Such hinges are sometimes referred to as lamina emergent torsional (LET) joints. The stiffness and elastic range of LET joints, which are controlled by geometric parameters and the mechanical properties of the thin plate, have been the object of previous research.

LET joints enable the integrated design of morphing structures that can be manufactured from flat sheets. Additionally, it is easy to tailor the elastic stiffness of individual joints, to achieve a desired energy landscape for the structure. The chosen energy landscape can be exploited to produce compliant mechanisms with specific properties, such as multi-stability in particular configurations. An additional feature that is introduced in our conceptual design is the pre-flip and post-connection of LET joints, to easily introduce prestress into the structure. With this approach, both the stiffness and the rest position of each torsional hinge are design parameters that can be varied. As an illustrative example, a bi-stable Miura-origami structure made from one spring steel sheet was designed and manufactured using this approach.

This structural concept can also be used to achieve other shapes of energy landscape. For instance, unstable equilibrium configurations are desired in some applications. Additional elements, such as contact blocks and nonlinear springs, can also be introduced to achieve sharper energy local minima and thus enhance the local stiffness of the structure.

The Effect of Kirigami on Rigid-foldability

Wednesday, 19th June - 16:15: MS46 - Origami/Kirigami Inspired Structures and Metamaterials (153 Noyes (134)) - Oral - Abstract ID: 160

Mr. Zeyuan He (University of Cambridge), Prof. Simon Guest (University of Cambridge)

In this presentation, we will apply kirigami to a creased paper - the union of an almost everywhere flat paper with simple straight-line crease pattern. We consider “kirigami” as cutting along finitely-many disjoint continuous curves on the creased paper. If a cut curve is closed, a region whose boundary is this cut curve will be removed, otherwise a cut curve will be split into two boundary components. It has been shown that the configuration space of each creased paper is constrained by a system of polynomial equations, and the consistency constraints around each cut correspond with the singular case in this polynomial system.

We wish to understand the effect of cutting on the rigid-foldablility of a creased paper, and will show how this can be done using the tools from algebraic geometry. We expect that our results will give a complete description of how cutting will change the rigid-foldability of a creased paper.

Inspired by Nature – Fluidic Origami Metastructures

Wednesday, 19th June - 16:30: MS46 - Origami/Kirigami Inspired Structures and Metamaterials (153 Noyes (134)) - Oral - Abstract ID: 82

Prof. Kon-Well Wang (University of Michigan, Ann Arbor, MI)

In recent years, the concept of mechanical metastructures developed based on nature-inspired synergistic modular architectures has been explored. For example, inspired by the physics behind the plant nastic movements and the rich designs of origami folding, a class of multifunctional metastructures is created through exploring the innovation of fluidic origami cellular systems. The idea is to connect multiple Miura folded sheets along their crease lines into a space-filling structure, and fill the tubular cells in-between with working fluids. The fluid pressure and flow in these cells can be strategically controlled much like in plants for nastic movements. The relationship between the internal fluid volume and the overall structure deformation is primarily determined by the kinematics of folding. This relationship is exploited to achieve actuation & morphing, programmable & recoverable energy absorption, and tunable mechanical properties. In addition, changes in fluid pressure can tailor the existence of the multiple stable folding configurations. As a result, fluidic origami can switch between being monostable, bistable and multistable with pressure control, and provide a rapid snap-through type of shape change based on similar principles as in plants. The ongoing research efforts in origami modular metastructures include uncovering and harnessing their dynamicscharacteristics, such as their nonlinear dynamics, deployment dynamics, and wave control features; as well as exploring the mixed designs of multi-modular origami metastructures for multiple functionalities. This presentation will highlight some of these interdisciplinary research advances in origami-based multifunctional adaptive metastructures.

Local Actuation of Self-Stressed Origami Structures

Wednesday, 19th June - 16:45: MS46 - Origami/Kirigami Inspired Structures and Metamaterials (153 Noyes (134)) - Oral - Abstract ID: 455

Mr. Steven Grey (Bristol Composites Institute (ACCIS), University of Bristol), Prof. Fabrizio Scarpa (Bristol Composites Institute (ACCIS), University of Bristol), Dr. Mark Schenk (Bristol Composites Institute (ACCIS), University of Bristol)

Using origami structures in deployable or morphing engineering systems requires some form of actuation; many of the self-folding structures currently in the literature follow a pre-programmed response to an external stimulus, such as heat or moisture. However, to truly realise the potential of origami as a morphing structure, independently controlled embedded actuators could be distributed across different folds to work in concert to achieve the desired shape. In order to select the location and power of these actuators and design the geometry of the origami structure that they are embedded in, it is important to understand how a localised actuation propagates in origami structures. Origami structures, such as the Miura-ori, consist of a series of kinematically linked folds. If made from a creased sheet material like paper, these folds have a natural rest angle. However, due to the kinematics of the Miura-ori unit cell, not all folds can assume the same angle. Instead, the origami structure rests at a minimum energy state,effectively leaving the system in a state of self-stress. We use reduced order models and Finite Element Analysis (FEA) to investigate how this self-stressed state influences the response of Miura-ori tessellations to a localised actuation. Furthermore, we show the importance of the 'folding history' in the analysis of self-stressed origami structures.

Origami wrapping patterns that are non-planar when unfolded

Wednesday, 19th June - 17:00: MS46 - Origami/Kirigami Inspired Structures and Metamaterials (153 Noyes (134)) - Oral - Abstract ID: 399

Dr. Manan Arya (Jet Propulsion Laboratory, California Institute of Technology)

Algorithms for generating origami patterns that wrap planar sheets around a polygonal hub while accounting for the finite thickness of the sheet have been described previously. Here we describe an extension to these algorithms that allows for the wrapping of non-planar sheets, including sheets that are conical, paraboloidal, or “ruffled” when unfolded. The focus of this work is to generate origami patterns for use in deployable or unfoldable spacecraft structures. For instance, the Starshade spacecraft concept requires an unfoldable conical sheet, and unfoldable paraboloidal structures have applications as deployable spacecraft antenna reflectors. This work allows for the in-extensional thickness-accommodating folding of such structures. The third class of structures that will be discussed are “ruffled”; they self-lock in a state where they have significant out-of-plane depth, imparting these structures with out-of-plane stiffness when unfolded. As such, they do not require external supporting elements when unfolded, saving system mass and complexity. Such “ruffled” structures can be applied to the design of unfoldable reflectarray antennas or solar arrays for spacecraft.

Active Reconfigurable Origami Reflector Antenna (ARORA) for Shaping Radiation Contours

Wednesday, 19th June - 17:15: MS46 - Origami/Kirigami Inspired Structures and Metamaterials (153 Noyes (134)) - Oral - Abstract ID: 501

Mr. Gregory Wilson (Texas A&M University), Dr. Sameer Jape (Texas A&M University), Mr. Milton Garza (Texas A&M University), Mr. Collin Invie (Texas A&M University), Prof. Edwin Peraza Hernandez (UC Irvine), Dr. Dimitris Lagoudas (Texas A&M University), Dr. Darren Hartl (Texas A&M University)

Origami design allows for the transformation of a flat sheet with discrete *face*and *fold* regions into complex three-dimensional shapes. Origami-inspired engineering structures possess attractive characteristics such as reconfigurability, portability, compact storage/deployment, and reduction in weight and manufacturing complexity. A special class of origami named *active origami* leverages the unique property of active materials to produce macroscopic shape change when activated by external non-mechanical stimuli. Folds within an origami structure provide intuitively compliant regions for active material actuation and such active structures *self-fold* when exposed to external stimuli. The origami driven application of a parabolic reflector antenna will be discussed in this work. This active reconfigurable origami reflector antenna (ARORA) provides the aforementioned desired characteristics of origami structures. Novel computational origami techniques of smooth tuck-folding and self-folding enabled by pre-strained polystyrene shape memory polymer (SMP) actuators are exploited to fabricate a physical ARORA prototype. The far-field radiation from an idealized parabolic reflector antenna is broadcast in a circular contour but can be modified into more complex shapes to fit desired coverage. In this paper, contour shaping of the ARORA prototype is accomplished by placing shape memory alloy (SMA) wire actuators in the antenna structure and using Joule heating to control antenna contour via SMA thermal actuation. Experimental analyses using data acquisition and digital image correlation, and numerical simulations using finite element analysis are used to investigate various actuation strategies. Lastly, computational simulations are performed on the antenna to examine the effect of SMA actuation on shaped radiation contours.

3D experimental micromechanics at the grain scale: what for?

Thursday, 20th June - 08:30: Plenary 3 (Beckman Auditorium (1,136)) - Oral - Abstract ID: 329

Prof. Cino Viggiani (Université Grenoble Alpes / Laboratoire 3SR)

With x-ray micro tomography it is now possible to acquire 3D full-field measurements of granular materials at suitable resolutions. Digital Image Correlation has been used to determine the distribution of strain in a specimen and/or individual grain kinematics, i.e., displacements and rotations of individual grains. These works have provided a deep insight into the micro-mechanics of the processes governing the behavior of granular materials.

This lecture will present recent advances in experimental micro (geo)mechanics achieved thanks to x-ray tomography and digital image analysis. In particular, we will focus on some recent experimental measurements of a 3D fabric tensor and its evolution during shearing of granular materials. Triaxial compression experiments on natural sands are chosen to investigate the evolution of fabric. Two different subsets of the specimen are chosen for the contact fabric analysis: one inside and another one outside a shear band. Individual contact orientations are measured using advanced image analysis approaches within these subsets. Fabric is then statistically captured using a second order tensor and the evolution of its anisotropy is related to the macroscopic behaviour. Finally, some very recent results obtained on fabric evolution from triaxial compression of lentils (i.e., very anisotropic grains!) are also presented.More generally, the lecture will try to convey the following two messages: 1) to convince the audience that x-ray imaging is a measurement tool, not only a way to provide fancy images, and 2) to discuss what sort of modeling applications these rather exotic data can help to inform or inspire.

A universal attribute-based zero-shot knowledge graph learning framework for structural damage identification

Thursday, 20th June - 10:30: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 1 (Ramo (371)) - Oral - Abstract ID: 88

Mr. Yang XU (Harbin Institute of Technology), Prof. Yuequan Bao (Harbin Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

The problem of structural damage identification in the complicated real-world situations is studied when training and test classes are disjoint or significantly coupled. The motivation is considering about the fact that real structural local damages contain a variety of classes in view of material categories, surface roughness situations and structural components. However, only limited image collections are annotated with manual labels both in the category-wise and pixel-wise levels. In addition, different damage classes are relevant, e.g. concrete cracking may develop to form concrete spalling in a local area, and eventually lead to rebar corrosion because of the failure of concrete protection and rebar exposure to wet atmosphere. An attribute-based zero-shot classification network is introduced to deal with the unfamiliar damage category by transferring the attribute knowledge obtained from the prior known familiar classes, including arbitrary semantic attributes such as shape, color and geographic information. Such properties are pre-learned from the training image datasets by learning a visual classifier for a category with zero training examples using Graph Convolutional Network (GCN) to obtain a learned knowledge graph (KG). Afterwards, new classes can be detected based on their attribute representations of visual category without the need for a new training process. The proposed method is validated on a structural damage image dataset for more than 20 pure and coupled damage classes. Experiments show it is promising to build a gradually-learned damage detection system that does not require any training images of the target classes.

Neural Compressive Sensing for Structural Health Monitoring

Thursday, 20th June - 10:45: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 1 (Ramo (371)) - Oral - Abstract ID: 93

Prof. Yuequan Bao (Harbin Institute of Technology), Mr. Zhiyi Tang (Harbin Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

Compressive sensing (CS) has been studied and applied in structural health monitoring for wireless data acquisition and transmission, structural modal identification, and spare damage identification. The key issue in CS is finding the optimal solution for sparse optimization. In this paper, we propose a machine-learning-based approach to solve the CS data-reconstruction problem. By treating a computation process as a data flow, the process of CS-based data reconstruction is formalized into a standard supervised-learning task. The prior knowledge, i.e., the basis matrix and the CS-sampled signals, are used as the input and the target of the network; the basis coefficient matrix is embedded as the parameters of a certain layer; the objective function of conventional compressive sensing is set as the loss function of the network. Regularized by l1-norm, these basis coefficients are optimized to reduce the error between the original CS-sampled signals and the masked reconstructed signals with a common optimization algorithm. Benefiting from the nature of a multi-neuron layer, multiple signal channels can be reconstructed simultaneously. The disassembled use of a large-scale basis makes the method memory-efficient. A numerical example of multiple sinusoidal waves and an example of field-test wireless data from a suspension bridge are carried out to illustrate the data-reconstruction ability of the proposed approach. The results show that the approach can obtain high reconstruction accuracy. The parameters of the network have clear meanings; the inference of the mapping between input and output is fully transparent, making the CS data reconstruction neural network interpretable.

A Sparse Bayesian Learning Approach for Guided Wave Propagation Distance Inference

Thursday, 20th June - 11:00: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 1 (Ramo (371)) - Oral - Abstract ID: 452

Ms. Meijie Zhao (School of Civil Engineering, Harbin Institute of Technology), Prof. Wensong Zhou (School of Civil Engineering, Harbin Institute of Technology), Prof. Yong Huang (School of Civil Engineering, Harbin Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

Ultrasonic guided wave testing has been demonstrated to be an effective technique for detecting defects occurring in plate, tube and pipe during the last two decades. The wave packet propagation distance plays an important role in the defect localization using guided waves. To compute the wave packet propagation distance, the typical strategy is using the product of time-of-flight (ToF) and group velocity. However, there are some inherent difficulties that it is impossible to exactly obtain the ToF and group velocity values with high accuracy and there are always modeling and measurement uncertainties involved. For example, waveform distortion may induce the variation of ToF measurements. In this study, based on a robust sparse Bayesian learning (RSBL) technique, a novel wave packet propagation distance inference method is proposed. An over-complete dictionary is first designed by using the dispersive waveforms with various propagation distances and mode conversion occurrence. The dictionary is then employed to decompose the multi-mode signals by running the RSBL algorithm. The model sparseness of the coefficient vector is enforced and the coefficient posterior means of the retained basis vectors in the dictionary can be used to determine the distance between the sensor and possible effects with high confidence. Furthermore, the posterior uncertainties give a measure of the inference confidence. Finally, a numerical study is performed to validate the proposed method and the results also show that the proposed method is capable to identify pulse-echo and pitch-catch patterns with high accuracy.

Vision-based SHM Case Study on Highway Bridge Test

Thursday, 20th June - 11:15: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 1 (Ramo (371)) - Oral - Abstract ID: 518

Dr. Zheng Yi Wu (Bentley Systems, Incorporated), Mr. Maadh Hmosze (Bentley Systems, Incorporated), Prof. Harry W Shenton III (University of Delaware)

The I-295 Southbound Reconstruction Project led to the decommissioning of a steel bridge, which Delaware River and Bay Authority (DRBA) agreed and allowed the researchers to conduct a destructive test. The test involved placing numerous sensors on the steel bridge to determine its responses when forces, significantly greater than those resulting from worst case traffic conditions, were applied. The damage was induced into a single girder of a multi girder bridge by cutting into it with increasing severity. This allowed the team to see how severe damage sustained by one girder affects the remaining parts of the bridge. During the bridge test, the video camera as sensor approach has been applied and captured more than 100 videos simultaneously when the conventional displacement sensors, accelerometers, strain gauges and tilt meters were recording the structural responses. The videos are analyzed for the measurements of displacements and tilt that are compared with the conventional sensing results. The comparison provides the insightful understanding on the performance of computer vision-based approach for structural testing and monitoring.

Early-Stage Vision-Based Displacement Sensing Studies on Long-Span Suspension Bridges

Thursday, 20th June - 11:30: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 1 (Ramo (371)) - Oral - Abstract ID: 626

Dr. Ekin Ozer (Middle East Technical University), Dr. Rupa Purasinghe (California State University, Los Angeles), Dr. Dongming Feng (Thornton Tomasetti, Inc)

Understanding deformation pattern and vibration behavior is critical to assess bridge infrastructure's mechanical characteristics. With the help of structural health monitoring (SHM) systems, identifying bridge features can lead to calibration of mathematical models, detection, location, and quantification of damage, and eventually assessment of bridge life span in a probabilistic manner. To counteract advanced labor work and expensive equipment in conventional SHM systems, computer vision technologies are adopted into SHM studies to produce cost-efficient sensing and monitoring frameworks. In this study, operational vibration response of a long-span suspension bridge is remotely monitored through a camera and lens configuration. The video images are post-processed to convert image frames into structural displacement. Using displacement time series, modal identification is conducted to obtain modal frequencies, mode shapes, and damping ratio. The analysis output is compared with other findings existing in the literature as well as high-fidelity reference sensing and data acquisition system results. The initial tests show that long-span suspension bridge vibrations can be successfully captured by a non-contact vision-based sensing approach and can provide a portable and scalable alternative to conventional SHM systems with dedicated sensor positions.

Physics-informed Structural Identification using Video Data

Thursday, 20th June - 11:45: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 1 (Ramo (371)) - Oral - Abstract ID: 814

Dr. Zhilu Lai (ETH-Zürich), Prof. Eleni Chatzi (ETH-Zürich), Mr. Ignacio Alzugaray (ETH-Zürich), Prof. Margarita Chli (ETH-Zürich)

Vision-based structural identification and monitoring using image/video data has recently been proposed as a promising tool for inspection and monitoring of civil engineering structures. Contrary to traditional inspection methods and the typical monitoring schemes, this option offers the benefits of contactless sensing, spatially dense measurements, and relative ease of deployment. The philosophy of vision-based identification, as so far adopted within the context of Structural Health Monitoring (SHM), lies in extracting structural motion information out of video data, and subsequently performing structural identification on the basis of the extracted motion. However, factors such as changing lighting conditions, resolution, or loss of tracking points affect the performance of motion extraction, and further affect the robustness of identification. This work exploits information from a high-frequency camera and presents a machine learning scheme that fuses information from the physics governing the structural dynamics. The scheme imposes constraints on the type temporal and spatial form of the characteristic underlying dynamics equation, thus resulting in robust identification. A numerically simulated example is offered for illustrating the workings of the proposed methods, while the method is further validated on a small-scale experimental case study. The results indicate that the proposed vision-based monitoring scheme is able to achieve a robust identification, while rendering high-spatial-density strain maps.

Novel Workability Test Method for Fresh Concrete using 3D Depth Sensor and 4D Slump Processing Algorithm

Thursday, 20th June - 10:30: MS85+86+84 - Human-Machine Interfaces and Cyber Physical Systems for Visual Inspection, Non-Destructive Examination, and Structural Health Monitoring, Advanced Vision-Based SHM, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 1311

Prof. Jung-Hoon Kim (Yonsei University), Mr. Minbeom Park (Engineering & Construction Group, Samsung C&T Corporation)

Monitoring of concrete workability is important since it is related with structural integrity, safety and performance of the hardened concrete. The conventional workability test methods are basically measured by a ruler or a stop-watch, and hence measurement errors are inherent and the result may vary depending on the operator. In this paper, we propose a digital workability measurement using 3D depth sensor and 4D slump processing algorithm. After acquiring the dynamically changing 3D surface of fresh concrete using a 3D depth sensor during the slump flow test, the stream images are processed with the 4D slump processing algorithm. Here, the depth data in the camera frame are transformed into the data in slump frame where the slump cone is initially located. The scattered data are then interpolated in the regularly spaced grid. By collecting the cross sections of the slump flow at each time frame, a compressed 4D slump image is generated. It represents the dynamically spreading cross section of fresh concrete along the time axis. The boundaries in the 4D slump image can be processed using edge detection, filtering, and subtraction algorithm to obtain the graph showing the slump flow diameter over time. Experiment demonstrates that the slump flow diameter, slump flow time, and slump height at any location can be simultaneously obtained. It can be also used for a slump test since it only requires measurement of the static height of concrete slump. The proposed 4D slump test will contribute to the digitalization of quality monitoring of concrete.

Combining image-based documentation and augmented reality to create a cyber physical system for the built environment

Thursday, 20th June - 10:45: MS85+86+84 - Human-Machine Interfaces and Cyber Physical Systems for Visual Inspection, Non-Destructive Examination, and Structural Health Monitoring, Advanced Vision-Based SHM, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 472

Ms. Rebecca Napolitano (Princeton University), Mr. Ameen Moshirfar (Princeton University), Mr. Zachary Liu (Princeton University), Prof. Branko Glisic (Princeton University)

With the present rate of deterioration for existing infrastructure, intervention and preservation efforts such as structural health monitoring (SHM), building pathology, and non-destructive evaluation are increasing. While these processes have been proven to be effective for interventive and preventive efforts, they can produce large, heterogenous datasets which are unintuitive and difficult to work with. In the past, this has led to the mismanagement of existing infrastructure as well as the complete abandonment of SHM systems. The aim of this work is to develop a framework for a cyber physical system which can organize and visualize these complex datasets. The present framework was developed in Unity Game Engine and leverages the benefits of both image-based documentation and augmented reality. Augmented reality provides an on-site user with existing information about a structure (ie locations of sensors, locations of previous damage) as well as allows them to add new information about a structure (ie changes in sensor functionality, exacerbation of damage) on-site. While this method is reliable for on-site usage, it is not feasible for off-site access. Thus, image-based documentation has been added to the framework. Using this approach, every time a user makes an annotation while on-site, a photograph of what they are looking at is also captured; any annotations a user makes while on-site are then projected back onto the image so that a user off-site can access the information in an intuitive and contextualized manner. This approach has been applied to case studies in structural health monitoring and building pathology.

Use of Augmented Reality for time critical decision making in hazardous built environment

Thursday, 20th June - 11:00: MS85+86+84 - Human-Machine Interfaces and Cyber Physical Systems for Visual Inspection, Non-Destructive Examination, and Structural Health Monitoring, Advanced Vision-Based SHM, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 429

Mr. Dilendra Maharjan (University of New Mexico), Ms. Maria del Pilar Rodriguez (University of New Mexico), Mr. Marlon Aguero (University of New Mexico), Mr. David Mascarenas (Los Alamos National Laboratory), Dr. Fernando Moreu (University of New Mexico)

Recent advancement in Augmented Reality (AR) space has opened door for development of applications that can be used in built environment. The ability to overlay virtual environment on top of real world has created new tool for rapid assessment and critical decision making in hazardous built environment. AR can enhance human perception of surrounding environment with virtual objects in identifying, measuring, quantifying, acquiring and visualizing information quickly, without much friction. Researcher have been trying to find the sweet spot where the virtual world and real world intersect that can create value for users. One area that has stood out is design and construction. AR researchers as well as industry practitioners have explored new user-friendly application using AR capability to experience digital information in more intuitive visualization. Often, the people who work in outdoor environment such as inspectors, facility managers, first responders, field technicians are exposed to safety related hazards. They are responsible for taking time-critical decisions which we believe, can be augmented by use of advance technological tools such as AR. This research strives to find the use of AR for the people who are working in hazardous environment. The work presented in this research discusses the applications developed for nuclear material storage facility management and post-earthquake inspection using AR. The feedback and survey from the experiments form an integral part of the research for necessary modification in the AR application and future direction of the research.

Damage Assessment of Structure Using Vision-Based Floor Stiffness Evaluation Method

Thursday, 20th June - 11:15: MS85+86+84 - Human-Machine Interfaces and Cyber Physical Systems for Visual Inspection, Non-Destructive Examination, and Structural Health Monitoring, Advanced Vision-Based SHM, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 623

Mr. Insub Choi (Yonsei University), Prof. Junhee Kim (Yonsei University)

This paper introduces a vision-based stiffness evaluation method to assess structural damage of soft-story building structures. First, a marker-free vision-based displacement sensor (MVDS) is developed to measure the dynamic displacement of building structures using image convex hull algorithm. Since the MVDS extracts the dynamic displacement using the convex hull of the building structures, there is an advantage that the displacement of the region of interest (ROI) of the building structures can be measured without any ancillary marker. Second, a technique to evaluate the stiffness from the dynamic displacement data was formulated through the equation of motion. Since the proposed technique aims at deriving the stiffness directly related to the damage of the structures, the cause of the structural damage can be directly assessed based on stiffness rather than natural frequencies and mode shapes where stiffness was indirectly considered. Finally, the experimental tests of a three-story scaled model were performed with various floor stiffness. The results demonstrate that the proposed vision-based floor stiffness evaluation method can estimate the damage location by evaluating the floor stiffness of the structure using the image-based displacement data. Since the proposed system would directly evaluate the floor stiffness associated with structural damage, it is expected to solve the limitations of the existing damage assessment methods using the mode shapes or natural frequencies.

Fatigue crack monitoring of metallic structures through vision-based surface motion tracking using unmanned aerial vehicles

Thursday, 20th June - 11:30: MS85+86+84 - Human-Machine Interfaces and Cyber Physical Systems for Visual Inspection, Non-Destructive Examination, and Structural Health Monitoring, Advanced Vision-Based SHM, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 750

Prof. Jian Li (University of Kansas), Mr. Sdiq Taher (University of Kansas)

Fatigue cracks initiated in metallic structures such as steel bridges are challenging to detect especially in their early stages, partly due to their low contrast to structural surface and small crack opening. In this presentation, a novel computer-vision-based fatigue crack monitoring methodology is presented enabled by a consumer-grade video camera and an unmanned aerial vehicle (UAV). By using feature detection and tracking techniques, this unique approach first captures the structural surface motion under loading through a short video, and identifies fatigue cracks by parsing the pattern of the surface motion to uncover the discontinuities induced by fatigue cracks. It is therefore able to distinguish real fatigue cracks from other crack-like features or complex surface textures, overcoming a major challenge facing many existing vision-based crack detection methods. To compensate the effect of the unavoidable motion of the UAV, which can greatly degrade the performance of the proposed method, a video stabilization algorithm based on feature-based geometric transformation is adopted. The proposed methodology is validated through a laboratory test setup and a consumer-grade camera carried by a flying UAV.

Accuracy of UAV Photogrammetry

Thursday, 20th June - 11:45: MS85+86+84 - Human-Machine Interfaces and Cyber Physical Systems for Visual Inspection, Non-Destructive Examination, and Structural Health Monitoring, Advanced Vision-Based SHM, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 889

Mr. Shanglian Zhou (University of Alabama), Prof. Wei Song (University of Alabama)

Structure from Motion (SfM) is an effective and popular computer vision technique that is used to reconstruct three-dimensional (3D) surface models from two-dimensional (2D) images. In recent years, this technique has been adopted for contactless measurement in civil engineering such as ground survey and condition assessment of civil infrastructure in post-disaster environment. Despite the rapid development and extensive applications of SfM in civil engineering, further investigations are needed to evaluate the accuracy of this computer vision technique, and facilitate its application on civil infrastructure where high-resolution monitoring and measurements are required. This paper presents an application of damage detection based on SfM, and investigates the factors that impact the accuracy for high-resolution measurement. Structural models are reconstructed through SfM from images captured by Unmanned Aerial Vehicle (UAV). The measurements taken from these 3D models are compared with the ground truth to investigate the impact factors on the accuracy of SfM in civil applications.

Deep Convolutional Neural Networks for Corrosion Detection and Semantic Segmentation

Thursday, 20th June - 10:30: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 114

Dr. Zheng Yi Wu (Bentley Systems, Incorporated), Mr. Atiqur Rahman (College of William & Mary), Dr. Rony Kalfarisi (Bentley Systems, Incorporated)

The latest study conducted by NACE shows that the total cost of infrastructure corrosion in US is more than $22.6 billion. This indicates the importance of detecting and preventing corrosion. To do so, regular inspection is essential. It is usually conducted by taking photos and videos. Due to large number of images collected during the inspection, it is imperative to develop effective method for processing the images. Computer vision and deep learning technology have been applied to corrosion detection in recently published literature. It results in the bounding boxes around corrosions but fails to precisely segment a corrosion area. In this project, a deep convolutional neural network is applied to detect and segment corrosions in images. Firstly, an image segmentation and classification tool, developed by authors using computer vision methods, has been employed for preparing the training images, in each of which the corrosions are segmented and a corresponding mask image is produced for as part of training dataset. A CNN model is then trained for corrosion detection and semantic segmentation. Secondly, a color-based corrosion index is defined to classify each pixel of a corrosion segment into different categories such as heavy corrosion, medium corrosion and light corrosion. Thus, the detected corrosions can be evaluated in terms of areas per corrosion category. It enables engineers to conduct corrosion statistics and assessment for a target area. The approach has been tested on the images collected for infrastructure inspection. Good results have been achieved for the study.

Real-time Video Crack Detection Based on Fully Convolutional Network and Naïve Bayes Score Map Fusion

Thursday, 20th June - 10:45: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1126

Mr. Fu-Chen Chen (Purdue University), Dr. Mohammad Jahanshahi (Purdue University)

To ensure safe operations of nuclear power plants, frequent inspection of the reactor internal components is necessary. Current practice, however, involves human technicians who review the underwater inspection videos and identify cracks on metallic surfaces of components, which is costly, time-consuming, and subjective process. Detecting these cracks is challenging since they are tiny and surrounded by noisy patterns. This study proposes a new approach that is substantially faster than the two previous studies while having better hit rates. A fully convolutional network (FCN) is proposed that generates crack patch score maps of video frames efficiently. Then, the Naïve Bayes score map fusion scheme fuses the score maps to enhance the robustness of detection. The proposed approach achieves 98.5% hit rate while requiring only 0.017 seconds to process a 720x540 frame and 0.1 seconds for a 1920x1080 frame. Based on its capability and efficiency, the proposed approach is a significant step toward real-time autonomous nuclear power plant inspection.

Concrete crack identification using RGB-D camera

Thursday, 20th June - 11:00: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 281

Mr. Hyunjun Kim (Ulsan National Institute of Science and Technology (UNIST)), Prof. Sung-Han Sim (Ulsan National Institute of Science and Technology (UNIST))

Surface cracks in concrete structures are important indicators of structural durability. Cracks are monitored visually by inspectors, recording observed information such as length, width, size, and location. Although the visual inspection is a common practice, it is insufficient and ineffective in terms of inspection time, safety issues, cost-effectiveness, and assessment accuracy. An innovative alternative to the visual inspection is digital image processing, which can possibly measure crack information using RGB images captured by a digital camera. One of the important issues here in practice is that the crack width can be viewed differently depending on the angle of the camera with respect to the concrete surface. This is particularly important when the camera cannot be conveniently aligned to the concrete surface: for example, taking images using UAV or located higher than the inspector. This study proposes a crack identification strategy based on an RGB-D camera that can effectively calculate crack information regardless of the angle of view. The RGB image included concrete cracks, which is processed by a deep learning approach, extracting only pixels on the crack segment. The three-dimensional coordinates estimated by the depth image are utilized with the obtained crack pixels to accurately measure crack width and length regardless of the angle of view of the used camera.

A semantic segmentation and motion identification method based on convolutional neural network

Thursday, 20th June - 11:15: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 486

Mr. Jin Zhao (Harbin Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

Camera can capture visual information of target within its field of view theoretically. This capability allows a camera to act as a sensor for obtaining displacement or distortion of targets at a large range of distance. Considering that there are so many cameras in public society (including the camera in smartphone) and the cameras will record the vibration of structures in an earthquake event, which will be very helpful for structural health and monitoring. With the development of AI, people begin to use CNN(convolutional neural network) to refine more useful information from images and videos. In this paper, a new CNN is designed to identify the displacement field of a framework structure model subjected to earthquake ground motion on a shaking table. An efficient training sample generation method is also proposed to help train the network. The network is based on traditional network U-Net, which can tell the semantic segmentation information from images. The displacement field as well as semantic segmentation results of the framework structure model is finally obtained through this method.

Multi-Class Classification for Pavement Surface Images Using Multi-Scale Convolutional Neural Networks

Thursday, 20th June - 11:30: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 872

Ms. Elham Eslami (University of Central Florida), Prof. Hae-Bum Yun (University of Central Florida)

The goal of this study is assigning a class label to each pixel of road surface images which is essential for automated pavement surface distress inspection. We propose a multi-scale convolutional neural network (CNN) for multi-class classification of pavement surface images which allows us to consider different region sizes around each patch to be labeled. The multi-scale CNN is composed of four convolutional layers with non-linearities and downsampling followed by seven fully connected layers labeling each pixel in pavement surface images with one of 11 different classes, including asphalt, concrete, cracks, crack seals, markers, manholes, potholes, curbing, shoulders, and patches. CNN shows an end-to-end training for automatic learning of hierarchical feature representations which removes the need to hand-crafted features. It is difficult to assign a class to each pixel without looking at the surrounding pixels. The proposed network is trained on three different patch sizes, 50×50, 250×250, and 500×500 with the same center capturing both short-range and long-range information. Rich feature presentation by combining the features extracted from the smallest patch to the largest one gives us local and global views to predict the label for each pixel in the image. It also allows us to have a model with shared weights across scales which prevents having extra parameters to train. The proposed method improves the classification results for all classes comparing to single-scale approach. In addition, multi-scale CNN eliminates the need to have complex post-processing methods to ensure the consistency of labeling.

Pruning Deep Convolutional Neural Networks for Efficient Edge Computing in Structural Health Monitoring

Thursday, 20th June - 11:45: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1073

Mr. Rih-Teng Wu (Purdue University), Mr. Ankush Singla (Purdue University), Dr. Mohammad Jahanshahi (Purdue University), Dr. Elisa Bertino (Purdue University)

Current inspection practices for large-scale civil infrastructures are time-consuming and labor-intensive since they are manual. One viable solution to this problem is the use of robotic systems (e.g., a swarm of unmanned aerial vehicles (UAVs)) that can autonomously collect and analyze data. Such mobile inspection robots need to have on-board data analysis capabilities for efficient inspection path planning. To this end, deep learning algorithms, as the state-of-the-art damage detection approaches, need to be incorporated into the inspection robots. However, such devices are typically limited in their computing and memory resources. This study introduces a solution to achieve quick inference and low memory demands through transfer learning and network pruning. Results from comprehensive experiments on two pre-trained networks (i.e., VGG16 and ResNet18) and two types of prevalent surface defects (i.e., crack and corrosion) are presented and discussed in details with respect to damage detection performance, memory demands, and the inference time for damage detection. The experiments show that with the NVIDIA Jetson TX2 GPU, simulating the on-board computing platform, the approach achieves an inference time which is nine and four times faster than the original VGG16 and ResNet18 networks, respectively. Also, the network size is reduced by 80% and 95% for the VGG16 and ResNet18 networks, respectively. Cross-validation and stopping criterion for pruning are addressed, and an optimization scheme is proposed for VGG16 feature extraction. Results demonstrate that the proposed approach significantly enhances resource efficiency without decreasing damage detection performance.

Effects of Simulated Magnitude 9 Earthquake Motions on RC Wall Structures in the Pacific Northwest

Thursday, 20th June - 10:30: MS60 - Earthquake Resilience and Cascading Effects; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 427

Prof. Jeffrey Berman (University of Washington), Dr. Nasser Marafi (University of Washington), Prof. Marc Eberhard (University of Washington)

The Cascadia Subduction Zone (CSZ) can produce long-duration, large-magnitude earthquakes that could severely affect structures in the Pacific Northwest (PNW). Deep sedimentary basins, which underlie several cities (e.g., Portland, Seattle, and Vancouver, BC) in the Pacific Northwest are expected to amplify these motions. The effects of long duration and basins are poorly understood for the CSZ because no recordings are available for large-magnitude earthquakes in this region. A research team at the UW and the USGS generated ground motions using a 3D seismic velocity model for the Cascadia subduction zone, which includes several sedimentary basins for many possible magnitude 9 rupture scenarios. These motions are used to study the behavior of reinforced concrete wall structures that have been designed for the Seattle seismic hazard.

The walls were designed for a variety of heights ranging from 4 to 40 stories tall. Their performance was evaluated in terms of several damage states (e.g., repair, collapse). Response using both simulated and MCE ground-motions is compared and explained using ground-motion intensity measures that capture various ground-motion characteristics, i.e., the spectral acceleration, spectral shape, and ground-motion duration.

The calculated performance varied among the earthquake scenarios (M9 vs. MCE) because of: (1) long-period basin amplification, (2) the influence of the basin on spectral shape, and (3) the duration of shaking. Additionally, the collapse risk for these structures exceeded values targeted by current codes. The damage estimates correlated well with a new measure of ground-motion intensity that reflects the contributions from spectral acceleration, spectral shape, and duration.

Probabilistic seismic and tsunami damage analysis (PSTDA) for community resilience assessment

Thursday, 20th June - 10:45: MS60 - Earthquake Resilience and Cascading Effects; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 421

Dr. Hyoungsu Park (Oregon State University), Prof. Daniel Cox (Oregon State University), Mr. Mohammad Alam (Oregon State University), Dr. Andre Barbosa (Oregon State University), Prof. John Van De Lindt (Colorado State University)

A general multi-hazard probabilistic seismic and tsunami damage analysis (PSTDA) framework will be presented. This framework can be used to estimate the damage incurred to the built environment (e.g., buildings, transportation, power, water, and communication networks) of coastal communities due to cascading earthquake shaking and tsunami inundation from tsunamigenic earthquake events. The framework makes use of results of a probabilistic seismic-tsunami hazard analysis (PSTHA), requires an inventory of the built environment, and sets of the built environment component fragility functions. The PSTDA evaluates stochastically the accumulated damage due to seismic shaking and subsequent tsunami inundation. A case study is used to illustrate the framework, which includes the buildings as an example of a component of the built environment in the coastal community of Seaside, Oregon. Deaggregation of damage assessment of buildings shed light on how each hazard contributes to the total damage hazard, depending on building typologies, level of design, geospatial location, and hazard recurrence interval. The proposed PSTDA framework can be integrated as a step within a resilience-focused risk-informed decision making process, which includes the assessment of direct and indirect socio-economic losses due to tsunamigenic earthquake events.

Characterizing Performance of Tessellated Structural-Architectural Systems

Thursday, 20th June - 11:00: MS60 - Earthquake Resilience and Cascading Effects; Part 1 (Firestone 384 (76)) - Poster - Abstract ID: 1379

Mr. Mohammad Moeini (State University of New York at Buffalo), Prof. Negar Elhami-Khorasani (University at Buffalo), Dr. Pinar Okumus (State University of New York at Buffalo), Dr. Brandon Ross (Clemson University), Dr. Michael Carlos Barrios Kleiss (Clemson University)

This presentation introduces the concept of a tessellated structural-architectural (TeSA) shear wall system that has pre-fabricated concrete tessellated elements (repetitive patterns of similar tiles) and the ability to localize structural damage. Since TeSA walls are built of repetitive discrete tiles, they are ideal for automated construction, reconfiguration, disassembly, and reuse. This study focuses on topologically interlocking TeSA walls in two directions (2D interlocking), in which the separation of tiles is prevented in two directions through interlocking of each piece to neighboring pieces. Finite element analysis is used to understand the fundamental behavior and capacity of TeSA walls. An existing conventional shear wall is transformed into a TeSA wall, assuming same material properties and overall dimensions. Monotonic push-over analysis is conducted, and lateral load-displacement behavior of the conventional and TeSA walls is compared. The results indicate that the TeSA wall behavior is affected by the continuity of the tiles along the edge of the wall. Therefore, different configurations of edge tiles (non-continuous, continuous, and staggered) are investigated and compared. Progression of damage in tiles at different drift ratios are investigated, and the number of damaged tiles, that would need replacement, is studied. The results show that the TeSA wall, in staggered and continuous configurations, can reach ultimate capacities similar to a conventional wall by adjusting the reinforcement ratio in the tiles. Future work will investigate different tile patterns and configurations, and include experimental testing of the proposed concept.

A case study on generating building level fragility for functionality of a non-structural component

Thursday, 20th June - 11:15: MS60 - Earthquake Resilience and Cascading Effects; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 496

Dr. Negar Moharrami Gargari (WSP, USA), Mr. Amir Sarreshtehdari (University at Buffalo), Prof. Negar Elhami-Khorasani (University at Buffalo)

Maintaining functionality after an earthquake is key to minimize disruption and ensure resiliency, where functionality refers to the availability of building facilities to be used for the intended purpose. Damage to non-structural building systems, including partition walls, ceilings, facade, and fire protection systems, can affect functionality of a building. It is evident from previous earthquakes that these components can contribute significant percentage losses during earthquakes, one example is 2010/2011 Christchurch earthquakes with NZ$16 Billion losses. The FEMA P-58 project presents a methodology for seismic performance assessment of individual buildings and provides assessment of downtime and losses from damage to structural and non-structural systems. However, this analysis is completed at individual buildings and cannot be extended to community level studies. In this presentation, nonlinear dynamic analysis of a 16-story prototype building with special moment frame is completed under ground motion scenarios with different characteristics. Damage to a drift sensitive non-structural component (e.g. partition wall) is quantified at every story and then aggregated along the building height to arrive at a total damage. The procedure is validated using the FEMA P-58 tool, PACT. The results are then used to map performance of the structural system to the level of damage in the non-structural component, and the associated functionality damage states, to generate building level fragilities. The results will demonstrate the dynamic demand for a sample non-structural component if it has to maintain functionality after an earthquake.

A Stochastic Inventory Model with Disruptions across the Supply-Chain

Thursday, 20th June - 11:30: MS60 - Earthquake Resilience and Cascading Effects; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 536

Mr. Fabrizio Nocera (University of Illinois at Urbana Champaign), Prof. Paolo Gardoni (University of Illinois at Urbana-Champaign)

Supply chain disruptions are unanticipated events that disrupt the normal flow of goods within a supply chain, and may impede businesses' ability to run their regular activities. Past catastrophic events highlight the vulnerability of supply-chains to natural and anthropogenic hazards, as well as emphasize the need for the development of mitigation strategies and business policies that can help reduce the impact of hazards. Businesses typically use inventory models to estimate the optimal level of inventories to provide an uninterrupted service to their customers. Current inventory models under disruptive conditions typically assume a single supplier and a single retailer. Disruptions may occur at both the retailer and the supplier, assuming that a disruption to the retailer leads to a zero inventory, whereas a disruption at the supplier prevents the inbound flow of goods to the retailer. Furthermore, current approaches typically assume (i) a constant deterministic demand imposed on the retailer, (ii) an infinite supplier capacity to provide goods to the retailer, and (iii) a constant deterministic order quantity. To overcome these limitations and better predict the impact of hazards on supply-chains, we propose a stochastic inventory model considering disruptions at both the retailer and the supplier after the occurrence of a hazard. Our model differs from the past literature in four important ways. First, we consider a system of multiple retailers and multiple suppliers. Then, we assume that retailers have a stochastic demand and suppliers have finite capacity. Finally, we relax the assumption of a constant deterministic order quantity.

Development of Underwater Shaking Table Array Testing Framework Considering FSI and SSI Coupling Effects: Identification and Verification

Thursday, 20th June - 11:45: MS60 - Earthquake Resilience and Cascading Effects; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 568

Prof. Ning Li (Tianjin University), Mr. Jun Chen (Tianjin University), Mr. Chen Zhou (Tianjin University), Prof. Zhong-xian Li (Tianjin University)

It is highlighted in the past that shaking table tests produced significant promotes for structural engineering. An innovative underwater shaking table array was built in China, recently, which could add the spatially variable ground motion effect and the fluid-structure interaction (FSI)/soil-structure interaction (SSI) dynamic effects during a shaking table test. Since the high fidelity shaking table test method with these coupled effects using the new facility is a challenge in one trial test for important structures, to facilitate the test, a model-based framework for testing using the underwater shaking table array is presented in this paper. The framework includes the shaking table array model, the soil substructure, and the fluid boundary condition part. A model-based underwater shaking table array model including all the components of servo-hydraulic system was developed in Simulink. The numerical soil substructure model for foundation and site is developed and the SSI impedance function is presented as the recursive discrete filters. The FSI boundary condition for hydraulic dynamic system, which is driven by a low-frequency closed-loop control system, also was coordinated by the shaking table controller. The connection between different parts is based on a memory reflection-based low-time delay data transmitting technique. All the parameters of the framework were identified with specific test specimen. Each part of the framework can be executed separately or jointly. Finally, the seismic testing of a bridge model in cases of considering FSI/SSI effects is illustrated. The procedure provided means to tackle coupled issues in multi-hazard testing using underwater shaking table array.

DEM Simulations of the Seismic Response of Flexible Retaining Walls

Thursday, 20th June - 10:30: MS67 - Soil Dynamics and Soil-Structure Interaction (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1085

Mr. Saman Farzi Sizkow (Southern Methodist University), Dr. Usama El Shamy (Southern Methodist University)

In this study, a three-dimensional analysis of soil-retaining wall dynamic interaction is conducted using the Discrete Element Method (DEM). In this method, soil grains are treated as rigid spherical particles which are allowed to overlap one another at contact points. The forces and motions inside the assembly are calculated utilizing Newton's second law of motion together with force-displacement laws. The deformable sheet pile-type retaining wall is simulated using rigid balls glued together by parallel bonds with specific strength and stiffness to mimic the physical properties of the real wall. Due to computational limitations, the high g-level concept and scaling laws for dynamic centrifuge testing are employed to decrease the domain size and simulation time. In addition, absorbing boundaries are employed at lateral sides of the model to prevent the reflections of the propagating waves back to the assembly. Seismic excitation is introduced to the system through the base wall, which represents the bedrock. The effects of different characteristics of the input seismic wave such as its frequency and amplitude on the dynamic response of soil-sheet pile system are analyzed. Furthermore, data on lateral thrust on the wall and its deflection is collected. It is shown that the numerical method is a competent tool to evaluate and predict the dynamic response of soil-sheet pile systems.

Model order reduction for holistic SSI modelling in earthquake and railway engineering applications

Thursday, 20th June - 10:45: MS67 - Soil Dynamics and Soil-Structure Interaction (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1289

Dr. NIKOLAOS LESGIDIS (University of Bristol), Prof. Anastasios Sextos (University of Bristol), Dr. Lukas Moschen (Vienna Consulting Engineers ZT GmbH)

A rigorous simulation of a soil-structure interacting system mandates the detailed representation of the complex phenomena of wave propagation within the inelastic, semi-infinite soil medium. Such detailed representation is often associated with high computational cost, thus considered as a non-viable option for performance assessment tasks where time effective solutions are more preferable. To this end, model order reduction techniques can provide with a robust alternative. Within the current paper a frequency dependent macrolement methodology is presented, capable of significantly reducing the computation cost of SSI simulation, while maintaining a detailed representation of the semi-infinite soil medium. The methodology is further implemented in the simulation of different SSI systems under railway and earthquake induced vibrations.The numerical results, and comparison with measurements, highlight that in both fields the computation time is greatly reduced while maintaining a high accuracy of prediction.

Passive-Seismic Material Inversion in a Truncated Halfspace

Thursday, 20th June - 11:00: MS67 - Soil Dynamics and Soil-Structure Interaction (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 267

Dr. Chanseok Jeong (The Catholic University of America)

This work aims to identify the material profile of a one-dimensional truncated halfspace, subject to a known incoming seismic wave, by using surficial seismic motion measured by a sensor on the ground surface.
This work casts the problem into a minimization problem such that a numerical optimizer iteratively estimates a shear-modulus distribution of a solid column that can replicate a measured wave response due to a targeted shear-modulus profile. To resolve the minimization problem efficiently and effectively, this work employs a partial-differential-equation (PDE)-constrained optimization framework, which allows for semi-analytical evaluation of the gradient of an objective functional with respect to material parameters. To accelerate the convergence of the inversion solution toward a targeted material profile, this works uses a regularization factor continuation scheme and the Newton's method.

The numerical examples present that the presented method can successfully reconstruct various spatial distributions (e.g., multi-layered, asymptotic, and curved) of shear modulus over the depth of a truncated solid column that is subject to a known incoming seismic wave. This work will lay foundation for solving a futuristic joint-inversion problem to reconstruct the material profile of a multi-dimensional, truncated halfspace subject unknown, incoherent incoming seismic waves.

Numerical modeling of single piles in improved soils under seismic loading

Thursday, 20th June - 11:15: MS67 - Soil Dynamics and Soil-Structure Interaction (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 411

Ms. Sumangali Sivakumaran (The University of Oklahoma), Prof. Muralee Muraleetharan (The University of Oklahoma)

αGround improvement has proven to be an effective and economical solution to enhance the lateral stiffness and strength of weak soils under seismic loading. The ground improvement around piles, however, often results in unwarranted conservative volumes of soil improvement due to the lack of availability of methods to analyze the piles in improved soils. In this study, a stand-alone computer code is developed to analyze the static and seismic response of a single pile in improved soils using the Beams on Nonlinear Winkler Foundation (BNWF) approach. The code is based on the finite element solution of the coupled nonlinear governing equations for seismic soil-pile interactions. The pile is represented by nonlinear beam-column elements and the soil behavior is represented by nonlinear p-y springs and viscous dashpots. The extent of the lateral ground improvement is taken into account using a novel technique. The Hilber-Hughes-Taylor (HHT) α-method is used to integrate spatially discrete equations in time. The predictions made by the computer code are verified using the results from centrifuge model tests and full-scale field tests.

Measurement and numerical prediction of railway induced vibration in a three-storey building

Thursday, 20th June - 11:30: MS67 - Soil Dynamics and Soil-Structure Interaction (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 461

Prof. Geert Degrande (KU Leuven, Department of Civil Engineering), Dr. Manthos Papadopoulos (KU Leuven, Department of Civil Engineering (presently at CDM, Belgium)), Dr. Matthias Germonpre (KU Leuven, Department of Civil Engineering (presently at Stabo, Belgium)), Dr. Kirsty Kuo (KU Leuven, Department of Civil Engineering (presently at Wood, Australia)), Prof. Geert Lombaert (KU Leuven, Department of Civil Engineering)

Accurate numerical prediction of railway induced vibration in buildings is very challenging given the complexity of the problem, the uncertainty involved and the extended frequency range of interest. This paper reports on an extensive measurement campaign that was conducted at a site where a railway track passes in close proximity to a three-storey office building. Dynamic soil characteristics were determined by means of in situ geophysical tests. The modal characteristics of the reinforced concrete building were identified by means of system identification techniques using both ambient excitation as well as hammer impacts on the slabs. Measurements were also performed on the track, in the free field and in the building during impact loading on the sleepers and during the passage of freight and passenger trains.

A coupled FE-BE track model is calibrated based on the measured track receptance and transfer functions between the track and the free field; it is used to simulate the incident wave field for impacts on the sleepers and passing trains. A detailed coupled FE-BE model of the soil-building system is developed and calibrated using the identified modal characteristics. The incident wave field is very sensitive to uncertainty in the dynamic soil properties, while the modal characteristics of the building are rather insensitive. The uncertainty of the subsoil conditions explains to a large degree the deviation between the predicted and measured response in the free field and the building. The measurements and numerical predictions are also used to validate hybrid prediction methods.

Effects of Soil-Structure Interface Modeling on the Predicted Seismic Responses of a Tunnel

Thursday, 20th June - 11:45: MS67 - Soil Dynamics and Soil-Structure Interaction (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1385

Dr. Omer Erbay (Simpson Gumpertz & Heger), Dr. shugang tian (Tongji University), Dr. Qingjun Chen (Tongji University), Prof. Ertugrul Taciroglu (University of California, Los Angeles)

Buried structures primarily follow the deformations and strains developing in the surrounding soil during a seismic event. The differences in stiffness of the structure and the soil may result in formation and closure of gaps at the soil-structure interface. In regions that are close to an active fault or with liquefiable soils, the occurrence of permanent relative deformations in the soil medium may impose high shear demands on the body of the structure. All these complex interactions affect the loads and deformations that need to be considered in the design of buried structures. This paper, investigates the effect of separation and frictional contact at the soil-structure interface on the seismic response of tunnels. The analyses considering separation at the soil-structure interface are performed in ABAQUS using the Mohr-Coulomb friction model and user-defined-element based on the Goodman zero-thickness element formulation. The structural response obtained from results are compared to the response obtained from analysis considering fully bonded soil-structure interface. The analyses showed that the distribution as well as peak values of the predicted seismic pressures varied significantly among different modeling options. The analyses considering separation and frictional contact at the soil-structure interface resulted in larger pressures and stresses on tunnel structure compared to fully bonded interface. The differences between tunnel displacements and accelerations were minor among the different modeling options. As such, detailed interface models may be required when seismic analysis and design of tunnels, whereas a fully-bonded interface model can be adequate for determining response of non-structural components within tunnels.

Automated Prediction of the Failure Response of Composite Materials: New Algorithms and High-Performance Computing

Thursday, 20th June - 10:30: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 4 (107 Downs (71)) - Oral - Abstract ID: 73

Prof. Soheil Soghrati (The Ohio State University), Mr. Anand Nagarajan (The Ohio State University), Mr. Ming Yang (The Ohio State University), Dr. Bowen Liang (The Ohio State University), Dr. Hossein Ahmadian (The Ohio State University)

We present an integrated computational framework relying on a novel virtual microstructure reconstruction algorithm and a new parallel non-iterative mesh generation technique for creating high fidelity finite element (FE) models and simulating the failure response of composite materials. A NURBS-based reconstruction algorithm is introduced to synthesize the material microstructure by packing arbitrary shaped particles, morphologies of which are extracted from digital data such as scanning electron microscopy (SEM) and micro-computed tomography images. A genetic algorithm (GA) based optimization phase is then employed to replicate target statistical microstructural descriptors. The FE model is then generated using a meshing algorithm named Conforming to Interface Structured Adaptive Mesh Refinement (CISAMR) algorithm, which transforms an initial structured mesh into a high-quality conforming mesh. CISAMR can handle problems with highly intricate geometries, including material interfaces with sharp edges/corners and pre-existing cracks. The parallel implementation of CISAMR is also introduced, which is capable of generating meshes with hundreds of millions elements while achieving a super-linear speedup. We show the application of the computational framework built by integrating these reconstruction/meshing algorithms for simulating the micromechanical behavior and damage process in various materials systems, including fiber reinforced/particulate composites, and lithium ion battery electrodes. Some of these problems involves highly nonlinear simulations, involving continuum damage and cohesive-contact models.

Multiscale Virtual Element methods for heterogeneous media

Thursday, 20th June - 10:45: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 4 (107 Downs (71)) - Oral - Abstract ID: 140

Mr. Abhilash Sreekumar (University of Nottingham), Prof. Savvas Triantafyllou (University of Nottingham), Dr. François-Xavier Bécot (Matelys Research Lab), Mr. Fabien Chevillotte (Matelys Research Lab), Dr. Luc Jaoeun (Matelys Research Lab)

The Enhanced Multiscale Finite Element Method [1] (EMsFEM) is an upscaling technique used to reduce computational costs in problems with highly heterogeneous parameters without explicitly resolving these heterogeneities. The macroscopic and microscopic scales are generally meshed with quadrilaterals in 2D or hexahedral elements in 3D. However, complex domains necessitate more flexible mesh generation capabilities. This is the case in, e.g., elastomer/ metallic foam bi-materials where the geometry of the inclusions is highly irregular. The Virtual Element Method [2] (VEM) is a Generalized Finite Element Method that accommodates more complicated element geometries and/or higher-order inter-element continuity within its framework. This is achieved by choosing spaces and degrees of freedom in such a way that the stiffness matrices are evaluated without explicitly computing basis functions.

We apply the VEM to the EMsFEM for the analysis of heterogeneous elastic media to obtain a novel Enhanced Multiscale Virtual Element Method. The resulting computational scheme naturally allows for generalized polygonal and non-convex elements at the microscopic scale. We discuss the computation of the multiscale basis functions and corresponding virtual projection operators. The accuracy and performance of the method is evaluated through a set of numerical benchmarks using MATLAB.

[1] Triantafyllou, S.P. and Chatzi, E.N., 2014. A hysteretic multiscale formulation for nonlinear dynamic analysis of composite materials. *Computational Mechanics*, 54(3), pp.763-787.

[2] Beirão da Veiga, L., Brezzi, F., Cangiani, A., Manzini, G., Marini, L.D. and Russo, A., 2013. Basic principles of virtual element methods. *Mathematical Models and Methods in Applied Sciences*, *23*(01), pp.199-214.

Thermal instabilities in frontally polymerized polymers and composites

Thursday, 20th June - 11:00: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 4 (107 Downs (71)) - Oral - Abstract ID: 772

Mr. Elyas Goli (University of Illinois at Urbana-Champaign), Ms. Suzanne Peterson (University of Illinois at Urbana-Champaign), Mr. Nil Parikh (University of Illinois at Urbana-Champaign), Dr. Philippe Geubelle (University of Illinois at Urbana-Champaign)

Frontal Polymerization (FP) has recently been proposed as a faster and more energy efficient curing technique for fabrication of polymers and fiber-reinforced polymer composites, in comparison with traditional manufacturing methods based on bulk polymerization. FP is a process in which a localized reaction zone propagates through a monomer by converting it into a polymer. The heat generated by the exothermic reaction of monomer and catalyst is consumed to move the front forward and cure the surrounding area, resulting in a self-sustained reaction-diffusion process, which relies on a balance between the heat generated by the reaction and the heat consumed by the advancing front. In the absence of this thermal equilibrium, the front either quenches or presents an oscillatory response.

The main focus of this work is to investigate these thermal instabilities of the polymerization front in dicyclopentadiene (DCPD). To that effect, we adopt a continuum-level nonlinear multiphysics finite element solver to solve the coupled thermo-chemical equations and study the FP-driven thermal instabilities in neat DCPD resin and carbon-fiber-reinforced DCPD-based composites.

Special emphasis is placed on characterizing the effects on the FP-driven instability of some of the key parameters entering the frontal polymerization process including the initial temperature of the monomer, the initial degree of cure and the fiber volume fraction. Of particular interest are the impact of these parameters on the wavelength and amplitude of these oscillations.

A Variational Multiscale Discontinuous Galerkin Method for Periodic Boundary Condition Modeling of RVE

Thursday, 20th June - 11:15: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 4 (107 Downs (71)) - Oral - Abstract ID: 526

Mr. Sunday Aduloju (University of Tennessee, Knoxville), Dr. Timothy Truster (University of Tennessee, Knoxville)

We present the Variational Discontinuous Galerkin method (VMDG) for weakly enforcing periodic boundary conditions on the representative volume element (RVE) boundaries. This method, which is derived from the strong form of a microscale problem using variational multiscale ideas, is suitable for modeling material response of conforming and nonconforming meshes of RVEs. The penalty term which emerges naturally during the derivation process is found to account for element geometry and material properties. Therefore, no calibration of artificial parameters is required and the method is suitable for modeling deformation of both block and truly (self) periodic RVEs. The results from the numerical studies show that the VMDG method is robust, accurate, and variationally consistent for modeling conforming and nonconforming RVEs and complex 3-dimensional microstructures.

Transient Stress Analysis of Skew Sandwich Plate with FGM core subjected to Thermal Shock

Thursday, 20th June - 11:30: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 4 (107 Downs (71)) - Oral - Abstract ID: 439

Dr. Shashank Pandey (National Institute of Technology, Jamshedpur), Dr. Pradyumna Sathyasimha (Indian Institute of Technology Delhi)

In this work, transient stress behavior of functionally graded material (FGM) sandwich skew plate (FGSSP) is studied using layerwise finite element formulation. Elastic properties of FGSSP are considered to be position and temperature dependent. The upper and lower surfaces of the FGSSP are assumed to be made of pure ceramic and pure metal, respectively and the core is graded in the thickness direction according to rule of mixture (ROM). The top surface of FGSSP is subjected to a thermal shock, whereas the bottom surface is maintained at a reference temperature or is thermally insulated. The solution to Fourier's one dimensional heat conduction equation for unsteady state is obtained using a central difference scheme in conjunction with the Crank-Nicolson method.A C^0 higher-order layerwise finite element formulation using an eight noded isoparametric element is developed for transient stress analysis of FGSSP. The governing equations are solved using Newmark average acceleration method. Parametric studies are carried out to study the effects of different geometric and elastic properties like skew angle, length to thickness ratio, geometrical and thermal boundary conditions, volume faction index and facesheet to core ratio on the transient stress behavior of FGSSP.

Multiscale Dynamic Reduction for Spent Nuclear Fuel Systems

Thursday, 20th June - 11:45: MS13 - Computational Methods and Applications for Solid and Structural Mechanics; Part 4 (107 Downs (71)) - Oral - Abstract ID: 560

Mr. Xiaoshu Zeng (University of Southern California), Dr. Olivier Ezvan (University of Southern California), Dr. Bora Gencturk (University of Southern California), Prof. Roger Ghanem (University of Southern California)

This paper concerns the dynamics of a spent nuclear fuel (SNF) system by means of a highly-resolved model. The system consists of 68 nominally identical fuel assemblies, which hold thousands of fuel rods, inside a basket that is placed into a canister. Due to the complexities and large number of sub-components, the computational model has hundreds of millions of degrees-of-freedom, which makes an analysis by standard methods nearly intractable. This paper first presents an efficient implementation of the Craig-Bampton (CB) substructuring technique, which is adapted to leverage the particular structure of the system, namely, its pseudo-periodicity, the localized structural connections between its sub-components, and its high modal density induced by the small structural scales. It is based on spectrum slicing (with shift-invert Lanczos) in conjunction with block factorization by Schur complement. Next, a two-level CB model is proposed to reduce the computational cost while maintaining reasonable accuracy to capture local behaviors both within the fuel rods and at the supporting frame systems. The inner level is the CB eigenvalue analysis of the fuel assembly, while the outer level is the system-level CB model that uses the inner CB fuel assembly modes as component modes. A mode filtering strategy is then employed to remove the numerous insignificant modes of the fuel assembly, resulting in a much cheaper construction of the outer CB. The various CB truncations and mode filtering are validated by comparing against a reduced set of dominant modes, which are exactly and efficiently computed through substructuring and spectral shifts.

Design of Auxetic Metamaterials under Finite Strain via Topology Optimization and Nonlinear Homogenization

Thursday, 20th June - 10:30: MS12 - Topology Optimization: From Algorithmic Development to Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 503

Mr. Guodong Zhang (University of Notre Dame), Prof. Kapil Khandelwal (University of Notre Dame)

Materials with negative Poisson's ratio, also known as auxetic materials, have attracted much attention due to their unusual mechanical properties. In the past, topology optimization methods for designing auxetic materials under small strain has been investigated through inverse linear homogenization methods. However, for metamaterials that can undergo finite deformations, these linear designs can be sub-optimal or even misleading. To bridge this gap, past studies have employed heuristic methods for designing nonlinear auxetic materials. However, without rigorous homogenization framework, the transition from the microstructure behavior to macroscale properties is not clear in such cases. In this study, a novel computational framework is presented for designing metamaterials with negative Poisson's ratio over a large strain range through topology optimization together with nonlinear homogenization methods. The auxetic behavior with respect to different loading directions and with different unit-cell periodicities is explored. A variety of new auxetic designs are obtained and the extension to multimaterial auxetic materials design is also explored. To investigate the stability of these metamaterials, a post multiscale stability analysis is carried out using the Bloch wave method. It is shown that without incorporation of stability constraints short and/or long wavelength instability can occur during the loading process leading to a change of periodicity of the microstructure.

Accelerating Topology Optimization by means of the Scaled Boundary Finite Element Method and Hierarchical Meshes

Thursday, 20th June - 10:45: MS12 - Topology Optimization: From Algorithmic Development to Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 642

Mr. Adrian Egger (ETH Zurich, D-BAUG, IBK), Dr. Albert Saputra (University of New South Wales, CIES), Prof. Savvas Triantafyllou (University of Nottingham, CSEI), Prof. Eleni Chatzi (ETH Zurich, D-BAUG, IBK)

The ever-increasing need for sustainable, economical and accountable use of resources has led many sectors, e.g., construction, aerospace and automotive, to adopt topology optimization (TO) into engineering practice. TO of continuum structures typically involves the repeated solution of a computationally expensive forward problem, with the intent of defining an optimal structural layout. This contribution aims at accelerating TO by recasting the forward problem into a form that directly interacts with the structural solver.

The scaled boundary finite element method (SBFEM), a semi-analytical numerical method, permits the treatment of star-convex polytopes by introducing a scaling center in every element, thereby retrieving an analytical solution in radial direction, while only necessitating discretization of element boundaries. The polytope nature of SBFEM elements is exploited on quad-/octree meshes to alleviate issues associated with hanging nodes. Furthermore, a balancing operation applied to the mesh results in a manageable number of precomputable element configurations, which significantly accelerates the forward analysis. The analysis mesh for each optimization iteration is obtained via automated image-based decomposition of the element densities.

Several benefits arise from this combination of methods. First, the use of unstructured meshes and the ease with which higher order elements may be incorporated, combat the formation of checker-boarding. Second, computational effort only arises where necessary, and adaptivity is automatically provided. Third, preliminary results, employing soft-kill bi-directional evolutionary strategy optimization (BESO) in 2D, indicate a reduction in the degrees of freedom required by an order of magnitude, significantly alleviating computational cost and memory requirements.

Topology Optimization of Rocking Braced Frames for Nonlinear Earthquake Response

Thursday, 20th June - 11:00: MS12 - Topology Optimization: From Algorithmic Development to Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 932

Mr. Amory Martin (Stanford University), Prof. Gregory Deierlein (NHERI SimCenter, Stanford University)

Topology optimization offers engineers and architects creative design opportunities to develop efficient and visually striking structural forms. Applications of topology optimization for seismic design presents unresolved challenges due to the complexity of capturing nonlinear response history loading effects under earthquake ground motions. Since inelastic deformations are confined to allocated energy-dissipating elements, modified modal analyses can accurately capture the nonlinear earthquake response of structures using equivalent linear properties.

Employing strategies from these simplified analyses, a new method for applying topology optimization for earthquake design is proposed for design of rocking braced frames, where the inelastic deformations are confined to the rocking base and the braced frame is designed to remain elastic. Nonlinear dynamic loading effects are approximated based on modified modal analysis, whereby the total modal compliance is calculated through the superposition of modified modal compliances. Standard topology optimization methods for multiple load cases are employed by treating the dynamic effects through surrogate modes, developed based on equivalent linear properties for the capacity design nonlinear components.

Example applications to design of rocking steel braced frames demonstrate conceptual design considerations. A case study is presented, comparing an optimized rocking spine with conventional X-braced frame system, where a 18% steel weight reduction is achieved in the optimized solution. Nonlinear response history analyses run using a suite of 50 ground motions are presented to validate the proposed methodology and demonstrate that the member forces in the optimized configuration are less sensitive to ground motion variability.

Stochastic Methods for Topology Optimization with Many Load Cases

Thursday, 20th June - 11:15: MS12 - Topology Optimization: From Algorithmic Development to Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 963

Prof. Xiaojia Shelly Zhang (University of Illinois at Urbana-Champaign), Prof. Eric De Sturler (Virginia Tech), Prof. Alexander Shapiro (Georgia Institute of Technology), Prof. Glaucio Paulino (Georgia Institute of Technology)

Practical engineering designs typically incorporate a large number of load cases. For topology optimization considering many deterministic load cases with a weighted-average formulation, a large number of linear systems of equations must be solved in each optimization step, leading to an enormous computational cost. In this work, we present stochastic methods that drastically reduce the total computational time. We reformulate the deterministic objective function and gradient into stochastic ones, which can then be estimated at the cost of a few iterative linear system solves, possibly as few as one. Note that the solution of this stochastic optimization algorithm solves the original deterministic optimization problem. The stochastic optimization method is combined with a damping strategy related to simulated annealing. Through numerical examples, we demonstrate that the use of the stochastic techniques allows us to solve large topology optimization problems at a drastically reduced computational cost while obtaining similar design quality. For example, for a simple 2D design problem, the number of linear solves could be reduced by a factor of about 40. The results indicate that the damping scheme is effective and leads to the rapid convergence of the proposed methods.

Topology Optimization considering AM Support Structures

Thursday, 20th June - 11:30: MS12 - Topology Optimization: From Algorithmic Development to Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 1000

Mr. Mikhail Osanov (Johns Hopkins University), Mr. Justin Unger (Johns Hopkins University), Prof. James Guest (Johns Hopkins University)

Additively manufactured components often require temporary support structures to prevent the component from collapsing or warping during fabrication. Whether these support materials are removed chemically or mechanically, the use of sacrificial material increases total material usage, build time, and time required in post-fabrication treatments. Although manufacturing technology development and feedstock material development will play important roles in addressing this issue in the future, we explore here the role that design methods can play in reducing the use of support structures in additive manufacturing (AM). Recent advancements regarding topology optimization considering overhang constraints [1-2], part orientation optimization, and support structure design will be discussed. Key features of the presented approaches are that the underlying design objectives related to support structures are embedded within the topology optimization formulation and algorithm, creating a mathematically consistent design optimization approach. The resulting projection-based approaches are applied to 2D and 3D structural design domains.

[1.] Gaynor A.T., Guest J.K. (2014). Topology Optimization for Additive Manufacturing: Considering Maximum Overhang Constraint. Proceedings of the 15th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Atlanta, GA, 1-8.

[2.] Gaynor A.T., Guest J.K. (2016). Topology optimization considering overhang constraints: Eliminating sacrificial support material in additive manufacturing through design. Structural and Multidisciplinary Optimization, 54(5):1157–1172.

A stress-based topology optimization of frame structures under loading uncertainty based on the second deviatoric stress invariant

Thursday, 20th June - 11:45: MS12 - Topology Optimization: From Algorithmic Development to Applications; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 812

Mr. Navid Changizi (Pennsylvania State University), Dr. Gordon P. Warn (Pennsylvania State University)

Civil structures are subjected to a variety of external forces all having some amount of uncertainty. It is generally understood that this uncertainty should be considered when designing these civil structural systems to avoid designs that are highly tuned and lack robustness. Topology optimization is a system-level design methodology that has been shown to produce efficient design solutions while accounting for uncertainty in both the external loading and uncertainty in the force resisting system. A methodology is proposed for the stress-based topology optimization of frame structures in which the uncertainty in the magnitude and direction of the external forces are considered. A Taylor series expansion of the second deviatoric stress invariant (J_2 stress) to the second order is derived along with analytical gradients to facilitate efficient gradient-based optimization such that the uncertainty is propagated from the input to the response analytically. The second deviatoric stress invariant is used as a proxy for the von Mises stress, and it is shown, by comparison to more computationally expensive Monte Carlo (MC) simulation, that it provides better accuracy for the stress objective function than von Mises stress for large input variance even when higher order terms are considered in the expansion. Through applications, the J_2formulation is shown to agree well with the MC method for all levels of input uncertainty. Furthermore, optimized designs derived from the suggested method are compared to the solutions from a corresponding deterministic problem to illustrate the benefit of considering uncertainty in the problem formulation.

An appropriate crack driving force function for the phase field approach to model mixed-mode brittle fracture

Thursday, 20th June - 10:30: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 530

Mr. Vignesh Kumar Devendiran (Vanderbilt University), Dr. Ravindra Duddu (Vanderbilt University)

Most engineering and natural materials exhibiting brittle fracture are characterized by disparate critical strain energy release rates (or fracture energies) under mode I (opening) and mode II (sliding) fracture. However, most existing phase field approaches, using the crack driving force function proposed by Miehe et. al. (IJNME, Vol 83, 2010), do not consider different mode I and mode II fracture energies; so they may not be appropriate to capture crack propagation under mixed-mode conditions. Recently, Zhang et. al. (CMAME, Vol 322, 2017) proposed a modified phase field approach for mixed-mode fracture, wherein the crack driving force is additively split into mode I and mode II components. Although this modified approach was shown to perform well in the case of rock-like materials under certain loadings, it does not appropriately account for the pure mode I and mode II fracture energies. To address this limitation, we propose an appropriate crack driving force function such that the definition of the strain energy release rate is consistent under simple loadings, such as, uniaxial tension and simple shear. Furthermore, we derive a semi-analytical expression to relate the components of the crack driving force function to mode I and mode II fracture energies. We validate the proposed model by simulating complex mixed-mode fracture patterns observed in experiments, namely, wing and secondary crack patterns in rock-like materials under uniaxial and biaxial compression, and curvilinear crack pattern in concrete under combined shear and tensile loadings.

X-ray Tomography and Diffraction Measurements to Study Elasticity and Fracture in Concrete

Thursday, 20th June - 10:45: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 95

Dr. Ryan Hurley (Johns Hopkins University), Dr. Darren Pagan (Cornell High Energy Synchrotron Source)

In-situ x-ray computed tomography (XRCT) has traditionally been employed to study elasticity and fracture during compression of granular materials, rocks, and concrete. While XRCT facilitates studying particle kinematics and full-field strain, it does not provide information regarding the stress concentrations within brittle material microstructures that nucleate and propagate fractures. To measure stress concentrations in microstructural inclusions, we have employed in-situ 3D x-ray diffraction (3DXRD) in the same experiment as XRCT, making both measurements simultaneously before and after small increments of strain applied to a sample of concrete fabricated with single-crystal quartz sand grains. 3DXRD permits measuring positions, orientations (with 0.05-degree resolution) and strain tensors (with 0.0001-resolution per component) in individual crystalline inclusions. Our experimental measurements therefore provide both full-field kinematics of the concrete microstructure during deformation and fracture, as well as stresses experienced at distinct locations within the microstructure. We will discuss how these measurements can provide unique insight into local stress-strain responses within quasi-brittle microstructures, an assessment of the local accuracy of continuum damage models, and the causes and effects of fracture nucleation and coalescence on in-situ stresses. We will also discuss ongoing efforts to project microstructural phases from XRCT images directly onto finite element meshes, and to calibrate these mesoscale models using full-field strain and 3DXRD measurements, in an effort to better understand properties and mechanical responses of the microstructure.

Strength and Cohesive Behavior of Thermoset Polymers at the Microscale: A Size Effect Study

Thursday, 20th June - 11:00: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 451

Mr. Yao Qiao (University of Washington), Mr. Shiva Goutham Pattapu (University of Washington), Prof. Marco Salviato (University of Washington)

This study investigated, experimentally and numerically, the fracturing behavior of thermoset polymer structures featuring cracks and sharp u-notches. It is shown that, even for cases in which the sharpness of the notch would suggest otherwise, the failure behavior of cracked and pre-notched specimens is substantially different, the failure loads of the former configuration being about three times lower than the latter one. Although this result is not surprising for blunt notches with large tip radii, it was not expected for the notches investigated in this work which featured a tip radius significantly smaller than the Irwin's characteristic length of the material.

To capture this interesting behavior a two-scale cohesive model is proposed. The model is in excellent agreement with the experimental data and its predictions allow to conclude that (a) residual plastic stresses cannot explain the very high failure loads of notched structures; (b) the strength of the polymer at the microscale can be from six to ten times larger than the values measured from conventional tests whereas the fracture energy at the microscale can be forty times lower; (c) the pre-notched specimens investigated in this work failed when the stress at the tip reached the microscale strength whereas the cracked specimens failed when the energy release rate reached the total fracture energy of the material. The foregoing considerations are of utmost importance for the design of microelectronic devices or polymer matrix composites for which the main damage mechanisms are governed by the strength and cohesive behavior at the microscale.

Size Dependent Strength Distribution of Polycrystalline Silicon MEMS Structures

Thursday, 20th June - 11:15: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 513

Prof. Jia-Liang Le (University of Minnesota), Mr. Zhifeng Xu (University of Minnesota), Prof. Roberto Ballarini (University of Houston)

Abundant experiments have shown that the failure strength of Microelectromechanical Systems (MEMS) structures exhibits a considerable degree of variability, which arises from the randomly distributed sidewall defects. The prediction of strength statistics plays an important role in the design of MEMS devices. Previous studies have also indicated that the strength distribution of MEMS devices exhibits a strong size effect, which cannot be captured by the conventional Weibull statistics. In this study, we develop a renewal weakest-link model for the strength statistics of polycrystalline silicon (poly-Si) MEMS structures. The model takes into account the detailed statistical information of the sidewall defects, which includes the defect geometry and spacing, as well as the local random material strength. Based on the postulate of stability, we show that, at the large-size limit, the model converges to the Weibull distribution. However, at the small and intermediate-size ranges, the model deviates significantly from the Weibull distribution. We show that the model provides optimum fittings of the measured strength distributions of poly-Si MEMS specimens of different sizes, which is essential for design extrapolations for MEMS devices across a wide size range.

Fracturing behaviors in discontinous fiber composite structures with different thicknesses

Thursday, 20th June - 11:30: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 516

Mr. Seunghyun Ko (University of Washington), Mr. James Davey (University of Washington), Mr. Sam Douglass (University of Washington), Mr. Shiva Goutham Pattapu (University of Washington), Mr. Joshua Huang (University of Washington), Dr. Jinkyu Yang (University of Washington), Dr. Mark Tuttle (University of Washington), Prof. Marco Salviato (University of Washington)

We investigate experimentally and numerically the mode I intra-laminar fracture and size effect of Discontinuous Fiber Composites (DFCs) for four different plate thicknesses (4.1, 3.3, 2.2, and 1.1 mm). We test four geometrically-similar sizes of single edge notched specimens with a constant platelet size of 50×8 mm. The tested specimens present strong size effects for every investigated thickness. The experimental results clearly show the deviation from Linear Elastic Fracture Mechanics (LEFM) as the structure sizes decreased. The deviation is enhanced for the increased thickness of DFCs. Consequently, the thicker DFCs exhibit more pronounced pseudo-ductile fracturing behaviors. Also, the scatter of strengths reduce noticeably as the thickness increased.
To analyze the size effects, we utilize Bažant's Size Effect Law. We combine the equivalent fracture mechanics with a stochastic finite element modeling. The finite element model explicitly generates the platelets, therefore it accounts for the complex, heterogeneous mesostructures of DFCs. As a result, the fracture energy and the effective length of the fracture process zone of DFCs with different thicknesses are found. Surprisingly, the fracture energy depends significantly on the thickness of the structure. By increasing the thickness from 1.1 to 3.3 mm, the fracture energy increases by 78.9 %. After reaching the thickness of 3.3 mm, the fracture energy saturates around 48.1 N/mm. The present work provides an important guideline for the design of DFC structures. The fracturing behaviors of DFC structures depend highly on their thickness, therefore changing the thickness of the parts must be chosen carefully.

Spectral Stiffness Microplane Model for Unidirectional Composites

Thursday, 20th June - 11:45: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 347

Mr. Sean Phenisee (University of Washington), Prof. Marco Salviato (University of Washington)

The use of unidirectional (UD) composites for primary and secondary structures is becoming broader and broader with applications including aerospace, wind energy, marine and automotive industry. However, the efficient use of these materials requires the development of proper computational tools for design. Leveraging the spectral stiffness decomposition of the stiffness tensor and a *microplane* formulation, the present contribution proposes a computational model to capture the main damage and fracturing mechanisms in UD composites. A key feature of the microplane model is that the constitutive laws are formulated in terms of the stress and strain vectors acting on a generic plane of any orientation within the material meso-structure, called the microplane. These planes can be conceived as the tangent planes of a unit sphere surrounding every point in the three-dimensional space. The microplane strain vectors are the projections of the macroscopic strain tensor, whereas the macroscopic stress tensor is related to the microplane stress vectors via the principle of virtual work. Furthermore, the *Spectral Stiffness Decomposition* theorem is used to decompose the stiffness matrix and to define energetically orthogonal strain modes at the microplane level. In this way, the anisotropic behavior is automatically described in the microplane formulation. Material systems used in this study are chosen from the “World Wide Failure Exercise.” All the numerical simulations performed in this study are validated by comparing to this collection of experimental data. Preliminary results show a good predictive capability of the model both for uniaxial and biaxial loading conditions.

NeXT-Grenoble: The Neutron and X-ray Tomograph in Grenoble

Thursday, 20th June - 10:30: MS34 - Experimental and Computational Methods for Particulate Materials; Part 1 (103 Downs (50)) - Oral - Abstract ID: 1210

Dr. Alessandro Tengattini (University of Grenoble Alpes - Laboratoire 3SR), Dr. Nicolas Lenoir (University of Grenoble Alpes - Laboratoire 3SR), Dr. Edward Ando (University of Grenoble Alpes - Laboratoire 3SR), Prof. Cino Viggiani (Université Grenoble Alpes / Laboratoire 3SR)

Neutrons and x-rays interact differently with the atomic structure of materials, which means that in radiography techniques they can provide different information about the same material. Notably, neutrons interact with hydrogen-rich substances more readily than x-rays, simplifying the identification of water and hydrocarbons. The high complementarity of neutron and x-rays can be taken advantage of to explore a plethora of processes of great relevance to the geomechanical and engineering communities at large. Their combination (made possible by recent mathematical developments) also provides phase identification, with much more ease than with either image individually.

D50/NeXT (Neutron and X-ray Tomograph) was born in February 2016 from the collaboration between the Universite Grenoble Alpes, UGA (and specifically Laboratoire 3SR) and the Institut Laue Langevin, ILL.

Beside the complementary x-ray and neutron setup, this instrument takes advantage of the world's highest neutron flux offered by the Institut Laue-Langevin, allowing for unprecedented resolutions (<4 μm true resolution) and speeds (1 second tomographies). While these are not unique in the domain of x-ray imaging they set a new record in the domain of neutron imaging.

A multi-million euro upgrade of the instrument is foreseen in the forthcoming two years to further improve its performances as well as to add further options (e.g, monochromation, polarised neutrons, grating interferometry). This instrument is open for proposals through its dedicated website (https://next-grenoble.fr/).In this talk, we'll present a few relevant examples of successful application of NeXT.

In-Situ Studies of Grain Kinematics and Micromechanics Using X-Ray Techniques

Thursday, 20th June - 10:45: MS34 - Experimental and Computational Methods for Particulate Materials; Part 1 (103 Downs (50)) - Oral - Abstract ID: 438

Dr. Chongpu Zhai (Johns Hopkins University), Dr. Ryan Hurley (Johns Hopkins University), Dr. Stephen Hall (Lund University), Dr. Eric Herbold (Lawrence Livermore National Laboratory)

Grain kinematics and micromechanics were experimentally studied by incorporating both X-ray computed tomography (XRCT) and 3D X-ray diffraction (3DXRD). The two X-ray techniques enable concurrent evaluation of the contact fabric, crystal orientation and average grain intra-stress, thus allowing us to elucidate the micromechanics at contact and grain levels. We investigated packings of slightly cemented angular quartz, and packings of ruby spheres under uniaxial compression with different levels of lateral confinements. For quartz samples, we characterized the reinforcement fabric formed by grain contacts and epoxy connections. The added epoxy was found to play an important role in controlling grain rotation, stress/strain anisotropy, sample strength, and fragmentation. For ruby samples, we inferred inter-particle through a multi-objective optimization procedure that sought to satisfy particle equilibrium and volume-averaged stress measurements for each grain. We used forces and highly-resolved particle kinematics to characterize contact mircomechanics and evaluate the contact-level origin of macroscopic energy dissipation during compression. This work highlights new applications of XRCT and 3DXRD for studying deformation and energy dissipation mechanisms in granular materials. The results provide insight into the complex nature of granular micromechanics and unique 3D data that may be used to validate computational models.

Introducing X-ray Rheography to uncover velocities in arbitrarily deforming granular media

Thursday, 20th June - 11:00: MS34 - Experimental and Computational Methods for Particulate Materials; Part 1 (103 Downs (50)) - Oral - Abstract ID: 1187

Dr. James Baker (The University of Sydney), Dr. François Guillard (The University of Sydney), Dr. Benjy Marks (The University of Sydney), Prof. Itai Einav (The University of)

A new unobtrusive X-ray technology is presented with which we can measure three-dimensional velocity fields in generally deforming opaque materials. The new approach is fundamentally different compared to existing experimental technologies. Indeed, this is the first time that X-rays have been used to reconstruct full internal velocity fields for continuously flowing media, a feat beyond the capabilities of classical X-ray tomography. The capabilities offered by the new method are particularly exciting for people working on granular materials, who have long desired three-dimensional experimental measurements to provide analytical insight and validate their theoretical models. In this presentation we will detail the ingredients of our new technique and demonstrates how it applies to confined granular flows. Of particular interest is our somewhat surprising finding of the flow of granular media adjacent to non-planer walls – an example of where intuitive results from Newtonian fluids do not translate to granular media. We anticipate that our new method may reveal much more about the rich granular rheology, be it non-locality, compressibility, intrinsic particle length scales or friction effects. Our field alone has implications for many industries, such as food processing, bulk materials handling and pharmaceuticals. However, beyond particles and grains, any material which has a fabric with sufficient macroscopic texture may be amenable to our X-ray technology in the future and, with the continuous improvement in source and detector technologies, the accessible time and length scales will continue to shrink, opening up even more opportunities.

Packings in granular ensembles – insight from micro-computed tomography and contact dynamics.

Thursday, 20th June - 11:15: MS34 - Experimental and Computational Methods for Particulate Materials; Part 1 (103 Downs (50)) - Oral - Abstract ID: 366

Mr. Abhijit Hegde (Indian Institute of Science Bangalore), Mr. Saurabh Singh (Indian Institute of Science Bangalore), Dr. Tejas Murthy (Indian Institute of Science Bangalore)

The problem of random packing has been studied extensively by physicists and engineers alike to address the structure of liquids, packing of coal, cannon balls, powders, and grains. These packings are characterized by packing fraction, distribution of coordination number, radial distribution function, distribution of local mean voidage. Traditional experimental techniques used in literature such as use of paints or acetic acid to identify the contacts is prone to errors. Further, the difficulty in measuring the number of contacts presents a restriction on the number of particles and size of the container and hence leads to boundary effects on the structure of packing. A simple counting argument based on equilibrium and impenetrability of frictional grains suggests that the range of coordination number should lie between four and six. Experimental results on average coordination number are often higher than the values reported in simulations using periodic boundary condition. We investigate the boundary effect on the structure of random packings using x-ray micro-computed tomography and contact dynamics simulations.

Dense Slow Sheared Angular Sand and Spherical Glass Beads in a Powder Rheometer

Thursday, 20th June - 11:30: MS34 - Experimental and Computational Methods for Particulate Materials; Part 1 (103 Downs (50)) - Oral - Abstract ID: 1232

Mr. Han-Hsin Lin (California Institute of Technology (Caltech)), Prof. Melany Hunt (California Institute of Technology (Caltech))

Jamming and shear-thinning are interesting, time-dependent behaviors found in granular materials; however, most prior research has focused on the steady-state behavior under different shear rates. We study the transition phenomenon from unsteady to steady state by using a Couette cell and controlling the torque and speed of the inner cylinder. When controlling the torque, the system cannot reach a steady state when it is below a critical stress. When controlling the speed of the boundary, the shear stress at the wall increases slowly over a period of time that depends on the initial state of the bed, wall friction, shear rate, and flow along the free surface. At steady state, the stress decreases at the highest rotation speeds. Simulations show a recirculation cell driven by gravity and the free surface, which results in the increasing stress observed in the measurements. The effective friction of the inner wall matters. When using the smooth cylinder, the system needs more time to reach a steady state than using the rough cylinder. At steady state, its wall stress decreases more significantly at the highest rotation speeds compared to the rough cylinder.

Experiments probing sub-yield granular creep in the (near) absence of disturbances

Thursday, 20th June - 11:45: MS34 - Experimental and Computational Methods for Particulate Materials; Part 1 (103 Downs (50)) - Oral - Abstract ID: 1075

Mr. Nakul Deshpande (University of Pennsylvania), Dr. Behrooz Ferdowsi (Princeton University), Prof. Douglas Jerolmack (University of Pennsylvania)

Soil and dirt are relentlessly dragged along hillslopes by gravity. We typically conceptualize transport as either being driven by agencies external to the grains themselves (eg. bioturbation, freeze-thaw, fluctuations in hydrology) or as an excess of a critical friction criterion. The existence of sub-yield deformation violates both of these perspectives as well as non-local models of granular rheology. Here, we render the problem of sediment transport on hillslopes via an interpretation of soil creep as the deformation of an amorphous solid and seek to probe this phenomenology with Diffusing Wave Spectroscopy (DWS), a technique that allows us to probe strain rates on the order of the optical wavelength.

We begin by developing a model system. symmetric pile of loose grains (glass beads, d = 100 microns) is prepared below the angle of repose in an enclosed box at a fixed temperature and relative humidity. The system rests on a vibration-isolation table and is allowed to sit for 15 minutes. Although apparently static, we measure micron-scale displacements of grains which occur in discrete, localized zones. Averaged over the duration of the experiment, we recover an exponential-like decay of the strain rate with depth from the free surface. We then proceed to test a suite of material sizes and shapes and find that rates of creep change with material properties, but the qualitative features and functional form of the strain rate profile remain consistent with the model system.

A New Interpretation of Three-Dimensional Particle Geometry: M-A-V-L

Thursday, 20th June - 10:30: MS72 - Mechanics and Physics of Granular Materials; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 101

Prof. Seung Jae Lee (Florida International University), Ms. Sumana Bhattacharya (Florida International University), Prof. Chang Hoon Lee (Western New England University), Prof. Moochul Shin (Western New England University)

This study provides a new interpretation of 3D particle geometry that unravels the 'interrelation' of the four geometry parameters, i.e., morphology M, surface area A, volume V, and size L, by proposing a new formula, M = A/V×L/6, which translates the 3D particle morphology as a function of surface area, volume, and size. The value of A/V×L for a sphere is invariantly 6, thus M indicates a relative morphological irregularity compared to the sphere. The minimum possible value of M is clearly 1, and may range to approximately 3 for typical coarse grained mineral particles based on the Krumbein and Sloss chart. This study also demonstrates how the proposed formula can be leveraged to systematically describe the distributions of those interrelated 3D particle geometry parameters, which would be useful to predict the mechanical property of granular materials. An experimental study is performed to demonstrate the predictive capability of the proposed formula, where a set of 3D particle models are developed and 3D printed for use in the direct shear test. This presentation will highlight the test results and demonstrate the effectiveness of the 'marvelously' simple formula that robustly interprets the interrelation of three-dimensional particle geometry parameters, M-A-V-L.

Critical fabric-based constitutive modeling of granular soils

Thursday, 20th June - 10:45: MS72 - Mechanics and Physics of Granular Materials; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 337

Dr. Yida Zhang (University of Colorado Boulder)

The Critical State Theory (CST) is one of the most important milestones in modern soil mechanics research. The theory states that, upon continuous shearing, granular materials will eventually reach to their critical state which is characterized by a unique void ratio *e*– mean stress *p'* – deviatoric stress *q* relation. Recently, Li and Dafalias (2011) extended the CST by by introducing anisotropic fabric tensor **F**in the state space. The new Anisotropic Critical State Theory (ACST) emphasizes that, critical state is only attained when **F** reaches to its critical value $\mathbf{F}_c$ in addition to the conventional requirement.

If we accept that soils at critical state processes a unique microstructure, the definition of critical state by ACST could still be incomplete. Specifically, fabric tensors are only approximations of directional statistics that characterizes material's internal structure. The zero-order approximation is reflected through void ratios as used in CST, while the second order approximation is the anisotropic fabric **F**as used in ACST. In this contribution, the author will attempt to cast a unified framework, referred to as the critical fabric theory to interpret the recent DEM results on microstructure evolution of sands during quasi-static shearing. Then it follows that the CST and ACST are special cases of the proposed theory with different orders of truncation. A constitutive model is then established pertaining to the critical fabric theory. The model recovers a unique critical state line as in the classical CST models and its performance is evaluated against the Toyoura sand data.

Simulating poroelastic effects in the undrained loading of granular materials

Thursday, 20th June - 11:00: MS72 - Mechanics and Physics of Granular Materials; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 343

Dr. Matthew Kuhn (University of Portland), Dr. Ali Daouadji (University of Lyon, INSA-Lyon)

The saturation condition of sands is known to affect strength and liquefaction during undrained loading. The presentation focuses on the quasi-saturated condition, which occurs when the pore volume contains less than 10% gas, the remainder being liquid. In this condition, gas is present as immobile bubbles which greatly increase the pore fluid's compressibility. A fully saturated condition is typically simulated with discrete element (DEM) models by disallowing volume change during deviatoric loading. However, the constant-volume condition is not equivalent to the undrained condition, as the pore volume can change, even when the fluid is fully saturated and certainly when the fluid is quasi-saturated. A model is presented for computing fluid compressibility and for incorporating this compressibility in DEM simulations. The method includes the effects of gas dissolution within the liquid phase, surface tension at liquid-gas menisci, and vapor pressure of the liquid phase. By incorporating these factors in a DEM simulation, the approach allows direct computation of both effective stress and total stress during simulations. For example, one can compute the so-call B-value during back-pressure saturation, the dissolution and cavitation of gas during undrained conditions, and the change of pore volume during both drained, undrained, and partial drainage conditions. The effect of quasi-saturation is demonstrated by showing simulations of undrained triaxial compression and cyclic undrained triaxial loading. The presence of gas is shown to increase undrained strength and cyclic resistance.

Characterization of cement-based materials for 3D printing

Thursday, 20th June - 11:15: MS72 - Mechanics and Physics of Granular Materials; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 355

Dr. Claudiane Ouellet-Plamondon (ETS Montreal)

Additive manufacturing for cement-based materials is gaining interest these past years. Printing concrete has the potential to remove the time allowed to casting and molding. Nevertheless, new issues specific to 3D printing emerge. For example, the preservation of the mechanical properties and the stability of the printed layers. The objective is to identify the characteristics needed for a printed mortar to fulfill its role and propose a mixture that fills the required characteristics. A framework for testing several characteristics of mortar and cement paste are designed. The mixtures tested are composed of various combinations of superplasticizer (SP), accelerator (A), nanoclay (C) and viscosity-modifying admixture (VMA). Viscosity is measured following the National Institute of Standards and Technology (NIST) method for Standard Reference Material 2492. The flow of the mortar is determined following the standard ASTMC1437. To propose a value of stability of the mortar the deformation under a force of 100 N progressively applied. Finally, the percentage of the height decreasing of a printed mortar layer is computed. Mechanical tests are conducted to study the hardened properties of the mortar. Finally, the aim is to be able to predict the physical behavior only with the composition of the mixture. Doing so, characteristics of printed mortar can be predicted before any test. Next steps are to increase the number of admixture to have a larger database and to validate the mix design to larger printed forms.

Nonlinear acoustic wave-induced softening in dense granular matter through flow heterogeneities

Thursday, 20th June - 11:30: MS72 - Mechanics and Physics of Granular Materials; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 510

Dr. Charles Lieou (Los Alamos National Laboratory), Dr. Laurent Jerome (Institut Langevin, ESPCI Paris), Dr. Paul Johnson (Los Alamos National Laboratory), Prof. Xiaoping Jia (Institut Langevin, ESPCI Paris)

We report a series of experiments on the softening of a dense granular pack through acoustic pressure and shear waves. Softening is manifested by a reduction of standing-wave resonance frequency, and of the traveling-wave speed, as the amplitude of the disturbance increases beyond some threshold. We explain these observations using a theoretical model, based on shear transformation zones (STZs), that directly attributes these observations to dynamical heterogeneities and slipping contacts in the granular pack. In so doing, we demonstrate the fundamental connection between nonaffine granular rearrangements, mesoscopic glassy dynamics, jamming and unjamming, and matter-wave interactions.

Stress Wave Propagation in Granular Columns

Thursday, 20th June - 11:45: MS72 - Mechanics and Physics of Granular Materials; Part 1 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1401

Mr. Christopher Kubik (New Jersey Institute of Technology), Prof. Anthony Rosato (New Jersey Institute of Technology), Dr. Denis Blackmore (New Jersey Institute of Technology)

The dynamics of granular materials across the flow regimes – from quasi-static to rapid – involve the transmission of stress waves through a network of particle contacts. The global objective of our research is to determine the role of material properties *on the propagation of these waves through the system, and to understand how the contacts evolve. In order to approach the more complex problem, we are investigating the stress wave in a simple one-dimensional, unconstrained column of inelastic grains subjected to a force or displacement impulse at the base. We model the physical process via Impetus-AFEA, an explicit, discrete finite element code capable of simulating the rapid dynamics inherent in the problem. This work essentially extends our earlier discrete element findings [1,2] on stainless steel beads.*

Initial validation of the simulation model was done by computing the wave speed through a prismatic bar, with results that were within 20% of the theoretical value (E/ρ)ˆ0.5. Additional validations completed include agreement with experimentally-measured restitution coefficients reported in the literature for different materials, and a comparison of the evolution of the floor contact force with experiments [3]. It was found that results are insensitive to the contact penalty stiffness within an order of magnitude.
Preliminary simulations have been conducted with one to four inelastic, stainless steel spheres to track the progression of the stress wave through the assembly. Contact force evolutions at each sphere interface, and the spatial distribution of normalized kinetic energy was monitored.

Two-Way Multi-scaling for Predicting Fatigue Crack Nucleation in Titanium Alloys Using Parametrically Homogenized Constitutive Models

Thursday, 20th June - 10:30: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 286

Prof. Somnath Ghosh (Johns Hopkins University), Mr. Deniz Ozturk (Johns Hopkins University), Mr. Shravan Kotha (Johns Hopkins University)

This paper develops a two-way (bottom-up or hierarchical) and top-down) multi-scale modeling framework for predicting fatigue crack nucleation in structural components of Titanium alloys, e.g. Ti-7AL. Pure micromechanical analyses are deficient in this regard. A parametrically homogenized constitutive model (PHCM) and a parametrically homogenized crack nucleation model (PHCNM) are developed from computational homogenization of crystal plasticity finite element (CPFE) simulation results performed on microstructural statistically equivalent RVEs or M-SERVEs. Image-based CPFE of the M-SERVEs predict time-dependent plastic deformation, as well as location and time-dependent fatigue crack nucleation in the microstructure. Micromechanical analysis data is utilized by a machine learning code to derive functional forms of PHCM and PHCNM coefficients. Macroscopic FE models for Ti-7AL test specimens are created next, by matching correlation functions of the micro-texture and other microstructural variabilities in EBSD scans. Macroscopic simulations of dwell and cyclic loading are performed and nucleation hotspots are identified by PHCNM. Top-down simulations of the local M-SERVEs are then used to probe microstructural fatigue crack nucleation sites and cycles. The multi-scale simulations predict sub-surface nucleation for a majority of dwell cracks, which is corroborated by fractography images. The computed nucleation cycles and spatial distributions across a range of loading conditions follow experimentally observed characteristics of dwell effect in Ti alloys.

Shear Bands and Mechanical Behaviors of Metals using Taylor Impact Testing

Thursday, 20th June - 10:45: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 402

Dr. George Voyiadjis (Louisiana State University, Baton Rouge, Louisiana), Dr. Yooseob Song (Louisiana State University, Baton Rouge, Louisiana), Dr. Alexis Rusinek (Lorraine University), Ms. Reem Abo Znemah (Louisiana State University, Baton Rouge, Louisiana), Mr. Juyoung Jeong (Louisiana State University, Baton Rouge, Louisiana)

To study material behavior at high strain rate and the failure mode, Taylor test was conducted in this work. Rod specimens were impacted against a rigid surface.Knowing the initial dimensions and the final one after impact, the average stress strain and strain rate may be estimated. The velocity for the tests is varying from 40 to 200 m/s allowing to reach a maximum strain rate close to 10ˆ5/s. *Three materials were used during this work, copper, brass and TA6V (tungsten) to observe how the failure modes are changed in these materials. The results of the Taylor test were reproduced through numerical simulations based on a physically based Voyiadjis-Abed-Rusinek (VAR) model. The VAR model was recently proposed by the authors by means of the Weibull probability density distribution function which is established from a physically based mechanism of evolution of the dislocation density. The proposed VAR model was implemented by writing an user-defined material subroutine (VUMAT) in ABAQUS/Explicit. Using the finite element implementation, the dynamic behaviors of the abovementioned three materials at high strain rates as well as their failure modes were investigated and compared to the experiments.*

Spectral Variational Multiscale Approach for Transient Dynamics of Phononic Crystals and Acoustic Metamaterials

Thursday, 20th June - 11:00: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 379

Mr. Ruize Hu (Vanderbilt University), Prof. Caglar Oskay (Vanderbilt University)

Phononic crystals and acoustic metamaterials are architectured composites exhibiting tremendous capabilities in controlling mechanical waves. With these materials, unique wave phenomena such as band gaps due to Bragg scattering for phononic crystals and local resonance for acoustic metamaterials, can be controlled, enabling remarkable novel engineering applications such as seismic wave mitigation, impact wave mitigation, elastic cloak, and acoustic superlens.

A number of multiscale methods have been previously proposed to study the dynamic response of these materials based on the principle of scale separation. This principle considers that deformation length of the wave propagating in the structure is larger than the size of the material microstructure, which if often violated in the high-frequency loading regime of interest. In this study, we present the spectral variational multiscale enrichment approach that does not restrict the relative deformation wavelength with respect to the microstructure size, and allows the analysis of a broad range of material microstructures for phononic crystals and acoustic metamaterials. The spectral coarse-scale representation is proposed to capture the salient transient wave phenomena, such as wave dispersion and band gaps that occur in the short wavelength regime. A material phase based model order reduction strategy is devised at the fine-scale. By using the reduced basis for the fine-scale problem, significant numerical efficiency is achieved. Transient elastic wave propagation in two-dimensional phononic crystals and acoustic metamaterials are investigated and the proposed multiscale approach is verified against direct numerical simulations.

Using High Performance Computing to Enable Data-informed Multiscale Modeling with Application to Additive Materials

Thursday, 20th June - 11:15: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 570

Dr. Tim Wildey (Sandia National Laboratories)

Multiphysics systems are typically strongly coupled, highly nonlinear and characterized by multiple physical phenomena that span a large range of length- and time-scales. Performing direct numerical simulation of such systems that resolves all the relevant length- and time-scales is often prohibitive, even on the modern leadership-class computing platforms. Consequently, we are interested in developing multiscale methods to allow the incorporation of fine scale information into a coarse scale approximation. The process of injecting information from unresolved, or subgrid, scales into a coarse scale discretization has been pursued in several different ways by different communities. Many of the existing approaches are based on computational homogenization and while tremendous progress has been made both theoretically and computationally, this approach usually requires rather strict assumptions, such as periodicity of the media, and is difficult to generalize to multiphysics applications.

In this presentation, we describe our recent efforts to develop a general concurrent multiscale framework for multiphysics systems on massively parallel computational architectures that does not rely on homogenization. We describe some of the similarities between our approach and existing methods and discuss the utilization of heterogeneous computational architecture to efficiently perform the calculations. We also discuss a multi-fidelity approach for solving a stochastic inverse problem approach to develop data-informed multiscale models with enhanced predictive capabilities. Numerical results will be presented to demonstrate these capabilities on examples motivated by additive manufacturing.

Microstructural Scale Modeling and Homogenization of Damage Evolution in Thermal Barrier Coatings

Thursday, 20th June - 11:30: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1351

Prof. Jason Mayeur (University of Alabama in Huntsville)

Special technology coatings are used in gas turbine engines to protect structural components from the extreme environmental and temperature conditions experienced during service. Since the coatings act as a barrier between the underlying structural materials and the harsh operating environment, it is desirable to understand the evolution of the integrity of the coatings as a function of service load cycles so that maintenance schedules can be further refined and next generation coating systems can be developed. In this work, we present a multiscale modeling approach to predict damage evolution in a thermal barrier coating under combined thermo-mechanical loading. A particle-based continuum framework (peridynamics) is used at the microstructural scale for its ability to handle the evolution of discrete damage evolution. Microscale simulation results are then used to calibrate a macroscale continuum damage and cohesive zone model of the coating system that can be used to evaluate coating performance in engineering scale simulations.

Adaptive Multi-Material Design Optimization with Material and Geometric Nonlinearities

Thursday, 20th June - 11:45: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 1 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 962

Prof. Xiaojia Shelly Zhang (University of Illinois at Urbana-Champaign), Dr. Heng Chi (Georgia Institute of Technology), Prof. Glaucio Paulino (Georgia Institute of Technology)

Topology optimization is a computational design tool for finding optimal layouts of structures and material microstructures. In this talk, we explore the connection between topology optimization and hierarchical design through a multi-material formulation. Within the field of topology optimization, multi-material topology optimization is an emerging trend. However, most work has been focused on linear material behavior with limited constraint settings. To address these issues, we propose a general multi-material topology optimization formulation considering material and geometric nonlinearities. The proposed formulation handles an arbitrary number of candidate materials with flexible properties and features a generalized setting of local and global volume constraints. To efficiently handle such arbitrary volume constraints, we employ and tailor the ZPR (Zhang-Paulino-Ramos) design variable update algorithm for the proposed formulation, which is based upon the separability of the dual objective function of the convex subproblem with respect to Lagrange multipliers. The tailored ZPR update performs robust updates of the design variables associated with each volume constraint independently in parallel.

To efficiently solve nonlinear state equations resulting from material and geometric nonlinearities, we introduced the Virtual Element Method (VEM) in conjunction with an adaptive meshing scheme, which greatly improves the convergence speed. Through examples using various nonlinear materials, we demonstrate that the proposed multi-material design optimization framework, with VEM and mesh adaptivity, leads to a practical design tool that not only finds the optimal topology but also selects the proper type and local distribution of materials, which offers a potential avenue to design hierarchical materials from bottom up.

Design Framework for Resilient Extraterrestrial Habitats

Thursday, 20th June - 10:30: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 732

Dr. Amin Maghareh (Purdue University), Mr. Ali Lenjani (Purdue University), Prof. Shirley Dyke (Purdue University), Prof. Karen Marais (Purdue University), Prof. Antonio Bobet (Purdue University), Prof. Julio Ramirez (Purdue University), Dr. Dawn Whitaker (Purdue University), Dr. Anahita Modiriasari (Purdue University), Mr. Audai Theinat (Purdue University)

Beyond the protection of Earth, elements of a habitat system will be subjected to anticipated and unanticipated threats. Conventional risk analysis and health management techniques across space systems are based on passive and fixed reliability capabilities, driven by avoiding or minimizing the occurrence of known/anticipated threats. This design philosophy is inadequate in the context of a long-term habitat system for two main reasons: (i) high reliability is inefficient and uneconomical; and,(ii) disruptive events are inevitable, yet difficult to foresee.
For a long-term habitat system, resilience is a key contributor to success. Indeed, not only should the ability of the system to resist (preventive capability) be a critical design requirement, but requirements also include the ability of the system to anticipate, monitor, and adapt (interventive capability), and restore to a functional state (mitigative capability) within an acceptable period of time (rapidity). Here a new design paradigm is provided, a resilience-oriented design approach to dynamic performance of habitat systems. Using this approach, the habitat system will be designed to have multiple defense layers (or resilience capabilities), resistance layer (or preventive capability), proactive layer (interventive capability), and recovery layer (or mitigative capability). This design approach is proposed as a multi-objective optimization problem, in which the three objectives are to maximize the rapidity, to maximize the elasticity and to minimize the life cycle cost. Finally, the proposed approach is illustrated using a lunar habitat system case study.

An Analysis of Externally-Induced Temperature Gradient Fluctuations through Shielding Layers of a Lunar Habitat

Thursday, 20th June - 10:45: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 591

Mr. Jeffrey Steiner (University of Connecticut), Prof. Ramesh Malla, Ph.D., F. ASCE (University of Connecticut)

The lunar environment presents a multitude of technical challenges to be overcome that are not restricted to: a hard vacuum, lack of substantial atmosphere, susceptibility to multiple forms of dangerous cosmic radiation, potential for micrometeoroid impacts at hypervelocity, and a broad range of temperature extremes, the last of which is the focus of this study. The construction of a self-sustaining, resilient lunar habitat requires a design that addresses all of these technical challenges in a cost-effective manner.

The purpose of this paper is to present an accurate and detailed analysis of the effects of external temperature fluctuations on the interior living environment of future lunar habitats if active temperature controls were to become non-functional. Three different passive shielding conditions have been considered in this study: a hybrid (frame-membrane) habitat with insulation common to terrestrial applications, to act as a control condition, a regolith shielding layer, as well as a prefabricated aluminum-polyethylene (UHMWPE) composite shielding layer attached directly to the habitat frame. The analysis in this paper utilizes the Thermodynamic Equation of Heat Conduction and Radiation to produce a depth-dependent temperature gradient from the exterior to the interior environment that changes continuously with time during the lunar diurnal cycle. The results of this study are able to both validate different shielding methods with respect to their resilience towards thermal loads, as well as allow for the determination of emergency response time in the event of a membrane puncture or other exposure to the hazardous lunar environment.

Design, Dynamics and Control of a Tensegrity Lunar Lander

Thursday, 20th June - 11:00: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 997

Mr. Raman Goyal (Texas A&M University, Aerospace Engineering), Dr. Dipanjan Saha (Texas A&M University), Prof. Robert Skelton (Texas A&M University, Aerospace Engineering, Ocean Engineering)

Tensegrity Structures provide minimal mass for a variety of loading conditions and shape control problems in all engineering disciplines. Tensegrity has also shown to provide an optimum structure to take impact loading by storing energy in elastic strings. Low-mass/high-energy absorption tensegrity components form the basis for topology optimization of space exploration landers. This research would provide more insights into the topology optimization, dynamics and controls of a tensegrity structure to provide a soft landing for the payload. The idea is to distribute the impact energy to elastic energy throughout the structure. The research will show the results on the passive and actively controlled structure to bound the l-infinity norm of the acceleration (maximum acceleration) of the payload during the landing operation. The structure is controlled by actively controlling the force densities (tension/length) in the strings. The control variable can be converted to a physical variable to rest length of the strings. The structure is designed to consider both landing operation and planetary exploration.

Thermally activated envelope for habitats under extreme environment

Thursday, 20th June - 11:15: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 965

Dr. Hongyu(Nick) Zhou (University of Alabama in Huntsville), Mr. Babak Salarieh (University of Alabama in Huntsville), Ms. Yawen He (University of Alabama in Huntsville)

Homoeothermic animals regulate deep and surface body temperature through hydronic exchanges with the circulatory and integumentary systems that use the skin as thermal source and sink. Owing to the capillary mat blood vessels and regulated blood flow, living skin develops an extraordinarily high thermal emissivity and absorptivity. This research seeks to utilize hydronic circuits embedded in the load-bearing backbone to create next-generation envelope systems that are capable of performing the full range of structural functions, while in the meantime, possess the ability to convey and distribute thermal energy for thermal load management. The initial work was inspired by the thermoregulation mechanism of homoeothermic animal skins and the recognition of the impacts of fluidic properties on both the mechanical and heat conductive properties of hydronically activated systems. This study presents several approaches for optimizing the topology of convective channels within a building envelope, including adaptive spatial Voronoi tessellation, and more.

Technology Advancements for Lunar Exploration

Thursday, 20th June - 11:30: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 400

Ms. Rebecca Thoss (Ball Aerospace), Dr. Melissa Sampson (Ball Aerospace)

As the closest astronomical object to Earth, the Moon has long held fascination. The first steps on the Moon in 1969 inspired the world and continue to be a source of inspiration today for government space agencies and commercial companies alike. Yet despite its proximity, much of the Moon is still unknown. Few robotic missions and no human missions have ever endured the 14- Earth day long equatorial lunar night, and no missions have explored the permanently shadowed regions at the lunar poles, leaving open extensive opportunities for technical challenge and scientific exploration.

In this presentation, various technologies will be discussed that enable survival and operation in dark, unexplored lunar regions. Specifically, recent innovations in imaging and thermal management will be shared. Sensor and instrument miniaturization advancements have resulted in low-light cameras, thermal cameras, and flash lidars that can provide valuable scientific and exploratory data in a small format. Thermal management is a challenge given the wide temperature range on the Moon, and multi-layer insulation is another enabler for landers and rovers, in addition to in space applications. Innovative engineering technologies and manufacturing will enable exploration and advancement of the engineering field.

Lunar and Martian Vertical Takeoff & Vertical Landing (VTVL) Pad Concepts

Thursday, 20th June - 11:45: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1062

Mr. Robert Mueller (NASA Kennedy Space Center), Mr. Nathan Gelino (NASA Kennedy Space Center)

Landing space craft rocket plume exhaust interactions with the regolith surfaces on the Moon and Mars will result in cratering and regolith particle ejecta traveling at velocities up to 2,000 m/s in the vacuum surroundings. This phenomenon creates hazards for the spacecraft that is landing or launching and may also cause damage to surrounding assets, personnel and infrastructure. One potential solution to this issue is to construct vertical takeoff and vertical landing (VTVL) pad infrastructure systems which will mitigate these rocket plume exhaust effects. Concepts will be presented for the construction and maintenance of such VTVL pads in lunar and martian environments.

Mechanics of vessel pressurization in soil under biaxial stress: a 3D analysis using CT scanning

Thursday, 20th June - 10:30: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 302

Mr. Fernando Patino-Ramirez (Georgia Institute of Technology), Dr. Chloe Arson (Georgia Institute of Technology)

The expansion of flexible bodies in granular media is a complex process with a variety of applications, from tunneling, resource withdrawal and directional drilling, to root growth and annelids locomotion. The efficiency and adaptability exhibited by burrowing organisms motivated us to explore the mechanics of vessel pressurization.

We seek to expand the capabilities of in-situ testing devices to anisotropic stress conditions, typical of shallow subsurface networks. To this end, we built a root-inspired prototype that was inflated in dry sand subjected to biaxial stress, within an X-ray 3D tomography scanner. We analyze the 3D images to explain the strain in the soil during the pressurization cycles. The mechanical parameters and initial stress state of the soil dictate the deformation of the probe, while it induces elasto-plastic strains in the soil, which eventually lead to the generation of failure surfaces.

Our end goal is the development of an algorithm that infers the coefficient of Earth pressure at rest and the soil elasto-plastic parameters from the pressure and deformation of the probe and from the locus of the soil failure surface. Furthermore, we prototype a device, instrumented to measure the deformation around the flexible body as a function of the applied internal pressure. This device would be deployed in the field as a standalone instrument or as an add-on coupled to an excavation machine to determine soil mechanical properties on the fly. We discuss the feasibility of mimicking multi-functional biological systems such as roots, which grow by coupling sensing and burrowing.

Leaf Inspired Drainage Networks: A Hybrid Numerical-Experimental Study

Thursday, 20th June - 10:45: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 539

Dr. Nariman Mahabadi (Arizona State University), Mr. Fernando Patino-Ramirez (Georgia Institute of Technology), Dr. Leon van Paassen (Arizona State University), Dr. Chloe Arson (Georgia Institute of Technology)

Nature has been solving flow optimization problems for millions of years. Plant leaves contain a vascular system of interconnected veins which ensure effective and efficient evapotranspiration through their medium while providing high resilience in case of injury to the main veins. This work aims to investigate the potential use of the leaf venation-inspired networks to design and build optimal drainage systems. In this study, leaf venation growth under various spatial distributions of auxin sinks are simulated to mimic several plant species and select plants that yield optimal bio-inspired paths. An image processing algorithm is developed to detect and extract the geometric characteristics of the venation patterns of the selected leaf species with the highest path efficiency. The topological information of the extracted networks are used to 3D print leaf-like microfluidic chips in order to manifest the transport functioning of the modeled networks. Using the microfluidic chips, a sensitivity analysis is performed to determine the most prominent topological features of the leaf venation networks. A CFD model is developed in COMSOL Multiphysics to extend the sensitivity analysis, validate the flow models against the experimental results, compare the flow simulations in bio-inspired networks with non-bio-inspired flow paths and validate or invalidate the bio-mimicry concept. The results of this study will help us to evaluate the feasibility of leaf inspired networks, with the objective of providing a breakthrough in the way that we design optimal drainage systems.

3D observation and kinetic analysis of root growth in sand

Thursday, 20th June - 11:00: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 559

Mrs. Floriana Anselmucci (University Grenoble Alpes, Laboratoire 3SR), Dr. Edward Ando (University of Grenoble Alpes - Laboratoire 3SR), Dr. Luc Sibille (University of Grenoble Alpes - Laboratoire 3SR), Dr. Robert Peyroux (University of Grenoble Alpes - Laboratoire 3SR), Dr. Nicolas Lenoir (University of Grenoble Alpes - Laboratoire 3SR), Prof. Gioacchino Viggiani (University of Grenoble Alpes - Laboratoire 3SR), Dr. Chloe Arson (Georgia Institute of Technology)

The study of root growth in varying soil conditions has been a recurrent field, but, the reasons why roots reinforce soils, are still not fully understood. To address this issue, we propose to observe the effect of root growth in soil. We measure, model and simulate the kinematics of root growth and the subsequent soil fabric evolution in different types of sand. Maize and chickpea roots were grown in Hostun sand of various grain sizes (HN31, HN1.5-2) and densities (dense vs. loose packing). X-ray CT scan images of the experiments were acquired once a day for a week. 3D images were trinarized to separate root, soil and fluid phases. The root pictures were skeletonized and the graphs were described in terms of root length, trajectory and diameter. Displacements of each individual soil grain using Digital Image Correlation (DIC) are tracked.

Results for the zones around the root tips show that the grains in contact with the root move in the direction opposite to that of root growth. Grain displacement, typically, has a magnitude of up to 1.5 times the mean grain size. Additionally, spatial tracking of the root tips over time was performed in order to quantify the effect of the penetration process on soil local porosity and deformation. We proposed a model based on Discrete Element Method (DEM) to simulate the growth of the main root in the tested sands. Kinematic measurements were used for model calibration and validation. DEM results, such as force chains, were interpreted and discussed.

Mechanics of a three-dimensional spider web

Thursday, 20th June - 11:15: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 713

Ms. Isabelle Su (Massachusetts Institute of Technology), Dr. Zhao Qin (Massachusetts Institute of Technology), Mr. Tomás Saraceno (Studio Tomás Saraceno), Dr. Roland Mühlethaler (Studio Tomás Saraceno), Dr. Ally Bisshop (Studio Tomás Saraceno), Prof. Evan Ziporyn (Massachusetts Institute of Technology), Prof. Markus Buehler (Massachusetts Institute of Technology)

Spiders are abundant in most ecosystems in nature, making up more than 47,000 species. This ecological success is due to the web architectures and the exceptional mechanical properties of spider silk. Silk's combination of strength, elasticity, toughness, and robustness originates from its hierarchical structure and has been a template for high-performance material design. In particular, spiders have optimized and adapted their web architecture to survive in their environment.

The most studied and familiar spider web is the 2D orb web which is composed of radial and spiral threads. However, 3D webs, such as sheet, funnel, or cob webs, are more common in nature. In contrast to 2D webs, where the spider is vulnerable to attacks, 3D webs surround the spider and offer a defensive advantage by warning the spider of intruders, blocking its predators and entangling prey.

Here, we investigate the mechanical properties of a *Cyrtophora citricola* 3D web, the architecture of which has been digitally modeled with micron-scale details from full-scale laboratory experiments (Su, Qin, Saraceno, Krell, Mühlethaler, Bisshop, Buehler, Royal Society Interface, 2018). Extending this work, we use a coarse-grained bead-spring model based on the 3D spider web network model to study the response of a realistic web structure to mechanical loads and the interplay between material and performance.

Understanding the roles of structure and material in the functionality and evolutionary fitness of spider webs could lead to innovative 3D spider web-inspired structures such as high performance light-weight long-span structures or fiber reinforced composite materials.

Investigating the Successive Regeneration of Hydrogel-based Microbial Mortars

Thursday, 20th June - 11:30: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 946

Ms. Sarah Williams (University of Colorado), Dr. Jishen Qiu (University of Colorado Boulder), Dr. Juliana Artier (University of Colorado Boulder), Prof. Chelsea Heveran (Montana State University), Prof. Sherri Cook (University of Colorado Boulder), Prof. Jeffrey Cameron (University of Colorado Boulder), Prof. Mija Hubler (University of Colorado Boulder), Prof. Wil Srubar (University of Colorado Boulder)

Over the past 20 years, it has become widely recognized that microbial-induced calcium carbonate precipitation (MICCP) can enable regenerative self-healing behavior in cement-based materials by sealing microcracks. However, it is also known that the viability of MICCP microorganisms can be threatened by harsh environmental conditions that are intrinsic to ordinary portland cement (OPC) concrete, including high pH, elevated temperatures during hydration, and nutrient depletion, in turn threatening the longevity of the self-healing capability of bacterial concrete. In this work, we present a novel biocementation approach that leverages MICCP. More specifically, we show that Synechococcus sp. PCC 7002, a photosynthetic cyanobacterium capable of MICCP, can be used to create a cement-free, hydrogel-based “living” mortar. Gelatin reinforced with biogenic calcite from MICCP acts as both the binding agent and as a scaffold for microbial growth and activity. Furthermore, the calcium-carbonate-reinforced gelatin possesses acceptable mechanical properties when cured, and, unlike traditional mortar, has the ability to be melted, reprocessed, and reformed at moderate temperatures and pressures. These mortars were examined for their microstructural properties, cell viability, and propensity to regenerate when subjected to temperature and humidity gradients. Results show that the gelatin-based microbial mortars exhibited greater regenerative capacity and cell viability than has been previously observed in cement-based mortars.

Repeatable self-healing by combination of biochar immobilized bacteria and superabsorbent polymer in fiber reinforced concrete

Thursday, 20th June - 11:45: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 1 (147 Noyes (84)) - Oral - Abstract ID: 988

Mr. Souradeep Gupta (National University of Singapore), Ms. Anastasia Aday (University of Colorado Boulder), Prof. Wil Srubar (University of Colorado Boulder), Dr. Harn Wei Kua (National University of Singapore)

Repeatable self-healing of cracks in civil infrastructure is essential to provide long-term durability of concrete structures. Previous research on the efficacy of repeated autogenous and bio-based healing in structural concrete is limited.
This study aims to compare two self-healing approaches – autogenous healing through superabsorbent polymers (SAPs) and healing using immobilized calcium carbonate ($CaCO_3$)-precipitating bacteria, to seal cracks and recover mechanical and permeability properties after multiple damage cycles in PVA- and steel-fiber reinforced concrete.

Experimental results demonstrate that combination of biochar immobilized bacteria lead to appreciable sealing (40-45%) of micro-cracks (500-800 μm) after third damage cycle compared to only 5-10% sealing by autogenous healing in control and SAP containing concrete. Sealing of cracks and densification of aggregate-matrix zone by bacteria precipitated carbonate contributed to complete recovery of strength and elastic modulus compared to 65% recovery in case of control after third damage cycle. The PVA fiber was found to act as nucleation sites for bacterial carbonate precipitation, which was instrumental in sealing internal micro-cracks of concrete. It led to relatively low capillary absorption and high recovery of permeability in BS-BC + SAP after repeated healing, which was significantly improved compared to concrete with only SAP or directly added bacteria spores. In summary, we demonstrate that the proposed material combination of biochar immobilized bacteria, SAP and short fiber can potentially self-heal micro-cracks and enhance long term durability of concrete structures. This suggests that application of the proposed material can reduce repair cost and extend service life of concrete infrastructure.

A cooperative game for automated learning of elasto-plasticity knowledge graphs and models with AI-guided experimentation

Thursday, 20th June - 10:30: MS35 - Computational Geomechanics; Part 1 (142 Keck (72)) - Oral - Abstract ID: 711

Mr. Kun Wang (Columbia University), Prof. Wai Ching Sun (Columbia University), Prof. Qiang Du (Columbia University)

We introduce a multi-agent meta-modeling game to generate data, knowledge, and models that make predictions on constitutive responses of elasto-plastic materials. Based on concepts from directed multigraph theory, we introduce deep reinforcement learning to train two artificial intelligence agents tasked with generating models and data respectively. In this cooperative game, the modeling agent explores all the possible ways to interpret and represent the cause-and-effect relationships among physical attributes and finds an optimal subgraph. This subgraph is the resultant information flow that optimizes an objective function designed to make the most plausible blind prediction for history-dependent materials. We focus on an idealized situation in which the modeling process of path-dependent materials can be represented by a sequence of choice-making decisions where choices (e.g. yield surfaces, flow rules for plastic deformation, strain hardening laws) are made to formulate a sequence of actions to generate constitutive laws. As such, we introduce a new concept where all the modeling options can be recast as a directed multi-graph and each instant/configuration of the model can be understood as a path that links the source of the directed graph (e.g. strain history) to the target (e.g. stress). Meanwhile, the data agent, which is tasked with generating data from real or virtual experiments (e.g. molecular dynamics, discrete element simulations), interacts with the modeling agent sequentially and uses reinforcement learning to design new experiments to optimize the prediction capacity.

An adaptive ensemble phase field predictions for localized failures in geological materials

Thursday, 20th June - 10:45: MS35 - Computational Geomechanics; Part 1 (142 Keck (72)) - Oral - Abstract ID: 723

Mr. Kun Wang (Columbia University), Prof. Wai Ching Sun (Columbia University)

This work presents an adaptive phase field method to employ ensemble predictions for history-dependent materials. We consider a case in which the material responses of a domain can be captured by a weighted sum of constitutive responses from surrogate models, each associated with one phase field and is specialized in one type of predictions (e.g. contractive shear band, mixed-mode fracture). A deep recurrent network is used to generate the driving force that governs the weight function in the space-time continuum. Consequently, the high-fidelity sub-scale modeling is only used to generate incremental constitutive updates in the regions where all surrogate models fail to make good blind predictions and hence become necessary. Meanwhile, the region of less importance is first identified, then assign to a fast surrogate model to enhance efficiency. In the transiting zone where new model is activated, we propose methods to transfer variables that represent loading history among different models. The surrogate models can be automatically generated from our previously developed meta-modeling procedure using experimental data according to different objective functions. As an example, we apply this idea to formulate this multi-model framework to predict two common classes of material failures, brittle fracture and strain localization. A multi-fold cross-validation exercise is conducted to examine the speed, robustness and accuracy of the multi-model predictions.

A micromorphic-regularized anisotropic Cam-clay-type model for capturing size-dependent anisotropy

Thursday, 20th June - 11:00: MS35 - Computational Geomechanics; Part 1 (142 Keck (72)) - Oral - Abstract ID: 752

Mr. Eric Bryant (Columbia University), Prof. Wai Ching Sun (Columbia University)

We introduce a micromorphic-regularized anisotropic modified Cam-clay model which captures the size-dependent anisotropic elastoplastic responses for clay, mudstone, shales, and sedimentary rock. To capture the distinctive anisotropic effect induced by the micro-structures of clay particle aggregate, clusters, peds, micro-fabric, and mineral contact, we use a mapping the links the anisotropic stress state to a fictitious stress space to introduce anisotropy to the modified Cam-clay model at the material point scale. Meanwhile, the meso-scale aniostropy is captured via an anisotropic micromorphic regularization model such that the gradient-enhanced plastic flow may exhibit anisotropic responses via a diffusivity tensor. This diffusivity tensor enables the micromorphic regularized model to exhibit plastic flow non-co-axial to the stress gradient of the yield function without introducing non-associate flow rules and hence provide additional degree of freedoms for modelers to capture the size-dependent ansiotropy of geomaterials that exhibits different anisotropic responses across different length scales.

Numerical examples are used to examine the volumetric locking and numerical stability issues that may occur at the critical state where isochoric plastic flow dominates the deformation mode. In particular, we present evidence that the micromorphic regularization could also be a potential remedy to overcome the volumetric locking and the spurious checkerboard modes. The influence of the size-dependent anisotropy on the formation and propagation of shear band in the anisotropic material is demonstrated. In the future, we will explore coupling to a phase field fracture model, in order to predict the wide spectrum of brittle and ductile anisotropic responses.

COUPLED ANALYSIS OF WAVE-SLOPING SEABED INTERACTION: GLOBAL SHEAR FAILURE

Thursday, 20th June - 11:15: MS35 - Computational Geomechanics; Part 1 (142 Keck (72)) - Oral - Abstract ID: 826

Mr. Amin Rafiei (North Carolina State University), Prof. Shamim Rahman (North Carolina State University), Prof. Mo Gabr (North Carolina State University), Prof. Alejandra Ortiz (North Carolina State University)

Instability of sloping seabed is a vital factor in foundation design of marine structures and geohazard studies of submarine landslides. Water surface waves may cause local (e.g. liquefaction-induced scour) and global instability due to shear failure (over a large zone) of sediments within the sloping seabed. The wave-induced sliding of sloping seabed was reported after Hurricane Carla (1961) damaging South East of US. The related studies of global failure evaluation of sloping seabed have been focused mostly on slightly inclined (<5^{o}*) bathymetry and utilized decoupled analysis approach. However, some of the marine structures are founded on (or anchored to) seabed with steeper slopes. In this study, the global shear failure of the sloping seabed due to wave and geostatic forces is evaluated using finite element with strength reduction method. The coupling of response for fluid and porous soil domains (i.e. enforcing continuity of pressure and water flux) is considered. The progressive generation of pore water pressure associated with nonlinear deformation of soils and potential for accumulation of volumetric strain is included in the analyses. The results indicate that the wave action reduces the stability of the slope. The effective stress path (for points inside the seabed) demonstrates that under the combination of wave and geostatic forces the stress state becomes closer to the critical state line in comparison to geostatic condition. Such finding imply the decrease in the factor of safety of the slope. The effects of wave and sediment characteristics on the stability of the sloping seabed are evaluated.*

Shift domain material point method: an image-to-simulation workflow for solids of complex geometries undergoing large deformation

Thursday, 20th June - 11:30: MS35 - Computational Geomechanics; Part 1 (142 Keck (72)) - Oral - Abstract ID: 861

Dr. Chuanqi Liu (Columbia University), Prof. Wai Ching Sun (Columbia University)

We introduce a mathematical framework designed to enable a simple image-to-simulation workflow for solids of complex geometries undergoing large deformation in the geometrically nonlinear regime. In particular, we adopt the integration scheme of the material point method to resolve the convergent issues for Lagrangian meshes due to mesh distortion, while using a shifted domain technique originated from Main and Scovazzi 2018 to represent the boundary condition implicitly via a level set or signed distance function. Consequently, this method completely bypasses the need to generate high-quality conformal mesh to represent complex geometries and therefore allows modelers to select the space of the interpolation function without the constraints due to the geometrical need.This important simplification enables us to simulate deformation of complex geometries inferred from voxel images. Verification examples on deformable body subjected to finite rotation have shown that the new shifted domain material point method is able to generate frame-indifference results. Meanwhile, simulations using microCT images of a Hostun sand have demonstrated that this method is able to reproduce the quasi-brittle damage mechanisms of single grain without the excessively concentrated nodes commonly displayed in conformal meshes that represent 3D objects with local fine details.

Modeling High Strain Rate Impact Experiment Using the Finite-Discrete Element Method

Thursday, 20th June - 11:45: MS35 - Computational Geomechanics; Part 1 (142 Keck (72)) - Oral - Abstract ID: 898

Dr. Viet Chau (Los Alamos National Laboratory), Dr. Esteban Rougier (Los Alamos National Laboratory), Dr. Zhou Lei (Los Alamos National Laboratory), Dr. Earl Knight (Los Alamos National Laboratory), Dr. Ke Gao (Los Alamos National Laboratory), Dr. Abigail Hunter (Los Alamos National Laboratory), Dr. Gowri Srinivasan (Los Alamos National Laboratory), Dr. Hari Viswanathan (Los Alamos National Laboratory)

Plate-impact experiments are generally used to better understand the inelasticity of many brittle materials. Modeling these brittle materials impact experiments is a challenging problem because of the complexity of the involved physics and the high computational cost. Under extreme loading conditions, brittle materials fail suddenly through dynamic fracturing processes. These failure mechanisms are typically a result of nucleation, interaction and coalescence of micro-cracks present throughout the sample. In this study, the Finite-Discrete Element Method (FDEM), which merges the finite element based analysis of continua with discrete element based transient dynamics, contact detection, and contact interaction solutions, is used to simulate the response of a flyer-plate impact experiment in sample that contains a randomized set of cracks. FDEM has demonstrated to be a strongly improved physical model as it can accurately reproduce the Velocity Interferometer System for Any Reflector (VISAR) plot and capture the spall region obtained from the flyer plate experiment.

These FDEM capabilities, in the context of rock mechanics, are very important for two main reasons. First, the FDEM can be further applied to many complex industrial problems such as planetary impact, rock blasting, seismic wave propagation, characterization of material failure around explosive crater formations, and the detection of hydrocarbon flow in petroleum industry, etc. Second, it can be used to validate high strain rate impact experiments and essentially, via virtual experimentation, replace these high cost experiments by very cost- and time-effective simulations.

Robophysical Analysis and Gait Development for the NASA Resource Prospector Rover

Thursday, 20th June - 10:30: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 410

Mr. Siddharth Shrivastava (Georgia Institute of Technology), Mr. Andras Karsai (Georgia Institute of Technology), Dr. Yasemin Ozkan Aydin (Georgia Institute of Technology), Mr. William J Bluethmann (NASA), Mr. Robert O Ambrose (NASA), Dr. Daniel Goldman (Georgia Institute of Technology)

Planetary rovers can become entrapped in soft substrates. The LCROSS lunar mission in 2009 showed that regolith was less consolidated at the lunar poles than at the equator. This led NASA JSC to develop RP-15, a 300 kg prototype rover able to lift and sweep each wheel to create a crawling behavior. To investigate the mechanics and principles of this crawling action, we created a small (2.1 kg) robophysical rover with similar capabilities to RP-15 and conduct systematic experiments in an automated tilting and fluidizing bed of granular media. We analyze the interactions of the rover and media with motion capture and PIV. Using stepping and rotating wheels together generates higher drawbar pull (up to 4x on a 0˚ slope of poppy seeds) than rotating wheels alone. We validated the findings on our small rover through experiments on RP-15 at JSC (2x drawbar pull on a 0˚ sand incline). Force measurements on a single stepping/rotating wheel showed a 2x increase in normal force per gait cycle over pure rolling. On steep granular slopes (up to 27˚, near the max angle of stability), a novel gait allowed our small rover to climb the hill through controlled avalanching causing posterior mound formation. This terrain remodeling via a combined wheel-step gait allowed the rover to effectively climb the slope past its initial position, where wheel-only and step-only gaits were far slower in climbing.

Stability of a Crab-Like Amphibious Robot in on Sandy Surfaces

Thursday, 20th June - 10:45: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 924

Ms. Nicole Graf (Case Western Reserve University), Mr. Alexander Behr (Case Western Reserve University), Prof. Kathryn Daltorio (Case Western Reserve University)

Sandy beaches can be smooth access points for future amphibious robots to enter and exit oceans and lakes, but the terrain is challenging, especially for smaller scale robots. Sandy ground gives under shear, which makes locomotion less efficient especially when contending with hydrodynamic forces from waves. Looking to animals that navigate these conditions, crab-like legs and gaits are distinctive and different from land animals and robots. In order to better understand the potential advantages of these legs for surf-zone terrain, our goal is to evaluate crab-like legs on dry, wet, and submerged sandy terrain. With our modified 1.2 kg HEXY robot, we demonstrate two important advantages of crab-like legs. First, crab-like legs can allow the robot to resist vertical forces greater than the body weight. This is important because, in contrast to robots that increase traction by adding weight, using the legs to effectively increase normal forces means that robots can be built lighter and smaller to traverse the same environments. Secondly, we show that this grasping feet reduce wave-induced displacement in lab tests. The modified foot designs of the robot are compatible with legged walking gaits. In future, these leg designs and grasping strategies can be used to convert other land-based robots for amphibious locomotion.

Continuum modeling of legged locomotion interaction with granular substrate

Thursday, 20th June - 11:00: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1313

Dr. Guanjin Wang (University of Maryland, college park), Dr. Amir Riaz (University of Maryland, college park), Dr. Balakumar Balachandran (University of Maryland, college park)

Legged or hybrid locomotion has advantages when navigating flowable ground or terrains with obstacles, which widely exist in nature. Traditional terra-mechanics theory captures only large curvature interaction with the ground, such as large wheel vehicle terrain interaction. Legged locomotion on granular substrate is small curvature interaction with the terrain which cannot be investigated by existing terra-mechanics theory. A numerical multi-body simulation has been developed and coupled with an experimentally validated Smooth particle hydrodynamics (SPH) model. The mesh-free nature of SPH facilitates the capture of large deformation as well as the post-failure behavior of the granular substrate. Parametric studies carried out to evaluate the dependence on key parameters will be reported. The results are expected to help understand robot navigation and exploration in complex terrains.

Assessing beach trafficability from remote sensing

Thursday, 20th June - 11:15: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 734

Dr. Nina Stark (Virginia Tech), Ms. Julie Paprocki (Virginia Tech), Mr. Matthew Florence (Virginia Tech), Mr. Christopher Mcbride (Virginia Tech), Dr. Hans Graber (CSTARS University of Miami)

The rapid assessment of beach trafficability is of interest for naval applications as well as emergency response management. For both of these applications, physical access to the sites is often impossible due to time or access restrictions, and therefore, an assessment framework based on remotely sensed data is needed. Towards this goal, a number of issues need to be solved: What are key parameters governing beach trafficability? Can geotechnical parameters be determined from remote sensing techniques? How does groundwater behavior influence the trafficability, and be assessed from remotely sensed data that covers limited sediment depths? How can different information be merged in one analysis framework? Here, initial results will be discussed towards answering these goals. For example, an assessment of in-situ friction angles was performed based on shadows in optic satellite imagery, and photogrammetric reconstruction of local morphology from aerial imagery. Furthermore, first attempts were made to estimate moisture contents from optic and radar satellite imagery, and to assess the impact of partial saturation on local in-situ strength. Infiltration and drainage behavior with tidal fluctuations were measured in the beach sediments and related to surface moisture content measurements. Finally, a sensitivity study of different parameters used for traditional expressions for beach trafficability assessment will be discussed.

Large-scale DEM analysis of plate drag in dry granular materials

Thursday, 20th June - 11:30: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1249

Dr. Murino Kobayakawa (Osaka University), Mr. Shinichiro Miyai (Osaka University), Prof. Takuya Tsuji (Osaka University), Prof. Toshitsugu Tanaka (Osaka University)

Plate drag in granular materials is a simple but important because it provides an understanding of how tools interact with the soil in soil cutting and tillage. We numerically study the response of dry granular materials to plate drag as a function of initial volume fraction of the materials using a large-scale discrete element method (DEM) simulation. In the simulation, a vertical flat plate is translated horizontally through initially homogeneous materials with different volume fraction and the drag force acting on the plate is examined. The results show that a volume fraction-dependent bifurcation occurs in the force: in an initially loose granular bed, the force reaches an approximately constant value as the plate advances, while in an initially dense bed, the force oscillates with a large amplitude. The force oscillation is attributed to the periodic evolution of a shear band formed only in the dense bed. The behaviors of the drag force and shear band are in close agreement with those obtained experimentally in previous studies. Further analysis shows that the formation of the shear band is explained by the local dilatancy of the granular materials induced by the plate drag. In the dense bed, the materials largely dilate in a disturbed flow region formed in front of the plate. Because a denser undisturbed region is more stable compared to the flow region, the flow region is strongly confined. As a result, the shear strain is localized along a flow boundary between these regions, and the shear band develops.

A Position-Based Discrete Element Method for Wheel-Soil Modelling

Thursday, 20th June - 11:45: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1372

Mr. Eric Karpman (McGill University), Mr. Daniel Holz (CM Labs Simulations), Dr. Jozsef Kövecses (McGill University)

The Discrete Element Method (DEM) is widely seen as a very accurate, albeit computationally demanding approach for terramechanics modelling. Part of its appeal is its explicit consideration of gravity in the formulation, making it easily applicable to the study of soil in reduced gravity environments. The position-based (PB) dynamics approach to terramechanics modeling is an alternate approach to traditional DEM that is computationally more efficient at the cost of some assumptions. Thus far, this method has mostly been applied to soil excavation maneuvers. The goal of this work is to implement and validate the PB approach on a single wheel driving over soft soil in order to evaluate the method's applicability to the study of wheel-soil interaction. This was done by building a model and first tuning numerical simulation parameters to determine the critical simulation frequency required for precise results then tuning the physical simulation parameters to obtain accurate results. The former were tuned via the convergence of particle settling energy and soil settling level plots for various frequencies. The latter were tuned via comparison to drawbar pull and wheel sinkage data collected from experiments carried out on a single wheel testbed in a reduced gravity environment. Preliminary results have shown promise in the method for determining simulation frequency and results for the full maneuver have also produced promising data when compared to experiments. We will present these results and comparisons to experiments.

Discrete Computational Model for Thin Foldable Composite Origami Structures

Thursday, 20th June - 10:30: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 1371

Mr. Antonio Alessandro Deleo (University of Washington), Prof. Marco Salviato (University of Washington)

A new manufacturing methodology combined with the use of advance composite materials allowed us to prove the feasibility to manufacture novel types of flexible, foldable, yet-stiff, structures based on both simple shapes and more complicated ones such as origami. In the recent years, these avant-garde structures received attention from both academic and industry communities due to their high compactness and self-deployability capabilities which are leading new areas of research for space, disaster relief, medical, biomimicry, and architecture applications. By using Vacuum Bag Only (VBO) technique, a flexible composite origami is manufactured with the use of CFRP facets and glass fiber crests permeated using compliant urethane and silicon resins. These resins allow a firm and secure bonding between facets and crests but still maintaining a high level of flexibility in the glass fibers, which allow the structures folding numerous times without noticeable overall structural damage. Furthermore, a novel computational discrete approach will be introduced to model the kinematics of these foldable thin structures by modeling the structure using beams elements for both fibers and the resin. Multiple specimens will be fabricated and tested both for kinematic and folding behaviors. Material characterization will be carried out in order to be able to properly calibrate the computational model and compare results with the experiments. At the same time, damage from fatigue will also be characterized by running folding and deployable tests.

Elastic energy behaviours of curved-crease origami: a summary of recent progress

Thursday, 20th June - 10:45: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 895

Mr. Ting-Uei Lee (University of Queensland), Dr. Joseph Gattas (University of Queensland)

This presentation will summarise recent progress in understanding the energy behaviours of elastically-deformed curved-crease origami. Curved-crease origami are an interesting subset of origami patterns that utilise curved crease lines to induce a non-zero principal curvature in origami pattern panels, once folded. Precise characterisation of their folding motion and folded shape is challenging, due to the interactions between the developability constraint imposed by the crease line and the large elastic bending behaviours of the panels.

A special class of “elastica-generated curved crease origami” has been developed, which adopts elastica curves, the deformed shapes of an elastically-deformed slender rod, as the generating curvatures for curved-crease pattern construction. This approach is shown to enable several key advancements in characterisation of pattern behaviour. This presentation will summarised these advancements, including: i) exact analytical surface definition of folded curved-crease forms, validated with 3D scanning of folded prototypes; ii) characterisation of elastic strain energy and folding motion in curved-crease compliant mechanisms, with subsequent use in development of a compliant mechanism with a programmable force-displacement response; and iii) control over a set of elastic buckling modes in thin-walled cylinders using a crease line pre-embedment technique, with buckled modes corresponding to stabilised high-order elastica curvatures.

Bistability of Generic Creased Vertices

Thursday, 20th June - 11:00: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 367

Dr. Martin Walker (University of Oxford)

The analysis of origami structures is dominated by ‘rigid origami’, which assumes rigid facets connected by revolute hinges. Global mechanical behaviour is obtained by including torsional springs at the hinges. However, many creased structures feature continuum shell deformations and thus do not conform to the kinematic constraints of rigid origami. A fundamental example is the intersection of multiple same sense creases, which is the subject of this study

We begin by approximating a creased vertex as a set of rigid facets connected by revolute hinges. A Gauss mapping approach is applied to obtain kinematically admissible shapes. An energy expression, relating hinge rotations to developable shell-bending, is derived and used to solve for the equilibrium shape. This approach is generalized for an arbitrarily large number of facets, asymptotically approaching a continuous developable surface. We use this model to show that creased vertices are generically bistable and we obtain the equilibrium shapes. However, this approach cannot establish if the equilibrium is robustly stable, which requires both bending and stretching deformations be included.

We therefore modify the rigid faceted model to allow the hinges to both bend and stretch. We analyse the kinematics and develop energy expressions relating hinge stretching and rotation to continuum shell deformations. By increasing the number of facets, the equilibrium and stability of the continuous case is assessed.

This study relates the kinematic behaviour of rigid origami to continuum shell mechanics, offering a new approach for the analysis of generically creased structures.

Crushing of origami tubes for tunable energy absorption

Thursday, 20th June - 11:15: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 28

Dr. Evgueni Filipov (University of Michigan), Mr. Zhongyuan Wo (University of Michigan)

Thin structures are commonly used as energy absorbing devices that convert the kinetic energy from an impact into heat generated by crushing of a typically ductile material. Using origami-inspired designs for such a system adds benefits including the ability to fabricate from a developable sheet, and a more prescribed crushing sequence that can improve the energy absorption characteristics. In this work, we explore the crushing of zipper-coupled origami tubes that can fold, deploy and lock into stiff structures. We use numerical simulations and experimental tests to study these structures at different stages of deployment. By changing their configuration, the tubes can tune their stiffness and change their overall energy absorbing properties. These characteristics could enable energy absorbing devices and metamaterials that actively tune their properties to better mitigate different impact scenarios.

Active Origami, a new biomaterial for architecture

Thursday, 20th June - 11:30: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 630

Ms. Emily Birch (Newcastle University), Dr. Martyn Dade-Robertson (Newcastle University), Dr. Beate Christgen (Newcastle University), Dr. Meng Zhang (University of Northumbria)

This research interrogates a new active biomaterial for architecture which responds to changes in environmental humidity. The aspirations for this new biomaterial are that it will be appropriate to integrate into systems within buildings to improve user wellbeing and sustainability. This novel solution could help to tackle excessive use of electricity and fossil fuels in architecture to create passive, dynamic and environmentally responsive systems.

*Bacillus subtilis*spores have been incorporated into a latex bilayer structure where their hygromorphic response to relative humidity generates a deflection and kinetic force required to produce working hygromorphic actuators.

These spore actuators' properties were investigated experimentally to demonstrate that performance of the bio-hybrid actuators showed a rapid, reversible and repeatable deflection.This deflection was reliably increased by increasing the number of *B. subtilis*monolayers applied to the latex substrate.

Further investigations pushed the understanding of this new biomaterial toward the architectural scale though force investigations. Experimental data gathered from these investigations showed that the actuators were able to lift masses greater than their own mass and across a meaningful and predictable distance.

To scale up this microtechnology, investigations began into harnessing the dynamic properties of origami. As one actuator acts as one 'fold', with a given force and displacement distance, then multiple folds (actuators) lined up together in coordinating fashions could produce an 'Active Origami' structure. First pilot prototypes of this nature have just begun investigation, showing some positive results with greater refinement to be hopefully seen in the future.

Designing Systems of Compliant Joints for Deployable Origami-Based Structures

Thursday, 20th June - 11:45: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 878

Mr. Nathan Pehrson (Brigham Young University), Dr. Larry Howell (Brigham Young University), Dr. Spencer Magleby (Brigham Young University)

Deployable origami-based structures which use compliant joints to enable folding can also self-deploy via release of strain energy in the joints. This can be useful to reduce complexity of systems by removing the need for deployment actuators. Non-rigid-foldable origami-based structures require compliance somewhere in the system to achieve motion; this needed motion can be achieved by incorporating compliant joints.

Lamina emergent torsion (LET) joints have been used in origami-based systems due to their ability for large angular deflections. LET joints are particularly useful when stiffness in other degrees of freedom (DOF) is not needed, such as z-fold patterns. However, origami structures that have two-dimensional expansions require interior vertices. Joints that make up interior vertices react forces and moments in these other DOF.

Placing LET joints in arrays (in parallel and in series) offers tailorability of stiffness in other DOF. The other DOF of LET arrays enable such complex folding yet little work has been done to characterize them until recent work by the authors. The recent work characterizes the stiffness and stress relationships, enabling further design of the systems treated here.

We present a method to design LET arrays for use as compliant joints for these deployable origami-based structures. These joints work together as a system to achieve target functions of such structures (i.e. desired motions). The method considers the folding, extension/compression, and in-plane rotation DOF of the joints and involves multibody dynamic simulations of the structures throughout deployment to obtain optimal system performance.

Structures as Sensors: Using Structures to Indirectly Monitor Humans and Surroundings

Thursday, 20th June - 13:00: Plenary 4 (Beckman Auditorium (1,136)) - Oral - Abstract ID: 589

Prof. Hae Young Noh (Carnegie Mellon University)

Smart structures are designed to sense, understand, and respond to various situations involving the structure itself, the humans within, and the surrounding environment. However, traditional monitoring approaches using dedicated sensors often result in dense sensing systems that are difficult to install and maintain in large-scale structures. This talk introduces "structures as sensors" approach that utilizes the structure itself as a sensing medium to indirectly infer multiple types of information relating to the structure (e.g., humans and surrounding) through their influence on the physical response of structure. For example, we can infer human location and walking status through their activity induced building floor vibrations and conditions of surrounding infrastructures like roads and bridges through vehicle vibrations. By using only structural responses for extracting multiple types of information, we significantly reduce the number and type of sensors needed to install and maintain. Challenges lie, however, in creating robust inference models for analyzing convoluted noisy structural response data (e.g., building responses due to human activities and outside traffic). To this end, we developed physics-guided data analytics approaches that combine statistical signal processing and machine learning with physical principles. Specifically, I will present two projects as examples; 1) Vehicles as Sensors: indirect infrastructure health monitoring through vehicle responses; and 2) Buildings as Sensors: occupant tracking and characterization through footstep-induced building vibrations. In these projects, new learning methods are developed incorporating structural dynamics, wave propagation, and human gait models. These methods are evaluated with real-world experiments, including our 5-year railway and eldercare center deployments.

Design of One-Dimensional Acoustic Metamaterials Using Machine Learning and Cell Concatenation

Thursday, 20th June - 14:00: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 817

Mr. Rih-Teng Wu (Purdue University), Mr. Ting-Wei Liu (Purdue University), Dr. Mohammad Jahanshahi (Purdue University), Dr. Fabio Semperlotti (Purdue University)

Recent advances in artificial intelligence and machine learning algorithms have opened several opportunities for material discovery and design. Conventional material design processes require precise physical modeling of the material along with the extensive use of optimization methods to achieve target performance. This approach is computationally intensive and severely limits the possibility to explore the vast design space offered by engineered materials. In addition, these optimization techniques typically target properties defined in the physical space (e.g. displacements and stresses) and do not allow direct access to properties in a transformed space. A typical example is the inability to prescribe a target dynamic behavior in the reciprocal-space, where quantities like frequency-wavenumber dispersion and band structure are defined. This study presents two machine learning-based design frameworks for the design of periodic and non-periodic material systems. For periodic materials, a reinforcement learning-based approach is proposed in order to design the unit-cell properties according to a user-defined dispersion behavior. For non-periodic materials, a neural network based approach capable of learning the behavior of individual material units is presented. In this case, the design of the engineered material is achieved by assembling the neural network representation of individual units within a general optimization framework that targets a user-defined material response. Interestingly, this latter framework is capable of synthesizing different material assemblies (based on the available cells) while requiring only one-time network training. Numerical examples are provided for both the periodic and non-periodic material designs to demonstrate the performance of the proposed framework.

Physics-Reinforced Deep Learning for Modeling and Identification of Structures via Heterogeneous Data Fusion

Thursday, 20th June - 14:15: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 949

Mr. Zhao Chen (Northeastern University), Dr. Ruiyang Zhang (Northeastern University), Dr. Yongchao Yang (Argonne National Laboratory), Prof. Hao Sun (Northeastern University)

Recent advances in deep learning and computation make possible to explore and model complex dynamical systems, where big data is often a necessity for enhancing reliable learning. Nevertheless, in data-driven modeling and identification of structural systems, researchers are often faced issues associated with scarce, noisy data or massive amount of, yet seemingly unrelated, measurements. To this end, we present a physics-reinforced deep learning framework for modeling full field spatiotemporal structural responses as well as identifying unknown structural parameters based on small heterogeneous sensing data. By encoding deep learning with governing equations of the physical system, the proposed method can leverage a limited amount of measurement data for reliable and accurate structural system modeling and identification. The heterogenous measurements (e.g., accelerations and displacements with multi-rate sampling) are fused to strengthen the reliability of the proposed method. We validate this method on beam and plate structures with data from numerical simulations and lab experiments. The experiment data consists of both acceleration time histories and low frame rate videos. Results of the proof-of-concept study indicate the generalizability and efficacy of the proposed method for modeling and identification of structural systems.

Structural Health Monitoring of Concrete Structures Affected by Alkali-Silica Reaction using Acoustic Emission

Thursday, 20th June - 14:30: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 1086

Mr. vafa soltangharaei (University of South Carolina), Mr. Taeyong Shin (Georgia Institute of Technology), Mr. Rafal Anay (University of South Carolina), Mr. David Bianco (University of South Carolina), Prof. Paul Ziehl (University of South Carolina), Dr. Ying Zhang (Georgia Institute of Technology)

Alkali-Silica Reaction (ASR) is a chemical reaction, which occurs between Alkaline and silica ions that exist in some aggregates in hardened concrete when they are exposed to high humidity. The reaction resultant is hygroscopic, which imbibes water and expands. The expansion imposes pressure to the aggregates and cement matrix which eventually causes cracking and damage to concrete structures. Different methods such as DAMEC gauge, visual inspection, petrographic analysis, and coring are utilized for monitoring the structures affected by ASR, whereas these methods are usually limited and not efficient enough. Acoustic emission (AE) can be an alternative for monitoring ASR effects on concrete structures due to the sensitivity and capability of the method for continuous monitoring. In this study, AE is employed for health monitoring of medium-size concrete specimens exposed to accelerated ASR. Correlation of AE data with strain is studied, and AE damage indices are determined.

Digital image correlation for deflection measurement of bridges: a technical review

Thursday, 20th June - 14:45: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 1010

Prof. Xinxing Shao (Southeast University), Prof. Xiaoyuan He (Southeast University), Prof. Zhenning Chen (Nanjing University of Aeronautics and Astronautics)

Digital image correlation (DIC) technique is now the most popular deformation measurement technique in experimental solid mechanics. With the developments of DIC technique, DIC technique is being widely used in both scientific and engineering fields.

This paper reports a technical review on applying DIC technique for deflection measurement of bridges. We introduce three different measurement methods and DIC technique is used for sub-pixel matching in all these three methods. The first method is two-dimensional DIC using a single camera. The second method is three-dimensional (3D) DIC using two cameras (or single-lens 3D camera). The last method uses the one-dimensional camera array technique. All technical details of these three methods are introduced and the related measurement results are given. The advantages and disadvantages of these methods are discussed, including the error resources and related compensation methods.

With the further development of sensing technology and computer technology, vision-based measurement techniques will have wider applications in civil engineering.

Noncontact stress measurement from bare UHPC surface using Raman piezospectroscopy

Thursday, 20th June - 15:00: MS82 - Computer Vision/Machine Learning for Structural Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 881

Prof. Hae-Bum Yun (University of Central Florida), Ms. Elham Eslami (University of Central Florida), Mr. Kevin Conway (University of Central)

Raman piezospectroscopy was applied for noncontact stress measurement from bare ultrahigh-performance concrete (UHPC). Microstructure and chemical characterization were conducted for 3 phases of UHPC samples, including unmixed concrete ingredients (Sample 1), cured concrete (Sample 2), and pulverized concrete (Sample 3). Rich contents of polycrystalline silica (quartz) were observed from all samples. The global and local piezospectroscopy coefficients were measured from compressive loading frame tests at 3.47 cm^{-1}/GPa and 1.62–9.10 cm^{-1}/GPa, respectively. The quartz fingerprint peak was observed at 460.50 cm^{-1} from stress-free UHPC powder, which can be used as the zero-stress state to determine absolute stress in existing concrete structures. The global absolute stress equation is presented using the global piezospectroscopy coefficient and the zero-stress state.

Real-time detection of fatigue fracture in metal bridge components by the assessment of Acoustic Emission Entropy

Thursday, 20th June - 14:00: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 167

Mr. Danilo D'Angela (University of Greenwich), Dr. Marianna Ercolino (University of Greenwich)

The real-time detection of fatigue fracture damage in bridges is still challenging, and fracture remains one of the main sources of economical and human losses among infrastructure collapses. The recent development of advanced structural health monitoring techniques determined a significant increasing of efficiency requirements and regulation severity. Acoustic Emission (AE) testing represents the state-of-art of non-destructive assessment of bridges and infrastructures. The traditional analysis of acoustic data is hardly efficient in case of real monitoring of bridges. This is essentially due to the signal noise caused by service conditions, and to the limited data caused by discrete time-spaced visits to the bridge for the data detection.

The paper presents a novel approach for the real-time assessment of fatigue fracture in metal bridge components. The approach is based on the assessment of the Information Entropy of the AE data using the Shannon formulation. Novel experimental correlations between the fracture damage and the AE features are used to define a monitoring protocol that is validated by laboratory fatigue tests on plates under cyclic tensile loading.

The results of the application demonstrate that the proposed monitoring protocol is reliable and efficient for the real-time detection of the fracture onset, and the (early) prediction of the fatigue failure in in bridges. The reliability of the acoustic Entropy as a real-time damage descriptor is also confirmed if a discrete number of inspection/monitoring visits is performed, covering a quite limited percentage of the real infrastructure lifetime.

An early attempt in quantifying the value of OMA based fatigue stress estimation with uncertainties

Thursday, 20th June - 14:15: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 661

Dr. Henning Brüske (Aalborg University / The Danish Hydrocarbon Research and Technology Centre), Mrs. Bruna Nabuco (Technical University of Denmark), Prof. Rune Brincker (Technical University of Denmark), Prof. Michael Faber (Aalborg University / The Danish Hydrocarbon Research and Technology Centre)

We propose a methodology based in Operational Modal Analysis (OMA) and Bayesian decision theory that maybe used in order to model andidentify improved operation strategies fore.g. offshore oil and gas platforms. By monitoring, the structural integrity is evaluated with reduced uncertainties based on the actual state of the structure. The displacements of a scaled model have been measured during random vibrations excitation.The strains at any point of the model can be estimated based on OMA and the accuracy will be improved by calibrating with strain gauge measurements. The obtained strains are used to evaluate the equivalent stress range, which is further used to compute fatigue failure probabilities and risk estimates. The subsequent fatigue reliability analysis will compare the OMA updated reliability estimation and the design assumption based reliability estimation.Because measurements are affected by uncertainties, we will present how these uncertainties can be considered in the fatigue reliability analysis and demonstrate how this impact reliability estimation. Obtaining information comes at a cost. Value of information analysis is applied in order to establish, in a simple academic example, what cost is acceptable.

Towards Automated Creation of As-is High-fidelity Structural Models of Deteriorated Bridges with UAV-assisted Visual Sensors

Thursday, 20th June - 14:30: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 683

Mr. Yujie Yan (Northeastern University), Prof. Jerome Hajjar (Northeastern University)

Recent advances in unmanned aerial system (UAS) and visual sensing technologies provide an effective tool to capture the as-is conditions of structures and infrastructures accurately. Acquired raw geometric and color information, coupled with state-of-the-art processing and interpretation strategies, could facilitate the assessment and maintenance of deteriorating infrastructures. The authors' previous work has focused on utilizing the geometric information from laser point clouds to create structural models of bridges. The developed algorithms are capable of extracting and interpreting the surface data of each structural element to generate volumetric finite element (FE) meshes as well as assembling the FE meshes to establish high-fidelity FE models. In this study, we present a novel approach toward automated localization and quantification of existing surface damage in bridges through processing the laser point clouds and image sequences taken from a customized UAS platform. In the proposed method, acquired laser point clouds are exploited to extract object information as well as to detect surface damage that reflects predominantly on geometric changes. That includes both damage with small deformation (e.g., concrete spalling, steel section loss) and large deformation (e.g., bent members, local buckling). Extracted object information is then integrated with acquired image sequences to inform surface damage that mainly reflects color and textural changes such as concrete cracking and rebar exposure. Observed surface damage in each structural element are then utilized to update the generated FE meshes and hence to establish the structural models that can be used to assess as-is conditions of deteriorated bridges through FE analysis.

Using Neutron Diffraction to Understand the Multiscale Internal Mechanics of Suspension Bridge Cables

Thursday, 20th June - 14:45: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 850

Dr. Adrian Brügger (Columbia University), Mr. Jumari Robinson (Columbia University), Prof. Raimondo Betti (Columbia University), Prof. Ismail Cevdet Noyan (Columbia University)

We present results and subsequent numerical modeling work from a number of experiments performed at the Los Alamos and Oak Ridge National Lab neutron beam sources designed to investigate the behavior of a suspension bridge cable strand after wire fracture, as commonly caused by pitting corrosion, embrittlement, local material flaws, and fretting. We experimentally quantify the redistribution of service stresses in the case of wire fracture within a cable under load by considering both the distribution of confinement forces – a consequence of wire wrapping, compaction straps, and cable clamps – and the friction transfer mechanisms between various wires in the strand. By interrogating each individual wire inside the strand with neutrons, we show that the internal mechanics of parallel wire cables are highly heterogeneous and not easily represented by prescribed smooth distributions. Rather, the forces within each wire depend heavily on the micron-scale dimensional variations and the resulting contact mechanics between the wires in the packing regime. The understanding of the mechanics of this multi-body system is critical in the creation of reliable numerical models that inform us about this multibody system, and ultimately provide an estimate of the cable strength. We use these experimental data to generate and tune rigorous companion finite-element models to quantify stochastically the internal mechanics of parallel wire bridge cables and assess the resulting collapse risk of a damaged cable.

Vehicle-Based Bridge Condition Monitoring

Thursday, 20th June - 15:00: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 851

Mr. Jase Sitton (Southern Methodist University), Prof. Dinesh Rajan (Southern Methodist University), Prof. Brett Story (Southern Methodist University)

Recently, researchers have focused on the use of vehicles as mobile bridge inspection instruments. This comprises instrumenting the vehicles with electronic transducers, e.g. accelerometers, to record data as the vehicle traverses the bridge. In this scenario, the vehicle plays two roles: that of the measurement device, and that of the excitation source. This eliminates the need for permanent in-situ monitoring installations that can be expensive. For successful vehicle-based inspection, the dynamic interaction between bridge and vehicle behaviors must be understood. This project obtained closed-form solutions for the bridge and vehicle vibration as a vehicle traverses a 2-span continuous bridge with unequal span lengths.Results are validated using finite element simulations and compared against the literature, which contains studies of single-span simply-supported bridges traversed by a moving vehicle. Results show that, for lower modes, bridge frequencies observed by the vehicle manifest as two peaks shifted below and above the fundamental bridge frequency. For a given bridge, these shifts are linear functions of velocity. It is shown that these shifted bridge frequencies can be averaged to estimate the fundamental bridge frequency, without prior knowledge of specific bridge properties, to within 7% error; this error decreases to 2% for equal span lengths.

Identifying Time-Varying Modes of a Train-Bridge System Using Train Induced Vibration Data

Thursday, 20th June - 15:15: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 1 (Steele 102 (130)) - Oral - Abstract ID: 1138

Mr. Ashish Pal (IIT Kanpur), Prof. Suparno Mukhopadhyay (IIT Kanpur)

In vibration based system identification, measured structural dynamic responses are often used to identify the modal parameters of a system. In railway bridges, when trying to identify the modal parameters using vibration responses measured under train loading, the problem becomes challenging if the mass of the train is not negligible as compared to that of the bridge. In such a case, the moving heavy mass of the train influences the measured dynamic responses, making the modal parameters of the train-bridge system time-varying. Thus, to identify these parameters, techniques for identifying time-varying systems would need to be used. Additionally, if the mass and speed of the moving train are unknown, the modal identification problem becomes even more challenging. In this study, a variant of the Eigensystem Realization Algorithm, developed for identifying time-varying systems, is explored in the context of this train-bridge system identification problem. To capture the time variability in the system properties, state matrices are obtained at each time instant, which are in a transformed coordinate system related via some transformation matrices. The consistent state matrices corresponding to the original system are then computed using the transformation matrices and the identified state matrices at each time instant. The capability of the method and different associated issues are illustrated using numerical examples.

Physics-based Graphics Models for Development of Computer Vision-based Inspection and Monitoring

Thursday, 20th June - 14:00: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1022

Mr. Vedhus Hoskere (University of Illinois at Urbana-Champaign), Mr. Yasutaka Narazaki (University of Illinois at Urbana-Champaign), Prof. Billie F. Spencer (University of Illinois at Urbana Champaign)

Computer vision-based inspection and monitoring of civil infrastructure is an effective means of assessing infrastructure condition in a non-contact fashion. Two major applications where computer vision techniques are being used include (i) the detection of visually perceivable damage from images and, (ii) measurement of displacement information from videos of structures. The development and testing and verification of vision algorithms for both these applications require large amounts of labeled data which is often difficult to obtain. For example, for deep learning-based damage detection, large annotated datasets are required. For vision-based dynamic measurements, ground truth displacements or other sensors often need to be installed on lab specimen of field structures to verify the efficacy of new measurement techniques. In this paper, we propose the generation of such data synthetically using computer graphics, informed by the analysis of a finite element model. Parametric noise-based graphics texture models are created for defects such as cracks and corrosion. The parameterization of the texture models allows for generation of a range of different surface conditions, thereby providing increased flexibility over data generation. Frames can be rendered over time using information form the finite element model, thereby simulating the capture of video data. The framework for generation of such synthetic data is presented along with results toward vision-based damage detection and displacement measurement.

Human pose estimation-aided safety helmet wearing detection in construction site based on computer vision

Thursday, 20th June - 14:15: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 188

Mr. Di Wu (Harbin Institute of Technology), Mr. Zhiyi Tang (Harbin Institute of Technology), Prof. Yuequan Bao (Harbin Institute of Technology)

A safety helmet is an important safety measure to prevent construction personnel from accidents. However, conventional methods for non-helmet-use detection usually consider a helmet or a human body as combinations of fundamental information such as edges and colors without high-level semantic abstraction and contextual understanding, leading to moderate accuracy and environmental adaptability. This paper proposed a safety helmet wearing detection method, which combines a deep learning-based objective detection algorithm and a computer vision-based human pose estimation algorithm, to detect non-helmet-use at construction sites. Specifically, given the relatively fixed aspect ratio between the constructor and the safety helmet in the surveillance video, the K-means clustering method is used to select the number of candidate frame and aspect ratio dimensions. Then a deep neural network is trained using images of multi-scale resolution. The position of construction workers and safety helmets in the monitoring video can be readily located through the neural network. In order to achieve accurate non-helmet-use detection, a human pose estimation algorithm is simultaneously used to identify the key points of human skeleton, i.e., the two-dimensional articulation point images of constructors. Then we determine a worker is wearing a helmet or not by evaluating the relative position of the head joint point and the helmet. The method can achieve good detection accuracy and scene adaptability with a small sample set. It also further the application of artificial intelligence in safety monitoring and safety status assessment of construction site workers.

Augmented Reality – assisted structural inspections

Thursday, 20th June - 14:30: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 304

Mr. Apostolos Athanasiou (The University of Texas at Austin), Dr. Salvatore Salamone (The University of Texas at Austin)

Health monitoring of concrete structures is an important issue for public safety. Over the past decade more structures are exhibiting severe cracking and require regular inspection and assessment efforts. Visual inspection is the first step in the assessment of a concrete structure. The monitoring of cracks over time can serve as an estimator of a structure's structural performance. However, the data obtained during inspections are complex and hard to visualize on-site. Only after careful review of acquired data, the inspector can assess the condition of a structural component. The procedure developed to bridge this gap between the advancements of computer vision and on-site structure health monitoring is based on the utilization of Augmented Reality tools. More specifically it includes the projection of holograms that present the cracking information obtained during previous structural inspections, data about the structural condition of the component, and 3D models including as-built drawings. The inspector can interact with the holograms without using any input/output hardware. All the input and output are performed through gestures and voice commands. The holographic crack visualization eliminates the time required to make a first assessment of a structure. Moreover, it increases efficiency and makes the inspection procedure safer, since the inspector doesn't have to carry any special equipment other than the holographic headset. The application of the proposed approach is inexpensive because the holographic headset is the only hardware required. A showcase video is presented to reveal the full potential of the proposed approach.

Topology-aware 3D reconstruction for cable-stayed bridges

Thursday, 20th June - 14:45: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 368

Dr. Fangqiao Hu (School of Civil Engineering, Harbin Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

3-Dimensional reconstruction (3D reconstruction) generates a 3D computer model of a real object or scene from data such as images, it involves many stages and open problems. Existing methods focus on point clouds and their reconstructed polygonal mesh within Manhattan-world constrains in urban scenes reconstruction. However, there still remains a challenge when dealing with structures like steel truss cable-stayed bridges with complex topology (i.e., connectivity and genus). In this case, existing methods fail to recover an appealing polygonal mesh from highly unstructured and noisy point clouds. A topology-aware 3D reconstruction method which can obtain high-level structures and low-level shapes is proposed in this paper. A Multi-View Convolutional Neural Network (MVCNN) is designed to encode multi-view images into a compact code, which is then decoded into structures (i.e., a hierarchical structural parsing tree) and shapes (polygonal mesh for each leaf node) by designing a Recursive Neural Network (RvNN) and a Graph Convolutional Neural Network (GCN) respectively. By assembling these 2D images into a 3D digital model, it enables inspectors to engage with these images in a more intuitive manner. It also provides a better monitoring scheme by recording and visualizing the life cycle of the entire structure. We demonstrate the feasibility of this method by testing on two real long span steel truss cable-stayed bridges.

Automated Image Localization and 3D Reconstruction for Post-Event Building Reconnaissance

Thursday, 20th June - 15:00: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 668

Mr. Xiaoyu Liu (Purdue University), Prof. Chulmin Yeum (University of Waterloo), Prof. Shirley Dyke (Purdue University), Mr. Ali Lenjani (Purdue University), Mr. Jongseong Choi (Purdue University)

After natural hazards, a large quantity of images are collected to document the consequences of the hazard event on infrastructures. This image data provides an opportunity for post-event building assessment. However, the lack of information to localize the image data collected at a building site hinders the analysis and organization of these data. To understand the damage, it is helpful to locate those photos within the structural drawings. In this work, a systematic tool is developed to automatically localize the inspection images on the drawing of the site and selectively generate relevant 3D reconstructions. Besides the normal inspection images taken from the field, we collect two additional types of images: path images and partial drawing images. The processing of these image data is mainly divided into three steps: (1) the path of the inspector through the site is reconstructed using a state-of-art Visual odometry technique; (2) the drawing of the site is rebuilt given the partial drawing images engaging the method proposed by Yeum et al. 2018; and, (3) the inspection images are automatically localized, employing timestamp information by overlaying the reconstructed path on the drawing image. Finally, for each localized inspection image, overlaid on the drawing, we can reconstruct the nearby 3D environment using structure-from-motion algorithm. An experiment has been carried out in a building at Purdue University to validate and demonstrate this tool. This capability will facilitate automated building assessment in the future, and this approach can also serve as a framework for assisting other image-based inspection tasks.

Automated Decision Support for Flood Risk Mitigation Using Google Street View Images

Thursday, 20th June - 15:15: MS93 - Advances in Vision-Based Structural Health Monitoring; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1130

Mr. Fu-Chen Chen (Purdue University), Dr. Mohammad Jahanshahi (Purdue University), Dr. David Johnson (Purdue University), Prof. Edward Delp (Purdue University)

Floods are the most common and most damaging natural disaster worldwide, both in terms of economic losses and human casualty. With the expected climate changes for the next century including sea level rise, assessing flood risk become important for coastal area residents and governments to make effective decisions about risk mitigation. In this study, an interactive decision support system is developed to tackle the grand challenge of increasing coastal flood risks. Louisiana state in the U.S. have launched Comprehensive Master Plan and laid out $50 billion USD for coastal protection and restoration. However, most data for assessing flood risk in Louisiana are from street-level surveys in 1991 that are obsolete since it is expensive to collect comprehensive data. To tackle the gap between current flood risks and out-of-date data, this study proposes a vision-based approach using deep learning that can collect comprehensive data effectively and efficiently without human-involved street surveys. The proposed approach analyzes Google street view (GSV) images and predicts attributes of buildings simultaneously that are necessary for assessing flood risks. With the proposed feature fusion and multi-task fusion network, the proposed approach can predict foundation type and height, building type and building stories as well as square footage. Individual property owners can use the tool to decide what measures to take to protect their assets, and local planners and policy makers will be able to develop "adaptation timelines" that prioritize infrastructure projects using estimates of current and future risk.

Modeling of Kinetic Umbrellas for Coastal Hazard Mitigation

Thursday, 20th June - 14:00: MS60 - Earthquake Resilience and Cascading Effects; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 572

Mr. Shengzhe Wang (Princeton University), Prof. Maria Garlock (Princeton University), Prof. Branko Glisic (Princeton University)

We introduce an innovative armoring solution in the form of deployable four-sided hyperbolic paraboloidal (hypar) umbrellas as hard countermeasures against nearshore hazards. Inspired by the works of Spanish-Mexican architect-engineer Félix Candela, the proposal seeks to formalize the amalgamation between structural art and coastal engineering. A symmetrical four-sided hypar roof is modified to incorporate a rotational hinge at the vertex. During normal operation, the umbrellas provide shade over boardwalks commonly found on US shores. However, when simultaneously deployed in a row, the panels form a physical barrier against coastal inundation during surge or tsunami induced flooding. This effectively introduces the concept of flexibility into coastal hazard adaptation strategies not demonstrated by classical shoreline armoring initiatives. The structural feasibility of such a system was assessed via the consideration of fluid-structure interaction (FSI) in the hydrostatic regime. A decoupled numerical scheme constituting smoothed particle hydrodynamics (SPH) and the finite element method (FEM) was introduced to simulate fluid inundation on the concave surface of a deployed umbrella, enabling the determination of shell bending and forces in the supporting column. A proof-of-concept study was considered where 5.6 m of hydrostatic inundation was resolved via the open source CUDA-enabled SPH solver DualSPHysics and applied to a FEM model constructed using OpenSees. Bending demands within the shell and supporting column were extracted and compared against reinforced concrete sectional capacities determined within Response-2000. This work ultimately establishes a theoretical foundation for FSI studies involving dynamic hypar shells, enabling future research into coastal interactions under hydrostatic and hydrodynamic regimes.

Robustness analysis for fire following earthquake scenarios considering power-water dependencies

Thursday, 20th June - 14:15: MS60 - Earthquake Resilience and Cascading Effects; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 744

Mr. Maxwell Coar (Princeton University), Prof. Maria Garlock (Princeton University), Mr. Amir Sarreshtehdari (University at Buffalo), Prof. Negar Elhami-Khorasani (University at Buffalo)

The Pacific Northwest faces the looming threat of a 9.0 earthquake from the Cascadia Subduction Zone of the Juan de Fuca plate. City officials, emergency managers, and researchers are preparing for this event by examining the earthquake itself, plus the cascading hazards that will follow it, such as fire and tsunami. Additionally, they must measure the effects of these hazards not only on the infrastructure systems they affect, (e.g. water, power, transportation, communication, emergency services, etc.) but also how each system is affected by the failure of one or more of the others (i.e., dependency and interdependency of systems). This presentation discusses the effects of two cascading hazards – earthquake and fire – and the consequences of failing or damaged water lines and power sources (considering dependencies), plus debris fields, focusing on the needs of firefighters and other emergency services in the 12 hours following a major seismic event. It then frames these methodologies in the context of a fine-grain case study of Seattle downtown. Predictions are made for ignition locations and available pressure at hydrants to combat fires given various earthquake and power outage scenarios. The discussion (1) identifies areas that are especially vulnerable to fire following earthquake, (2) includes general best practices for increased robustness, (3) recommends actions to improve performance in the Seattle study area, and (4) compares the results of this study to an independently submitted analysis of the Seattle Public Utility water network.

Emergency Response Time During Post-Earthquake Fires

Thursday, 20th June - 14:30: MS60 - Earthquake Resilience and Cascading Effects; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 824

Mr. Amir Sarreshtehdari (University at Buffalo), Prof. Negar Elhami-Khorasani (University at Buffalo)

The likelihood of a fire event is typically amplified following an earthquake, while historical events confirm the risk of fire spread across city blocks and even conflagration if the fire ignitions are not controlled immediately and effectively. For example, approximately 110 earthquake-related fires were recorded following the 1994 Northridge earthquake with magnitude 6.7. Meanwhile, emergency response teams and firefighters' response time is affected by the already disrupted community and damaged infrastructure such as bridges and blocked roadways by debris. Delayed response to structurally significant fires can increase the likelihood of fire spread and consequent losses. This research takes an integrative approach at the community level to provide a realistic estimate for change in post-earthquake fire engine response time given an earthquake scenario, building inventory of the community, likelihood of ignition locations, and damage to the transportation network including bridges. Response time from the location of fire department to locations with potential ignition is compared for intact and post-earthquake conditions. Methods and sources of inventory data collection for application of the methodology is discussed. The methodology is then applied to the Centerville community, a virtual community that was designed by the NIST Center for Risk-Based Community Resilience Planning. As part of developing holistic community level plans, the results of this research can be used for preparedness, mitigation, and response. Vulnerable parts of the community can be identified, critical bridges can be strengthen, and scouting routes can be updated, leading to a more resilient community.

Multi-hazard Risk Assessment of a Bridge-Roadway-Levee System considering Downtime Losses

Thursday, 20th June - 14:45: MS60 - Earthquake Resilience and Cascading Effects; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 1029

Mr. Alexandros Nikellis (University at Buffalo), Prof. Kallol Sett (University at Buffalo)

This presentation deals with multi-hazard risk assessment of spatially distributed interdependent networks. A regional system consisting of a transportation network (bridges and roadway stretches) and a levee, is selected and analyzed. During the analysis of this dynamic and relatively complex system, the following hazards are considered: (i) flood hazard due to extreme rainstorms which can cause overtopping of the levee and, (ii) seismic hazard and its triggering effects which can cause structural damage to the bridges and the levee, and liquefaction-induced damage to the roadway stretches. The risk assessment of the network is conducted through a probabilistic event-based analysis. The flood hazard is quantified through an analysis of historical gage height (water elevation) measurements available for the river being protected by the levee, whereas the seismic hazard is quantified through a probabilistic seismic hazard analysis for the whole network. The technique of incremental dynamic analysis is employed to simulate the behavior of the bridges under seismic excitation. The liquefaction hazard along the roadway stretches is quantified by analyzing available SPT and CPT data, while utilizing the Kriging technique. Results from prior studies are incorporated in this analysis for the quantification of the vulnerability of the levee system against both hazards. The results of this analysis will be presented in terms of direct economic losses related to the damage of the components of the network and indirect economic losses due to traffic disruption of the network. An optimum risk mitigation strategy will also be discussed.

DYNAMIC SEISMIC RISK ASSESSMENT TOWARD MORE RESILIENT NUCLEAR POWER PLANTS

Thursday, 20th June - 15:00: MS60 - Earthquake Resilience and Cascading Effects; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 1174

Mr. Mohamed Elsefy (McMaster University), Dr. Mohamed Ezzeldin (McMaster University), Prof. Wael El-Dakhakhni (McMaster University), Dr. Lydell Wiebe (McMaster University)

A nuclear power plant (NPP) is a complex system-of-systems that requires a full understanding of its component and system behaviors and their dynamic interaction under normal and abnormal operation conditions. According to the International Atomic Energy Agency, seismic hazard has a significant contribution to the total frequency of core damage. Probabilistic risk assessment (PRA) for seismic events uses static event and fault tree analysis methods for quantifying the likelihood of cascading failure inside the NPP after a damaging event. However, recent literature has shown serious limitations of current methodologies that neglect the potential for such cascading failures to be amplified through time-dependent interaction among the physical behavior of various NPP components. Additionally, lessons learned from recent NPP accidents have highlighted the importance of enhancing such PRA approaches through a paradigm shift that will enable accurate treatment of the complex dynamic behavior of NPPs following a variety of potential independent or interrelated hazards. In this respect, the current study develops a seismic *dynamic* PRA approach to overcome the limitation of static event and fault tree analysis methods in an effort to enhance the safety and resilience of NPPs. The developed approach considers the nonlinear feedback mechanism among NPP components, including their seismic structural response and deterministic physical behavior, to simulate the cascading failures through a dynamic event tree analysis. This dynamic PRA approach is expected to provide a more realistic representation of NPP behavior following seismic events.

Performance-Based Engineering of Steel Frames under Cascading Events of Earthquake and Fire

Thursday, 20th June - 15:15: MS60 - Earthquake Resilience and Cascading Effects; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 1388

Prof. Hussam Mahmoud (Colorado State University)

The occurrence of fires igniting during and immediately following a seismic event represents an important design scenario that should be accounted for. Building concentration, construction type, weather conditions, and other factors can combine to create a situation in which fire following an earthquake is the principal cause of damage. Records from past earthquakes show that the damage caused by the subsequent fire can be very significant, often exceeding the damage caused by the earthquake. The current seismic design philosophy permits certain degree of damage during earthquakes, making the structures more vulnerable when exposed to the additional demand of fire loading. Fire resistance of steel frames is implemented using passive or active fire resisting systems, which have shown high variability in their sustained damage due to the seismic event. In this paper, a new framework for performance-based fire following earthquake engineering is developed and discussed. The framework is established through combining stability analysis of isolated columns with system-level finite element analysis of a steel building while accounting for randomness in parameters associated with post-flashover fire, passive fire protection, and mechanical loads. Fragility surfaces for column instability as a function of various levels of fire load density and inter-story drift ratios are produced. The results demonstrate that instability can be a major concern in steel structures, both on the member and system levels, under the sequential events and highlights the need to develop provisions for the design of steel structures subjected to fire following earthquake.

Parallel Iwan Models for 3-D Cyclic Loading

Thursday, 20th June - 14:00: MS67/57 - Soil Dynamics and Soil-Structure Interaction, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1397

Dr. Ethan Dawson (AECOM), Dr. Wolfgang Roth (AECOM)

For nonlinear, three-dimensional (3-D) dynamic analyses involving complex loading paths, it is important to have a reliable, numerically robust soil model capable of simulating Masing (hysteretic) behavior in multiple dimensions. This paper explores the performance of a 3-D plasticity model for frictional soils which is a generalization of the 1-D Iwan parallel-series model. Because of their simplicity, parallel Iwan models are widely used in structural engineering to represent hysteretic behavior of individual components or connections, and are also used in earthquake engineering and seismology for 1-D site response studies. Remarkably, this simple technique can also be adapted for use in 3-D plasticity models for simulating general non-proportional cyclic loading (Chiang & Beck, 1994). Parallel Iwan models (also called overlay models or distributed element models) have also been shown useful for simulating the type of cyclic-strain paths relevant for 3-D seismic analyses of soils. These paths involve simultaneous cyclic straining in multiple directions with cycle amplitudes varying over several orders of magnitude.

From their earliest use, Iwan models have played a dual role, both as practical numerical tools for simulating hysteretic behavior, and as micromechanical explanations for hysteretic behavior. The explanatory power of these models extends to non-proportional loading, where the models automatically produce realistic non-coaxial behavior, and shed light on the micromechanical origins of non-coaxiality.

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From Performance-Based to Resilience-Based Pre- and Post-Earthquake Management of Highway Networks

Thursday, 20th June - 14:15: MS67/57 - Soil Dynamics and Soil-Structure Interaction, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1417

Prof. Anastasios Sextos (University of Bristol), Dr. Ioannis Kilanitis (Aristotle University of Thessaloniki)

Network seismic risk is the probability that the network will incur a certain level of loss given its components vulnerability and the earthquake hazard exposure. Apart from direct loss, damage to network components may cause prolonged traffic disruption, which in turn results in large indirect loss in the affected area. Network resilience is a key concept in network risk assessment since it can express the extent of both direct and indirect loss as well as the system's ability to quickly recover its pre-earthquake state. We here present a methodology for the multi-criteria, resilience-based assessment of the possible loss that a highway network may experience due seismic events with different probability of recurrence and subsequent intensity measure distributions over the network region. It also proposes a framework for qualitatively and quantitatively assessing the time-variant loss that a highway network may experience from the onset of the earthquake throughout the recovery period, using resilience-based and scalar quantities, respectively. The above indicators also consist a useful risk management tool at pre-and-post-earthquake level. At pre-earthquake level, they can be used for the identification of the optimum retrofit scheme, among a pool of alternatives, on the basis of two conflicting factors, namely the initial investment cost and the future network loss mitigation. At post-earthquake level, the emergency and recovery actions that lead to the minimum post-earthquake network loss can be defined. In the proposed approach, the two aforementioned levels of highway risk management are interdependently considered towards the adoption of an efficient loss mitigation plan.

Study on the hit probability of dropped cylindrical objects on the pipeline

Thursday, 20th June - 14:30: MS67/57 - Soil Dynamics and Soil-Structure Interaction, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 672

Dr. Xiaochuan Yu (University of New Orleans)

Dropped objects are one of the main causes of fatalities and serious injuries in the oil and gas industry. Objects may accidentally fall down from offshore platforms during lifting or any other offshore operations. In the risk assessment of pipeline protection, it is necessary to estimate the hit probability of freely falling objects on the pipelines on the seabed. Similarly, it's also mentioned in ABS's guideline that specialized techniques are needed to predict the trajectory of objects and the subsequent likelihood of striking additional structure and equipment as well as predicting the consequences of such impacts. In this paper, a sample field layout, in which both the pipeline approach and crane location determined already, is selected as the study case, the trajectory of objects falling into the water, their landing points and the hit probability are numerically calculated from the in-house tool – DROBS. Further, these results will be compared with the current industrial practice.

Transient Response of Structures Interacting with Soil Profiles Through a Modified Modal Analysis Methodology

Thursday, 20th June - 14:45: MS67/57 - Soil Dynamics and Soil-Structure Interaction, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 724

Ms. Tamara Lousada (University of Campinas), Prof. Euclides Mesquita (University of Campinas), Prof. Josue Labaki (University of Campinas), Mr. Luis Filipe do Vale Lima (University of Campinas)

The transient dynamic response of a structure interacting with the soil can be modelled in many ways. Most DSSI (Dynamic Soil-Structure Interaction) procedures require a simulation scheme for the stationary or transient response of the soil domain. Full computaitonal transient description of soil response is very difficult to obtain and aslo requires a lot of computational resources. This paper expands an idea presented in Wu (1995), in which the transient dynamic response of a structure interacting with the soil is obtained by a modified classical modal analysis superposition. The original modal parameters, eigenfrequencies and eigenvalues, of the structure are modified to include the soil dynamic behavior. In this work the structure response is obtained for the case of an external excitation force acting on the structure and also for the case of an impinging wave field. The considered soil profiles include the classical homogeneous half-space, a layered media over a bedrock and over a half-space. The numerical studies will address the number of modified modes that are required to precisely describe the transiente structure response as a function of the soil profile. This methodology should allow the determination of long term time responses of structures interacting with soil profiles requiring much smaller computational resources than the concurrent methodologies.

[1] Wen-Hwa Wu, H. Allison Smith, Efficient Modal Analysis for Structures with Soil-Structure Interaction. Earthquake Engineering and Strucutural Dynamics, v24, pp283-299, 1995.

Effects of Ground Improvement Zone Dimensions on the Modal Characteristics of Pile Founded Structures

Thursday, 20th June - 15:00: MS67/57 - Soil Dynamics and Soil-Structure Interaction, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 733

Dr. Hoda Soltani (Shannon and Wilson Inc.), Prof. Muralee Muraleetharan (The University of Oklahoma), Prof. Joseph Havlicek (University of Oklahoma)

We apply subspace state-space system identification (4SID) and transfer function methods to experimental results from two centrifuge tests and analyze the effects of cubic cement-treated improvement zones on pile performance in soft clay under three consecutive earthquake motions. We show that a few dominant modes can effectively capture the essential features of the soil-pile-superstructure systems. We use the measured pile bending moment data and acceleration measurements of the soil and superstructure to identify the natural frequencies of the improved and unimproved systems. We discuss the relationships between the modal parameters and the dimensions of the improved zones, investigate the dependence of the modal parameters on the base excitation, and use the modal parameters to synthesize sparse prediction models for the system dynamic response. Our most significant finding is that, while it is widely understood that ground improvement can be beneficial for reducing the lateral displacement of piles under static loads, there are conditions under which ground improvement can actually have an adverse effect on the seismic response of pile founded structures.

As there is now growing interest in the application of ground improvement in seismic retrofit of existing structures, our results should be interesting and valuable to practicing engineers in validating some of the simplified models currently being used for preliminary design purposes. Our findings also provide improved understanding into the fundamental mechanisms determining the kinematic and inertial interactions between soil, pile, and superstructure by evaluating the relative contributions of soil and superstructure subsystem responses in the overall system response.

Soil-structure interaction of buried pipelines subjected to transient Rayleigh waves

Thursday, 20th June - 15:15: MS67/57 - Soil Dynamics and Soil-Structure Interaction, Recent Advances in Performance-Based Engineering for Single and Multiple Hazards (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1031

Mr. Kien Nguyen (California Institute of Technology), Dr. Kami Mohammadi (California Institute of Technology), Prof. Domniki Asimaki (California Institute of Technology)

Ground deformation, permanent and transient, poses a major threat to buried pipeline systems. While numerous studies have focused on the response of pipelines to quasi-static deformation and body wave propagation (shear and compressional), however, only few studies have investigated the response of pipelines to Rayleigh waves, which have been further constrained to harmonic time-series. Realistic seismic scenarios, however, are characterized by broadband, transient motions, and synthesizing the response of pipelines to these motions by superimposing monochromatic analyses is a computationally expensive process. Furthermore, soil-pipeline interaction is ignored in these studies, which assume that pipelines perfectly conform to, and do not influence, soil deformation. In this study, we highlight some of the above gaps by investigating the effects of soil-pipeline interaction for the case of transient Rayleigh waves. We use finite element analyses to model the three dimensional scattering of transient Rayleigh waves by buried pipelines, and their effects on the spatiotemporal response of the structure. We perform a systematic parametric study, in which material properties of surrounding soil, impedance contrast between soil and pipe, pipe embedment, and the excitation characteristics (dominant frequency of the input Ricker wavelet) are taken into account through a set of dimensionless parameters. The results reveal the effects of these parameters on the internal forces (axial force, bending moment, and shear force) of the pipe.

Determining Dynamic Elastic Modulus and Poisson's Ratio of Rectangular Timoshenko Beams

Wednesday, 19th June - 16:45: MS95 - Nondestructive Evaluation and Sensing Technologies for Characterization of Concrete Materials (Kerckhoff 119 (174)) - Oral - Abstract ID: 1396

Thursday, 20th June - 14:00: MS107 - Advances in Computational Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 1396

Prof. Roger Chen (West Virginia University), Mr. Guadalupe Leon (West Virginia University)

\textbf{Determining Dynamic Elastic Modulus and Poisson's Ratio of Rectangular Timoshenko Beams} Hung-Liang (Roger) Chen~and Guadalupe Leon West Virginia University, Morgantown, WV 26506 In this study, direct determination of the dynamic elastic modulus and the Poisson's ratio using a simple vibration testing is presented. First, the exact solution of the Timoshenko beam vibration frequency equation under free-free boundary condition is determined with an accurate shear shape factor. The exact solution is compared with a 3-D finite element calculation using ABAQUS program, and the difference between the exact solution and the 3-D FEM are within 0.05\% for both the transverse and torsional modes. Based on the exact solution, a relationship between the resonance frequencies and the Poisson's ratio was proposed which can directly determine the elastic modulus and the Poisson's ratio simultaneously, without the need for iteration, unlike the equations provided by ASTM C215. Using this relationship, the frequency ratio between the first bending mode and the first torsional mode for different combination of specimen dimensions can be determined directly.~ Rectangular concrete beam specimens produced using three different mix designs were tested, and the transverse and torsional frequencies of these beams were measured.~ Results show that using the equations proposed in this study, the Young's modulus and Poisson's ratio of the concrete beams can be determined more directly than those obtained from the ASTM C215 and with better accuracy.~~\\

Stabilization of Linear Isotropic Thermoelasticity in Meshfree Methods

Thursday, 20th June - 14:15: MS107 - Advances in Computational Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 768

Prof. Mike Hillman (The Pennsylvania State University), Mr. Kuan-Chung Lin (The Pennsylvania State University)

In simulation of natural materials such as metals, the mechanical response is often assumed to be uncoupled from its temperature response due to the fact that the ratio of parameters controlling thermomechanical coupling is sufficiently small [1]. However, when the ratio is large, such as composite materials, the temperature variation caused by mechanical deformation could have significant influence on the solution, and a fully coupled system should be considered.

In this work, a meshfree approach for solving the governing equations for the fully coupled theory of thermoelasticity is developed. In order to obtain an effective meshfree solution, accurate, low order quadrature is desired, such as a stabilized and corrected nodal integration. To this end, a naturally stabilized nodal integration [2] is proposed for thermoelasticity to provide a stable nodal integration technique for this problem. Several benchmark problems solved to demonstrate the effectiveness of the proposed method for fully coupled thermoelasticity problems.

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- Hillman, Michael, Chen, J. S., 2016. An accelerated, convergent, and stable nodal integration in Galerkin meshfree methods for linear and nonlinear mechanics. *International Journal for Numerical Methods in Engineering*, 107(7), 603-630.

An adaptive quasi-continuum approach for modeling fracture in polymer networks

Thursday, 20th June - 14:30: MS107 - Advances in Computational Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 186

Mr. Ahmed Ghareeb (University of Illinois at Urbana-Champaign), Prof. Ahmed Elbanna (University of Illinois at Urbana-Champaign)

Polymer networks are the backbone for many natural and manmade materials such as gels, biological tissues, and rubbers. The load bearing structure of polymer networks may be abstracted as a complex network of non-linearly interacting polymer chains while inter-connected by cross-linkers. Understanding the multiscale behavior of polymer networks holds key for uncovering origins of fragility in many complex systems. However, these processes are intrinsically multiscale, and it is computationally prohibitive to adopt a full discrete approach for large scale structures. To overcome these difficulties, we introduce a new adaptive numerical algorithm for solving polymer networks using an extended version of the Quasi-Continuum method. In regions of high interest, for example near crack tips, explicit representation of the local topology is retained where each polymer chain is idealized using the worm like chain model. Away from these imperfections, the network structure is computationally homogenized, using Hill-Mandell's principle, to yield an anisotropic material tensor consistent with the underlying network structure, and only a fraction of the network nodes is solved. Dynamic adaptivity allows transition between the two resolutions. The method enables accurate modeling of crack propagation without apriori constraint on the fracture energy while maintaining the influence of large-scale elastic loading in the bulk. We demonstrate the accuracy and efficiency of the method by applying it to study the fracture of large-scale problems. We further use the method to study the effects of network topology on its fracture resistance. We discuss the method implications for the analysis of networked material systems.

The Reduced Condensation Domain Decomposition (RCDD) Method for simulations of heterogeneous structures

Thursday, 20th June - 14:45: MS107 - Advances in Computational Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 297

Mr. Minh Vuong Le (Université Paris-Est Marne-la-Vall´ee), Prof. Julien Yvonnet (Université Paris-Est Marne-la-Vall´ee), Dr. Nicolas Feld (Safran), Dr. Fabrice Detrez (Université Paris-Est Marne-la-Vall´ee)

Composite materials are a mature technology in many industrial fields including the aircraft and automotive industries. With the constant increase in computer performance, numerical methods play a crucial role in the study of heterogeneous structures. However, solving even small samples with all heterogeneities in complex materials, like woven composites, is a challenge as the corresponding finite element problem can involve billions of degrees of freedom. One possible strategy for tackling this issue is parallel computing based on domain decomposition methods. These methods often exhibit poor performance when the subdomain interface goes through the inclusions or when the size of the problem is large leading to a heavy computational cost.

We introduce here a new technique, called the Reduced Condensation Domain Decomposition method (RCDD), able to deal with highly heterogeneous structures. The technique is based on the enrichment of a solution on a coarse mesh with the condensation of parallel pre-computed solutions on subdomains. It uses the coarse mesh instead of interfaces for transferring the information between subdomains and, in the case of linear problems, does not require iterations to solve the global problem. The solutions in the subdomains are defined as a linear combination of modes capturing fine mesh fluctuations and may include strain gradient effects. Finally, the method offers the possibility to refine the coarse mesh around concentrated loads to improve the solution. The numerical example results are compared to a reference solution from a traditional finite element calculation, including a 3D structure with 1.3 billion deegres of freedom.

Optimizing electronic circuits for stretchability

Thursday, 20th June - 15:00: MS107 - Advances in Computational Mechanics; Part 1 (107 Downs (71)) - Oral - Abstract ID: 974

Mr. Reza Rastak (Stanford University), Prof. Christian Linder (Stanford University)

In recent years, researchers around the world are creating methods and materials to build fully stretchable and flexible electronics [1] with applications in wearable devices [2]. In a stretchable circuit, components possess different levels of stiffness and stretchability, producing a non-uniform strain distribution. During the stretched state, the electronic performance of the components may deteriorate, leading to the failure of the circuit. The shape and the topology of the stretchable circuit, including the placement of the components and the path of the connections, directly impact the mechanical and electrical performance of the circuit. Traditional procedures for designing circuits do not take into account large mechanical strains applied to the circuit, thus they are unable to design stretchable circuits.

We present an optimization framework driven by mechanical and electronic simulations for designing stretchable circuits. The design parameters include the coordinates of the electronic components within the circuit, as well as the dimensions of the circuit. For each design, a mechanical simulation is performed to obtain the state of strain in each component. Then, the change in the electronic properties is measured. For a resistor, as an example, we compute the change in the electrical resistance due to the applied strain. Using a circuit simulator, the performance of the circuit in the stretched state (compared with its undeformed state) is used to guide the design of the stretchable circuit.

References:

[1] Rogers, J. A., Someya, T., Huang, Y. (2010), Science, 327: 1603-1607

[2] Wang et al. (2018), Nature, 555:83-88

Optimizing fiber orientations across composite laminate structures

Thursday, 20th June - 14:00: MS12 - Topology Optimization: From Algorithmic Developments to Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1005

Mr. CHUAN LUO (Johns Hopkins University), Prof. James Guest (Johns Hopkins University)

The Discrete Material Optimization method has proven quite effective at tailoring the fiber orientations within a laminate composite for the purpose of maximizing component stiffness. The Discrete Material Optimization approach expresses elemental stiffness as a combination of the stiffnesses corresponding to candidate orientations, and local constraints are used to ensure solutions feature only one orientation at a location. We investigate the impact of integrating projection-based methods, commonly used in classical continuum topology optimization, within the Discrete Material Optimization framework. Existing projection-based implementations within Discrete Material Optimization are briefly reviewed and extensions to other projection-based schemes, including multi-material projection schemes, are presented with a particular eye towards improving manufacturability of obtained solutions. The problem is posed as a continuous optimization problem, penalized using traditional SIMP formulations, and solved using gradient-based optimizers such as the Method of Moving Asymptotes with sensitivities computed using the adjoint method. The various approaches are demonstrated on benchmark maximum stiffness design problems and compared with results from literature in terms of objective function, solution discreteness, and manufacturability. We consider problems of topology optimization as well as simultaneous optimization of fiber orientation and stacking sequence within the optimized structural topology. Numerical results suggest that projection-based methods can play an important role in controlling the manufacturability of optimized orientations in composite laminates and that solutions are near-discrete with performance properties comparable to benchmark examples found in literature.

Topology optimization of buildings subjected to stochastic ground motions

Thursday, 20th June - 14:15: MS12 - Topology Optimization: From Algorithmic Developments to Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1064

Mr. Fernando Gomez (University of Illinois at Urbana-Champaign), Prof. Billie F. Spencer (University of Illinois at Urbana Champaign)

The field of topology optimization has progressed substantially in recent years, with applications varying in terms of the type of structures, boundary conditions, loadings, and materials. Many of the most severe dynamic loads that civil structures withstand are stochastic in nature; nevertheless, topology optimization of stochastically excited structures has received relatively little attention. In this study, the ground motion excitation is modeled as a stationary zero-mean filtered white noise, the excitation model is combined with the structural model to form an augmented representation, and the stationary covariances of the structural responses of interest are obtained by solving a Lyapunov equation. An objective function of the optimization scheme is then defined in terms of these stationary covariances. This study implements the following details in the topology optimization of stochastically excited buildings: additional floor masses, gravity boundary elements, diaphragm constraints, and only floor responses are of interest; these details can improve the efficiency of the framework for this type of structures. The proposed topology optimization scheme is illustrated for a mid-rise building, subjected to stochastic ground motion excitation. The results presented herein demonstrate the efficacy of this approach for efficient topology optimization of buildings with stochastic ground motions.

Robust topology optimization using image-based deep learning

Thursday, 20th June - 14:30: MS12 - Topology Optimization: From Algorithmic Developments to Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1118

Mr. Mohammad Amin Nabian (University of Illinois at Urbana-Champaign), Dr. Vahid Keshavarzzadeh (Scientific Computing And Imaging Institute, University of Utah), Prof. Hadi Meidani (University of Illinois at Urbana-Champaign)

Topology optimization is a systematic computational framework for finding the optimal layout of given material resources in a pre-specifid domain. This problem is computationally intensive especially when an optimal design is sought in presence of uncertainty in various parameters such as loading, boundary conditions, geometry, etc. We present a data-driven framework for topology optimization under uncertainty using deep learning machinery. We use a limited number of input data which consist of optimal topologies corresponding to various simulation parameters as images, and performance metrics such as stochastic structural compliance and construct a deep neural network map between them with readily available sensitivities. Relying on this learned map and its sensitivity we use nonlinear programming to find an optimal design that is robust toward uncertainty in the simulation parameters. Our approach can be readily extended to challenging reliability-based topology optimization problems, in future extensions of this work.

Topology optimization under topologically evolving materials uncertainties

Thursday, 20th June - 14:45: MS12 - Topology Optimization: From Algorithmic Developments to Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1236

Dr. Alireza Asadpoure (University of Massachusetts Dartmouth), Prof. Johann Guilleminot (Duke University), Dr. Mazdak Tootkaboni (University of Massachusetts Dartmouth)

The application of topology optimization, as a powerful computational free-form design tool, for design and discovery of high-performance structures has accelerated in recent years. This, in addition to the availability of computational resources, is due to significant advances in additive manufacturing which has made the fabrication of parts with complex geometries mainstream. Additive manufacturing techniques, however, introduce a large scatter at the microstructural level, resulting in high levels of material uncertainties that eventually propagate across scales. In this presentation, we propose a framework for topology optimization under such uncertainties where we allow the structure of the uncertainty field to evolve with the topology. This is in contrast to common practice where standard stochastic models defined over the original design domain are used to account for uncertainty. We illustrate the application of the proposed framework in design under uncertainty for a few benchmark problems.

Efficient topology optimization of trusses under geometric uncertainties using reduced basis method

Thursday, 20th June - 15:00: MS12 - Topology Optimization: From Algorithmic Developments to Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1273

Mr. Mohammod Minhajur Rahman (University of Massachusetts Dartmouth), Dr. Alireza Asadpoure (University of Massachusetts Dartmouth), Dr. Yanlai Chen (University of Massachusetts Dartmouth), Dr. Mazdak Tootkaboni (University of Massachusetts Dartmouth)

The outcome of a deterministic topology optimization may become suboptimal if uncertainties, including those in the form of geometric perturbation, are not considered. However, if brute force methods are used, the computational burden associated with incorporating uncertainties into the optimization process is often prohibitively high. There is therefore a need for efficient and accurate uncertainty quantification (UQ) that could be readily integrated into the optimization process. Among existing UQ algorithms, stochastic perturbation provides an effective tool, particularly for design optimization under uncertainty where repeated simulations are needed at each design iteration. While this technique greatly facilitates the manipulation and propagation of uncertainties, it inherits the limitations associated with adopting the truncated series for the input and output.
In this work, we develop an enhanced stochastic perturbation method by drawing upon recent developments in the reduced basis methods (RBM). The key observation in our approach is that the structure of the series representation used in the stochastic perturbation allows for an offline-online decomposition procedure. We then proceed with performing full simulations at a set of judiciously selected perturbation levels during the offline phase of the algorithm. A highly efficient online solver, independent of the size of the full simulation, is then built to harness the offline investment. Arbitrary statistical measures of the quantity of interest are within reach thanks to the efficiency gain and the fact that no series approximation is performed on the output. Numerical examples from structural mechanics are used to demonstrate the applicability of the proposed methodology.

Nonlinear Topology Optimization with Microstructural Effects - A Micromorphic Approach

Thursday, 20th June - 15:15: MS12 - Topology Optimization: From Algorithmic Developments to Applications; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1316

Dr. Ryan Alberdi (Sandia National Laboratories), Dr. Remi Dingreville (Sandia National Laboratories), Dr. Joshua Robbins (Sandia National Laboratories), Dr. Timothy Walsh (Sandia National Laboratories)

New classes of engineered materials - namely architected materials and metamaterials - motivate the use of more advanced modeling techniques such as generalized continua theories due the role of an underlying microstructure. In this study we utilize a micromorphic formulation, wherein material points are endowed with additional degrees of freedom representing stretching and rotation provided by this microstructure. We couple this formulation with a topology optimization approach in order to find optimized configurations of architected materials within the non-linear regime. Motivation for our approach stems from the fact that most existing topology optimization approaches rely on homogenized properties of the underlying microstructure obtained from a representative volume element (RVE). However, for nonlinear problems such an approach necessitates solving a boundary value problem at each integration point of the finite element mesh, making it computationally intensive. Our coupled approach provides an alternative way to capture microstructural effects without carrying out such intensive two scale computations. Numerical examples involving optimization of architected materials in the nonlinear regime are provided to illustrate the efficacy and efficiency of our approach.

A Statistical Volume Element Averaging Scheme for Fracture Analysis of Microcracked Rock

Thursday, 20th June - 14:00: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 764

Dr. Reza Abedi (University of Tennessee), Mr. Justin Garrard (University of Tennessee)

We propose an approach based on statistical volume elements (SVEs) to characterize rock fracture strength at the mesoscale. The microcrack statistics of a Yuen-Long marble is used to develop a simulated two-dimensional material domain for analysis utilizing this process and compared against realistic fracture strengths from material tests. In addition, the crack length distribution type and shape are analyzed using the SVE averaging approach. While the Yuen-Long marble crack length distribution is shown to follow a Power-law distribution, due to the ease of changing the Weibull power parameter to change the crack length distribution shape four different Weibull shape distributions are analyzed. These different crack length distributions are then used in an averaging process to determine fracture strength of SVEs. Further, the effects of changing the SVE size and the domain crack density are investigated. Finally, the given minimum fracture strength fields calculated using the SVE process are used by the asynchronous Spacetime Discontinuous Galerkin (aSDG) method to obtain dynamic fracture patterns for each material microstructure. We derive a macroscopic strain-stress response and homogenize a bulk damage model from aSDG fracture simulations. It is shown that for the same mean crack length, the distributions of crack length with higher variability result in lower mesoscopic minimum averaged fracture strength for SVEs, and subsequently lower macroscopic ultimate stress in a uniaxial tensile example. The distribution of microcrack is also shown to greatly affect developed fracture patterns at the macroscale.

Predicting initial fragment sizes for granular flow under dynamic fragmentation of ceramics

Thursday, 20th June - 14:15: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 773

Mr. Amartya Bhattacharjee (Johns Hopkins University), Prof. Lori Graham-Brady (Joh)

Predictive models for dynamic fragmentation of brittle ceramics must account for granular flow in order to accurately capture the post peak stress-strain behaviour. The transition of ceramics from a highly comminuted stage to fragmentation and subsequent fragment mobility leading to granular flow isn't well understood. Granular flow characteristics are sensitive to the fragment size and angularity of fragments. The current work develops a numerical approach to estimate approximate fragment size and shape characteristics from previous knowledge of effective crack length and orientation. The approach is based on finding connected undamaged regions and eliminating physically unrealistic narrow necks of undamaged regions, by assigning a coalescence link length that ensures that crack tips spaced within the threshold length are joined. The approach has been extended to three dimensions by simulating equivalent elliptical cracks, but here instead of allowing just crack edges to connect within a threshold distance, they can connect anywhere along the crack provided that it initiates from a nearby crack edge. Subsequently, connected regions are dilated in order to fill the space, and the fragment size statistics are computed. Preliminary investigation hints at a power law distribution of fragment sizes. Despite the specific application to this problem, such connected region based algorithms can help us draw parallels between crack statistics and fragment statistics more broadly. It also gives an idea of whether the material has fragmented at a given crack size, which can provide support to previously developed hypotheses regarding a granular phase transition criterion.

A Stochastic Damage Model and Its Applications to Reinforced Concrete Structures

Thursday, 20th June - 14:30: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 993

Prof. Xiaodan Ren (Tongji University), Prof. Jie Li (Tongji University)

In the structural reliability assessment, the material damage and its influence on the response are often of particular concern. Materials are heterogeneous and shows non-uniformity and randomness at micro-level. This non-uniformity and randomness could lead to stochastic behavior of the concrete at constitutive/continuum level. In our work, a multi-scale stochastic damage model (SDM) for concrete is proposed and applied to the stochastic response analysis of reinforced concrete (RC) structures. The proposed SDM is constructed at two scales, i.e., the macro-scale and the micro-scale. The general framework of the SDM is established on the basis of the continuum damage mechanics (CDM) at the macro-scale, while the detailed damage evolution is determined through a random field describing the fracture strain distribution. To represent the random field, a random functional method is developed to quantify the stochastic damage evolution process with only two variables, thus the numerical efficiency is greatly enhanced. Numerical examples show that the proposed method can reflect the influences of randomness from material level to structural level, and is efficient for stochastic response determination and reliability analysis of reinforced concrete structures.

Modeling Earthquake Ruptures With High Resolution Fault Zone Physics

Thursday, 20th June - 14:45: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 1032

Prof. Ahmed Elbanna (University of Illinois at Urbana-Champaign), Mr. Xiao Ma (University of Illinois Urbana Champaign)

Earthquakes are among the costliest natural hazards on earth. The dynamical instabilities responsible for these events are linked to fundamental physics of fluid filled granular materials and rocks in the subsurface subjected to extreme geophysical conditions and coupled with long range static and dynamic stress transfer. Advances in computational earthquake dynamics are opening new opportunities in addressing the conundrum of scales in this extreme mechanics and societally relevant problem. Here, I will present a hybrid method that combines Finite element method (FEM) and Spectral boundary integral (SBI) equation through the consistent exchange of displacement and traction boundary conditions, thereby benefiting from the flexibility of FEM in handling problems with nonlinearities or small-scale heterogeneities and from the superior performance and accuracy of SBI. We validate the hybrid method using a benchmark problem from SCEC dynamic rupture simulation validation exercises and show that the method enables exact near field truncation of the elastodynamic solution. We demonstrate the capability and computational efficiency of the hybrid scheme for resolving off-fault complexities using a unique model of a fault zone with explicit representation of small scale secondary faults and branches enabling new insights into earthquake rupture dynamics that may not be realizable in homogenized plasticity or damage models. Specifically, we show that secondary faults may not only act as energy sinks but they could also be energy sources promoting transient accelerations of rupture propagation speed and slip rate on the main fault. I will close by discussing some possible future applications of this modeling framework.

Nacre-Inspired Fishnet Statistics for Quasbrittle Materials with Alternating Series and Parallel Links: Design for Failure Probability <10-6

Thursday, 20th June - 15:00: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 1103

Mr. Wen Luo (Northwestern University), Prof. Zdenek Bazant (Northwestern University)

The failure probability of engineering structures such as bridges, airframes and MEMS ought to be $<10^{-6}$. This is a challenge. For perfectly brittle and ductile materials obeying the Weibull or Gaussian distributions with the same coefficient of variation, the distances from the mean strength to 10^{-6} differ by cca 2:1. For quasibrittle or architectured materials such as concrete, composites, tough ceramics, rocks, ice, foams, bone or nacre, this distance can be anywhere in-between. This necessitates a new theory of strength probability distribution. The recent formulation of Gauss-Weibull statistics derived from analytical scale transitions and frequency of activation-energy controlled interatomic bond ruptures is reviewed. Then, motivated by imbricated lamellar architecture of nacre, a new probability model with alternating series and parallel links, resembling a diagonally-pulled fishnet, is developed. After the weakest-link and fiber-bundle models, it is the third model tractable analytically. It allows for a continuous transition between Gaussian and Weibull distributions, and is size-dependent. The strength of fishnets with quasibrittle links is solved by means of order statistics. The size effect on the mean fishnet strength is calculated and is proposed to be used for calibrating the fishnet distribution. Finally it is observed that random particulate materials such a concrete may follow the fishnet statistics in the low probability range. Comparisons with histograms and size-effect tests support the theory.

Strength size effect and post-peak softening in woven composites analyzed by cohesive zone and crack band models

Thursday, 20th June - 15:15: MS21 - Modeling and Characterization of Brittle and Quasibrittle Fracture; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 1270

Ms. Jing Xue (Stony Brook University (SUNY)), Prof. Kedar Kirane (Stony Brook University (SUNY))

In contrast to metals, the failure behavior of woven textile composites is quasibrittle, which entails salient structural behaviors such as the strength size effect and post peak softening. This study presents a detailed account of numerical analysis of these aspects in woven textile composites undergoing translaminar tensile fracturing. Two of the most established fracture modeling techniques viz. the cohesive zone model (CZM) and the crack band model (CBM) are evaluated in this regard. The predictions from both techniques are compared to each other as well as to available test data on various woven composites. With a linear softening law CZM and CBM are seen to yield virtually identical results. A linear softening law is seen to be adequate to predict the strength size effect but it is not always able to accurately capture the full post-peak softening. Adapting a bilinear softening law, formulated via the R-curve approach, is seen to improve the post-peak softening predictions. Subsequently, it is shown that various numerical and physical parameters, such as the finite element type, manner of time integration (implicit vs explicit), mesh size, fracture energy, the crack band width, mass scaling, and stress state assumption could have a significant effect on the accuracy of the results, if set sub-optimally. Accordingly, recommendations for optimal settings are made.

Kinetic Theory for Dense, Inhomogeneous, Granular Shearing Flows

Thursday, 20th June - 14:00: MS34 - Experimental and Computational Methods for Particulate Materials; Part 2 (103 Downs (50)) - Oral - Abstract ID: 883

Prof. James Jenkins (Cornell University), Dr. Diego Berzi (Politecnico Di Milano)

We outline the derivation of the equations for the balances of mass, momentum, and energy for dense, inhomogeneous, steady, granular shearing flows of inelastic, frictional spheres in the context of a kinetic theory which has been extended to incorporate the influence of velocity correlations on the rate of collisional dissipation.

We then focus on flows in which the volume fraction is greater than 0.49, above which a first order phase transition to an ordered collisional state is possible in an equilibrated elastic gas. In this regime, the dependence of the transport coefficients on the volume fraction can be replaced by a dependence on the particle pressure and the strength of the particle velocity fluctuations. Associated with the resulting differential equations of balance are boundary conditions for momentum and energy that permit boundary-value problems to be phrased and solved, numerically or, less often, in terms of known functions.

We indicate the form of such problems for a variety of dense shearing flows. All such flows have the capability of developing denser regions of slow, shearing, or creep, in which the diffusion of energy is balanced by its collisional dissipation. We relate such formulations to those of Kamrin and coworkers (e.g., Phys. Rev. Letts. 108, 178301, 2012) and highlight the similarities and differences of the two approaches. We provide example solutions of such problems and discuss their dependence on the parameters that characterize the particles interactions with particles and boundaries, and the geometry and dynamics of the flows.

Simulating Shear Localization Using a Hybrid Discrete-Continuum Approach

Thursday, 20th June - 14:15: MS34 - Experimental and Computational Methods for Particulate Materials; Part 2 (103 Downs (50)) - Oral - Abstract ID: 1247

Mr. Peter Yichen Chen (Columbia University), Mr. Maytee Chantharayukhonthorn (MIT), Dr. Yonghao Yue (The University of Tokyo), Prof. Ken Kamrin (MIT), Dr. Eitan Grinspun (Columbia University)

Shear localization is a frequent feature of particulate materials. While discrete element method is able to faithfully simulate such a phenomenon, it is excessively costly when applied to large scale systems. Continuum based finite element method is computationally tractable yet fails to capture the physics due to the well-known finite size effect. We propose an accurate and fast hybrid discrete-continuum technique that combines the best of both worlds: we simulate regions of localized deformation with slow-yet-accurate discrete method while simulating the rest of the domain using fast-yet-coarse continuum based method. Specifically, we start the simulation using continuum based material point method. As simulation runs, our strain rate and geometry based oracle will sense the formation of a shear band and enrich it to grain scale using discrete element method while leaving the rest of continuum based simulation untouched. We validate our technique in standard triaxial compression and annular shear cell tests, and show that our method is as accurate as a pure discrete element simulation while offering a speed comparable with a pure continuum based simulation.

Heterarchical multiscale modelling of granular flows

Thursday, 20th June - 14:30: MS34 - Experimental and Computational Methods for Particulate Materials; Part 2 (103 Downs (50)) - Oral - Abstract ID: 240

Dr. Benjy Marks (The University of Sydney), Prof. Itai Einav (The University of Sydney)

It is reasonably well established within the granular mechanics field that several distinct length scales exist for many problems. These are typically referred to as the micro- and macro-scales, conventionally corresponding to particle level information and continuum level information. Following this logic, when addressing problems that require a multiscale modelling approach, it is usual to employ a *hierarchical* approach, where one develops a micro-scale model (either analytically or computationally) which interacts via a constitutive model with a coupled macro-scale model. In this presentation, I will show a competing approach, which is to develop a *heterarchical* multi-scale model, which describes both length scales and problems uniformly, allowing for arbitrary information to be coupled between the length scales. I will further show how this idea can quantitatively describe a richness of multi-scale behaviour, such as particle crushing, porosity evolution, segregation and mixing. Finally, I will show how these models can be upscaled to produce homogenised multi-scale models, allowing for continuum descriptions of open systems, where material is free to advect in space between representative volume elements.

DEM modeling of coupled multiphase flow and granular mechanics: wettability control on fracture patterns

Thursday, 20th June - 14:45: MS34 - Experimental and Computational Methods for Particulate Materials; Part 2 (103 Downs (50)) - Oral - Abstract ID: 404

Ms. Yue Meng (Massachusetts Institute of Technology), Mr. Bauyrzhan Primkulov (Massachusetts Institute of Technology), Prof. Zhibing Yang (Wuhan University), Dr. Fiona Kwok (The University of Hong Kong), Prof. Ruben Juanes (Massachusetts Institute of Technology)

As one of the factors that influences multiphase flow in porous media, wettability has been studied for decades, yet many fundamental questions remain. In a recent experimental study, the impact of wettability on the fluid-fluid displacement pattern in a deformable granular pack was investigated [Trojer et al., submitted for publication]. The experiments show the emergence of fracture of the granular pack under certain conditions of injection rate and confining stress. They also show that changes in wettability lead to striking differences in the fracture network morphology.

Here we use discrete element modeling (DEM) to provide insight into the mechanisms underpinning these experimental results. We first develop a 2D model with single-phase flow, and validate it against results from fluid-driven deformation of a confined monoloayer of hydrogel particles [MacMinn et al., PRX 2015]. To study two-phase flow, we couple a dynamic pore-scale network description of fluid-fluid displacement with a DEM model of the mechanical deformation of the skeleton of solid grains. The two-way coupled model is able to reproduce the transition in a frictional granular pack from pore invasion in imbibition, to fracturing at neutral wetting, to a combination of cavity expansion and then fracturing in drainage condition. This modeling approach allows us to capture the effects of varying wettability on the fracture pattern, thereby offering a grain-scale mechanistic understanding of the fracturing process. The model also serves as an effective tool to extend the fracture morphology phase diagram, taking wettability, porosity, elastic modulus and coefficient of friction into consideration.

Source Ground Vibration in Sheared Granular Fault

Thursday, 20th June - 15:00: MS34 - Experimental and Computational Methods for Particulate Materials; Part 2 (103 Downs (50)) - Oral - Abstract ID: 495

Dr. Ke Gao (Los Alamos National Laboratory), Dr. Esteban Rougier (Los Alamos National Laboratory), Dr. Robert Guyer (Los Alamos National Laboratory), Dr. Paul Johnson (Los Alamos National Laboratory)

The devastating potential of earthquake to society calls for a thorough understanding of earthquake source dynamics. Stick-slips in sheared granular fault, as being the laboratory equivalent of natural earthquakes, are intensively studied recently. In these, numerous attentions have been paid to the mechanics of the granular gouge, with few detailed results being reported regarding the response of confining plates. Since the motion of the plates is analogous to the ground vibration in fault blocks, investigating the stick-slip induced ground vibration in sheared granular fault is necessary for unveiling the complex mechanism of earthquakes and may also shed light on the prediction of ground shaking and determination of hazard for future earthquakes. Here, a two-dimensional implementation of the combined finite-discrete element method (FDEM), which merges the finite element method (FEM) and the discrete element method (DEM), is used to explicitly simulate a sheared granular fault system. In the FDEM model, the deformation of plates and particles is simulated using the FEM formulation while particle-particle and particle-plate interactions are modeled using DEM-derived techniques. The results demonstrate that during the stick phases, both plates move at an approximately constant velocity in the direction of shearing. Whereas when slip occurs, the bottom of the upper plate bounces to the right and the top of the lower plate resets towards left. The simulations not only reveal the behavior of stick-slip dynamics in granular fault gouge, but also demonstrate the capabilities of FDEM for studying stick-slip type behavior of granular fault gouge system.

Discrete element modeling of chopped switchgrass: particle size and shape effects on bulk mechanical properties

Thursday, 20th June - 14:00: MS72 - Mechanics and Physics of Granular Materials; Part 2 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 548

Dr. Yuan Guo (Clemson University), Prof. Qiushi Chen (Clemson University), Dr. Yidong Xia (Idaho National Laboratory), Dr. Mohammad Roni (Idaho National Laboratory), Prof. Sandra Eksioglu (Clemson University)

Chopped switchgrass features fibrous particle shapes and high deformability, and is a source material commonly used for conversion into biofuels. The size and shape of individual particles collectively influence the bulk mechanical properties and flowability of such material. In this study, a bonded-sphere discrete element method (DEM) is employed for modeling chopped switchgrass particles and studying bulk mechanical properties of the particles based on calibrated model parameters. The complex particle shapes are represented with clustered spheres, where particle deformations are accounted for with elastic beams connecting neighbor spheres within a particle. The bulk compressibility and shear strength of the modeled material are calculated through simulations of uniaxial compression and ring shear tests at laboratory scales, which serve as calibration baseline for particle contact parameters in our model. A numerical study on effects of the particle sizes and shapes are studied. The results suggest that the presented DEM method is a promising approach for modeling bulk mechanical properties of biomass such as switchgrass.

Evaluation of Frictional Processes in Granular Materials Using Ultrasonic Transmission

Thursday, 20th June - 14:15: MS72 - Mechanics and Physics of Granular Materials; Part 2 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1360

Dr. Reza Hedayat (Colorado School of Mines), Mr. Amin Gheibi (Colorado School of Mines)

Ultrasonic wave propagation measurement is shown to be a suitable technique for studying granular materials and investigating the soil fabric structure, grain contact stiffness, frictional strength, and inter-particle contact area. Monitoring the variations in ultrasonic waves while shearing the granular material can provide insights about the sliding mode and fabric changes in materials. The main objective of our study was to investigate, utilizing ultrasonic measurements, the underlying processes during the friction process of granular materials. We have designed and constructed a direct shear apparatus instrumented with ultrasonic transducers with capabilities for simultaneous application of constant rate of displacement and measurement of transmitted waves through the granular materials. The central hypothesis was that monitoring ultrasonic waves (amplitude, velocity, and frequency) provides valuable insights for evaluating changes in the contact area between the grains. The evolution of the inter-particle contact area and particle crushing was monitored throughout the test by ultrasonic waves during both the compression and shearing stages of the test. The wave amplitude, velocity and dominant frequency were found to be sensitive to different aspects of friction. A close relation was found between variations in ultrasonic wave properties and the frictional underlying processes in both stable and unstable regimes. The test results show that the time-dependent variations of inter-particle contact area with sliding velocity are clearly captured in the variation of transmitted amplitude. The main contribution of this work was on illumination of micro-scale processes that were otherwise undetectable from conventional shear tests.

Particle-Scale Contact Response of 3D Printed Particle Analogs

Thursday, 20th June - 14:30: MS72 - Mechanics and Physics of Granular Materials; Part 2 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 655

Mr. Sheikh Sharif Ahmed (University of California Davis), Mr. Mandeep Singh Basson (University of California Davis), Dr. Alejandro Martinez (University of California Davis)

Recent developments in additive manufacturing technology have enabled the development of 3D printed particle analogs from scans of natural soil particles. While these analogs can satisfactorily reproduce the particle shape and size of sand and gravel particles, their particle-scale contact response has not yet been investigated in detail. This study presents a methodology to model the behavior of natural coarse-grained soil particles with 3D printed analogs. A normalization scheme based on Hertz contact theory is presented here, which can account for differences in elastic stiffness of the particle constituent materials on the contact force-displacement response. To investigate the usefulness of this scheme, particle-particle tests on equal sized spheres of different materials, including two 3D printed polymers, borosilicate glass, and stainless steel, are performed. The results indicate that the normalized contact force-displacement response is dependent on the particle surface roughness and the elasto-plastic behavior of the constituent material. The proposed framework is further applied to results from 1-D compression tests on spherical particle assemblies. The results indicate that the stress-strain behavior of the particle assemblies composed of different constituent materials can be collapsed to an almost unique curve in normalized space. In addition, this investigation is complemented with Discrete Element Modeling simulations to investigate the probability of yielding at interparticle contacts within an assembly of monosized spheres to further evaluate the applicability of the proposed Hertz-based normalization scheme. This study highlights aspects of soil behavior that can be satisfactorily modeled using 3D printed analogs

Recent Advances in Modeling, Analysis and Simulation of the Dynamics of Granular and Related Flow Fields

Thursday, 20th June - 14:45: MS72 - Mechanics and Physics of Granular Materials; Part 2 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 715

Prof. Anthony Rosato (New Jersey Institute of Technology), Prof. Denis Blackmore (New Jersey Institute of Technology)

We present a summary of recent results on our reduced 1D continuum model [1,2] for the velocity **u**(x,t) density ρ(x,t) in which the momentum equation takes the form of a partial integro-differential equation, coupled with equation of mass continuity. Energy loss is captured through a force kernal analogous to a bi-linear soft-sphere interaction of Walton-Braun. The model has a smooth, unique solution that depends continuously on the initial conditions **u**(x,0), ρ(x,0) provided they are globally C^2 and bounded. An important ingredient in well-posed continuum models for granular dynamics is that they are non-local, which is the case for our model [3].

Consequently, there is an accurate, semi-discrete scheme for obtaining approximate solutions. An earlier numerical implementation requiring smoothing in time to achieve limited stability of trajectories compared favorably discrete simulations of a tapped column of spheres [4]. The also model provides a simple formula for approximating wave speeds.

We are now developing a new scheme that incorporates a density bound that should ensure long-time stability. Upon completion, the model and its numerical implementation will be made freely available to the community.

[1]. D. Blackmore, R. Samulyak, A. D. Rosato 1999, *J. Nonlin. Math. Phys.* **6**, pp. 198-221.

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Mobility in Granular Materials upon Dynamic Loading

Thursday, 20th June - 15:00: MS72 - Mechanics and Physics of Granular Materials; Part 2 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 279

Mr. MD Tanvir Hossain (The University of Sydney), Dr. Pierre Rognon (The University of Sydney)

Granular materials can deform like solids or flow like liquid depending on the level of stress there are subjected to. This property underpins the conditions leading to the onset of mobility of large objects embedded into a granular packing. We investigated these conditions via controlled experiments, with a focus on situations where dynamic or cyclic loadings are applied to the object. Our experimental set-up is comprised of a horizontal plate (the “object”– diameter of 3 to 6 cm) embedded into a packing a glass beads (the “grains”-mean diameters of 0.05, 0.3 or 0.6mm). The plate is vertically pulled up using either force- or displacement-controlled loadings. Results evidenced a number of mobility pattern depending on the loading and on the presence or not of water in the pore space. With dry grains, we observed a large drag force instability developing when the plate is pulled slowly, which disappears at higher pull speeds. In fully saturated conditions, we observed a visco-elastic relaxation of the drag force when the plate is suddenly pulled over a small step distance, and a huge increase in peak drag force when the plate is continuously pulled-up at high constant speeds. Furthermore, we evidenced a phenomenon of creep whereby the plate incrementally moves up when subjected to cycles of uplift forces of low magnitude. We finally developed some mechanical analogues combining springs, dashpots, slider and mass elements to recover and rationalise these mobility patterns. These shed some lights on the elasto-visco-plastic processes controlling onset of motion and drag force.

Multiscale modeling of biomass feeding and handling: An investigation of discrete and continuum constitutive laws for milled corn stover

Thursday, 20th June - 15:15: MS72 - Mechanics and Physics of Granular Materials; Part 2 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 751

Mr. Nathan Gasteyer (Purdue University), Mr. Abhishek Paul (Purdue University), Prof. Carl Wassgren (Purdue University), Prof. Marcial Gonzalez (Purdue University)

Flowability of biomass materials is the greatest operational challenge for integrated biorefinery operations (DOE EERE Biorefinery Optimization Workshop, 2016) since feeding and handling of these granular materials is frequently interrupted by bridging, compaction, accumulation, plugging, and shear thinning behavior. Our work addresses this challenge by developing analytical models, validated by pilot plant runs, to enable a fundamental understanding of biomass flow phenomena and to facilitate specification of optimal operating conditions in existing biorefineries in a manner that is not currently possible. Specifically, we investigate complex constitutive relationships at the continuum scale, and complex contact laws at the particle scale, for modeling flow and densification of milled corn stover particles in an industrial compression screw feeder. The granular material is treated as a continuum using a coupled Lagrangian-Eulerian finite element modeling scheme and a Drucker-Prager Cap constitutive law, in order to model shear failure, cohesion and irreversible densification. This continuum-level description is complemented by a particle-scale description where the granular material is treated as a discrete Lagrangian system using novel interparticle contact laws that capture large permanent deformations and elastic recovery. These contact laws are in the spirit of the curvature-corrected nonlocal contact formulation for elastic particles and are in agreement with loading-unloading contact laws experimentally obtained from diametrical compression tests of micro-crystalline cellulose particles. Experimental efforts to calibrate these models, and the elucidation of systematic strategies for upscaling particle-scale properties to continuum-level parameters, are underway.

Chemo-mechanical Coupling and Curing in Multi-constituent Materials

Thursday, 20th June - 14:00: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 937

Prof. Arif Masud (University of ill)

Chemical reactions at bimaterial interfaces during manufacturing of fiber-matrixsystems result in an interphase that plays a dominant role in the response ofthe composite when subjected to mechanical loads. An accurate modeling of thedegree of cure in the interfacial region, because of its effect on the evolvingproperties of the interphase material, is critical to determining the coupledchemo-mechanical interphase stresses that influence the structural integrity ofthe composite and its fatigue life. A mixture model for curing and interphaseevolution is presented that is based on a consistent thermodynamic theory formulti-constituent materials. The mixture model is cast in a stabilized finiteelement method that is developed employing Variational Multiscale (VMS) ideasfor edge-based stabilization and consistent tying of the constituents at thedomain boundaries. The ensuing computational method accounts for curing andinterphase chemical reactions for the evolution of the density and materialmodulus of the constituents that have a direct effect on the interfacial stiffnessand strength. Several test cases are presented to show the range ofapplicability of the model and the method.

Identification of the Physics Underlying Pattern-Formation in Materials

Thursday, 20th June - 14:15: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1427

Mr. Zhenlin Wang (University of Michigan), Dr. Xun Huan (University of Michigan), Dr. Krishna Garikipati (University of Michigan)

We present a contribution to the field of system identification of partial differential equations (PDEs), with emphasis on discerning between competing mathematical models of pattern-forming systems. The motivation comes from materials physics, where phase transitions lead to microstructure.

There is a collection of nonlinear, parabolic PDEs that, over suitable parameter intervals and regimes of physics, can resolve the patterns or microstructures with comparable fidelity. This observation frames the question of which PDE best describes the data at hand. This question is particularly compelling because knowledge of the governing PDE immediately delivers insights to the physics underlying the materials systems. This is an important step toward simulation-based design of materials. While building on recent work that uses stepwise regression, we present advances that leverage the variational framework and statistical tests. We also address the influences of variable fidelity and noise in the data.

Computational Homogenization for Multiscale Nonlinear and Transient Effects in Locally Resonant Acoustic Metamaterials

Thursday, 20th June - 14:30: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1318

Dr. Ryan Alberdi (Sandia National Laboratories), Prof. Kapil Khandelwal (University of Notre Dame)

A concerted research effort has been devoted to the development and study of materials which have exotic emergent macroscopic dynamic properties – so called mechanical metamaterials. Specifically, Locally Resonant Acoustic Metamaterials (LRAMs) exploit the resonant vibration of microstructural features, resulting in unusual dynamic behavior such as negative effective mass and/or stiffness. The common approach of analyzing these materials based on Bloch-Floquet theory is limited to the case of steady-state harmonic plane waves and so cannot account for transient or nonlinear effects. Recently, several less restrictive simulation approaches for mechanical metamaterials have been developed within the framework of computational homogenization. While able to account for multiscale transient effects, these approaches typically invoke assumptions of linearity. In this work, we propose a multiscale simulation approach which can be used to obtain emergent macroscale dynamic behavior from transient nonlinear analysis of a representative volume element (RVE). Based on appropriate scale separation assumptions for LRAMs, multiscale models accounting for transient phenomena within the finite deformation regime are derived using the Method of Multiscale Virtual Power. Computational homogenization is then carried out by discretizing the resulting multiscale models using both standard finite element and isogeometric approaches. Numerical examples verify the efficacy of this computational homogenization approach and illustrate the influence of transient and nonlinear phenomena on emergent negative effective mass density.

The multiscale finite element method for nonlinear continuum localization problems at full fine-scale fidelity

Thursday, 20th June - 14:45: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 874

Prof. Dominik Schillinger (University of Minnesota), Dr. Lam H. Nguyen (Livermore Software Technology Corporation)

In the first part of this talk, we describe a local iterative corrector scheme that significantly improves the accuracy of the multiscale finite element method (MsFEM). Our technique is based on the definition of a local corrector problem for each multiscale basis function that is driven by the residual of the previous multiscale solution. Each corrector problem results in a local corrector solution that improves the accuracy of the corresponding multiscale basis function at element interfaces. We cast the strategy of residual-driven correction in an iterative scheme that is straightforward to implement and, due to the locality of corrector problems, well-suited for parallel computing. In the second part, we focus on a series of algorithmic and variational extensions that enable efficient residual-driven correction for nonlinear localization problems. These include a synergistic combination of Newton and corrector iterations to reduce the algorithmic complexity, the use of corrector degrees of freedom in the Galerkin projection to eliminate the repeated recomputation of multiscale basis functions during Newton iterations, and a natural residual-based strategy for fully automatic fine-mesh adaptivity. We illustrate through several numerical examples from phase-field fracture and plasticity that the MsFEM with residual-driven adaptive correction achieves full fine-scale fidelity while also being computationally more efficient than the pristine MsFEM.

Multiscale Stochastic Modeling for Additive Manufacturing Part Qualification

Thursday, 20th June - 15:00: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1170

Dr. Kyle Johnson (Sandia National Laboratories), Dr. John Emery (Sandia National Laboratories), Dr. Mircea Grigoriu (Cornell University), Dr. Jay Carroll (Sandia National Laboratories), Dr. Joseph Bishop (Sandia National Laboratories, New Mexico)

Metal Additive Manufacturing (AM) has the potential to revolutionize manufacturing processes by offering benefits such as increased geometric complexity, rapid prototyping, and locally-tailored properties. However, part qualification still remains a challenge due to variability in performance caused by residual stress, porosity, lack of fusion defects, and uncertainty in material properties. This variability often leads to significant scatter in part performance and makes failure prediction difficult. In this work, we propose a hierarchical approach that first uses engineering-scale, lower-fidelity models to identify hotspots where later concurrently coupled fine-scale models containing explicitly-represented materials defects are employed to refine performance predictions. Voids found in the AM material through high resolution uCT characterization are represented by locally seeding void volume fractions in a damage mechanics model at different locations in the mesh. The fine-scale models consist of subvolumes of AM material and explicitly mesh the geometries of statistically informed porosity. These models are then coupled to the engineering-scale models through multi-point constraints. Predictions of reliability are compared, and conclusions regarding computational efficiency are discussed. The effects of residual stresses, which are often at or above the yield strength of the material, are investigated by including these stresses in the reliability predictions.

Hierarchical Material Mechanics, Design and Analysis

Thursday, 20th June - 15:15: MS77 - Hierarchical and Multiscale Methods for Simulation Based Design of Materials; Part 2 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1058

Dr. Georgios Apostolakis (University of Central), Prof. Gary Dargush (University at Buffalo)

Engineered materials can have properties that are not found in nature, with their properties arising not from the elemental base materials used but rather by the architecture of the design. As a result, the design of engineered materials can be mathematically posed as a multi-objective optimization problem with primary variables the geometry or topology and accompanying length scales. Moreover, recent developments in additive manufacturing science and technology support the materialization of complex three-dimensional architectures with continuous gradient material variations. Consequently, architectures with patterns at multiple scales and continuous gradient variation in material properties will extend the range of applications, performance and effectiveness of engineered material designs. In this presentation, we present the development of design and optimization tools that attempt to take full advantage of the three-dimensional freedom that advanced manufacturing technologies enable and include both periodic and non-periodic material architectures. The proposed methodology is based on a novel design framework for the design, mechanics and optimization of engineered materials incorporating Self-organized Genetic Algorithm (SoGA), Mixed Lagrangian Formalism (MLF) and Mixed Convolved Action (MCA) variational principles, and hierarchical orthonormal wavelets as the evolutionary optimization, computational mechanics and analysis, and multiscale hierarchical components, respectively. Furthermore, the present study will investigate the use of the orthonormal wavelets not only as the multiscale hierarchical tool, but also the use of orthonormal wavelets as the analysis tool. Investigation of novel functionally graded material architectures are presented for various applications, e.g. band gap, protective systems, etc

High Energy Impact Test and Analysis Methods Development for Composite Materials at NASA Glenn Research Center

Thursday, 20th June - 14:00: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1264

Dr. Robert Goldberg (NASA Glenn Research Center)

The Ballistic Impact Laboratory at NASA Glenn Research Center and its affiliated researchers has an extensive testing and analysis program underway to evaluate, develop and validate experimental and numerical methods to explore, understand and predict the high energy impact response of advanced composite materials. The test methods and analysis approaches are designed using a building block approach, where the material and structural response at a variety of length scales is examined. The presentation will discuss the available ballistic impact testing facilities, including the advanced imaging capabilities that are utilized to gain further understanding of the composite impact response. Some representative results that have been obtained in recent composite impact tests will be described, including local temperature rises that have been observed to occur in composites under impact conditions. A new composite impact material model which is being designed to be implemented within the commercial transient dynamic finite element code LS-DYNA will be discussed. The new material model is a combined deformation, damage and failure model where the input is provided in a tabulated manner as opposed to providing point-wise properties. An orthotropic plasticity based model has been developed to analyze the composite deformation. A semi-coupled strain equivalent model has been developed to analyze the nonlinear unloading that takes place in composites. A tabulated failure model which can account for failure surfaces with general shapes in also being formulated. Additional modeling efforts which are underway to account for the complex fiber architecture in advanced textile composites will also be discussed.

The World Is Not Enough (WINE) - space mining robot with steam propulsion

Thursday, 20th June - 14:15: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 970

Dr. kris zacny (Honeybee Robotics), Mr. Phillip Morrison (Honeybee Robotics), Dr. Philip Metzger (University of Central Florida), Mr. Zak Fitzgerald (Honeybee Robotics), Mr. Vincent Vendiola (Honeybee Robotics), Mr. Sherman Lam (Honeybee Robotics), Mr. Nick Traeden (Honeybee Robotics), Mr. Zachary Mank (Honeybee Robotics), Mr. James Mantovani (NASA Kennedy Space Center), Mr. Robert Mueller (NASA Kennedy Space Center)

The World Is Not Enough (WINE) is a concept for a new generation of spacecraft that takes advantage of In-Situ Resource Utilization (ISRU) to explore space. WINE mines to extract water from planetary regolith, capturing the water as ice in a cold trap and heating it to create steam for propulsion. By propulsively “hopping” from location to location, WINE can explore Solar System bodies as well as individual bodies (e.g. WINE could cover much greater distances on Europa or the Moon than a rover, and can reach otherwise inaccessible regions). And by refueling itself as it goes, WINE’s range is not limited by consumables. This makes WINE particularly well suited to prospecting and reconnaissance missions.

A prototype of WINE was designed, fabricated and tested in a large vacuum chamber. The vehicle was used to demonstrate several of the primary operations that would be required of the WINE spacecraft including: mining and heating regolith to extract water; capturing water as ice in a cold trap; reorienting the vehicle to allow for further mining; pushing captured water into a propulsion tank; and heating propellant to create steam for thrust. All systems demonstrated are fully functional. All tests are conducted with regolith simulant in a vacuum chamber.

Study of a Gearless Mechanical Transmission (GMT) for use in Aerospace Applications

Thursday, 20th June - 14:30: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1354

Mr. Arun Malla (University of Connecticut), Dr. Kazem Kazerounian (University of Connecticut), Dr. Horea Ilies (University of Connecticut)

The purpose of this ongoing research is to study a gearless mechanical transmission (GMT) drive system, an efficient, low-maintenance torque reducer/increaser suited for multiple aerospace applications. This drive system can be designed to act as a gear reducer or increaser, and is set apart from existing systems by utilizing spheres moving along designed cam surfaces in place of gear teeth. This design leads to many advantages over geared systems, being lighter and more compact than corresponding drives. It also requires less maintenance, has a longer service life, and functions at a lower aural volume. These benefits make it ideal for any task that requires a gear reducer or increaser; especially those for in which size and mass are to be minimized, or environments where frequent maintenance would be disadvantageous such as on satellites or aircraft.

The study of the GMT will develop a thorough understanding of such a system, determine the source of existing issues, and redesign the drive for production. Study consists of a comprehensive kinematic, dynamic and mechanical analysis of the GMT system, to be followed by design change recommendations and prototyping in partnership with a partner company. Sources of current problems with the GMT design will be identified and addressed, and a methodology will be developed to design similar drives for use in a wide range of fields. These uses include satellite deployable structures, rover drive systems, and multiple other aerospace and extraterrestrial applications.

Origami Structure Actuation using Shape Memory Alloy for Space Related Applications

Thursday, 20th June - 14:45: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1045

Mr. Hunter Cocks (Western New England University), Prof. Anthony Santamaria (Western New England University), Prof. Moochul Shin (Western New England University)

This work examines the use of shape memory alloys (SMAs), such as Nitinol, to actuate origami designed structures. SMAs are a class of alloys showing unique behaviors (e.g. shape memory effect). Their phase transformation between martensite and austenite phases can be utilized for actuation of an origami structure. While the idea has been investigated in the past, this discussion focuses on the potential for space related applications from an engineering perspective. Their ability to deploy devices such as solar panels and heat exchangers may offer new solutions to the aerospace industry. For example, the Miura-ori tessellation, which may be a framework for many aerospace structures, may be expanded and collapsed using Nitinol based SMAs. Several origami tessellations were examined in conjunction with different methods of SMA actuation including radiative and electrical heating. A basic analytical model of a Nitinol wire in space was developed to study its thermal behavior where radiative heating and cooling are dominant.

Sensor placement and damage analysis of tensegrity structures

Thursday, 20th June - 15:00: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1026

Mr. Omar Aloui (University of Miami), Dr. Nizar Bel Hadj Ali (University of Gabès, Ecole Nationale d'Ingénieurs de Gabès), Dr. Landolf Rhode-Barbarigos (University of Miami)

Tensegrity structures are self-stressed form-found structures composed of axially loaded elements. Therefore, they are materially and mechanically efficient structures. Moreover, in the presence of multiple self-stress states, tensegrity systems can also be robust regarding the loss of an element. Tensegrity systems have been used to design lightweight yet strong structures, as well as reconfigurable and smart systems through the integration of sensors and actuators. Tensegrity structures are advantageous for active applications, such as planetary landing and exploration or space habitats, as they can combine sensors and active elements along with their structural elements. Active elements reflect members, such as cables and/or struts, that can change length in a controllable manner, thus inducing control over the shape and/or behavior of tensegrity structures. Moreover, through the exploration of infinitesimal mechanisms (displacements possible without deformation of the elements), optimal paths for the control of tensegrity structures can be identified and followed. Although many studies have focused on the use of tensegrity systems for active applications and their control, few studies have focused on their sensor configuration and state characterization. Therefore, this study focuses on a theoretical framework that allows the identification of the minimum number of sensors required and their placement on a tensegrity structure, as well as the analysis of their input for characterizing the state of the structure. The study builds upon the concepts of cellular morphogenesis of tensegrity structures developed by Aloui et al. (2019) analyzing tensegrity structures as a set of elementary tensegrity sub-systems.

Low Cost Wireless Smart Strain Sensors for Structural Health Monitoring of Launching Operations on Aerospace Vehicles

Thursday, 20th June - 15:15: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 976

Mr. Eric Robbins (University of New Mexico), Mr. Marlon Aguero (University of New Mexico), Mr. Dilendra Maharjan (University of new), Mr. Emmanuel Ayorinde (University of New Mexico), Dr. Fernando Moreu (University of New Mexico)

Government and commercial space vehicle companies such as NASA and Space X are interested in the reusability of structural components on space vehicles after missions, so they can launch their vehicles several times while saving costs and ultimately increasing the exploration of space. This project summarizes the development of a new low-cost wireless smart strain sensor for SHM of aerospace vehicles which was initially designed and tested on amateur rockets for proof of concept validation. The mobility and storage capacity of the strain sensor allows researchers to estimate the structural life of space vehicles, while retaining the capability to be used at multiple locations on space vehicles during missions. These sensors retain the ability to measure strain, accelerations, and vibrational types of data on specific structural elements according to user interests through the use of a code programmed in the sensor itself. This provides a safe and reliable medium through which measurements report the structural health for systems that function in extreme conditions such as launching, craft maintenance, management of structural-member life, and structural performance. A group of these smart sensors can even be combined into a communication network through wireless signaling between nodes after the launch. This will ultimately enhance better design, monitor safety, assess structural elements under functioning conditions, and provide an analysis on structural members for future lifespan and reusability.

Dynamics of Sequential Failure of Tree Root Foundations

Thursday, 20th June - 14:00: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 1114

Mr. Matthew Burrall (University of California Davis), Mr. Lin Huang (University of California Davis), Dr. Jason DeJong (University of California Davis), Dr. Daniel Wilson (University of California Davis), Dr. Alejandro Martinez (University of California Davis)

Tree root systems are efficient natural foundation systems. This project seeks to develop bio-inspiration from tree root systems that can be applied to engineer foundations which are more materially efficient, resilient, and sustainable relative to the linear foundation elements currently used in practice. To directly understand the biological system in the context of forms, behaviors, and principles, ten three-year-old fruit trees with different rootstocks were extracted vertically in the UC Davis Plant Science Department teaching orchard. Measurements during testing included load, displacements, accelerations, and photos for photogrammetry. Post-test measurements included 3D root architecture mapping based on photogrammetry and lidar.
A key feature of these tree root systems is sustained load resistance with continued deformation well beyond twice the trunk diameter. This sustained performance at large deformations is enabled by the complex 3D root structure, and specifically can be attributed to the geometric arrangement of root bifurcations, taper of root diameter with distance, and anisotropic material properties of the roots. During pullout testing, root failure progresses dynamically to allow for large deformations. Breakage of individual roots results in load transfer to the remaining roots. Individual root breakage events, identified and identified by spikes in the distributed acceleration measurements and short-term decreases in the trunk load, were located spatially and sequences of individual root breakage events analyzed. Results showed differences in initial stiffness and in peak and residual capacity between the various rootstocks. These differences can be traced to differences in load distribution between the numerous structural root elements as loading progresses.

Enhanced geothermal heat exchange through loop optimization and phase change: A bio-inspired strategy

Thursday, 20th June - 14:15: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 1229

Mr. Yimin Lu (Georgia Institute of Technology), Prof. Douglas Cortes (New Mexico State University), Prof. Xiong Yu (Case Western Reserve University), Prof. Sheng Dai (Georgia Institute of Technology)

Shallow-depth geothermal technologies are considered among the most sustainable alternatives for space heating and cooling. Ground-source Heat Pump (GHP) systems use buried closed-loop piping to exchange heat with the ground by circulating a water-based antifreeze solution. Depending on the location, GHP systems can consume 23-44% less energy than air-source heat pumps, and 63-72% less energy than electric resistance heaters. Despite the benefits of the systems, GHPs currently account for less than 2% of the North American heating, cooling, and air conditioning market. Major challenges to a wider implementation of GHPs in the US are high installation costs and performance uncertainty, which require innovative strategies to significantly improve its efficiency and competitiveness. This presentation demonstrates that the ground heat exchange systems can be transformed by incorporating two major biological thermoregulation strategies developed over 4 billion years of evolutionary adaptation: homeotherms circumvent progressive temperature change through phase change, and poikilotherms rapidly change internal temperature through sophisticated vascular circulation. The combination of experimental and numerical studies show that the energy efficiency of geothermal heat exchange systems can be significantly improved through the optimization of flow loops, and that the deployment of encapsulated phase change materials (ePCMs) to cope with thermal cycles through releasing or storing latent heat during phase change can prevent thermal performance degradation of geothermal heat exchangers in long-term due to ground heat depletion.

Self-organization in leaf vascular network development

Thursday, 20th June - 14:30: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 1230

Prof. Eleni Katifori (University of Pennsylvania), Dr. Henrik Ronellenfitsch (MIT)

Land plants have developed a vascular system of striking complexity to solve the problem of nutrient delivery and mechanical support of their leaves. The leaf vascular network is intimately linked to the fitness of the plant, as water abundance in the leaf blade is closely connected to photosynthetic efficiency. Despite its importance, the principles that govern the structure, topology, function, development and evolution of the leaf vascular network are still not well understood.

In this talk we present how the leaf vascular network utilizes principles of self organization to develop. Building on the auxin canalization hypothesis, we first discuss a general model on how a hierarchically organized vascular system can develop under constant flow. We show that under conditions of growth, the leaf will sequentially develop a reproducible network of primary and secondary veins, the architecture of which is strongly influenced by the shape of the leaf blade, followed by a stochastic network of higher order veins. Within this developmental model, we then show how variable auxin production and time-dependent flow can stabilize anastomoses and lead to a vascular topology dominated by cycles, and discuss the spectrum of optimal venation phenotypes.

Damage mitigation of a near-full-scale deployable tensegrity structure through behavior biomimetics

Thursday, 20th June - 14:45: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 29

Dr. Ann Sychterz (University of Michigan), Prof. Ian F.c. Smith (Swiss Federal Institute of Technology Lausanne (EPFL))

Current infrastructure is designed and built such that it must simultaneously comply with all possible loads. This leads to overdesigned structures that are inefficient in terms energy and cost. A structure that can self-identify damage, adapt, and learn for future events addresses the emerging field of intelligent infrastructure through inspiration from biology. The required material and embodied energy of structural elements is reduced while maintaining structural integrity with a small increase in operational energy for active control. Tensegrity structures are cable-strut systems held in equilibrium due to self-stress. There is potential for damage tolerance when they are kinematically redundant. This paper presents active control algorithms applied for damage mitigation and service loading of the tensegrity structure. Active control using a path-planning RRT*-connect algorithm and soft-constraint algorithm changes the shape of the tensegrity structure to reduce member stresses and to restrict vertical (downward) displacement caused by a damaged element. Though the effect improves the configuration of the structure, it cannot be fully restored to the design configuration. Effectiveness of the RRT*-connect and soft-constraint algorithms for the half structure depends on the relative change of nodal positions and feasibility to bring the structure back within serviceability limits. Since correction of end-node coordinates can be grouped according to the direction vector to mitigate the configuration of the structure and resulting cable-length changes, case-based reasoning (CBR) is useful to reduce time of execution and to avoid unnecessary cable-length changes. Mitigation techniques are successfully demonstrated for serviceability thresholds for a uniformly distributed load.

Multiphysical model for describing self-healing mortar containing biochar-immobilized bacteria

Thursday, 20th June - 15:00: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 1067

Dr. Harn Wei Kua (National University of Singapore)

This work aims to analytically and numerically describe and predict the ability of bacteria (Bacillus sphaericus) to heal cracks in mortar. The ureolytic bacteria induces microbial calcium carbonate by releasing urease enzyme, which in turn stimulates the degradation of urea into carbonate and ammonium; the carbonate then reacts with the calcium ions (in calcium nitrate) to produce calcite to heal cracks. The bacteria is immobilized in biochar, which is the solid by-product of pyrolysis; the biochar and bacteria are included in mortar mixture, together with special nutrient solution (the spore solution). Published studies found that biochar-immobilized bacteria heals cracks more efficiently.

The modeling approach consists of 4 major steps or sub-models.

Firstly, the Pore Wall Bubbling model describes the protrusion and expansion of pores in biochar. The predicted pore size distribution, hence porosity, was then used to calculate the overall porosity of the biochar-containing mortar using the second sub-model known as the Fractional Porosity Model. Next, an absorption model was used to describe uptake of the spore solution and used to estimate the spore concentration within the biochar. Finally, the rate of healing of a hypothetical cylindrical crack in mortar was estimated from the rate of production of calcite (due to the spore concentration calculated above), which depends on the rate of urea hydrolysis - the latter of which is described using a hydrolysis-diffusion model solved using Galerkin's finite element method.

Theoretical predictions agree very well with experimental results. Several deductions and possible improvements to the model are suggested.

Self-healing reactive powder concrete with nanofillers

Thursday, 20th June - 15:15: MS6+8+9 - Mechanics of Bio-Inspired Multi-Functional Systems, Biomimetics for Engineering Design: Understanding the Structure vs. Function of Bio-Structures, Self-Healing Materials Principles and Technology; Part 2 (147 Noyes (84)) - Oral - Abstract ID: 1409

Dr. Zhen Li (Dalian University of Technology), Dr. Jialiang Wang (Dalian University of Technology), Prof. Baoguo Han (Dalian University of Technology)

In this study, different types of nanofillers including nano-SiO_2, nano-ZrO_2 and nano-TiO_2 were separately incorporated into reactive powder concrete (RPC) for nano-modification, and the specimens were placed in water and air for curing. Both the compressive and flexural strengths of RPC were measured and the self-healing ability of RPC was characterized by using an AE instrument. Experimental results indicate that all incorporated nanofillers have the ability to enhance the self-healing ability of RPC. However, it is of note that the enhancement is more evident when RPC is cured in water. Composite with nano-SiO_2 has the largest self-healing coefficients of compressive (C_s) and flexural strength (F_s) with water curing of 1.31 and 1.19, which increases by 39.4% and 33.7% compared to RPC without nanofillers, respectively. The incorporation of nanofillers weakens and even eliminates the Kaiser effect of RPC under secondary loadings, indicating that to a certain extent, crack healing has taken place. The effect of the nanofillers modification mechanisms on the RPC self-healing properties is thought to be attributed to three main features: 1) The provision of nanofillers provide the hydration environment for unhydrated cement particles and nucleation sites for the hydration products. 2) Nanofillers improve the three-dimensional network structure of concrete matrix, produce more fine cracks and disperse the propagation direction of cracks. 3) The pozzolanic reaction of nanofillers (including nano-SiO_2 and nano-TiO_2), especially for nano-SiO_2, produces additional calcium silicate hydration, and increases the compactness of RPC.

Faults and Fractures in Deep Geological Carbon Storage

Thursday, 20th June - 14:00: MS35 - Computational Geomechanics; Part 2 (142 Keck (72)) - Oral - Abstract ID: 1129

Prof. Pania Newell (University of Utah), Dr. Mario Martinez (Sandia National Laboratories)

CO_2 sequestration is a process of capturing large amount of carbon dioxide (CO_2) from large sources and storing it in deep geological formations. The success of the overall performance of the geological carbon storage (GCS) units depends on various trapping mechanisms such as structural, capillary, solubility, and mineral mechanisms within the geological systems. Structural trapping within deep geological formations is highly influenced by the rock formation, newly-formed and pre-existing fractures and faults. The magnitude of the pore pressure due to injection of CO_2 not only depends on hydrological and geomechanical properties of rock formation, but also on the wellbore orientation, the injection rate and the injection schedule. In this presentation the impact of formation thickness, wellbore orientation, injection rate, presence of fault and pre-existing fractures within the caprock is computationally investigated at the reservoir scale. This study highlights that in addition to injection rate, wellbore orientation and number of the faults in the domain play critical roles in caprock integrity.
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Evolution of volumetric response in cyclic shearing using a memory-enhanced SANISAND model

Thursday, 20th June - 14:15: MS35 - Computational Geomechanics; Part 2 (142 Keck (72)) - Oral - Abstract ID: 1151

Mr. Ming Yang (The University of British Columbia), Mr. Andres R. Barrero (The University of British Columbia), Prof. Mahdi Taiebat (The University of British Columbia), Prof. Yannis Dafalias (University of California, Davis)

Capturing the rate and trend of pore water pressure generation in saturated sands under undrained cyclic shearing at different cyclic stress ratios (CSR) is closely related to proper modeling of inherent and induced fabric. Corti et al. (2016) introduced a locus termed "memory surface" for tracking the stress history of soil and influence the plastic stiffness. This surface can evolve in size and position according to the rules that can be linked with physical principles of particle fabric and interaction. In a recent study, Liu et al. (2018) incorporated a memory surface to a revised version of the SANISAND model for improved simulation of sand stiffening under drained cyclic shearing, which also contributes to pore pressure evolution of medium dense sand in undrained cyclic triaxial shearing at certain CSRs. The present study evaluates and extends this recent development with an aim of capturing the rate of excess pore pressure development of sands in undrained cyclic shearing at a range of CSRs. The capability of the extended model is explored and validated against recent laboratory data of cyclic torsional shear tests. Using a single set of model parameters, the model performance is summarized by the resulting liquefaction strength curves in terms of the excess pore pressure ratio approaching one.

Seismic effects on bearing capacity of footing strip using isogeometric analysis

Thursday, 20th June - 14:30: MS35 - Computational Geomechanics; Part 2 (142 Keck (72)) - Oral - Abstract ID: 1329

Mr. Hoang Nguyen (Imperial College London)

Abstract:

This paper presents an upper bound procedure using isogeometric analysis and second-order cone programming to estimate how seismic conditions affect bearing capacity factors and corresponding failure mechanisms. The isogeometric analysis was adopted to establish displacement fields, while the final form of upper bound analysis was formed as conic programming. Seismic effects were considered considering extra loads that are proportional to seismic acceleration. Results obtained confirm that the present approach can serve much better values of bearing capacity factors when compared with those derived from the same upper approach using finite element method and conic programming.

Numerical Simulation of Lateral Load Capacity of a Dynamically Installed Pile in Cohesive Soils

Thursday, 20th June - 14:45: MS35 - Computational Geomechanics; Part 2 (142 Keck (72)) - Oral - Abstract ID: 1343

Mr. Junho Lee (Texas A&M University, College Station), Prof. Charles Aubeny (Texas A&M University, College Station)

In this paper, the behavior of dynamically installed piles (DIPs) during horizontal loading in cohesive soils was evaluated using a three-dimensional nonlinear finite element model. The cohesive soil is simulated with solid continuum elements which include its nonlinear physical behavior and the large deformational characteristics. A DIP is also modeled with solid continuum elements, and it is considered as a rigid body for computational efficiency. The lateral load capacity at each depth of the DIPs is estimated by the current numerical simulations, and the optimum padeye position can be suggested. The validity of the numerical results is demonstrated through comparison to the plastic limit analysis (PLA) method and existing laboratory test data.

3-D X-Ray Computed Tomography Study of the Depositional Fabric of Sand from the San Francisco Bay

Thursday, 20th June - 15:00: MS35 - Computational Geomechanics; Part 2 (142 Keck (72)) - Oral - Abstract ID: 1428

Prof. Nicholas Sitar (University of California, Berkeley), Dr. Estefan Garcia (University of California, Berkeley)

In recent years there have been significant advances in the application of X-Ray computed tomography for 3-D imaging and characterization of granular media. To-date the various efforts have concentrated on characterizing grain shapes, packing, and triaxial tests on samples constructed in the laboratory. However, in a natural setting the depositional fabric depends on the mode of deposition and the shape, degree of rounding, orientation, and packing of the grains. The objective of our effort is to develop a technique for the characterization of the natural depositional fabric of sands by scanning and testing undisturbed samples obtained in routine geotechnical site investigations. To this end we obtained thin wall tube samples of sand collected during a site investigation at Treasure Island in the San Francisco Bay. The deposits at the site consist of hydraulic fill overlying a natural sand bar. We used small diameter plastic tubes to obtain undisturbed cylindrical samples for scanning and triaxial testing at the Laboratory 3SR at Université Grenoble Alpes. To date we scanned and obtained grain orientation data from 6 different samples, and we successfully performed two miniature triaxial tests. The results of the just completed experiments show that the natural sands exhibit a well-defined preferred grain orientation towards the horizontal, as would be expected given their mode of deposition. The stress-strain response in the triaxial tests reflects the significant influence of fabric.

Multiscale Modeling and Experimental Characterization for Poromechanical and Damage Behavior of Shales

Thursday, 20th June - 15:15: MS35 - Computational Geomechanics; Part 2 (142 Keck (72)) - Oral - Abstract ID: 717

Mr. Vasav Dubey (Texas A&M University, College Station), Dr. Sara Abedi (Texas A&M University, College Station), Dr. Arash Noshadravan (Texas A&M University, College Station)

The inherent complex multiscale and heterogeneous structure of organic-rich shale presents challenges in the development of a physics-based predictive model for poromechanical and transport properties. The objective of this research is to improve understanding of poromechanical and damage behavior of shale materials through multiscale modeling and small scale experimental characterization. Different effective medium approximations based on assumptions about subscale morphology are employed to model the homogenized poromechanical property at a given microstructural level. The Linear Elastic Fracture Mechanics (LEFM) framework is used to construct damage criterion in terms of thermodynamics force associated with crack density and formulation is developed for damage evolution in the transversely isotropic medium. The damage model is further extended to account for the effect of microcrack growth in the permeability variation. To account for statistical fluctuation of poromechanical, damage and transport properties at the macroscale, probabilistic description is assigned to key model input parameters at different length scales. In order to calibrate model parameters associated with the damage growth model, we conduct direct tensile experiments using a miniature tensile module which can be analyzed under scanning electron microscope (SEM). Using a miniature tensile module with small sample size makes it feasible to conduct more tests, in comparison to a typical direct tension test for brittle rocks with large sample size. The multiscale model along with stochastic upscaling presented in this work provides an important step forward in extending the existing multiscale poromechanical models of shale by incorporating the effect of microcracks and their evolution with loading.

GPU-Accelerated Simulation of Low-Speed Mobility over Fine Granular Terrain

Thursday, 20th June - 14:00: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 2 (Baxter Lecture Hall (296)) - Poster - Abstract ID: 1080

Mr. Nicholas Olsen (University of Wisconsin – Madison), Mr. Conlain Kelly (UW Madison), Prof. Dan Negrut (University of Wisconsin – Madison)

Some of our society's most ambitious and expensive engineering undertakings rely on the ability to accurately model and predict the performance of rovers under extra-planetary conditions. Such missions can encounter delays or failure in the event that the vehicle becomes trapped by the terrain. In this submission, we use a toolkit called Chrono::Granular to investigate the problem of low-speed, wheeled-vehicle traversal of fine-grained granular terrain. A parallel submission from Kelly et al. provides a more thorough software implementation description of this infrastructure, which allows us to leverage graphics processing units (GPUs) to efficiently simulate systems with over a billion degrees of freedom. The particulate terrain is modeled with the penalty-based discrete element method. The rover itself is modeled in a separate simulation via the Chrono::Vehicle module of the Project Chrono multi-physics engine. Coupling the vehicle dynamics of the rover with the high-resolution terrain in Chrono::Granular is done with a force-displacement co-simulation model. In this configuration, the rover's wheel geometries are represented as triangle meshes which accumulate forces from the terrain and convey them to the Chrono vehicle simulation, which advances the vehicle in time. We present results characterizing a given rover's ability to successfully navigate challenging scenarios on terrain composed of fine particles and rigid surfaces. Such scenarios include mounting an incline of loose material, traversing a region of deep loose material, and ascending a small step.

Inertial Phenomena and Resistive Force Theory in Wheeled Locomotion in Granular Media

Thursday, 20th June - 14:15: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 529

Mr. Andras Karsai (Georgia Institute of Technology), Mr. Shashank Agarwal (MIT), Prof. Ken Kamrin (MIT), Dr. Daniel Goldman (Georgia Institute of Technology)

We use an automated testbed to systematically conduct single-wheel (20 cm diam.) locomotion experiments in dry granular media (~1 mm poppy seeds) at angular velocities ω (0.7-6.4 rad/s). Resistive Force Theory simulations predict a linear increase in velocity with increasing ω, but at higher angular velocities the translation speed plateaus to a speed dependent on the wheel geometry and the system's force distributions. Frictional plasticity simulation shows a similar velocity plateau despite lacking a rate-dependent constitutive model. To correctly capture this system's physics, we must account for both the geometry of the wheel's sheared grains and the centrifugal reaction force the wheel effects on them. Wheel pressure on the sheared zone multiplied by a centrifugal acceleration term creates an extra force $F \approx Mr\omega^2$, creating an extra virtual drawbar force that reduces the wheel's equilibrium speed. This global force correction applied to the RFT sim shows a translation speed plateau matching experimental results. RFT is a local model which obeys superposition, so we hypothesize this global force correction can arise locally if we shift RFT into a new reference frame via the centrifugal acceleration at the wheel edge. For RFT simulations with circular wheels, this local correction can successfully create a velocity plateau differing from standard RFT's linear increase in velocity. This new type of correction could extend RFT into modeling diverse high-speed scenarios where acceleration is significant without sacrificing RFT's superposition and locality.

High-efficiency Models for Soil-Machine Interaction

Thursday, 20th June - 14:30: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1374

Prof. James Hambleton (Northwestern University)

Problems in soil-machine interaction (SMI) are ubiquitous on Earth, and they are beginning to play important roles elsewhere as we explore and perhaps eventually colonize the moon and other planets. Irrespective of the application, SMI problems are typically defined by the presence of large, plastic deformation as machine components come into contact with soils. While methods to simulate the machines themselves have developed rapidly, methods for predicting the forces and reactions generated through soil contact are underdeveloped and inadequate. Numerical techniques such as the material point method and the discrete element method have advanced to the stage that they can model SMI problems—and indeed they are the leading tool used by industry—but these methods suffer from significant drawbacks, particularly with respect to their prohibitive inefficiency. Focus in this presentation is on formulating, benchmarking, and validating a new numerical technique referred to as the "sequential kinematic method" for efficiently computing force-displacement histories under arbitrary tool motions and loading conditions. Early-stage work on a general, semi-analytical framework is also discussed. Theoretical predications are compared against experimental data obtained for fundamental configurations and soil types using the 6-axis robotic arm and soil test beds available in the Soil-Machine Interaction Laboratory (SMI Lab) at Northwestern University.

Modeling Mars Rover Mobility

Thursday, 20th June - 14:45: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1182

Dr. Rudranarayan Mukherjee (Jet Propulsion Laboratory, California Institute of Technology)

We present our efforts in modeling mobility of the MSL and Mars 2020 rover through a number of different modeling approaches. We discuss our different modeling approaches. We present the challenges and advantages of these models. We present results showing how model results compare against experimental and mission data. We also provide a glimpse into new modeling approaches that are evolving from our experience.

Dependence of the Pull Generated by the Interlock Drive System on Soil Conditions

Thursday, 20th June - 15:00: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1291

Dr. Volker Nannen (Sedewa), Mr. Damia Bover (Sedewa), Prof. Dieter Zöbel (University of Koblenz Landau)

The interlock drive system provides traction by penetrating narrow articulated spikes into the soil at regular intervals. Once inserted into the soil, the spikes provide sufficient motion resistance to pull a heavy implement or load, even on wet or inclined soil. Unlike the frictional connection of a tire, where the amount of pull depends on the amount of ballast, which shears, compresses and destroys soil structure, a spike transfers the draft force to the soil by interlocking with the intact soil structure. Nevertheless, spikes cannot generate traction entirely without ballast or dynamic weight transfer from implements. Pulling at a spike will create a rotational moment about the tip of the spike, which depends on the geometry of the spike and the penetration depth, which in turn depends on soil conditions.

Here we present experimental results which show how the penetration depth of the spikes depends significantly on soil strength and moisture, and how the rotational moment changes accordingly. Consequently, the amount of pull that can be safely generated with a given geometric configuration increases with soil strength and decreases with the degree of soil moisture. We find a maximum decrease in pull of 30% between dry and firm soil on one hand and wet and loose soil on the other hand.

Impact of Magnetorheological Damper Semi-active Suspension on Tyre Soil Interaction

Thursday, 20th June - 15:15: MS42 - Advances in Terramechanics: Soil-Machine Interaction, Mobility, Terrestrial Robotics, and Beyond; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1309

Mr. Brandon Lee James Ballard (Coventry University), Dr. Olivier Haas (Coventry University), Prof. Mike Blundell (Coventry University), Dr. Arash Moradinegade Dizqah (Sussex University), Dr. Stratis Kanarachos (Coventry University)

Background: Semi-active and active suspensions have been shown to improve vehicle dynamics in terms of ride comfort and road holding for use in on-road applications. The behaviour and use of semi-active Magnetorheological Dampers (MR Dampers) for vehicles travelling off-road across soft soiled terrains is an area of active research.

Aim: This study aims to identify the behaviour of the vehicle to highlight the difference in behaviour of an MR Damper when it is utilised for off-road vehicle suspension and the resulting impact this has on the pressure and sinkage at the tyre-soil interface.

Material and Method: A passive full car vehicle model with MR Dampers is simulated on off-road terrain using a rigid wheel tyre-soil interaction model to estimate sinkage into soft soil. An active suspension system using model predictive control (MPC) computes the optimal control action for the active MR Dampers taking into account constraints relating to the limitation associated with the vehicle's suspension operation and the control action. MPC exploits preview information about the terrain ahead of the vehicle.

Results: The parameterised MR damper model was shown to fit the LORD RD-8040-1 (R^2 = 0.9983, RMSE = 3.1921). The overall damper + vehicle model has been compared qualitatively with the literature. The MPC is shown to reduce the amplitude of the body acceleration compared to the passive system.

Conclusions: Active suspension using an MR damper can be used to evaluate the impact of the control action of the pressure and sinkage at the tyre-soil interface.

Geometric mechanics of origami patterns exhibiting Poisson's ratio switch by breaking Mountain/Valley assignment

Thursday, 20th June - 14:00: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1408

Prof. Glaucio Paulino (Georgia Institute of Technology), Dr. Phanisri Pratapa (Georgia Institute of Technology), Mr. Ke Liu (Georgia Institute of Technology)

We present a pattern, named Morph, that combines the features of its parent patterns. We introduce a four vertex origami cell that morphs continuously between a Miura mode and an Eggbox mode, forming an homotopy class of configurations. This is achieved by changing Mountain/Valley assignment of one of the creases, leading to a smooth switch through a wide range of negative and positive Poisson's ratios. We present elegant analytical expressions of Poisson's ratios for both in-plane stretching and out-of-plane bending, and find that they are equal in magnitude and opposite in sign. Further, we show that by combining compatible unit cells in each of the aforementioned modes through kinematic bifurcation, we can create hybrid origami patterns that display unique properties such as topological mode-locking (irreversible morphing under stretch by synchronized engagement of aligned panels in the Miura mode) and tunable switching of Poisson's ratio.

Degree-n Vertices and Dihedral Angle Propagation in Origami

Thursday, 20th June - 14:15: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 637

Mr. Luca Zimmermann (ETH Zurich), Prof. Kristina Shea (ETH Zurich), Dr. Tino Stankovic (ETH Zurich)

While a number of computational methods exist to simulate the kinematics of origami, none of these methods is able to determine analytical equations for the dihedral angles of arbitrarily complex crease patterns. To address this gap, our work first provides a new method that analytically determines the dihedral angles of a single degree-n vertex, and then analyzes the propagation of these angles throughout a crease pattern, thereby completely determining its kinematic behavior. The fundamental idea behind the method is that a single origami vertex, independent of its degree, can be represented as a single spherical triangle. Each side of this triangle can either correspond to a constant sector angle of the vertex or become an angle of variable size that is spanned by multiple sector angles with in-between dihedral angles that activate the folding motion. With this representation, an increasing number of vertex degrees only translates to a slight increase in complexity of the spanned angles, which facilitates the determination of the unknown dihedral angles. The method enables the assessment of important kinematic properties of a crease pattern, such as its kinematic determinacy, its degrees-of-freedom, and its rigid foldability. It further contributes to the facilitated design of origami because pre-defined sets of target dihedral angles can be satisfied directly. Both the assessment and the design of crease patterns are presented through a range of examples, including patterns that exhibit special properties such as symmetry.

Exploration of plastically annealed lamina emergent origami structures

Thursday, 20th June - 14:30: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 983

Dr. Yves Klett (Universität Stuttgart), Prof. Peter Middendorf (Universität Stuttgart)

The use of compliant hinges has been an implicit staple in origami, even before the nature of these hinges was ever formally described. With the use of lamina emergent hinges, the articulation of surrogate crease hinges can be realized in an elastic fashion. If those surrogate hinges are annealed in a non-trivial state, then they can act as integral actuators that return a folded structure to the annealed state. We will explore the nature of these plastically annealed lamina emergent origami (PALEO) structures, look into different possible implementations and applications, and present prototypes of different structures.

Development and Evaluation of a Prototype Shape Memory Polymer Shape-Changing Building Surface Tile

Thursday, 20th June - 14:45: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 375

Mr. Robert Zupan (University of Pittsburgh), Dr. Dale Clifford (California Polytechnic State University), Dr. Richard Beblo (University of Dayton Research Institute), Dr. John Brigham (Durham University)

A design concept for shape-changing smart material tiles with applications in environmentally responsive building facades is presented. The shape-changing tile concept is responsive to daily solar irradiance and lowers thermal transmission to the building interior. A lab-scale prototype system for smart material tiles composed of a 3D-printed thermally responsive shape memory polymer (SMP) activated by heat and uniform pressure actuation is examined. Physical tests have been conducted to experimentally validate a computational (finite element) representation of the adaptive surface tile system. Towards developing this computational representation, a strategy is presented to determine and validate the material parameters for the 3D-printed SMP tile by matching the tile shape predicted by the numerical model to the tile shape measured experimentally. A computational approach was derived from the numerical representation to explore the design space that correlates adaptive tile shape to solar irradiance. More specifically, a series of numerical examples are considered that determine the location and size of material activation zone(s) that minimize the area of the tile exposed to solar irradiance. Results indicate that a SMP tile that dynamically adapts to variation in solar incidence using the proposed mechanisms can considerably improve façade surface shading over the course of a day. Additionally, the importance of the control strategy for a multi-tile system is displayed, particularly with respect to the capability to significantly reduce the shape-changing energy cost and affect the solar irradiance to a higher degree by accounting for neighboring tile interaction.

Continuum Elasticity of Miura Tessellations

Thursday, 20th June - 15:00: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 615

Dr. Hussein Nassar (University of Missouri), Dr. Arthur Lebée (Laboratoire Navier - UMR 8205, CNRS, École des Ponts ParisTech, France), Dr. Laurent Monasse (INRIA)

Origami tessellations are curved two-dimensional discrete shells folded out of a periodic crease pattern. Unlike solid shells, Origami tessellations can morph and access a space of configurations each characterized by the list of folding angles of all creases. Due to inextensibility constraints imposed by Origami kinematics, not all combinations of folding angles are admissible meaning that the space of admissible configurations, is a priori unknown. In this talk, we present a model of Origami tessellations as continuum, rather than discrete, elastic shells. Most importantly, we suggest an asymptotic theory that translates the local constraints imposed on folding angles into global constraints weighing on the effective elongations and curvatures of the tessellation. Thus, the theory provides a characterization of the space of kinematically admissible configurations as the set of solutions to a system of non-linear PDEs. Furthermore, the elastic strain energy required by each configuration is calculated. In conclusion, the elastostatic equilibrium of the tessellation is formulated as a constrained continuous energy minimization problem. The theory is exemplified in the case of the Miura tessellation. Various finite deformation modes (large strains, large curvatures) are successfully predicted and constructed numerically under suitable boundary conditions.
Notwithstanding the costs of higher analytical complexity and lower accuracy, the suggested theory offers a deeper physical insight into the configuration space of Origami tessellations while significantly reducing calculation time. This compromise should therefore prove beneficial in time-sensitive applications, as for instance is the case when real-time control of Origami tessellations is desired.

Functional anisotropy: exploiting the mechanics of curved-creased origami systems

Thursday, 20th June - 15:15: MS46 - Origami/Kirigami Inspired Structures and Metamaterials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 380

Mr. Steven Woodruff (University of Michigan), Dr. Evgueni Filipov (University of Michigan)

Curved-creased origami systems are created by folding thin sheets about arbitrarily inscribed curved lines. The resulting three-dimensional structure differs from traditional origami-inspired systems in that the deformed sheets form smooth, curved surfaces as opposed to flat panels connected with hinges. Curved-creased origami patterns have been shown to possess global anisotropy of the folded structure. This anisotropy can be exploited in engineering problems, including metamaterials, compliant mechanisms, and biodesign. Additionally, curved-creased structures are self-restraining which can increase the stiffness of the global system and can be used to store potential energy for rapid deployment of the assembly.

In this talk, we present a simplified bar and hinge model to simulate curved-creased origami and use it to explore the peculiar nature of this class of foldable systems. The robustness of the model is exemplified with a variety of curved-creased structures including simple conical forms to complex, multi-fold systems. Results show the anisotropic behavior of these novel structures and their applications in real-life engineering solutions.

Stochastic dynamical response of a non-smooth dynamical system under filtered noise excitation

Thursday, 20th June - 16:00: MS83 - Computational Methods for Stochastic Engineering Dynamics; Part 1 (Ramo (371)) - Oral - Abstract ID: 310

Prof. Arvid Naess (NTNU), Mr. Saeed Gheisari Hasnijeh (University of Isfahan)

In this study, the dynamics of a spur gear pair under stochastic loading is investigated by using numerical path integration (PI) technique. The mathematical model is a nonlinear time-varying (NTV) system since it includes nonlinear backlash and time-varying mesh stiffness. The uncertainty is modeled by a Gaussian white noise in combination with a first order linear filter which keeps the Markov property of system. Four cases are addressed, based on how the noise is incorporated in the loading terms. A first order filter is employed to generate various filtered noises with the same energy but different power spectrum. In order to increase the accuracy of PI technique for the non-smooth system, an adaptive time-stepping scheme is adopted base on the marginal probability at the non-smooth boundaries. The results are verified by comparing with Monte Carlo simulations. The effect of the noise spectrum on the response probability is evaluated for loading cases. Since the PI technique provide solutions of unprecedented numerical accuracy, the response PDF contains subtle information, which can be interpreted according to the relevant application.

Functional series expansions and quadratic approximations for enhancing the accuracy of the Wiener path integral technique

Thursday, 20th June - 16:15: MS83 - Computational Methods for Stochastic Engineering Dynamics; Part 1 (Ramo (371)) - Oral - Abstract ID: 39

Mr. Apostolos Psaros (Columbia University), Prof. Ioannis Kougioumtzoglou (Columbia University)

A Wiener path integral (WPI) based stochastic response determination technique for diverse dynamical systems/structures is developed herein by resorting to functional series expansions in conjunction with quadratic approximations. The technique can be construed as an extension and enhancement in terms of accuracy of the standard (semi-classical) WPI solution approach (e.g. [1]). Specifically, in comparison to the standard approach [1], where only the "most probable path" connecting initial and final states is considered in determining the joint response probability density function (PDF), the herein developed technique accounts also for fluctuations around it; thus, yielding an increased accuracy degree. An additional significant advantage of the proposed enhancement as compared to earlier developments relates to the fact that low probability events (e.g. failure probabilities) can be estimated directly in a computationally efficient manner by determining a few only points of the joint response PDF. In other words, the normalization step in the standard approach [1], which requires the evaluation of the joint response PDF over its entire effective domain, is circumvented. The efficiency and accuracy of the technique are assessed in several numerical examples, where analytical results are set vis-à-vis pertinent Monte Carlo simulation data.

[1] Psaros A. F., Brudastova O., Malara G., Kougioumtzoglou I. A., "Wiener Path Integral based response determination of nonlinear systems subject to non-white, non-Gaussian, and non-stationary stochastic excitation." Journal of Sound and Vibration 433 (2018): 314-333.

Computationally efficient stochastic response determination of high-dimensional dynamical systems via a Wiener path integral variational formulation with free boundaries

Thursday, 20th June - 16:30: MS83 - Computational Methods for Stochastic Engineering Dynamics; Part 1 (Ramo (371)) - Oral - Abstract ID: 555

Mr. Ioannis Petromichelakis (Columbia University), Prof. Ioannis Kougioumtzoglou (Columbia University)

A novel Wiener path integral based variational formulation with free boundaries is developed herein for determining the stochastic response of high-dimensional dynamical systems in a computationally efficient manner. Specifically, although recent work based on sparse representations and compressive sampling [1] has increased drastically the computational efficiency of the WPI technique as compared to its standard implementation, the cost of computing the joint response probability density function (PDF) still unavoidably explodes relatively fast with an increasing number of degrees-of-freedom (DOFs). In this paper, the above limitation is circumvented by marginalizing the joint response PDF based on a variational formulation with free boundaries. In this regard, the associated computational cost becomes independent of the number of DOFs; and thus, high-dimensional systems can be readily treated by the WPI technique. Several numerical examples indicate that the developed technique is potentially orders of magnitude more efficient than a Monte Carlo simulation solution treatment.

References

[1] Psaros, Apostolos F., Ioannis A. Kougioumtzoglou, and Ioannis Petromichelakis. "Sparse representations and compressive sampling for enhancing the computational efficiency of the Wiener path integral technique." *Mechanical Systems and Signal Processing* 111 (2018): 87-101.

Approximate closed-form solutions for a class of nonlinear stochastic differential equations with applications in engineering dynamics

Thursday, 20th June - 16:45: MS83 - Computational Methods for Stochastic Engineering Dynamics; Part 1 (Ramo (371)) - Oral - Abstract ID: 272

Mr. Antonios Meimaris (Monash University), Prof. Ioannis Kougioumtzoglou (Columbia University), Prof. Athanasios Pantelous (Monash University), Dr. Antonina Pirrotta (Università degli Studi di Palermo)

In this paper, an approximate analytical solution is determined for a certain class of first-order stochastic differential equations with nonlinear drift and nonlinear diffusion coefficients. Specifically, a closed form expression is derived for the response process transition probability density function (PDF) based on the concept of the Wiener path integral and on a Cauchy-Schwarz inequality treatment. This is done in conjunction with formulating and solving an error minimization problem by relying on the associated Fokker-Planck equation operator. The developed technique can be construed as a generalization of earlier work in [1] to account for nonlinear diffusion coefficients. It is shown that this significant enhancement of the technique, in conjunction with a stochastic averaging treatment, enables the stochastic response determination of a wide range of oscillators exhibiting diverse nonlinear and hysteretic behaviors. The herein developed technique, which requires minimal computational cost for the determination of the response process PDF, exhibits satisfactory accuracy and is capable of capturing the salient features of the PDF as demonstrated by comparisons with pertinent Monte Carlo simulation data. In addition to the mathematical merit of the approximate analytical solution, the derived PDF can be used also as a benchmark for assessing the accuracy of alternative, more computationally demanding, numerical solution techniques.

[1] Meimaris A., Kougioumtzoglou I. A., Pantelous A., (2018). “A closed form approximation and error quantification for the response transition probability density function of a class of stochastic differential equations”, *Probabilistic Engineering Mechanics, vol.54: 87-94*

Analytic solutions in implicit form for the nonlinear Euler-Bernoulli beam equation with fractional derivative terms

Thursday, 20th June - 17:00: MS83 - Computational Methods for Stochastic Engineering Dynamics; Part 1 (Ramo (371)) - Oral - Abstract ID: 1068

Dr. Konstantinos Liaskos (American University of the Middle East), Prof. Athanasios Pantelous (Monash University), Prof. Ioannis Kougioumtzoglou (Columbia University), Mr. Antonios Meimaris (Monash University)

In this work we present some results on the nonlinear Euler-Bernoulli beam equation with a fractional derivative term. We reduce the initial-boundary value problem for the corresponding partial differential equation to an initial value problem for an ODE in the Hilbert space. Applying the abstract theory for second order ODEs in Hilbert spaces which involves cosine and sine families of operators, we introduce a variation of parameters representation of the solution map and we obtain the well posedness of the abstract problem. Based on the regularity properties of cosine and sine families, the form of the nonlinear term, and the properties of the fractional derivative, the solution map of the abstract problem is translated into a derivative-free analytic solution in implicit form for the initial-boundary value problem. Analytic solutions in implicit form for the elastic case and the pure viscous case are also provided under the same functional background. Numerical examples illustrate the effectiveness of the theoretical findings.

The Dynamic Response of Multi-Span Euler-Bernoulli Beams, Fitted with Tuned Mass Dampers, to Poissonian Loading

Thursday, 20th June - 17:15: MS83 - Computational Methods for Stochastic Engineering Dynamics; Part 1 (Ramo (371)) - Oral - Abstract ID: 719

Mr. Iain Dunn (Università degli Studi di Palermo), Dr. Alberto Di Matteo (Università degli Studi di Palermo), Prof. Giuseppe Failla (Università degli Studi Mediterranea di Reggio Calabria), Dr. Antonina Pirrotta (Università degli Studi di Palermo)

This contribution considers the dynamic response of Euler-Bernoulli beams equipped with multiple tuned mass dampers, subjected to random moving loads.
The theory of generalised functions is used to find the discontinuities of the response variables at the exact locations of the tuned mass damper attachments. This involves deriving exact, complex eigenvalues and eigenfunctions from a characteristic equation built as the determinant of a 4 x 4 matrix, this is always the case, regardless of the number of tuned mass dampers attached to the beam. Orthogonality conditions are then built for the deflection eigenfunctions and the stochastic responses, under Poissonian loads, are evaluated.
To show the applicability, accuracy and efficiency of the proposed procedure, a numerical application is presented. A beam with multiple tuned mass dampers, acted upon by random moving loads, in the form of a filtered Poissonian process, is considered and a comparison is made to show the difference in response between no attachments, one attachment, and five attachments.

Effect of Alkali-Silica Reactivity Damage on the Shear Strength of Reinforced Concrete Beams

Thursday, 20th June - 16:00: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 218

Mr. Hadi Aryan (University of Southern California), Dr. Bora Gencturk (University of Southern California), Dr. Mohammad Hanifehzadeh (University of Southern California), Ms. Clotilde Chambreuil (ENS Paris Saclay)

This study investigates the shear behavior of three full-scale reinforced concrete beams affected by different rates of alkali-silica reaction (ASR). All the beams were built using highly reactive fine aggregate and one of the beams was cast with added alkali, 1.25% by weight of cement, to accelerate ASR. The expansion of the beams, caused by the ASR, was measured from 14 days of age once every two weeks until the testing day, which varied from six months for the first beam to 14 months for the third beam. The concrete degradation was monitored until the day of testing through compression and tensile tests on the cylinder samples prepared from the same concrete and expansion measurements on the beams. The first beam with only reactive aggregate was kept in the lab environment for 6\six months prior to the test. The second beam, again with only reactive aggregate, was in the Los Angeles outdoor environment for 13 months and was sprayed with water twice per week to maintain a close to 100% relative humidity inside the concrete. The beam with reactive aggregate and additional alkali was also in the outdoor environment with the same conditioning for 14 months. Two shear tests were conducted on each beam and the results of the beams were compared in terms of strength, deformation, and rebar and concrete strains.

Seismic Performance Assessment of RC Structures accounting for Aging Effects

Thursday, 20th June - 16:15: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 759

Mr. Codi McKee (Texas A&M University), Dr. Petros Sideris (Texas A&M University), Prof. Mija Hubler (University of Colorado Boulder)

This presentation will investigate the effect of aging on the seismic performance of reinforced concrete (RC) framed structures. Resilient structures should withstand earthquake hazards at any point in their lifetime. However, structural assessments under earthquakes typically consider the original non-aged structures, thereby neglecting changes in structural properties over time. Aging in RC structures may include a wide range of phenomena, such as the ongoing hydration reaction, which usually increases the concrete strength, alkali-silica or alkali-carbonate reaction, which is primarily dependent on the mineral characteristics of the aggregates, and corrosion of the steel reinforcement. Furthermore, creep and shrinkage may also affect the long term seismic performance of RC structures by causing stress redistribution over the structure as an outcome of the resulting creep- and shrinkage-induced deformations.

This study considers two aging mechanisms: the ongoing hydration reaction and the corrosion of the steel reinforcement. Using predictive equations for the concrete mechanical properties over time, as well as the mechanical properties of corroded rebar over time, estimates of such properties are obtained for mild and highly corrosive environments for three different life spans, namely, 25, 50 and 75 years. Using these “aged” properties, three RC framed structures are studied, namely, a two-story, a four-story and an eight-story structure. All structures are subjected to pushover analyses and incremental dynamic analyses (IDAs) using the ground motion ensembles from FEMA P695. From the IDA results, fragility curves are formulated for various damage states, include collapse, demonstrating differences with respect to the considered aging factors.

Performance Enhancement of Unreinforced Masonry Structure using RC Seismic Bands

Thursday, 20th June - 16:30: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 1285

Ms. Lakshmi L (IIT Kanpur), Prof. Suparno Mukhopadhyay (IIT Kanpur), Dr. Prishati Raychowdhury (Indian in), Prof. Samit Ray Chaudhuri (indi)

Unreinforced masonry walls are widely used for construction of buildings in many counties such as India. Since, masonry is brittle and highly nonlinear material with good compressive but poor tensile strength, performance of masonry buildings under past severe earthquakes has been found to be inadequate. For performance enhancement of existing masonry structure, various retrofitting strategies have been proposed in the past. This study focuses on one such approach wherein reinforced concrete seismic bands have been considered on masonry walls to enhance its strength as well ductile performance with a minimally intrusive, economical and aesthetically elegant construction approach. Micro modeling technique with separate damage models for masonry and masonry-concrete interface is used to model the retrofitted wall. A widely used finite element software is used for the numerical modeling. Effect of aspect ratio of wall and wall pre-compression is studied in terms of change in response of un-reinforced wall due to the change in these parameters. Vulnerability assessment of un-reinforced and retrofitted walls is carried out using fragility curves while considering ground motions of different hazard levels. A simplified equivalent SDOF system model of un-reinforced or retrofitted wall is considered for fragility analysis separately. Results of the study show that the seismic bands significantly improve the ductility and overall performance of the masonry wall. The level of such performance enhancement however depends on the seismic band configuration adopted.

A Decision Analytical Framework for Systems Modeling

Thursday, 20th June - 16:45: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 469

Mr. Sebastian Glavind (Aalborg University / The Danish Hydrocarbon Research and Technology Centre), Prof. Michael Faber (Aalborg University / The Danish Hydrocarbon Research and Technology Centre)

In the present paper, we propose a novel decision analytical framework for systems modeling in the context of risk informed integrity management of engineered facilities. Appreciating that system models in general serve to facilitate the optimal ranking of decision alternatives, we formulate the problem of systems modeling as an optimization problem to be solved jointly with the ranking of decision alternatives. Taking offset in recent developments in structure learning and Bayesian regression techniques, a generic approach for the modeling of environmental loads is established which accommodates for a joint utilization of phenomenological understanding and knowledge contained in databases of observations or collected real-time. In this manner, we provide a framework and corresponding techniques supporting the combination of bottom-up and top-down modeling. Moreover, since phenomenological understanding as well as analysis of databases may lead to the identification of several competing system models, we include these in the formulation of the optimization problem. The proposed framework and utilized techniques are illustrated on a principal example addressing systems modeling and decision optimization in the context of possible evacuation of an offshore facility in the face of an emerging storm event

A computationally efficient unscented Kalman filter variant for nonlinear system identification

Thursday, 20th June - 17:00: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 877

Ms. Mariyam Amir (Pennsylvania State University), Dr. Kostas G. Papakonstantinou (Pennsylvania State University), Dr. Gordon P. Warn (Pennsylvania State University)

In this work, an efficient nonlinear system identification approach based on a Unscented Kalman Filter (UKF) variant is presented. The computational demand of the filtering process is contingent on the number of model calls required at each time step for the unscented transformations, which is determined by the number of selected sample/sigma points. A reduced number of sigma points is therefore desirable for an efficient filtering performance, without compromising, however, the accuracy of the output estimates. To that end, in this work a UKF variant is suggested that requires almost half sigma points compared to the state-of-art UKF, while nearly achieving the exact same accuracy in all cases. The filtering performance is further enhanced by complementing it with our developed fully parametrized damage consistent hysteretic modeling framework, where the tangent stiffness matrix is not required to be updated at each time step but is instead replaced by constant stiffness and hysteretic matrices, evaluated only once at the beginning of the analysis. Nonlinearities and complex damage phenomena can be then effectively captured in the suggested model through first order ordinary differential equations, enabling ideal compatibility with the filtering process in terms of computational implementation and performance. Theoretical proofs and verifications are presented as well, together with several numerical examples and comparisons that showcase the capabilities and advantages of the suggested approach.

Multi-sensor data fusion for structural health management of New Jubilee Railway Bridge

Thursday, 20th June - 17:15: MS91 - Safety Assessment of Aging Infrastructure: From Data to Decision; Part 2 (Steele 102 (130)) - Oral - Abstract ID: 1036

Mr. Adarsh S (Indian Institute of Technology Kanpur), Prof. Samit Ray Chaudhuri (Indian Institute of Technology Kanpur)

Long span bridges have the tendency to vibrate under different dynamic loads such as wind, earthquake, and traffic loads. Dynamic loading of the long span bridges has been a matter of concern historically. The loss of strength/stiffness, whether gradual or sudden, can deteriorate the conditions of the bridge structures, which generally may remain unnoticed until the conditions become extreme or result in a catastrophic failure. Hence, it has become necessary to continuously monitor the condition of bridges in order to prevent any undesirable damaging events. This work focuses on structural health management of a recently constructed Railway Bridge over river Hoogly in India, named New Jubilee Bridge. The superstructure of the bridge is a 3-span continuous steel truss having total span of 415m. The central span is a steel arch supporting the deck system through hangers with the maximum height of hangers of 28m. The structural health monitoring of such a bridge become more robust and accurate, if data of physical quantities from a large number of structural nodes, members, bearings, etc. are available. However, considering the practical issues and the large economic investments involved, in this work, only a few but different types of sensors such as accelerometers, GPS, strain gauges, anemometers and LVDT are considered in the framework of multi-sensor data fusion in conjunction with model updating to better predict the present state of the structure. It is envisioned that the proposed approach will be highly efficient to identify various physical parameters of the bridge.

Experimental verification of servo-hydraulic actuator modeling for RTHS of a multi-degree-of-freedom system

Thursday, 20th June - 16:00: MS94 - Integration of Physics-Based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 437

Ms. Herta Montoya (Purdue University), Dr. Amin Maghareh (Purdue University), Mr. Johnny Condori (Purdue University), Prof. Shirley Dyke (Purdue University)

Real-time hybrid simulation (RTHS) is a versatile testing technique that allows simultaneous computational and experimental modeling to further examine structural behavior and validating performance. Hydraulic actuators have been extensively used in RTHS as the transfer system enforcing boundary conditions between computational and experimental substructures. The use of hydraulic actuators attached to the experimental substructure results in a dynamic coupling between the actuator and the substructure (a.k.a. control-structure interaction). Thus, neglecting the dynamics of the hydraulic actuators may affect the stability and performance of RTHS. In a previous study, a servo-hydraulic actuator coupled with a single degree-of-freedom nonlinear physical system was developed and experimentally validated. Herein, the dynamic nonlinear system is extended to a multiple degree-of-freedom physical specimen coupled with servo-hydraulic actuators.

Physics-Based Flood Risk Modeling to Quantify the Effect of Policy Change on Losses at the Community Level

Thursday, 20th June - 16:15: MS94 - Integration of Physics-Based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 543

Mr. Omar Nofal (Colorado State University), Prof. John Van De Lindt (Colorado State University)

Flooding is a devastating natural hazard whose consequences include loss of life, damage to community infrastructure, and cascading socio-economic impacts in and around the flooded community, with even further impacts resulting from interdependencies of physical and non-physical systems. Flood risk prediction is a critical component of a comprehensive risk-informed decision framework and is used in combination with information on community resilience planning strategies, flood impacts, and recovery. In this research, a physics-based flood risk model was developed to determine flood hazard characteristics and their corresponding level of damage at the community level. The modeling methodology includes hydrologic analysis to capture flood discharges in the main streams that deliver water to the community of interest. Then, a hydrodynamic analysis was conducted to capture the spatial distribution of the flood hazard characteristics within the community. The flood hazard information was then combined with the exposure information of the community (e.g. building location, archetype, occupancy, first-floor elevation, number of stories, value, etc.). Fragility functions for flood damage from an extensive past field study were used to predict damage probability to the building stock in the illustrative example community. Finally, an example of the effect of a policy change on losses to the example community is presented. This framework can provide policymakers the ability to explore the financial affect of policy changes and allow them to better mitigate flood risk and increase the community resiliency.

Prediction of storm surge evolution with time-dependent feedback

Thursday, 20th June - 16:30: MS94 - Integration of Physics-Based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 552

Dr. Alessandro Contento (University of Illinois at Urbana-Champaign), Prof. Paolo Gardoni (University of Illinois at Urbana-Champaign)

or many hurricanes, storm surge causes a significant damage. Aside from the well-known case of Hurricane Katrina, recent examples are Hurricanes Florence and Michael. Accurate and timely predictions of storm surge can improve the emergency preparedness and the development of intervention actions aimed to increase the safety of people and property. Critical emergency management decisions that are usually made few hours before the landfall, such as evacuations, closures of critical structures and infrastructure, and deployment of emergency personnel, require accurate estimates of the inundation. However, storm surge predictions are usually done a priori (i.e., before the occurrence of an actual hurricane). Consequently, there is the need to predict storm surge with models that follow the actual time evolution of the hurricane and can be updated to take advantage of the latest forecasts. Hi-fidelity models are computationally expensive, and consequently not suitable for timely predictions as an actual hurricane forms. Probabilistic models can overcome these limitation, still providing good accuracy in the results. The proposed probabilistic model provides the time evolution of a storm surge. As a hurricane approaches landfall, the model takes advantage of the increased amount and accuracy of the information that is available continuously updating the prediction with real-time feedbacks. The latest forecasts of the hurricane track and intensity, and early records of storm surge are used to update the model and improve the accuracy of the prediction. The proposed formulation can help emergency management decisions by providing the latest and most informed predictions of the storm surge.

Integrating physics-based and probabilistic models for forecasting induced seismicity

Thursday, 20th June - 16:45: MS94 - Integration of Physics-Based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1109

Ms. Mina Karimi (Carnegie Mellon University), Prof. Kaushik Dayal (Carnegie Mellon Univ), Prof. Matteo Pozzi (Carnegie Mellon University)

Fluid injection related to shale gas extraction in deep underground formations has increased the potential of induced seismicity in these areas. Understanding this mechanism and identify the stress field are crucial steps for better assessing the seismic hazard and for developing appropriate regulations for the energy industry. Injected fluid in porous deformable elastic media increases the pore pressure at critical locations in pre-existing cracks, consequently reducing the effective normal stress across the crack. Reducing normal stress can lower the frictional force so that slip can occur, triggering seismic events. In this paper we investigate the relation between the magnitude and frequency of earthquakes and the fluid injection rate, via the seismogenic. We consider several possible framework to model this relation. This seismic induction is simulated using nonlinear pressure diffusion equation, to characterize the stress and strain pattern after the start of the injection process, and results are verified via analytical solutions for testbeds of isotropic materials. A probabilistic model is developed to identify the critical points for crack initiation and estimate the earthquake magnitude.

Key words: induced seismicity, fluid injection, probabilistic model.

Integration of Physics-based Models with Data, An Overview for Civil Structure applications

Thursday, 20th June - 17:00: MS94 - Integration of Physics-Based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1332

Dr. Babak Moaveni (Tufts University), Mr. Mingming Song (Tufts University)

Structural identification methods using sensor data have received increased attention in the civil engineering research community with the objective of identifying structural performance, and evaluating the remaining useful life of structures. While many researchers have successfully applied various approaches to numerical and/or small-scale laboratory models of structures, the literature lacks many successful applications to large‐scale civil structures under real loading environment. This presentation highlights some of the challenges of model updating methods for applications to large‐scale civil structures, especially when dealing with changing ambient and environmental conditions. A hierarchical Bayesian framework is presented for probabilistic model updating and damage identification to account for inherent as well as parameter estimation and measurement uncertainties. It is shown that the proposed hierarchical framework allows to explicitly account for pertinent sources of variability such as ambient temperature and/or excitation amplitude and therefore yields more accurate predictions. The study also highlights the value of using point cloud data in addition to vibration measurements for structural performance assessment. The point clouds are informative about identification of cracks at their early stages while the vibration data provide measure of stiffness at later stages of damage. Performance of the proposed approach is demonstrated through application to three large-scale building structures.

Time-Dependent Deflection Monitoring of the I-35W St. Anthony Falls Bridge

Thursday, 20th June - 17:15: MS94 - Integration of Physics-Based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 1 (Kerckhoff 119 (174)) - Oral - Abstract ID: 964

Mr. Riley Brown (Unversity of Minnesota), Prof. Brock Hedegaard (University of Minnesota Duluth), Prof. Carol Shield (University of Minnesota), Dr. Lauren Linderman (University of Minnesota)

The monitoring system of the I-35W St. Anthony Falls Bridge offers a unique opportunity to evaluate a structure from 'birth'. While concrete is known to creep over time under sustained load, an understanding of the phenomenon at scale over a long period of time has been lacking. As a result, there is a number of conflicting time-dependent displacement models that form the basis for design codes. The long-term time-dependent displacement of the bridge will be determined using a combination of multiple sensor types deployed on the structure: linear potentiometers at the bearings and thermistors distributed throughout the structure. For a structure that sees significant temperature loading and gradients, the temperature captured by the thermistors is essential to capture the temperature-dependent behavior used in evaluating time-dependent deflections and can account for significant strains. The as-built time-dependent response will be compared to the predicted behavior of existing creep models applied to the I-35W Bridge. This analysis will leverage an updated finite element model that captures the construction sequence of the structure. Previous assessment of the data through the first three years of the deployment showed that 1990 CEB/FIP Model Code and ACI-209 models best predicted the in situ creep behavior. As the structure and monitoring system approach 10 years, the as-built response indicates that the structure continues to creep. Therefore, models that asymptotically approach moderate ultimate deflection values over a longer duration are more appropriate.

The impacts analysis of plant spatial distribution on the turbulent flow

Thursday, 20th June - 16:00: MS64 - Fluid Dynamics of Natural Hazards (Firestone 384 (76)) - Oral - Abstract ID: 331

Dr. Guojian He (Tsinghua University), Prof. Hongwei Fang (Tsinghua University), Dr. Lei Huang (Tsinghua University)

Vegetation in shallow water systems plays an important role in altering flow resistance and turbulence. Submerged or emergent vegetation reacts to the drag of water by either remaining erect, oscillation in response to turbulent fluctuations, or bending. Direct Numerical Simulation (DNS) is performed for an open channel flow through idealized submerged vegetation with a water depth (h) to plant height (hp) ratio of h/hp = 1.5 according to the experimental configuration of Liu et al. (J Geophys Res Earth Sci, 2008) and Stoesser et al. (Transp Porous Med, 2009). In order to represent solid objects in the flow, the immersed boundary method is employed. The computational domain is idealized with a box containing submerged circular cylinders and periodic boundary conditions are applied in both longitudinal and transverse directions. The flow properties based on different spatial distribution and density will be analyzed. These results can be used for the engineering design and the evaluation of the flood risk and the sediment transport.

Molecular dynamics simulations of water molecules clustering

Thursday, 20th June - 16:15: MS64 - Fluid Dynamics of Natural Hazards (Firestone 384 (76)) - Oral - Abstract ID: 332

Prof. Hongwei Fang (Tsinghua University), Dr. Ke Ni (Tsinghua University)

The energy in turbulence is dissipated by cascade structures, with the smallest size of several microns. The interaction between structures smaller than the micron scale is often relied on empirical assumptions, thus resulting in some deviations between the simulation results and the experiments. In this work, we take into account the effects of temperature and velocity, and calculate the minimum energy configurations of water clusters of different size using molecular dynamics simulation. The clustering performance of molecules is summarized and the relationship between different cluster sizes is established. The results agree well with experiments and we reveal the mechanism of dissipations from large eddies to molecules in turbulence.

Boulder Transport by Tsunami

Thursday, 20th June - 16:30: MS64 - Fluid Dynamics of Natural Hazards (Firestone 384 (76)) - Oral - Abstract ID: 442

Mr. Samuel Harry (Oregon State University), Ms. Margaret Exton (Oregon State University), Prof. Bruce Kutter (University of California, Davis), Prof. H. Benjamin Mason (Oregon State University), Prof. Harry Yeh (Oregon State University)

Boulder transport models have been used to form an incomplete historical or pre-historical record of tsunami events. The study of boulder transport is challenging because of the variation in boulder size, shape, and composition in addition to complex flow conditions and topography. To investigate the mechanisms of boulder pick up, laboratory experiments of tsunami-like flow over spherical shaped boulders that are partially buried in a sediment bed are performed. The experiments are conducted in a large centrifuge apparatus to reduce scale effects; the corresponding dynamic similitudes are discussed. Proximity sensors are developed to detect precise timing of boulder movement. The existing approach to determine boulder pickup, i.e. estimating the drag, lift, and inertial forces to determine instability of a boulder, is adapted for the present case of a half-buried spherical boulder. The model predicts boulder pickup will occur before any measured movement. Inertial forces are found to play no role in initiating pick up of the half buried spherical boulder. To investigate the difference between predicted and measured pick up timing, two physical phenomena are discussed: pore pressure diffusion in the soil, and the impact of transient free surface flow on hydrodynamic forces. Furthermore, because of the boulder's spherical shape, the net upward force is essential to initiate pickup when the boulder is buried half way or more. It is also found that spherical boulders that are three-quarter buried in the sediment bed are not transported when exposed to flow conditions that initiate transport at lesser burial depths.

Momentum Balance in Waves and Surge over Vegetated Wetlands during Extreme Events

Thursday, 20th June - 16:45: MS64 - Fluid Dynamics of Natural Hazards (Firestone 384 (76)) - Oral - Abstract ID: 660

Dr. Ling Zhu (Northeastern University), Prof. Qin Chen (Northeastern University)

Coastal wetlands protect the shoreline by attenuating waves and reducing storm surge. The mean water level (MWL) is governed by the cross-shore momentum balance equation. To model MWL over vegetated wetlands during extreme events, e.g. tropical cyclones, an accurate estimation of the vegetal stress induced by waves and surge current is essential. Vegetal stress induced by waves can be parameterized with wave characteristics (i.e. wave height, wave period, water depth) and vegetation properties. The surge current is correlated with the shallow-water phase speed or the surge profile. With the help of storm surge models, an empirical expression of the surge current can be obtained, and thus, the vegetal stress induced by surge current can be approximated using a quadratic drag law.
Numerical simulations are designed and conducted using an extended version of FUNWAVE-TVD, a fully nonlinear Boussinesq wave model. The model incorporates phase-resolving wind stresses, which provides momentum input from the wind to individual waves, as well as the vegetal drag on waves over vegetated wetlands. A phase-average of the model output gives not only the wave integral properties but also MWL changes, including wind setup and wave setup. The vegetation effects on the total water level reduction are evaluated. The computed vegetal stress term is compared against the parametric model results. Moreover, the radiation stress, wind stress, vegetal stress and bottom stress terms in the momentum balance equation are examined to elucidate the interactions among wind, wave, surge and vegetation. Funding has been provided by the National Science Foundation.

Interaction of Residual and Momentary Liquefaction During Earthquake-Tsunami Multi-Hazards

Thursday, 20th June - 17:00: MS64 - Fluid Dynamics of Natural Hazards (Firestone 384 (76)) - Oral - Abstract ID: 742

Ms. Yingqing Qiu (Oregon State University), Prof. H. Benjamin Mason (Oregon State University)

Coarse-grained soils are prone to liquefaction and sediment instability during earthquake-tsunami multi-hazards. Earthquake shaking induces residual liquefaction, then the soil re-consolidates during the quiescent stage, and finally, momentary liquefaction is possible during tsunami wave loading stage. We use the OpenSEES finite element framework to simulate a one-dimensional, fully saturated soil column at the shoreline subjected to multi-hazard loading process. Notably, as a modeling simplification, we measure the one-dimensional pore water pressure response during the multi-hazard loading, and not the bed shear stresses caused by the tsunami loading. We are focused on Pacific Northwest events; therefore, to demonstrate our numerical model, we use an earthquake motion recorded during the 2011 Great East Japan Earthquake and a tsunami time series developed for the Oregon coast using SCHISM for our numerical experiments. The numerical experiment results show increasing positive pore pressure gradient during earthquake shaking induces residual liquefaction in parts of the soil column. Excess pore pressure dissipates but remain high in some parts of the soil column during the quiescent period. The subsequent tsunami run-up stage generates downward flow, which acts to stabilize the liquefied soil. However, the rapid tsunami draw-down stage generates upward flow again, and when the flow velocity is large enough, momentary liquefaction results. Soil movement potential during tsunami loading stage increases depending on the thickness of the mobile liquefied layer. A parametric study shows that the predicted mobile layer depth during tsunami wave loading is strongly impacted by quiescent stage length, seabed thickness, and the soil's hydraulic conductivity.

Evolution of Wind and Wave Driven Currents During Hurricane Joaquin

Thursday, 20th June - 17:15: MS64 - Fluid Dynamics of Natural Hazards (Firestone 384 (76)) - Oral - Abstract ID: 1353

Dr. Jay Veeramony (Naval Research Laboratory), Dr. Allison Penko (Naval Research Laboratory), Ms. Kacey Edwards (Naval Research Laboratory), Dr. Meg Palmsten (Naval Research Laboratory)

Hurricane Joaquin was a powerful tropical cyclone that caused severe damage in the Bahamas, parts of the Greater Antilles, and Bermuda. Although the storm never directly affected the United States, signatures of the storm were evident at multiple locations along the east coast of the United States. Joaquin evolved from a non-tropical low to become a tropical depression on September 28, 2015, and underwent rapid intensification reaching hurricane status on September 30 and Category 4 major hurricane strength on October 1.

The Coastal Model Test Bed (CMTB) at the U.S. Army Corps of Engineers Field Research Facility (USACE FRF) allows for the unique integration of operational coastal wave, circulation, and morphology coastal models with real-time observations. A nested Delft3D simulation was set up to model the waves and currents at the USACE FRF. A high-resolution nest was set up to drive the circulation using the measured wave data at the boundary prescribed at the 26m bathymetry contour. Tides from the TPXO 7.2 model and winds from the operational forecast model COAMPS was used to drive the circulation of a large scale domain spanning the Chesapeake Bay to the South Carolina border which provides the flow boundary conditions to the high resolution nest as well. The model results are used to analyze the wind and wave driven circulation at the USACE FRF and to study the circulation in the periods before and during the passage of the storm and are compared to the wave and current data collected in the region.

Wind Induced Effects on Roof-to-Wall Connections of Residential Buildings

Thursday, 20th June - 16:00: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 1 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 245

Prof. Amal Elawady (Florida International University), Prof. Arindam Chowdhury (Florida International University), Dr. Ehssan Amir Sayyafi (Florida International University), Prof. Peter Irwin (Florida International University)

Wind hazards are of the most hazardous events that frequently occur in the United States. Hurricane Irma, which hit the southeast coast in 2017, left majority of damage concentrated on low-rise buildings and wooden construction. Roof-to-wall connections play an important role in the behavior of wood-frame buildings when exposed to wind induced loading. These connections help in resisting wind induced uplift pressures experienced by roofs. However, wind actions on roof-to-wall connections have not been adequately estimated yet. An extensive large-scale aerodynamic testing study is conducted at the NSF-Natural Hazard Engineering Research Infrastructure (NHERI) Wall of Wind (WOW) Experimental Facility to investigate wind actions resulting from simulated hurricane winds on a gable wood frame building model, with roof-to-wall connections. The study adopted a length scale of 1:4 and a velocity scale of 1:2. Seven trusses were used to construct the roof and were connected to the wall top plate. Load cells were mounted at the roof-to-wall connection level to measure the effective net wind forces. Also, internal pressures were measured using pressure taps. The model was installed on the WOW 16-ft diameter turntable and tested under different wind directions varying from 0° to 315° with an increment of 5° under varying wind speeds. In addition, two different enclosure configurations (enclosed and partially enclosed) were considered to assess different internal pressure scenarios that affect the net loading on the roof-to-wall connections. The results were compared to pressure coefficients recommended by ASCE-7 10 and 16 versions for the cases of Component and Cladding.

An environment-dependent probabilistic tropical cyclone model

Thursday, 20th June - 16:15: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 1 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 387

Ms. Renzhi Jing (Princeton University), Prof. Ning Lin (Princeton University)

A new probabilistic tropical cyclone (TC) model is developed to simulate tropical cyclone climatology and assess TC risk for the North Atlantic Basin. The model consists of three components—a hierarchical genesis model, a data-driven track model, and a Markov intensity model—and describes storm activity under a given climate environment. The hierarchical genesis model is built by clustering similar local environmental conditions, and the track model determines storm's movement by both properties of selected historical similar tracks (determining the main movement direction) and the background wind (added as a random correction to the main direction). For the intensity along the track, we adopt a newly developed Markov environment-dependent hurricane intensity model (MeHiM) and add to it a model for simulating the initial condition. All three model components are dependent on environmental variables including the potential intensity, environmental wind, mid-level relative humidity, and ocean mixing characteristics.

The three components are firstly evaluated individually based on observed TC activities. Then, we integrate all three parts as a whole risk model and simulate 1979-2014 TC climatology. Various aspects of TC statistics are used to evaluate the risk model, such as the annual genesis rate, spatial genesis distribution, and their interannual variability; TC track density; TC intensity density; and the distribution of landfall location and landfall intensity. This TC risk model will be further coupled with TC hazard models to quantify wind, surge, and rainfall hazards and probabilities under various climate conditions.

Risk Assessment of Tropical Cyclones under Changing Climate: Wind and Rain Hazards

Thursday, 20th June - 16:30: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 1 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 491

Mr. Reda Snaiki (University at Buffalo), Dr. Teng Wu (University at Buffalo)

Mitigation of losses due to tropical cyclones under a changing climate has become an increasingly urgent and challenging issue in light of continued escalation of coastal population density, which highlights the need for more advanced methodologies to better quantify the global warming effects. This study proposed an improved methodology to effectively assess the climate change impacts on hurricane boundary-layer wind and rain fields. First, a new physically-based intensity model was developed to consider the contribution of several important environmental factors such as the sea surface temperature and environmental wind shear and was integrated in the risk analysis framework. Then, the gradient wind model was revisited to be used in conjunction with a recently developed height-resolving wind and rain models for rapid generation of the boundary-layer wind and rain fields. The RCP 8.5 climate scenario was used for the risk assessment simulation, where a total of 10,000 years of hurricane events have been generated for both observed and projected climate scenarios. The comparison of the two scenarios was conducted indicating a significant change of hurricane wind and rain under changing climate and suggesting a possible modification of the design codes and standards for buildings and infrastructure systems.

A Knowledge-Enhanced Deep Learning for Simulation of Idealized Storm Surge

Thursday, 20th June - 16:45: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 1 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 492

Mr. Reda Snaiki (University at Buffalo), Dr. Teng Wu (University at Buffalo)

Hurricanes are well known to be responsible for a substantial part of natural hazard-induced economic and life losses through high winds, torrential rain and storm surge, where the most significant portion of hurricane-related damages results from the coastal surge flooding. In this study, a data-efficient, physics-informed deep learning algorithm was developed to simulate the time history of the water elevation that can be utilized as an effective tool for storm surge flooding prediction in the early warning system. The underlying mechanisms of the storm surge based on the hydrodynamic equations are utilized to offer an essential information that helps in the effective regularization of the neural network with a small number of training datasets. More specifically, the governing equations as well as the boundary conditions are employed as part of the loss function in the deep learning algorithm. To differentiate the neural network with respect to the model parameters and assess the derivatives of the governing equations, the automatic differentiation technique, known to be more accurate and efficient compared to the standard numerical differentiation, is utilized. The input data of the developed physics informed deep learning consists of the hurricane parameters (e.g., storm size and intensity) and ocean bathymetry, and the output is the time history of the water elevation at selected locations. A case study of the hurricane-induced surge along the New York coastline was presented here, and good agreement between the simulated and measured data was highlighted.

The co-evolution of natural-engineered coastal systems under the threat of long-term climatic changes and short-term extremes events

Thursday, 20th June - 17:00: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 1 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 573

Dr. Donatella Pasqualini (Los Alamos National Laboratory)

Hurricanes are threatening our coastlines causing hundreds of billions of dollars in damages to coastal population centers and coastal military bases. The majority of historical economic damages are due to loss of electrical power and potable water servicesdue to strong wind and flooding of these critical infrastructure facilities. Sea level rise will worsen flood damage and contaminate water supplies with salt water.

Accurate assessment of the consequences of hurricanes on critical infrastructures, such as electrical power and potable water systems, is key tomitigate and adapt to these natural extremes, but is also a challenge. The coastline is a complex dynamical system, where the timing, extent, and distribution of flooding and salt intrusion changes over time due to crucial land-water-vegetation feedbacks. An assessment that doesn't include this complexity cannot properly predict the impacts on our infrastructures and support the search of an optimal adaptation strategy.

I will present a new approach to develop a risk impact assessment and adaptation model for complex natural-human-engineered systems. This approach integrates the needed natural coastal dynamics with highly detailed network models of electrical power and water systems to quantify the economic consequences of long term sea level rise and hurricanes.

Prioritizing Mitigation and Repair Resources to Enhance Resilience of Interdependent Traffic-Electric Power System

Thursday, 20th June - 17:15: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 1 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 632

Mr. Qiling Zou (Colorado State University), Prof. Suren Chen (Colorado State University)

It is important to consider the interdependencies among highly interconnected critical infrastructure systems with adequate details in assessing the community resilience and devising cost-effective resilience improvement strategies. This study presents a decision-making framework for prioritization of mitigation and repair resources to enhance the resilience of an interdependent traffic-electric power system under budgetary constraints. A bi-level, stochastic, simulation-based optimization problem is established with the objective of maximizing the expected resilience improvement of this interdependent system. The upper level seeks to find the optimal resource allocation plan to maximize the expected attainable functionality gain. And the lower level characterizes the functionalities of the traffic and electric power systems with their three types of interdependency using network analysis methods. The dynamic traffic assignment algorithm is used to capture more realistic traffic dynamics in the congested urban roadway networks. Uncertainties in disruptions, traffic demands, and costs of mitigation and repair actions are also considered. The problem is solved by a meta-heuristic optimization algorithm and the priority indices of disrupted components for mitigation and repair are then established based on the solutions. This decision model is demonstrated using a portion of the traffic-electric power system in Galveston. Results show that: (1) different mitigation and repair resource allocation plan can be obtained by setting corresponding weight coefficients in the objective function according to the decision maker's judgment; (2) the priority indices can reflect the importance and contribution of components in mitigation and repair actions to the resilience improvement of the whole coupled system.

Finite Element Analysis of the Seismic Response of RC Columns with Conventional and Modified Bond Properties

Thursday, 20th June - 16:00: MS14 - Advanced Analysis for Earthquake Engineering (107 Downs (71)) - Oral - Abstract ID: 321

Mr. Ghassan Fawaz (University of Texas at Austin), Dr. Juan Murcia-Delso (University of Texas at Austin)

Current seismic design procedures for RC bridges and buildings rely on the formation of plastic hinges in selected members, such as columns, to ensure a ductile response and avoid collapse during a severe earthquake. With the shift towards performance-based engineering, accurate computational tools are needed to simulate the damage and failure mechanisms of hinging members, and to study possible strategies to enhance their response.

This presentation will introduce and discuss three-dimensional finite element (FE) models to predict the seismic response of RC columns with conventional and modified bond properties. The FE models integrate advanced constitutive models for concrete, steel reinforcement, and bond-slip behavior of bars. Concrete is modeled with a triaxial constitutive capable of simulating material degradation due to cracking and crushing, crack opening and closing behavior, and the increase of strength and ductility under multiaxial compression conditions. The cyclic response of steel reinforcement is modeled with a Menegotto-Pinto law modified to account for the low-cycle fatigue of bars. The bond-slip behavior of longitudinal bars is modeled using a dedicated concrete-steel interface element capable of predicting bond deterioration caused by bar slip, cyclic loading and tensile yielding of steel. The FE models predict well the damage mechanisms and force-displacement responses of cantilever columns tested under fully-reversed lateral cyclic loading. Finally, the FE models have been employed to analytically investigate bond modification strategies to alleviate strain concentrations and delay fracture of longitudinal bars.

Reduced order modeling of hysteretic structural response for computationally efficient seismic loss assessment

Thursday, 20th June - 16:15: MS14 - Advanced Analysis for Earthquake Engineering (107 Downs (71)) - Oral - Abstract ID: 775

Mr. Dimitrios Patsialis (University of Notre Dame), Dr. Alexandros Taflanidis (University of Notre Dame)

Modern seismic loss estimation practices require simulation of structural behavior for different levels of earthquake shaking through time-history analysis. This behavior can be strongly inelastic/hysteretic and evaluating it through high-fidelity finite element models (FEMs) introduces a significant computational burden. A reduced order modeling approach is discussed in this study to alleviate this burden. The reduced order model is developed using data from the original high-fidelity FEM. Static condensation is first used to obtain the stiffness matrix and linear equations of motion for the dynamic degrees of freedom (Dof). The restoring forces prescribed by the linear stiffness matrix are then substituted with hysteretic ones by replacing the linear springs connecting each of the DoFs with hysteretic springs. Different models are examined for the latter, ranging from peak-oriented to Masing to Bouc-Wen type of hysteresis. Springs connecting all DoF combinations are examined and their parameters are calibrated by comparing the reduced order model time-history to the time-history of the initial FEM for a range of different excitations. This is posed as a least squares optimization problem and its efficient solution is facilitated through a sequential approach. The accuracy and the computational savings of the reduced order model are then examined for seismic loss estimation by comparing to the FEM predictions. A stochastic ground motion model is used to describe the seismic hazard in this setting and the accuracy for different levels of intensity is separately examined. Comparison extends to different structures with high-fidelity FEMs developed in OpenSees.

Advancing the Seismic Collapse Assessment of Reinforced Concrete Structures Using Nonlocal Frame Models

Thursday, 20th June - 16:30: MS14 - Advanced Analysis for Earthquake Engineering (107 Downs (71)) - Oral - Abstract ID: 822

Dr. Maha Kenawy (University of Nevada, Reno), Prof. Sashi Kunnath (University of California, Davis), Prof. Amit Kanvinde (University of California, Davis)

Evaluating the risks to civil structures subjected to earthquakes necessitates rigorous prediction of performance limit states up to structural collapse. In modern reinforced concrete (RC) building structures, global collapse is often triggered by localized damage in the structural components, leading to component strength and stiffness degradation under intense seismic shaking. Due to the limitations of commonly used analytical structural models, numerical simulation of damage localization phenomena has received much research attention in recent years. This study presents the development and application of an enriched computational framework for predicting localized damage in collapse simulations of RC structures. The framework consists of a frame finite element formulation and concrete constitutive models, which were developed using the nonlocal continuum theory to overcome the numerical issues associated with the presence of constitutive softening behavior. The performance of the framework was assessed using multiple structural applications including nonlinear quasi-static and dynamic analyses of RC components. The results of this study demonstrate the superior performance and predictive capability of the nonlocal framework, as compared to conventional modeling approaches and benchmark experimental data. The implications of the results are discussed in the context of a seismic collapse assessment study, with regard to the predicted structural collapse capacity and its associated uncertainty. The study highlights the potential impact of the proposed framework on advancing the evaluation of seismic risks to civil infrastructure.

ROBUST-TO-ERROR DYNAMIC RESPONSE OF PRIMARY-SECONDARY OSCILLATORS

Thursday, 20th June - 16:45: MS14 - Advanced Analysis for Earthquake Engineering (107 Downs (71)) - Poster - Abstract ID: 295

Dr. Arzhang Alimoradi (TranTech)

The upper limits of forcing frequency in response of primary-secondary oscillatory systems are established. Such systems are commonly encountered in industrial, pharmaceutical, and research facilities where a secondary oscillator (of usually uncertain properties during design) is supported by a primary structural system. Under stringent operational requirements for vibration mitigation of high-precision tools and processes (secondary systems), design of primary systems becomes too expensive or implausible. Moreover, as size of physically observable response quantities decrease noise and signal become indistinguishable further complicating the problem. We use the discrete frequency response of primary-secondary oscillators in a linear-algebraic formulation of maximum error-bound to arrive at the optimal system properties (mass and stiffness) that make the system robust under high-frequency excitation. Robustness in system is defined as a set of system parameters that produces minimum sensitivity in the dynamic response, in a normative sense, under perturbations in impedance and applied forces. The necessary optimality condition gives a 3rd-order characteristic equation of forcing frequency that can be solved for a set of mass and stiffness ratios of the primary and secondary systems expressed in the form of parallel lines in the design space. It is shown that as the forcing frequency increases the set of viable mass ratios for a robust system shrinks to a singleton of 1.0. The sufficient condition is presented next along with illustrative examples of optimal systems subjected to varying forcing frequencies.

Challenges and opportunities in interfacing earthquake science, engineering, and technology

Thursday, 20th June - 17:00: MS14 - Advanced Analysis for Earthquake Engineering (107 Downs (71)) - Oral - Abstract ID: 1391

Prof. Ting Lin (Texas Tech University)

Earthquakes are representative of extreme events that have an adverse impact on civil infrastructure. Earthquake science provides insights on ground motion prediction, whereas earthquake engineering examines structural performance critical for resilience. While rupture-to-rafters simulation, which connects geophysics and structural engineering, has the potential to address the question "What causes failure?", it does not answer the question "How likely is it?" due to its deterministic nature. On the other hand, traditional probabilistic seismic risk analysis (PSRA), which typically relies on probabilistic seismic hazard analysis (PSHA), answers the question "What is the probability of failure?", but is often limited to ground motion inputs selected from recordings and scaled to match a specific target intensity measure (IM) computed using ground-motion prediction equations (GMPEs). As earthquake rupture forecast and ground motion models advance, earthquake engineering analysis and design need to sync with state-of-the-art earthquake science to incorporate relevant causal earthquakes and prediction models. Inspired by the 2013 Caltech challenge that stimulates years of heated debate and the SCEC CyberShake project that offers an elegant physics-based probabilistic seismic hazard model, this research aims to integrate earthquake science and engineering to offer a probabilistic physics-based seismic risk analysis**(P^2SRA)** framework in the context of infrastructure resilience. P^2SRA answers the questions "What causes failure?" and "How likely is it?", therefore seamlessly combines the benefits of rupture-to-rafters simulation and traditional PSRA. This framework is further powered by advanced technologies including high-performance computing **(HPC)** and artificial intelligence **(AI)**, whose interplay contributes to vision for the future in structural engineering.

Resilience and Response of the Dual System Braced Frame with Frictional Damper

Thursday, 20th June - 17:15: MS14 - Advanced Analysis for Earthquake Engineering (107 Downs (71)) - Oral - Abstract ID: 944

Mr. Logan Couch (California State University, Fresno), Dr. Fariborz Tehrani (California State University, Fresno)

The paper aims to model and test the response factor and resilience of a dual system braced frame using a frictional damper. The testing of the damper provided empirical results for the target seismic response of a concentric friction damped braced frame. To develop an accurate seismic response factor, an analytical model of a simple 1-story tall was developed. The shake table testing involved testing a dual system of two intermediate moment frames and one friction damped braced frame uniaxially loaded with a dynamic lateral force. The response of the frame was tabulated using ASCE and FEMA design procedures. The outcome of the testing determined the seismic response of the dual moment frame and friction damped frame system.

Application of Wavelet-Enriched Hierarchical Finite Element Formulation in Simulating Crack Propagation in Polycrystalline Microstructure with the Coupled Crystal Plasticity-Phase Field Model

Thursday, 20th June - 16:00: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 163

Ms. Xiaohui Tu (Johns Hopkins University), Dr. Jiahao Cheng (Oak Ridge National Laboratory), Dr. Ahmad Shahba (Technical Data Analysis, Inc), Prof. Somnath Ghosh (Johns Hopkins University)

Polycrystalline alloys, such as Al and Ti alloys, are widely utilized in manufacturing critical components in automotive and aerospace industries. Failure of these components under service loads starts with the formation and propagation of short cracks at the microstructural level. Microstructural features, such as grain topology and crystallographic orientation, and dislocation-driven plasticity are known to affect the formation of microscale cracks. In order to adequately represent the complex crack surface as well as the ductile fracture mechanisms in polycrystalline microstructure, a coupled crystal plasticity-phase field model is implemented in finite element framework. However, the accuracy of the crack phase field solution is compromised when the element size does not match the length scale of a sharp crack. Thus, to avoid the prohibitive computational cost of a uniformly fine mesh simulation, wavelet-enriched hierarchical finite element formulation is incorporated to simulate crack propagation. Hierarchical finite element allows one to increase the resolution on the fly in the critical region, i.e. the crack path. In addition, the proposed adaptive finite element method converts hierarchical finite element basis into wavelet basis and adopts wavelet analysis to obtain the optimum discretization space for solving the phase field problem. It is shown that this method can accurately predict the fracture patterns in polycrystals with nearly 25 times less number of nodes, compared to traditional finite element method.

Hyperbolic phase field modeling of brittle fracture for air-blast-structure interaction

Thursday, 20th June - 16:15: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 289

Dr. Georgios Moutsanidis (Brown University), Dr. David Kamensky (Brown University), Prof. Yuri Bazilevs (Brown University)

We present a novel hyperbolic phase field model for brittle fracture coupled with an immersed formulation for air-blast-structure interaction. A fixed background discretization provides the basis functions to approximate the unknowns of the coupled fluid-structure interaction problem, while foreground particles provide the basis functions to solve the damage field's governing equation. In addition, the particles are used to track the position of the solid, store the history dependent variables, and perform numerical quadrature on the solid terms. Isogeometric functions are used for the background discretization, while reproducing kernel shape functions are assigned to the particles. The presented examples demonstrate the method's ability to handle fracture under blast loading.

Computational modeling of crack propagation in a heterogeneous medium under drying conditions

Thursday, 20th June - 16:30: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 316

Mr. Darith Hun (Université Paris-Est Marne-la-Vallée), Prof. Johann Guilleminot (Duke University), Prof. Julien Yvonnet (Université Paris-Est Marne-la-Vallée), Mr. Abdelali Dadda (Laboratoire Navier - UMR 8205, CNRS, École des Ponts ParisTech, France), Prof. Anh Minh Tang (Laboratoire Navier - UMR 8205, CNRS, École des Ponts ParisTech, France), Prof. Michel Bornert (Laboratoire Navier - UMR 8205, CNRS, École des Ponts ParisTech, France)

Computational modeling of crack propagation in a heterogeneous medium under drying conditions.

Abstract :

In this work, a computational framework to simulate crack propagation in a heterogeneous material under drying conditions is proposed. The numerical approach is based on a finite strain phase field formulation [1, 2], devised to reproduce experimentally determined crack paths and deformation patterns
(under given boundary conditions). The effects of geometry, mechanical parameters and uncertainties are first discussed by using parametric analyses. The modeling effort is next complemented by the development of specific experiments on wet clay samples, filled with solid stiff inclusions. The experimental data thus obtained are finally used to identify model parameters and assess the relevance of the framework.

Keywords :
Crack propagation, phase field approach, drying conditions, experimental-based simulation, randomness and deterministic separation.

References :
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Multiscale Discrete Damage Theory for Fatigue Failure Prediction of Heterogeneous Materials

Thursday, 20th June - 16:45: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 391

Mr. Zimu Su (Vanderbilt University), Prof. Caglar Oskay (Vanderbilt University)

We present a new reduced order multiscale modeling approac for failure response prediction of heterogeneous materials subjected to static and fatigue loading conditions. The proposed approach builds on the ideas of the Eigendeformation-based reduced order homogenization (EHM) method, but alleviates two key challenges before the EHM approach, i.e., the relative sensitivity of the model predictions to the level of discretization employed for the macroscopic structure; and the lack of direct correspondence between the fracture measures that can be experimentally measured (e.g., critical energy release rate).

The proposed approach represents the progressive fracture mechanisms at the scale of the material microstructure using a strong discontinuity approach. In order to achieve model efficiency in the context of spatially multiscale analysis, the failure processes are tracked along a number of “potential failure paths” - discrete interfaces which may form cracks under the applied loading condition. The progressive damage accumulation in each failure path is tracked using cycle-sensitive traction-separation (or cohesive) laws. At the scale of the macrostructure, mesh size sensitivity is alleviated by effectively adjusting the size of the microstructure size through analytically derived size scale formulae. Response predictions under fatigue loading are performed by employing the multiple time-scale homogenization method. The efficiency and accuracy characteristics of the model is verified in the context of three-dimensional laminated fiber-reinforced composite configurations.

Data-driven modeling and sampling of crack paths in random media using a machine learning approach

Thursday, 20th June - 17:00: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 521

Prof. Johann Guilleminot (Duke University), Prof. John Dolbow (Duke University)

We report on the use of a machine learning technique to sample stochastic crack paths in a random heterogeneous microstructure. Training datasets are first obtained for different types of boundary conditions using a phase-field formulation. A manifold learning approach is then deployed to investigate the underlying geometrical structure of the data and obtain additional crack paths consistent with the considered microstructure. A probabilistic dynamics is finally constructed to simulate the time evolution of crack patterns over the loading path.

Graph Theory Analysis of Rich Fiber-Scale Data Yields Very Fast Simulations of Damage Evolution in Composites

Thursday, 20th June - 17:15: MS19 - Multiscale and Computational Methods in Fracture and Damage Mechanics (269 Lauristson (104)) - Oral - Abstract ID: 627

*Dr. Brian Cox (none), Dr. Jerry Quek (ihpc, a*star)*

Mechanistic arguments suggest that the loci of cracks that initiate and propagate in stochastic heterogeneous materials might be predictable by fast graph-theoretic methods, without detailed fracture mechanics simulations. We use graph-theoretic methods to analyze microcracking in continuous-fiber composites loaded transversely to the fiber direction, using realistic fiber configurations acquired from computed tomography data, which describe the irregularity of the spatial distribution of the fibers and meandering of fibers within the population. Graph-theoretic analysis yields very fast predictions of the likely sites of crack initiation in the fiber composite, as well as plausible indications of the likely direction in which an initiated crack will grow, the developing shape of the crack, and the frequency of instances of fibers that will bridge the crack obliquely, thereby raising the fracture resistance. We infer a stochastic population of effective defects in the composite, whose location and effective strength are related to the Euclidean and topological characteristics of the fiber population in the vicinity of the defect. When the predicted distribution of defects is entered as an initial material condition in an homogenized finite element simulation of the composite, then the important effects of the stochastic fiber distribution, in regard to crack initiation, preferred directions of growth, and toughening due to fiber-bridging, can be captured in a simulation of tractable size. This strategy carries the pertinent spatial information content of any measured random distribution of fibers into a simulation in which the fibers are not represented explicitly.

Numerical and Experimental Modeling of Time-Dependent Material Behavior of Sprayed Concrete Shells

Thursday, 20th June - 16:00: MS25 - Modeling Time-Dependent Behavior and Deterioration of Concrete (Lees-Kubota (118)) - Oral - Abstract ID: 285

Dr. Matthias Neuner (University of Innsbruck), Dr. Magdalena Schreter (University of Innsbruck), Prof. Günter Hofstetter (University of Innsbruck)

Shotcrete shells (sprayed concrete shells) constitute an essential part of the New Austrian Tunneling Method (NATM), serving as a temporal securing measure during the construction of tunnels. Shotcrete is characterized by a highly nonlinear and time-dependent constitutive behavior, including hydration-dependent evolution of material properties, hardening and softening behavior, creep, and shrinkage. In contrast to normal concrete structures, shotcrete shells in tunnels are utilized to a very high extent compared to the material strength due to the imposed deformations by the surrounding rock mass. An advanced material model for describing this highly nonlinear and time-dependent material behavior in numerical simulations was presented in [1].

In this contribution, the application of the model in 3D finite element simulations of deep tunnel advance is presented, with special focus on the time-dependent long-term behavior of the shotcrete shell due to creep and shrinkage. It is demonstrated that these material phenomena result in considerable long-term deformations of the support structure which must be taken into account properly. In addition, a comparison with experimental results and in-situ measurement data obtained at a tunnel-site is shown, confirming the realistic prognosis capabilities of the advanced material model.

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Spatial variability of rebar corrosion and structural performance evaluation of corroded RC structures under uncertainty

Thursday, 20th June - 16:15: MS25 - Modeling Time-Dependent Behavior and Deterioration of Concrete (Lees-Kubota (118)) - Oral - Abstract ID: 330

Prof. Mitsuyoshi Akiyama (Waseda University), Prof. Dan Frangopol (Lehigh University)

Corrosion of steel reinforcement isspatially distributed over RC structures due to several factors such asenvironmental exposure, covers, and concrete qualities, among others. It isessential to identify the factors influencing the spatial steel corrosion andstructural performance of corroded RC structures. An experimental research wasconducted to study the effects of several parameters, including currentdensity, concrete cover, rebar diameter, and fly ash, on the spatialvariability of steel weight loss, corrosion crack, and structural performanceof corroded RC beams using X-ray and digital image processing technique. Thetest results showed that low current density induced highly non-uniformcorrosion associated with few large pits and cracks at certain locations whilehigher current density produced more even corrosion and crack over the lengthof RC beams. Gumbel distribution parameters were derived from the experimentaldata of steel weight loss to model spatial steel corrosion. A numericalapproach was established to assess the reliability of RC structures usingfinite element analysis considering the effects of modeled spatial variabilityin steel weight loss based on X-ray images.

Investigation on the effects of rebar corrosion on the progressive collapse performance of RC frame structures

Thursday, 20th June - 16:30: MS25 - Modeling Time-Dependent Behavior and Deterioration of Concrete (Lees-Kubota (118)) - Oral - Abstract ID: 605

Dr. Xiao-Hui Yu (School of Civil Engineering, Harbin Institute of Technology), Prof. Dagang Lu (School of Civil Engineering, Harbin Institute of Technology)

The initial local damages can cause disproportional damage to the structure and cause the progressive collapse. In the available studies related to progressive collapse of RC structures, the corrosion effects have been ignored. Actually, the corrosion of steel bars can reduce the structural performance, although it has not been paid enough attention. In light of this, this paper conducts a comprehensive study on the progressive collapse performance of corroded RC structures. Through a parametric study, the effects of multiple parameters, i.e., corrosion rate, span-to-depth ratio and steel strength, on the progressive collapse performance of corroded RC structures have been investigated. The peak load and the ultimate load have been identified from the static pushdown curves as the indicators of progressive collapse capacity of structure. The corrosion-induced deduction ratios for the peak load and the ultimate load are calculated further to measure the influence level due to corrosion for the RC structures. By a sensitivity study, the effects of the above parameters on the collapse performance of corroded RC structures have been examined. The prediction models of the corrosion-induced deduction ratios on peak load, ultimate load and peak displacement have been derived.

Use Reinforcement Learning to Determine the Spatial Variation of Critical Chloride Concentration in Reinforced Concrete

Thursday, 20th June - 16:45: MS25 - Modeling Time-Dependent Behavior and Deterioration of Concrete (Lees-Kubota (118)) - Oral - Abstract ID: 709

Mr. Jie Wu (Stanford University), Prof. Michael Lepech (Stanford University)

Physics-based corrosion models can now be used to more accurately predict the life-cycle performance of reinforced concrete structures subjected to chloride-induced corrosion. An important component of these models is the critical chloride concentration at which steel depassivation occurs and corrosion initiates. However, there is little agreement on the value of critical chloride concentration in reinforced concrete due to the complexity of chloride-induced corrosion, which is influenced by both environmental conditions and material properties. Probability distributions can be used to represent the minimum critical chloride concentration on a steel rebar. But apart from this minimum value, little data exists on the spatial variation of critical chloride concentration along the reinforcement surface within a reinforced concrete element. This research represents the spatial variation of critical chloride concentration using a Gaussian random field whose minimum value follows a Beta distribution as proposed by the *fib* 2010 Model Code. The correlation function applied to generate the random field is designed to be a function of relative distance between points on the reinforcement surface. The parameters of the correlation function are modeled and validated from experimental data using a reinforcement learning algorithm.

Unified Prediction of Selfdesiccation, Autogenous Shrinkage, Drying Shrinkage, Swelling and Creep of Concrete

Thursday, 20th June - 17:00: MS25 - Modeling Time-Dependent Behavior and Deterioration of Concrete (Lees-Kubota (118)) - Oral - Abstract ID: 1206

Mr. Mohammad Rasoolinejad (Northwestern University), Mr. Saeed Rahimi-Aghdam (Northwestern University), Prof. Zdenek Bazant (Northwestern University)

It is usually required that concrete structures such as bridges be designed for a lifespan of at least hundred years. But durability problems often shorten the lifespan drastically. To remedy it, an improved, physically based model, is needed. Recent works at Northwestern showed that the source of observed shrinkage, both autogenous and drying, is the compressive elastic or viscoelastic strain in the solid skeleton caused by a decrease of chemical potential of pore water which, in turn, is caused by the decrease in pore relative humidity. As a result, the self-desiccation, shrinkage and swelling can all be predicted from one and the same unified model, in which, furthermore, the low-density and high-density C–S–H are distinguished. A new thermodynamic formulation of unsaturated poromechanics with capillarity and adsorption is presented. It can account for the size effect in autogenous shrinkage in drying specimens. In presence of external drying and creep, the autogenous shrinkage must be treated as a consequence of the pore humidity drop caused jointly by self-desiccation due to hydration and by moisture diffusion, and requires solving the time evolution of humidity profiles, for which an improved nonlinear diffusion equation with a selfdesiccation sink term is used. One application is the filtering of shrinkage data in the NU database and updating the shrinkage formulas in model B4.

Mathematical Modeling of Time Varying Corrosion in Reinforced Concrete Structures

Thursday, 20th June - 17:15: MS25 - Modeling Time-Dependent Behavior and Deterioration of Concrete (Lees-Kubota (118)) - Oral - Abstract ID: 96

Mr. Amit Jain (University of Southern California), Dr. Bora Gencturk (University of Southern California)

Durability of reinforced concrete (RC) structures has become a major societal problem in the recent decades. The corrosion of the steel reinforcement is one of the main reasons for the degradation and premature failure of RC structures. However, this process is difficult to model and predict as it depends on various factors such as the concrete pore structure, electrical properties, the composition of the pore solution and the electrical connectivity of the steel reinforcement. Instead of a uniform corrosion rate, which has been the assumption of most studies to date, a time-varying corrosion rate is modeled in this study to estimate the degradation of RC structures due to corrosion. The two main categories of corrosion: micro-cell and macro-cell corrosion are considered on the steel, which can either have an active surface or a passive surface depending on the environmental conditions such as temperature and relative humidity during curing and exposure periods. With the ingress of chloride ions in the concrete structure, reduction in pH of the pore solution causes a breakdown of the passive film on the steel surface. As the chloride ion exceeds a threshold level, the passive steel surface becomes active. The developed mathematical is implemented in the Multiphysics Object-Oriented Simulation Environment (MOOSE) developed by the U. S. Idaho National Laboratory. The degradation in the flexural capacity of a RC beam is studied as an example.

Exploring the micromechanics of non-active clays via virtual DEM experiments

Thursday, 20th June - 16:00: MS34 - Experimental and Computational Methods for Particulate Materials; Part 3 (103 Downs (50)) - Oral - Abstract ID: 694

Dr. Arianna Gea Pagano (University of Strathclyde), Dr. Vanessa Magnanimo (University of Twente), Prof. Alessandro Tarantino (University of Strathclyde)

The micromechanical behaviour of clays cannot be investigated experimentally in a direct fashion due to the small size of clay particles. An insight into clay mechanical behaviour at the particle scale can be gained via virtual experiments based on the Discrete Element Method (DEM). So far, very few DEM models for clays have been designed, mainly on the basis of theoretical formulations of inter-particle interactions with limited experimental evidence.
This work presents a numerical investigation of the mechanical behaviour of non-active clays. The underlying microscale mechanisms were inferred by indirect experimental evidence and used in this study to design the constitutive contact laws of a simple two-dimensional DEM framework. Clay platelets were modelled as rod-shaped particles made of spherical elementary units, designed to behave as single elements. New contact laws including attractive and repulsive long-range interaction were designed in order to simulate the positive/negative charge characterising the clay particle surface.

The contact laws were tested against the ability of the DEM framework to reproduce qualitatively some aspects of the one-dimensional compression behaviour of clay observed experimentally. Specifically, these include the effect of pH and dielectric permittivity of the pore-fluid on the virgin loading and unloading-reloading lines, and the dependency of the slope of the unloading-reloading lines on the pre-consolidation stress. Despite the extreme simplicity of the proposed model, distinct microscale mechanisms could be effectively linked with clay response at the macroscale. The micromechanical model validated in this paper therefore aims at laying the ground for more advanced DEM analyses.

Thermal Percolation in Conductive-Insulating Granular Mixtures

Thursday, 20th June - 16:15: MS34 - Experimental and Computational Methods for Particulate Materials; Part 3 (103 Downs (50)) - Oral - Abstract ID: 1411

Mr. Matthew Evans (Oregon State University), Dr. Ali Khoubani (Jacobs Associates)

The connectivity of individual species in a locally heterogeneous granular mixture strongly influences assembly-scale behavior. A behavioral transition is observed at the percolation threshold for a given constituent; that is, the mixing fraction at which the constituent has statistical connectivity between two opposing boundaries. This behavior is particularly evident in conductivity phenomena, e.g., the percolation of conductive particles (thermal, electric) or the relative degree of connectivity of the void space (hydraulic). Hard-core (first nearest-neighbor or lattice) percolation has been extensively studied experimentally, theoretically, and numerically. That hard-core percolation occurs in dense randomly packed bi-phasic mixtures of monodisperse spheres occurs at a mixing fraction of 0.15 v/v is well-accepted. Radiant conduction (e.g., heat), however, is influenced by hard-core "soft-shell" percolation, which is an n^{th}-nearest neighbor problem and less well-studied. In the current work, we use discrete element method simulations coupled with a thermal network model that leverages a robust domain decomposition algorithm to simulate large assemblies of spheres to investigate soft-shell percolation numerically. Our results show that the thermal conductivity of a randomly packed assembly obeys a power law with respect to volume fraction of conductive particles while percolation threshold follows a power law with respect to coordination number. The ability of the pore fluid to transmit heat over a longer distance results in an increase of thermal conductivity and a decrease in thermal percolation threshold. Moreover, we observe that, contrary to previous findings, critical percolation density is not a dimensional invariant and depends on the microstructure of the assembly.

Discrete element modeling of granular flow of flexible woody biomass particles

Thursday, 20th June - 16:30: MS34 - Experimental and Computational Methods for Particulate Materials; Part 3 (103 Downs (50)) - Oral - Abstract ID: 586

Dr. Yidong Xia (Idaho National Laboratory), Dr. Zhengshou Lai (Sun Yat-sen University), Prof. Qiushi Chen (Clemson University), Dr. Tyler Westover (Idaho National Laboratory), Dr. Jordan Klinger (Idaho National Laboratory), Dr. Hai Huang (Idaho National Laboratory)

Biomass source materials such as pine chips, corn stover and chopped switchgrass are all irregular-shaped, deformable particles. Unlike traditional granular materials that are usually hard, biomass particles exhibit significant deformability in feeding and handling processes even under low-pressure compression. Such deformability has a profound impact on bulk flow behavior of biomass materials and makes it difficult for design of feeding and handling equipment. This work presents a bonded-sphere Discrete Element Method (DEM) approach for simulating and studying the flow behavior of irregular-shaped, deformable particles. In this approach, an individual particle is modeled by a cluster of elastically bonded spheres. The model is designed to simultaneously capture irregular particle shapes and particle-level deformations such as compression, deflection, and distortion. This approach is applied to simulate and study the behavior of a woody biomass source material of interest (i.e., fine chips) in a cyclic compression and hopper flow test. With calibration, the bulk densities and bulk moduli of elasticity calculated from the DEM simulations agree reasonably with those measured in the physical test. A sensitivity study of the impact of particle shapes and deformability on bulk flowability is conducted through simulations of a hopper test. Results show that hard particles have higher change to suffer from clogging issues, whereas deformable particles have less chance to. This indicates that particle deformation reduces the critical bridging width in hopper. Overall, this work has demonstrated the necessity to take into account of the particle deformability for the simulations of biomass particles in working conditions.

The solid-liquid transition in geophysical flows

Thursday, 20th June - 16:45: MS34 - Experimental and Computational Methods for Particulate Materials; Part 3 (103 Downs (50)) - Oral - Abstract ID: 476

Prof. Douglas Jerolmack (University of Pennsylvania), Dr. Behrooz Ferdowsi (Princeton University), Mr. Nakul Deshpande (University of Pennsylvania)

Hillslope soils are composed of diverse particulate materials and are perturbed by, for example, variations in pore-pressure and biological disturbances. Nevertheless their qualitative dynamical features - especially sub-critical creep and fast-flowing landslides - are consistent with observations of simpler granular systems. We examine the creep-landslide transition in hillslopes as a solid-liquid transition in amorphous materials. We compile previously reported field data on downslope soil movement, and find a common bipartite relation between velocity and slope that we interpret to represent distinct (sub-critical) creeping and (above-critical) landsliding regimes. These dynamics are consistent with a glass transition, and in particular with a view of yielding as a depinning transition resulting from percolation of plastic rearrangements. This is curious because granular systems are athermal, leading us to speculate that mechanical (environmental) noise in granular systems is akin to thermal fluctuations in traditional glasses. To probe further we examine creep in a sub-critical sandpile in the laboratory, using diffusing wave spectroscopy to sample exceedingly slow rearrangements. We find shear-localized plastic deformation that is consistent with simulations of molecular glasses, and time-averaged strain-rate profiles that are similar to those measured from creeping landslides. We then peform Discrete Element Method (DEM) simulations of a granular heap subject to varying slope, which reproduces the main elements of laboratory creep and the creep-landslide transition seen in field data. Finally, we generalize these ideas by examining laboratory creep for a range of materials, and through a new experiment that tracks the detailed dynamics of a collapsing granular pile underwater.

Geometric Partitioning of 3-D Granular Systems and Their Resulting Structural Characteristics

Thursday, 20th June - 17:00: MS34 - Experimental and Computational Methods for Particulate Materials; Part 3 (103 Downs (50)) - Oral - Abstract ID: 1410

Dr. Reid Kawamoto (University of Tsukuba), Prof. Takashi Matsushima (University of Tsukuba)

When allowed to self-organize, granular and cellular assemblies can be geometrically partitioned into structures whose properties are independent of physical parameters such as friction, particle shape, and packing density. The independence of these structures' properties on physical parameters is important in modeling and predicting behavior. Such structures have been found in 2-D and 3-D cellular systems and 2-D granular systems. They have also been found in 3-D granular systems, but a key aspect of granular stability, the connectivity information, is not preserved in this formulation. Preservation of connectivity information is important in modeling granular systems from a statistical mechanics framework. We present a method of geometrically partitioning 3-D granular assemblies into connectivity information-preserving structures based on a set- Voronoi tessellation and an additional subdivision of the resulting set-Voronoi cells using the connectivity information of each particle. We show that these structures' properties are independent of the physical parameters of friction, particle shape, void ratio, and packing method.

Development of HPC Framework for Numerical Simulation of Saturated Granular Soils

Thursday, 20th June - 17:15: MS34 - Experimental and Computational Methods for Particulate Materials; Part 3 (103 Downs (50)) - Oral - Abstract ID: 1084

Mr. Ataollah Nateghi (Southern Methodist University), Dr. Usama El Shamy (Southern Methodist University)

Saturated granular materials are multiphase materials that present a complex modeling problem to accommodate all the constituents of the different phases. One of the main challenges in such models is the interaction between the fluid and the soil particles. Realistic representation of such interaction requires particle scale models of the soil and pore scale idealization of the fluid. This represents a major computational challenge that could be handled effectively through the use of high performance computing (HPC). In this research, we present a coupled model for fluid interaction with discrete particles. The fluid phase is modeled using the Lattice Boltzmann Method (LBM), which considers the behavior for the collection of molecules or atoms instead of every single one. Parallelized LBM, which can lead to saving in computation time, decomposes the domain of the problem to discrete subdomains and solve them simultaneously. The Message Passing Interface (MPI) scheme, which makes it possible to exchange data through sending and receiving messages between subdomains, is used in this research for parallelizing the problem. Currently, the solid phase is being modeled using the discrete element method (DEM). For the sake of using HPC methods, an open-source code, YADE, for discrete numerical models focused on Discrete Element Method is being used. The envisioned coupled LBM-DEM framework will form the basis of investigating the response of geotechnical systems to extreme loading conditions such as earthquakes and floods. Research is underway to model soil liquefaction using coupled LBM-DEM with particle sizes that resemble actual sand grain sizes.

Discrete Element Method simulations of sound propagation in granular waveguides

Thursday, 20th June - 16:00: MS72 - Mechanics and Physics of Granular Materials; Part 3 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1052

Dr. Joe Calantoni (U.S. Naval Research Laboratory), Mr. Quinlin Riggs (Appalachian State University), Mr. Sam Bateman (U.S. Naval Research Laboratory), Dr. Julian Simeonov (U.S. Naval Research Laboratory)

The propagation and attenuation of sound in sediments is strongly affected by bulk properties such as the porosity and micro-mechanical properties such as the Young modulus, the Poisson ratio and the grain contact physics. Motivated by the lack of satisfactory models that relate sound propagation to the micro-mechanical properties we used Discrete Element Method simulations with the LIGGGHTS open source software to investigate the propagation of acoustic signals in 20 m long 3D granular waveguide composed of 0.5 mm diameter spherical particles. In the waveguides considered here, we used Hertzian contacts, fixed the particle density, the Poisson ratio, the contact friction and restitution coefficients, and varied the Young's modulus and the bulk porosity. The simulations were used to determine the wave speed and attenuation rates for sinusoidal signals with different amplitude and frequency ranging from 10 Hz to 10000 Hz. The simulated range of sound speeds were consistent with those of seafloor sediments for Young modulus in the range of 70 GPa to 140 GPa.

Particle orientations properties and dilatancy behavior in Clays

Thursday, 20th June - 16:15: MS72 - Mechanics and Physics of Granular Materials; Part 3 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1255

Dr. Qian-Feng GAO (Universite de Lorraine - LEM3 UMR CNRS), Dr. Mohamad Jrad (Universite de Lorraine - LEM3 UMR CNRS), Prof. Mahdia Hattab (Universite de Lorraine - LEM3 UMR CNRS)

The aim of this study is to characterize the evolution of particles orientation related to the dilatancy phenomenon. The analyses were performed using triaxial paths following different stress paths. The tested clayey material is remoulded saturated and submitted to a one-dimensional compression. The triaxial test consists in different stages: i) the isotropic consolidation stage (CD) allowing the specimen to be normally consolidated (NC) or overconsolidated (OC). Then, two different stress paths may be performed: the purely deviatoric stress path and the conventional constant σ_3‘stress path. The paths were conducted at the same unique stress level, which can be represented by a unique point in the (p’-q) plane. After triaxial testing, to carry out the microscopic observation, small cubic subsamples and a cylindrical subsamples were extracted from the core of the specimens. The first group of subsamples was used for scanning electron microscopy (SEM) observations, the second group for X-ray microtomography (XR-μCT) scans. The results permit to relate the micro-observations to the macro behaviour of the clay obtained from the mechanical tests. The stress path affects mainly the dilatancy initiation that, in this case, developed in the first stages of the purely deviatoric stress path whereas, in the conventional stress path, the dilatancy did not appeared yet. The micro observations seem to link the dilatancy initiation to a specific feature of particle orientations in form of microcracks.

Feasibility of using 3D printed analogue soils for laboratory testing and validation of 3D DEM models

Thursday, 20th June - 16:30: MS72 - Mechanics and Physics of Granular Materials; Part 3 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1271

Dr. Michelle Lee Barry (University of Arkansas), Mr. Matthew Watters (University of Arkansas), Dr. Anjana Kittu (University of Arkansas)

The fabric and overall strength of a granular soil are highly dependent on particle shape and angularity. Natural soils vary in shape, surface properties, and mineralogy making it very difficult to single out the influence of particle shape on the strength and dilatancy characteristics of granular soils. With the advent of 3D printing, analog soils can be manufactured and tested in the laboratory using traditional geotechnical experimental devices. The shapes of these particles can be varied while the material properties and surface characteristics remain the same, providing a means to examine the granular response with changing angularity. This paper presents a summary of the 3D printed analogue soils created including material characterization and corresponding results for triaxial shear tests on the granular material. The material properties (e.g. Young's modulus, Poisson's ratio, inter-particle friction, coefficient of restitution) for these analogue soils were obtained through laboratory testing. These analogue particles allow for the material grain properties to be directly input into discrete element method models and for the macro-scale laboratory results to be used to directly validate the models across a range of particle shapes.

Atomic level stress calculation at finite temperature

Thursday, 20th June - 16:45: MS72 - Mechanics and Physics of Granular Materials; Part 3 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1127

Dr. Ranganathan Parthasarathy (Tennessee State University), Dr. Anil Misra (University of Kansas), Dr. Lizhi Ouyang (Tennessee State University)

Continuum measures computed from atomistic simulations are useful to study the finite temperature thermomechanical, optical, and electrical properties of nanocrystals. Their development requires (a) the connection between the continuum deformation field and the lattice positions of the crystal both in terms of average positions and thermal vibration, and (b) equivalence of free energy between discrete and continuum descriptions. Localizable work conjugate stresses termed "Static Stress" and "Vibration Stress" have been derived for (a) first order deformation gradients corresponding to atomic equilibrium positions and for (b) vibration tensors corresponding to second moments of atomic position, respectively. Using MD simulation in NVT ensembles for fcc aluminum subjected to [100] uniaxial deformation, the effect of these stress measures on the mechanical behavior in the elastic range and in the vicinity of softening has been demonstrated. The Vibration Stress quantitatively demonstrates vibrational modes to be precursors to deformation-induced phase transition or mechanical instability. Under compression, the Vibration Stress goes through a softening regime prior to the onset of static non-affinity and mechanical instability. Under tension at ~0.9Tm, the computed stress differs from the first order approximation by almost 40%. As the material approaches softening under tension, the vibration tensor demonstrates localized zones of non-affinity and anisotropy before similar localization is observed in the static atomic displacements. The vibration tensor and vibration stress explore the local potential landscape at individual atomic sites, and have been used to analyze atomic level residual stress and strain fields in the vicinity of defects.

2D wet soil mechanics on-a-chip

Thursday, 20th June - 17:00: MS72 - Mechanics and Physics of Granular Materials; Part 3 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 420

Dr. Morgane Houssais (Levich Institute, City College of CUNY), Prof. Charles Maldarelli (Department of Chemical Engineering, City College of CUNY), Prof. Jeffrey Morris (Department of Chemical Engineering, City College of CUNY)

We present a novel microfluidic design to visualize the dynamics of a 2D, gravity-settled bed of submerged, 400 um polymeric particles, which is subject to an upward flow. The design allows for a precise, metered, interstitial flow, and a high accuracy measurement of the individual particle displacements and the bulk deformation of the bed due to the flow.

We have explored two simple configurations. In the first, a homogeneous vertical fluid flow is imposed to a flat and horizontal sediment, and criteria are established for local fluidization — and the subsequent establishment of chimney(s). These experiments allow quantification of small deformations before channelization, in the creep regime triggered by the porous flow. Surprisingly, the small particle rearrangements cause net compaction, even though the porous flow is upward.

In a second configuration, we repeat the experiments on a flat bed now tilted at different angles. The system then presents sub-criterion deformation — at angles as low as 3 degrees, with the bulk deformation rate depending on both slope and porous flow strength. The fluid flow and the network of particle contacts appear to be of importance in understanding the observed creep driven by the porous flow and gravity. Future development of this method could allow, 1) similar investigation of further miniaturized systems where cohesion between particles become important, and 2) tracking of both granular deformations and weathering reactions of dissolution and precipitation.

Non-Newtonian Fluid Injection Test to Estimate Fracture Network Dimensions

Thursday, 20th June - 16:00: MS79 - Flow and Molecular Phenomena in Porous Media (Salvatori Seminar Room (45)) - Oral - Abstract ID: 686

Mr. Hamza Jaffal (The University of Texas at Austin), Dr. Chadi El Mohtar (The University of Texas at Austin)

Lugeon tests are widely used to estimate the permeability of fracture networks, and their results are essential for grout selection. The Lugeon test consists of injecting water into a borehole section intersecting several fractures. Having the injection pressure and flow rate, an average permeability term is calculated. The calculated permeability is used to estimate an average fracture dimension, based on which a grout is selected. Since this test uses water, a Newtonian fluid, it does not provide information on the size distribution of different fractures within the same test section. In this paper, a method consisting of non-Newtonian fluids injection is suggested. Equations demonstrating the ability to estimate the dimensions of multiple fractures from non-Newtonian fluids injection tests are presented. Then, experimental results on simple fractures, made of parallel plates, are used to validate the derived model and evaluate its performance.

Numerical Assessment of Thermal Pressurization in Porous Media with Different Permeability

Thursday, 20th June - 16:15: MS79 - Flow and Molecular Phenomena in Porous Media (Salvatori Seminar Room (45)) - Oral - Abstract ID: 950

Mr. Mohammadreza Mir Tamizdoust (University of Louisville), Dr. Omid Ghasemi-Fare (University of Louisville)

Thermal loading might alter fluid density and lead to thermally driven pore fluid flow in high permeable soil. However, temperature increments induce excess pore pressure in porous media for both low and high permeability. However, the nature of the model, and the boundary conditions play a key role on the excess pore water pressure dissipation rate. Thermal pressurization under undrain condition is significant even for the high permeable soil (e.g., sandy soil); but the thermal pressurization rate and value in the ground with high permeability can be insignificant; however, it may lead to thermally driven pore fluid flow. Characterizing and quantifying the thermal pore pressurization and deformation around heat sources due to thermal or thermo-mechanical loadings have significant implication for heat and mass transfer in both saturated and unsaturated soils. The subject of this study is to develop a fully coupled numerical model to investigate the effects of various parameters, such as temperature-depended hydraulic properties, compressibility of the medium, and soil permeability on thermal pressurization. The numerical model developed in this study was validated through a series of temperature control Triaxial Cell tests. This analysis shows pore pressures at the vicinity of the heat source exceeds hydrostatics condition (i.e. thermal pressurization) and strongly influenced by the thermal loading variations. The influence zone surrounding a heat source where there is significant excess thermal pore water pressure is studied and identified. Results also illustrate that thermal pressurization highly depends on thermal pressurization coefficient (*) which depends on both temperature and soil type.*

Is pore water pressure always tensile in unsaturated soil?

Thursday, 20th June - 16:30: MS79 - Flow and Molecular Phenomena in Porous Media (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1044

Prof. Chao Zhang (Hunan), Prof. Ning Lu (Colorado School of Mines)

The pore water pressure in partially saturated soils is frequently believed to be tensile, negative or lower than the ambient air pressure, as capillarity imposes tensile pressure on the water phase. However, this understanding is incomplete due to the fact that not only capillarity but also adsorption contribute to the matric potential. In addition, recent experimental results on soil water density render that the pore water is more likely under compressive pressure and exhibits a positive pressure. To reconcile these controversies, the new concept of soil sorptive potential is employed to evaluate the pore water pressure distribution in the clay-water-air system. The soil sorptive potential originates from interactions between water molecules and soil matrix, e.g., van der Waals attraction, electrical double layer, surface hydration, and cation hydration. The magnitudes of these attractive interactions depend on the relative position between water molecules and soil particles, suggesting that the sorptive potential varies spatially. The pore water pressure is derived as a function of the sorptive potential, indicating the pore water pressure is not homogeneous and can even be positive. With the aid of the proposed theory, the pore water pressure distribution in equilateral triangular pores is formulated. A series of parametric study is conducted to qualitatively assess how soil and pore fluid properties impact sorptive potential and pore water pressure. The results reveal that the pore water pressure can be as high as 1148 MPa, implying that the sorptive potential can significantly depress freezing point and cavitation probability of pore water.

Molecular dynamics simulations of major mineral constituents with kerogen in Green River oil shale

Thursday, 20th June - 16:45: MS79 - Flow and Molecular Phenomena in Porous Media (Salvatori Seminar Room (45)) - Oral - Abstract ID: 265

Mr. H M Nasrullah Faisal (North Dakota State University), Mr. Keshab Thapa (North Dakota State University), Prof. Kalpana Katti (North Dakota State University), Prof. Dinesh Katti (North Dakota State University)

The limited supply of traditional petroleum reserves has spurred interest in finding newer sources of hydrocarbons. Oil shale, a sedimentary rock containing organic material (kerogen, a precursor to crude oil) trapped in the inorganic mineral matrix, has been considered as a potential alternative to conventional fuel sources. Green River formation in Utah, Wyoming, and Colorado is the largest deposit of oil shale in the world. This deposit is estimated to contain 1.2 to 1.8 trillion barrels of shale oil of which 800 billion barrels are recoverable. Currently, extraction of the shale oil involves the pyrolytic extraction of kerogen (an organic heteropolymer) from the mineral matrix which is expensive and detrimental to the environment. A better understanding of kerogen-mineral interactions could lead to more efficient extraction techniques. Molecular dynamics simulation is an effective tool to identify these interactions at the molecular level. A three-dimensional kerogen model of Type I has been developed to determine the molecular interactions with predominant minerals (Na-montmorillonite clay, quartz, and calcite) of Green River oil shale. The molecular models of these minerals have been built and merged individually with 3D kerogen molecules to analyze the interactions. These molecular interactions are analyzed based on the seven fragments and associated independent ammonium ions that constitute kerogen. The results indicate that the interactions of kerogen molecules vary with the mineral in proximity and also the underlying mechanisms are different. Efficient extraction of kerogen can be benefitted by reducing the attractive non-bonded interactions between minerals and kerogen.

Estimation of the Shale Gas Permeability Using A Pore Network Model

Thursday, 20th June - 17:00: MS79 - Flow and Molecular Phenomena in Porous Media (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1226

Mr. Di Zhang (New Jersey Institute of Technology), Prof. Jay Meegoda (New Jersey Institute of Technology), Mr. Haohao Guo (Tsinghua University), Prof. Liming HU (Tsinghua University)

The amount of shale gas that can be recovered from shale formation depends on the network connects pores containing trapped shale gas under high pressure. The shale gas flow is usually due to gas slippage and diffusion whereas flow in traditional laboratory permeability tests is due to viscosity and governed by Darcy Law. Hence the hydraulic conductivity values of shale formations measured using standard laboratory methods may not yield appropriate results. Also, it is necessary to study the micromechanics of seepage of porous geo-materials from a nano/microscopic perspective. The pore network model is a convenient tool to study the properties of pore structures and hence the gas flow. For the simulation, a random connection network was constructed to find the relationship between connections in the network and its statistical parameters. A generation algorithm was proposed to create corresponding connections according to the input parameters. This pore network model can account for the pore size distributions and low connectivity of shale pores. The characteristics of pore structure of geo materials are controlled by specific parameters: porosity, pore size and pore throat distribution, as well as pore space connectivity. The pore size, pore throat size and coordination number obey normal distribution. This 3-dimensional nano-scale pore network model was validated by extensive laboratory tests that included viscous flow, slip flow and Knudsen diffusion. The experimental data of various porous media agree well with the permeability calculated by numerical simulation, indicating the potential capability of the pore network model to simulate shale gas exploration.

Conceptualizing a series of connected, parallel plate fractures as a single, equivalent parallel-plate fracture

Thursday, 20th June - 17:15: MS79 - Flow and Molecular Phenomena in Porous Media (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1257

Mr. Ahmed Yosri (McMaster University), Dr. Sarah Dickson-Anderson (McMaster University), Prof. Wael El-Dakhakhni (McMaster University)

Fractured aquifers are of interest to different disciplines such as contaminant hydrogeology, petroleum engineering, and nuclear waste management. These aquifers conduct water, and contaminants if present, through a network of transmissive and connected fractures. Analytical solutions have been developed to simulate the transport of a range of contaminants through single fractures with walls idealized as parallel plates; however, the applicability of these solutions at the network scale has not been established and thus numerical techniques are typically adopted. The current study attempts to address colloid transport in fracture networks by conceptualizing the network as a group of equivalent parallel-plate fractures, each of which represents a series of connected fractures. Characterization of these equivalent fractures, including aperture, length, groundwater velocity, and coefficients of dispersion and deposition, enables the application of available analytical solutions. This study characterized each equivalent fracture through developing a system of coupled equations by imposing the conservation of mass (water and contaminant) on both the series of connected fractures and the equivalent fracture representing it. Additional conditions were established through comparing the head loss through each configuration, and equating the statistical moments of the effluent breakthrough curves. Colloid transport through the series of connected fractures was simulated numerically, and the results were compared to those obtained by applying an analytical solution to the equivalent fracture. The results support the efficacy of this proposed approach for modelling colloid transport and deposition in a series of connected fractures, and highlight the potential for extending it to the network scale.

Drilling mechanisms using piezoelectric actuators

Thursday, 20th June - 16:00: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 3 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1181

Dr. Yoseph Bar-Cohen (Jet Propulsion Laboratory, California Institute of Technology), Dr. Stewart Sherrit (Jet Propulsion Laboratory, California Institute of Technology), Dr. Mircea Badescu (Jet Propulsion Laboratory, California Institute of Technology), Dr. Hyeong Jae Lee (Jet Propulsion Laboratory, California Institute of Technology), Dr. Xiaoqi Bao (Jet Propulsion Laboratory, California Institute of Technology), Dr. Zensheu Chang (Jet Propulsion Laboratory, California Institute of Technology)

Drilling mechanisms are widely used for many applications including domestic, medical, industrial, military, geological and planetary ones. The drills are capable of penetrating a very large variety of materials. In extraterrestrial applications, we are generally limited by additional constraints not found on earth including power, volume, mass and limited pre-load. Increasingly, developers of drills to be used on other planetary bodies are seeking capabilities that address the complex challenges that are involved with the operation at extreme environments as needed for the in-situ exploration. The use of piezoelectric actuators offers effective capabilities of drilling particularly for operation in extreme environments. Over the last two decades, significant development has been made at the JPL's NDEAA Lab using piezoelectric actuation to perform percussive drilling where the formation under the bit cutting surface is fractured by impacts. The performance and cuttings removal is significantly enhanced by rotating the bit allowing the cuttings to be removed from the created borehole. This paper focuses on drilling mechanisms that are driven by piezoelectric actuators that have been developed in our laboratory.

The Regolith and Ice Drill for Exploration of New Terrain (TRIDENT) - A One-Meter Class Drill for Acquisition of Volatile-Rich Subsurface Samples

Thursday, 20th June - 16:15: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 3 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1063

Mr. Gale Paulsen (Honeybee Robotics), Dr. kris zacny (Honeybee Robotics), Mr. Zachary Mank (Honeybee Robotics), Mr. Jameil Bailey (Honeybee Robotics), Mr. Philip Beard (Honeybee Robotics), Mr. Paul Chow (Honeybee Robotics), Mr. Alex Wang (Honeybee Robotics), Mr. Leo Stolov (Honeybee Robotics), Mr. Daniel Hastings (Honeybee Robotics), Mr. Thomas Thomas (Honeybee Robotics), Dr. Dean Bergman (Honeybee Robotics), Mr. Luke Sanasarian (Honeybee Robotics), Mr. Albert Ridilla (Honeybee Robotics), Mr. Nick Traeden (Honeybee Robotics), Mr. Zachary Fitzgerald (Honeybee Robotics), Mr. Jared Atkinson (Honeybee Robotics), Mr. Bolek Mellerowicz (Honeybee Robotics), Mr. Philip Chu (Honeybee Robotics), Mr. Phillip Morrison (Honeybee Robotics), Mr. Ariel Gotti (Honeybee Robotics), Dr. Jacqueline Quinn (NASA Kennedy Space Center), Mr. James Smith (NASA Kennedy Space Center), Dr. Julie Kleinhenz (NASA Glenn Research Center)

For the past decade, Honeybee Robotics has been developing a one-meter class drilling system for acquisition of volatile rich samples from planetary subsurfaces. The latest iteration, a fourth-generation design that has been tested to TRL6, is referred to as The Regolith and Ice Drill for Exploration of New Terrain (TRIDENT). This technology was planned for implementation on the recently cancelled Resource Prospector (RP) mission. The goal of the RP mission was to land at the Southern Polar Regions of the Moon, traverse into volatile-rich areas, and perform detailed analysis of volatile content in lunar regolith there. This is a natural next step in lunar exploration, since reconnaissance missions of this type will pave the way for any future science and In Situ Resource Utilization (ISRU) endeavors to the Moon and also Mars.

TRIDENT consists of two vertical z-stages (deployment and feed) and a rotary-percussive drill head/auger. The system was designed to collect and deliver subsurface drill cuttings to a variety of instruments for volatiles analysis using a “bite” sampling concept to improve depth resolution and keep parasitic losses low. The option to embed sensors at the tip of the drill string also enables additional down hole science. Multiple generations of the drill have been extensively tested in the Arctic Circle, Antarctica, the Atacama Desert, and various environmental chambers simulating Martian and lunar conditions. TRIDENT has also been tested on a vibrating table for survivability in launch ascent random vibration conditions and sine-sweep modal analysis.

Mortar Testing Methods for Regolith as a Building Material

Thursday, 20th June - 16:30: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 3 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1142

Ms. Sarah Seitz (NASA-Ames Research Center), Dr. Brian Glass (NASA-Ames Research Center)

Construction of infrastructure on the Moon and Mars will require techniques for assessment of regolith as a building material. Planetary analog sites on Earth have been used by NASA and partner organizations to evaluate the operation and performance of robotic technologies and analytical tools for future planetary exploration missions. One such site exists at Haughton Crater on Devon Island in Nunavut, Canada. Soil samples retrieved during field testing in summer 2016 were used in a series of tests to evaluate their suitability for in-situ resource utilization (ISRU) as structural materials. These materials were compared with non-cementitious mortar and plaster materials used in heritage masonry restoration and low-carbon building construction. Results of sieve analyses and compressive strength testing are provided. Tests were conducted using a modified mortar testing method based on ASTM C109, with adjustments in test protocol based on EN1015 and DIN18947 for lime-based mortars and clay-based plaster products. Further modification of these methods for field testing is discussed. Based initial rounds of testing, recommendations are provided for refinement of test methods, systematization of material performance data, and coordination of future testing activities.

Densification Behavior and Mechanical Characteristics of FJS-1 Lunar Soil Simulant Using Spark Plasma Sintering (SPS) Method

Thursday, 20th June - 16:45: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 3 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1106

Mr. Xiang Zhang (U. Nebraska), Ms. Mahdieh Khedmati (U. Nebraska), Prof. Bai Cui (U. Nebraska), Prof. Yong-Rak Kim (U. Nebraska), Dr. Hyu Shin (Korea Institute of Civil Engineering and Building Technology), Dr. Janggeun Lee (Korea Institute of Civil Engineering and Building Technology), Dr. Young-Jae Kim (Korea Institute of Civil Engineering and Building Technology)

This study used a novel spark plasma sintering (SPS) process to solidify lunar soil simulants (FJS-1) as potential structural materials in the mission of space exploration. Compared to conventional pressureless sintering, SPS can accelerate the densification process of FJS-1 because of the applied pressure and pulse electric current, which may contribute to accelerated atomic diffusion and the rearrangement and plastic deformation of particles. The effect of SPS conditions, such as temperature and pressure, on the densification behavior, microstructural evolution, phase transformation, and nanomechanical properties of FJS-1 has been investigated. The density of the SPSed samples increased with the sintering temperature. During the SPS of FJS-1, phase transformation from anorthite and pigeonite to augite and jadeite, and glass formation from the decomposition of jadeite occurred as the sintering temperature increased above 900 ºC. At 1050 ºC, a dendritic schorlomite crystal formed from the dissolution of iron titanium oxide particles. The microhardness of SPSed samples was 9.2% higher than pressureless sintered samples.

Percentage of Water Retained In Icy Lunar Regolith Simulant During Transfer into a Sample Container

Thursday, 20th June - 17:00: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 3 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1312

Mr. Aaron Paz (NASA Johnson Space Center)

We now know that water ice exists on the lunar surface thanks to the findings of multiple lunar missions such as LRO and LCROSS. However, before we develop systems that can utilize this precious resource at a useful scale, we need to acquire more data about the concentration of water in the lunar regolith and how it may vary by depth and location. The OVEN (Optimized Volatile Extraction Node) system is designed to determine the concentration of water as part of an instrument called WAVE (Water Analysis & Volatile Extraction) which can be deployed during a lunar resource prospecting mission. Experiments were carried out at the Johnson Space Center in order to better understand the potential losses of water that may occur during a prospecting mission when a sample is transferred from a drill to the OVEN. A description of the experiment as well as the results will be presented here.

UTILIZING OF MAGNESIUM OXY-SULPHATE BINDERS FOR ADDITIVE CONSTRUCTION APPLICATIONS

Thursday, 20th June - 17:15: MS99 - Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications; Part 3 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 693

Dr. Hunain Alkhateb (The University of Mississippi), Dr. Hatem Almaseid (The University of Mississippi), Dr. Jennifer Edmunson (ESSCA Technical Fellow in Science and Optics Jacobs Technology/NASA-Marshall), Mr. Michael Fiske (Jacobs Space Exploration Group/NASA-Marshall)

Additive construction (AC) has its challenges that are facing the researchers from both the materials and the technical aspects to adopt this technology in a traditional field. There is an immense need to address designing materials and 3D construction printers that can withstand extreme environmental conditions and to develop new construction codes to ensure the safety and sustainability of the printed structures. However, choosing suitable cementitious binders for each printing environment is the major challenge at this stage for this technology development. This research is serving multiple transdisciplinary top-notch material designs and technological topics related to the additive construction field. It is a proof of concept of the feasibility of 3D printing using Magnesium Oxysulphate (MOS) binder as an alternative to the ordinary Portland cement (OPC) to be utilized in terrestrial and extraterrestrial AC applications.

MOS is one of the strong binders' candidates to be used for extraterrestrial AC applications due to the presence of magnesia on both Mars and the Moon, the MOS mortar used in this research is utilized to study the effect of using Martian and Lunar regolith stimulants (MRS and LRS) as filling materials in the MOS binders to reduce the payloads and alter the properties. MOS paste and mortar are characterized physically, chemically, and mechanically. The characterization results conducted in this research show how MOS's properties can be controlled to match the 3D printing requirements by manipulating the MOS's ingredients proportions.

Earthworm-inspired cone penetration

Thursday, 20th June - 16:00: MS7+10+11 - Bio-Inspired Geoprobes and Geosensors, Biomaterials and Bio-Inspired Engineering, Bio-Inspired Ground Improvement and Non-Destructive Monitoring Techniques (147 Noyes (84)) - Oral - Abstract ID: 1116

Ms. Saeedeh Naziri (New Mexico State University), Ms. Luisa Bannister (New Mexico State University), Mr. Russell Buehling (New Mexico State University), Prof. Douglas Cortes (New Mexico State University)

The geomechanical advantages of earthworm burrowing strategies in dry coarse-grained soils have been demonstrated experimentally using a bio-inspired miniature cone penetration device. Test results show a significant decrease in penetration resistance compared to conventional penetration strategies. Changes in soil structure and redistribution of force chains have been identified as the primary underlying mechanisms; however, the available data is insufficient to judge the relative contribution of each. This work presents the results of tests conducted using a second generation of the earthworm-inspired miniature cone penetration devices. The new 3D printed bio-inspired geoprobes use water for pressurization of the flexible membrane. Thus, making it possible to monitor volume changes induced by inflation and deflation of the balloon. The experimental program includes penetration tests on dry and partially saturated sands, prepared at different initial densities and tested at multiple inflation pressures.

Measuring shear strength properties of sandy soils with grass roots

Thursday, 20th June - 16:15: MS7+10+11 - Bio-Inspired Geoprobes and Geosensors, Biomaterials and Bio-Inspired Engineering, Bio-Inspired Ground Improvement and Non-Destructive Monitoring Techniques (147 Noyes (84)) - Oral - Abstract ID: 305

Mr. Ryan Cardoza (California State University, Fresno), Dr. Lalita Oka (California State University, Fresno)

Cohesionless soils such as sandy or silty soils are more susceptible to landslides, slope failures and erosion because of lack of cohesion. Using grass roots to strengthen the cohesionless soils is widely acknowledged as a cost effective and sustainable solution. However, measuring the mechanical properties, especially shear strength of such bio-structured (with grass roots) soils can be very challenging because of lack of standard testing procedures, that are otherwise used for most soils without any bio-structured material. Therefore, it was decided to test soil samples with and without grass roots in the laboratory. Direct shear tests were conducted on specimens consisting of three types of soils: (i) Natural fine silty sand, (ii) Clean sand with medium and sub angular particles, and (iii) Clean sand with angular coarse-grained particles. All the soils were tested with and without grass roots to enable comparisons. Although there are no standard testing procedures for bio-structured soils, ASTM D-3080 was generally followed. The index properties such as particle size distribution, specific gravity, plasticity index, moisture content, and unit weight were measured for the specimens. The test results indicated that the presence of grass roots increased the angle of internal friction (Φ') by an average of 12% and the cohesion (c') by an average of 119% for all soil types tested. Overall, the tests clearly highlighted the effect of grass roots that could enhance the shear strength of sandy soils.

Geomechanical Characterization of Bio-Cemented Sands Using Continuum-Based Simulation

Thursday, 20th June - 16:30: MS7+10+11 - Bio-Inspired Geoprobes and Geosensors, Biomaterials and Bio-Inspired Engineering, Bio-Inspired Ground Improvement and Non-Destructive Monitoring Techniques (147 Noyes (84)) - Oral - Abstract ID: 262

Ms. Ronak Mehrabi (University at Buffalo), Dr. Kamelia Atefi-Monfared (University at Buffalo)

Microbially induced calcite precipitation (MICP) treatment has emerged as a novel method for strengthening granular unconsolidated soils. Bacteria and reactants are flushed through the porous soil matrix, promoting calcium carbonate precipitation that alters porosity and consequently soil reinforcement. Characterization of the resulting alterations in the bio-enhanced porous matrix, specifically at filed-scale, remains a challenge. Numerical simulation is an effective tool to assess the upscaling of bio-cementation. The current paper is aimed at numerically modeling bio-mediated cementation and assessing the resulting geomechanical alterations in sand through adopting a continuum finite-difference-based software. The newly developed model evaluates spatiotemporal changes in porosity, permeability, and stiffness parameters under injection of bacteria. The overtime progress of calcite precipitation is implemented into the model using Monod kinetics rate formulation. The modification in stiffness parameters is predicted using a cementation theory based on time-dependent porosity reduction under cement deposition in the soil matrix. The proposed developed numerical tool highlights the feasibility of a continuum-based numerical resource to capture the macro-scale mechanical behavior of sandy soils based on the evolution of calcium carbonate precipitation at granular scale. Results confirm the most influential factors affecting the macro-scale geomechanics to be the amount and location of the precipitated calcite. A comprehensive analysis is also presented to assess flow/pressure boundary condition effects on the production of cement. The final part of the paper assesses the mechanical response of the cemented soil under various mechanical loading conditions.

Enriching Indigenous Ureolytic Bacteria Using Bio-stimulation in Hawaiian Beach Coral Sand

Thursday, 20th June - 16:45: MS7+10+11 - Bio-Inspired Geoprobes and Geosensors, Biomaterials and Bio-Inspired Engineering, Bio-Inspired Ground Improvement and Non-Destructive Monitoring Techniques (147 Noyes (84)) - Oral - Abstract ID: 407

Mr. Yijie Wang (University of Hawaii at Manoa), Dr. Ningjun Jiang (University of Hawaii at Manoa)

Microbiologically Induced Calcite Precipitation (MICP) as an effective method can mitigate the coastal erosion effectively by inducing the calcite precipitation within the sand. Ureolytic bacteria make great contributions to the formation of precipitation via ureolysis process. Induced cement connects the adjacent sand particles together, enhances soil strength and reduces the permeability. Bio-stimulation is a promising approach to implement MICP. Compared with the traditional bio-augmentation via introducing exogenous ureolytic bacteria into the soil, the indigenous ureolytic bacteria can be enriched largely with bio-stimulation by injecting appropriately designed enrichment media into sand, which is potentially more economic and timesaving. In our research, batch-type experiments of enriching indigenous ureolytic bacteria from beach coral sand were conducted. The sand was sampled from the intertidal and supratidal zones of Waikiki and Kailua beaches, Oahu Island, Hawaii. Yeast extract, malt extract and nutrient broth based enrichment media were prepared as the selective enrichment media premixing 50 and 170 mM urea. The aim of this study is to identify the controlling factors for bio-stimulation and to provide suggestions for the enrichment media selection, through monitoring the changes of pH, electrical conductivity, and viable cell number. The results show that the indigenous ureolytic bacteria can be stimulated in beach coral sand in both intertidal and supratidal zone. To achieve best ureolytic activity using bio-stimulation method, it is necessary to consider the initial urea concentration, the optimal pH for ureolytic activity, the dominance of ureolytic activity, and intensity of bacteria's metabolism and proliferation during the bio-stimulation process.

Modeling of localized deformation in biopolymer treated pressure sensitive materials

Thursday, 20th June - 17:00: MS7+10+11 - Bio-Inspired Geoprobes and Geosensors, Biomaterials and Bio-Inspired Engineering, Bio-Inspired Ground Improvement and Non-Destructive Monitoring Techniques (147 Noyes (84)) - Oral - Abstract ID: 796

Mr. Antonio Soldo (Auburn University), Dr. Marta Miletic (Auburn University)

One of the most traditional processes to enhance engineering properties of problematic soils is chemical treatment using additives like cement, but its use raises several environmental concerns such as CO_2 emissions, groundwater contamination, vegetation growth prevention, etc. Therefore, the demand for sustainable soil improvement alternatives is increasing. One of the most promising sustainable alternatives are biopolymers. They showed a high potential for accomplishing significant gains in geotechnical engineering performance, but have not yet found their way into engineering practice. One of the main reasons may be the absence of computational models that would allow engineers to incorporate biopolymer-improved soil into their designs. A significant research in the development of analytical models and numerical tools is needed for an accelerated uptake of biopolymer-soil composites (BSC) in the engineering practice.

Therefore, the main goal was to numerically capture a stress-strain response and predict the inception of localized deformation in elastic-plastic BSC. The macroscopic elastic properties of BSC are derived from the characteristic of the composite constituents and the analysis of the microstructure using a multi-scale approach. The periodic homogenization is implemented and the BSC is described by a non-linear Drucker-Prager-plasticity model. Diagnostic strain localization analyses were conducted, thus providing strain and stress levels at the onset of strain localization, along with corresponding directions and modes of strain localization. Several unconfined compression and triaxial tests on the untreated soil as well as on the biopolymer-modified soil were modeled. Results showed that the presence of biopolymers significantly improved the mechanical behavior of the soil.

Durability against wetting–drying cycles of sustainable xanthan gum reinforced soil

Thursday, 20th June - 17:15: MS7+10+11 - Bio-Inspired Geoprobes and Geosensors, Biomaterials and Bio-Inspired Engineering, Bio-Inspired Ground Improvement and Non-Destructive Monitoring Techniques (147 Noyes (84)) - Oral - Abstract ID: 852

Mr. Antonio Soldo (Auburn University), Dr. Marta Miletic (Auburn University)

Given the ecological challenges that our world faces - almost every field of science and engineering is focusing on sustainable and environmental-friendly solutions. Therefore, new sustainable approaches for soil improvement also emerged. The utilization of biopolymers for soil improvement has been proven as a promising approach. Even though biopolymers were proved to be effective, their life-expectancy and durability is still unknown. The effectiveness of biopolymer-solution can be mitigated by high temperature, minerals, water, plants, and microorganisms. Therefore, it is important to understand their resistivity on the factors that they could be exposed to in the field.

This main aim of this study is to investigate the durability of biopolymer-improved soil on the cyclic processes of wetting and drying. Several cylindrical shaped biopolymer-sand specimens were subjected to wetting and drying cycles. For the comparison, plain sand specimens were treated in the same manner. Even though the biopolymer treated specimens showed improved wetting-drying resistance, it was noticed that both, treated and not treated samples have the same pattern of behavior. They both showed bulging and shrinking while constantly eroding until they completely lost their strength and collapsed. The property of biopolymer-sands that they lose their strength in water is an important feature that cannot be neglected. It gives a clearer picture about their utilization and makes them a good option for a temporary construction or for long-standing construction where soil will not be significantly exposed to water.

A geometry-based algorithm for cloning real grains 2.0

Thursday, 20th June - 16:00: MS35 - Computational Geomechanics; Part 3 (142 Keck (72)) - Oral - Abstract ID: 30

Mr. David Medina (Universidad San Francisco de Quito USFQ), Prof. Alex Jerves (Escuela Superior Politécnica del Litoral ESPOL)

We introduce an improved version of a computational algorithm that “clones”/generates an arbitrary number of new digital grains from a sample of real digitalized granular material. Our improved algorithm produces “cloned” grains that more accurately approach the morphological features displayed by their parents. Now, the “cloned” grains were also included in a discrete element method simulation of a triaxial test and showed similar mechanical behavior compared to the one displayed by the original (parent) sample. Thus, the present work is divided in four parts. First, we compute multivariable probability density functions from the parents’ morphological parameters (morphological DNA), i.e., aspect ratio, roundness, volume-surface ratio, and particle diameter. Second, an improved, nowparallelized and better tuned version of the geometric stochastic cloning algorithm (Jerves et al. in Granul Matter, 2017. https://doi.org/10.1007/s10035-017-0716-7), which is based on the aforementioned multivariable distributions and that, in the same way, introduces an enhanced radii sampling process, as well as a new quality control test based on the volume-surface ratio is discussed. Third, morphological DNA of the grains (i.e., aspect ratio, roundness, volume-surface ratio and particle diameter) is also extracted from the new “cloned” grains and compared to the one obtained from the parent sample. Fourth, clones and parents are subjected to a triaxial compression tests using a level set discrete element scheme (3DLS-DEM), and then, compared in terms of their mechanical response. Finally, the error of the “clones” in the morphology and mechanical behavior is analyzed and discussed for future improvements.

Modeling Breakage using LS-DEM

Thursday, 20th June - 16:15: MS35 - Computational Geomechanics; Part 3 (142 Keck (72)) - Oral - Abstract ID: 162

Mr. John Harmon (Caltech), Prof. José Andrade (Caltech)

Breakage is a critical aspect of materials for wide ranging applications such as in mining, earthquake mechanics, and mechanics of inhomogeneous materials to name a few. Despite this, many aspects of this phenomenon remain unknown due to the complexity of fracture driving modelers to make compromises for efficiency. In this talk, a development in grain-scale breakage modeling will be discussed that combines the recent capability of exact particle shape in discrete element modeling with a novel breakage method that together maintain the efficiency of sphere based methods while adding the accuracy from exact particle shape and complex fracture surface geometry. We will begin with an overview of how this technique is made possible due to revolutionary advancements in imaging techniques that opened the door for the creation of the Level Set Discrete Element Method (LSDEM). We will then show simulations using the technique and how those simulations compare with experiments both with constitutive relations and key breakage properties such as the evolution of grain size distribution.

Enriched Galerkin methods for locally mass conservative simulation of large-deformation poromechanics

Thursday, 20th June - 16:30: MS35 - Computational Geomechanics; Part 3 (142 Keck (72)) - Oral - Abstract ID: 191

Prof. Jinhyun Choo (The University of Hong Kong), Prof. Sanghyun Lee (Florida State University)

Numerical simulation of coupled poromechanical problems undergoing large deformations often involves a strongly heterogeneous permeability field. This is not only because many porous media are inherently heterogeneous, but also because non-uniform deformation gives rise to heterogeneous evolution of the permeability field. It is well-known that a locally (element-wise) conservative method is necessary to accurately simulate fluid flow in strongly heterogeneous porous media. This talk will introduce a new finite element framework for locally mass conservative solution of coupled poromechanical problems at large strains. At the core of this framework is the enriched Galerkin discretization of the fluid mass balance equation, whereby element-wise constant functions are augmented to the standard continuous Galerkin discretization. The resulting numerical method provides local mass conservation by construction, with a usually affordable cost added to the continuous Galerkin counterpart. The local mass conservation property of the proposed method has been verified through numerical examples involving saturated and unsaturated flow in porous media in the finite deformation range. The numerical examples also demonstrate that local mass conservation can be a critical element of accurate simulation of both fluid flow and large deformation in porous media.

An Elasto-plastic Homogenization Framework for Layered Materials with Plane of Weakness

Thursday, 20th June - 16:45: MS35 - Computational Geomechanics; Part 3 (142 Keck (72)) - Oral - Abstract ID: 209

Dr. Shabnam Semnani (University of California, San Diego), Dr. Joshua A. White (Lawrence Livermore National Laboratory)

Many composites and geological materials are multi-scale in nature. The overall properties and behavior of these materials are determined by the microscopic heterogeneities as well as properties, shape, and distribution of the constituents. Geomaterials such as sedimentary rocks commonly consist of distinct bedding planes or layers, which lead to transversely isotropic behavior. Continuum-scale constitutive models developed for plastic behavior of transversely isotropic materials typically consider a uniform material behavior, in which the effect of layers is introduced at the continuum level, and do not account for effect of bonding at the interfaces. It has been shown; however, that properties of the interface between the constituents can significantly affect the behavior of layered composites and geological materials.

In this work, we present a homogenization framework for elasto-plastic layered media. The proposed approach allows for separate micro-constitutive laws and properties for each layer, explicit representation of layers with different properties and their distribution, as well as incorporation of imperfect bonding between the adjacent layers. Simulation results show that the proposed model is able to capture the anisotropic behavior of rocks with brittle and/or ductile layers. Numerical results are presented to study the effects of bedding plane orientation, imperfect bonding, and the constitutive behavior of individual layers on the macroscopic mechanical response of layered materials.

Incremental elastoplastic response of a real granular material via virtual stress probing

Thursday, 20th June - 17:00: MS35 - Computational Geomechanics; Part 3 (142 Keck (72)) - Oral - Abstract ID: 269

Mr. Konstantinos Karapiperis (Caltech), Mr. John Harmon (Caltech), Prof. José Andrade (Caltech)

In this presentation we exhibit the incremental elastoplastic response of a granular assembly whose morphology and properties have been obtained experimentally. This is achieved through high-fidelity virtual stress probing combined with new theoretical developments regarding the decomposition of elastoplastic strain in terms of micromechanical quantities, that extend previous works on elastic assemblies of disks and spheres. Upon demonstrating the superiority of the approach against the state of the art, we provide insight through a series of investigations. In particular we will discuss findings that reveal the micromechanical signature of the onset of yielding and the influence of granular shape. We will conclude with more practical considerations culminating in the determination of the yield surface and flow potential in 3D principal space.

Molecular simulation framework for soil behavior

Thursday, 20th June - 17:15: MS35 - Computational Geomechanics; Part 3 (142 Keck (72)) - Oral - Abstract ID: 1043

Prof. Chao Zhang (Hunan University)

Molecular simulation stems from statistical thermodynamics and fully captures the intermolecular forces, thus can provide unique tool probing nanoscale phenomena in soil. These nanoscale phenomena have been continuously plaguing the physical understanding of various soil behaviors and resulted in many unresolved problems in classical soil mechanics, e.g., crystalline swelling of clay minerals, surface hydration of soil water, and super-cooling at extreme low temperature. Herein, molecular simulation techniques are halted to fill historical knowledge gaps in classical soil mechanics, to provide a novel angle to characterize soil behaviors and to promote the theoretical understanding of soil-water interaction. A molecular simulation framework is proposed to simulate a wide array of soil behaviors, e.g., phase equilibrium among gas, liquid, and solid, phase transition of soil water, effective stress evolution, and matric suction determination.

Effects of the atomic-structure and microstructure on micromechanical properties of glass powder-metakaolin based alkali-activated binder

Thursday, 20th June - 16:00: MS50 - Multi-Scale Control and Characterization of Cementitious Materials Undergoing Phase Change (153 Noyes (134)) - Oral - Abstract ID: 1055

Dr. Qingli Dai (Michigan Technological University), Mr. Ruizhe Si (Michigan Technological University)

This study aims to investigate the influence of the atomic-structure and microstructure on the micromechanical properties of glass powder modified metakaolin-based alkali-activated material. The glass powder was introduced into the metakaolin-based geopolymer as a precursor from 0% to 20% of the total precursor weight for the sample preparation. The change of the atomic-structure in metakaolin-based geopolymer with different glass powder content was evaluate by the Pair Distribution Function technique. The increased Si/Al ratios was observed in the geopolymer binders with the introduce of the glass powder, which indicated the increase of the high strength Si-O-Si bonds to facilitate the improvement of the mechanical properties at the atomic scale. The pore size distribution function of the geopolymer binder was evaluated by the nitrogen sorption test. The pore size tended to decrease with the addition of the glass powder, which indicated the formation of the denser microstructure in metakaolin-based geopolymer with the introduction of the glass powder. The nanoindentation technique was employed to evaluate the micromechanical properties of the synthesized geopolymer. The geopolymer samples with 10% glass powder showed the highest creep stiffness among the prepared samples due to the modified atomic- and micro-structure, which was determined as the optimized glass powder content in geopolymer binders. This study presented the factors that affect the micromechanical properties of the glass powder modified metakaolin based geopolymer from atomic structure to microstructure, which can help to gain more understanding on the mechanical properties of the glass powder modified alkali-activated materials.

In situ Submicron Raman Tracking of the Ordinary Portland Cement Hydration Process

Thursday, 20th June - 16:15: MS50 - Multi-Scale Control and Characterization of Cementitious Materials Undergoing Phase Change (153 Noyes (134)) - Oral - Abstract ID: 389

Mr. Hyun-Chae Loh (MIT), Prof. Admir Masic (MIT)

Concrete is the most widely used construction material, and its demand in recent decades has increased exponentially. The components of cement undergo complex phase transformations during the hydration process, and the cement paste itself transforms from a visco-plasitc paste to an elasto-plastic solid. Cement mixtures are easy to use when it stays viscous during the induction stage, and they develop their strength during the hardening stage. Despite the importance of these two stages, factors and mechanisms that determine and influence the early stage and long-term properties remain unclear. Here, we present an *in situ* characterization approach using Raman microspectroscopic imaging to obtain submicron resolution chemical characteristics of the cement paste during the hydration process. The distribution of the different clinker and sulphate phases and the transitions of these phases were mapped. Furthermore, analyzing the Raman signatures of the hydroxyl-containing mineral phases, such as carbon hydroxide, provide new insights into the chemical and mechanical environments of hydroxyl groups during the hydration process. The Raman peak shift (redshift) of the calcium hydroxide crystals indicates that the ettringite formation induce compressive stress in crystals. The Raman peak shift (blueshift) found on the surface of the calcium hydroxide crystals, however, indicates that the chemical environment of the crystal surface is different from the bulk crystal. The difference that generates the blueshift could be the increased sulfate ion concentration or the ionic substitution in the crystal lattice.

Characterization of rheological properties of cement paste based on the adsorption of superplasticizer

Thursday, 20th June - 16:30: MS50 - Multi-Scale Control and Characterization of Cementitious Materials Undergoing Phase Change (153 Noyes (134)) - Oral - Abstract ID: 634

Dr. Jin Young Yoon (Ulsan National Institute of Science and Technology (UNIST)), Prof. Jae Hong Kim (korea advanced institute of science and technology (KAIST)), Mr. Byungil Choi (korea advanced institute of science and technology (KAIST))

After the development of superplasticizers, they have become an essential component of concrete to obtain sufficient workability of high strength or self-consolidating concrete. The fluidity enhancement of fresh concrete can be achieved by the steric repulsion force between cement particles generated by adsorbed polymers. Several studies investigated the effect of various kinds of superplasticizer on the workability of cementitious material. The adsorption property of superplasticizer is also analyzed based on the molecular structure analysis. However, the comprehensive analysis of the interaction between the adsorption property of superplasticizer and rheological properties of cementitious material has not been fully studied yet. Thus, this study focuses on the evaluation of superplasticizer adsorption-based rheological properties of cement paste changing the concentration of various types of superplasticizers. In the aspect of fluidity enhancement of mixture, it is found that the fluidity of cement paste is highly increased at the critical dosage due to the saturation of abundant polymers on the surface of cement regardless of the types of superplasticizer. The adsorption-fluidity result is also used to classify the performance of superplasticizer as initial flow improving or consistency maintaining type. The rapidly adsorbed polymers increase early-age fluidity of mixture and the fluidity is decreased for a period of time. On the contrary, the delayed adsorbed polymers have slump retention property by hindering the agglomeration of cement particles continuously. The analysis of cement agglomeration rate supports the consistency maintaining property of cement paste.

Heterogeneous growth of Calcium-Silicate-Hydrate gels

Thursday, 20th June - 16:45: MS50 - Multi-Scale Control and Characterization of Cementitious Materials Undergoing Phase Change (153 Noyes (134)) - Oral - Abstract ID: 1268

Prof. Emanuela Del Gado (Georgetown University), Mr. Abhay Goyal (Georgetown University), Mr. Christopher Tiede (New York University), Prof. Pierre Levitz (Universite Pierre et Marie Curie), Dr. Katerina Ioannidou (LMGC), Dr. Roland Pellenq (Massachusetts Institute of Technology)

Due to the widespread use of cement, optimizing its mechanical properties and reducing the environmental impact of cement production is of great soci- etal interest. However, any modification of cement is hindered by an incomplete understanding of the setting process due to its complexity at the nano- and meso-scales. During setting, the precipitation and non-equilibrium ag- gregation of C-S-H particles into a percolating, porous network is responsible for the overall mechanical properties. This precipitation can occur in a very non-uniform way due to spatial gradients in ion concentrations and the effect of cement grain surfaces. We investigate the role of these heterogeneities on the overall setting process and find that their effect is controlled by the C- S-H particle interactions. Features of the interaction that are present during the early stages of hydration prove to be crucial in forming a percolating, stress-bearing network and are necessary to explain how the setting process of cement is so robust.

Structural build-up of fresh cement pastes incorporating viscosity modifying agents

Thursday, 20th June - 17:00: MS50 - Multi-Scale Control and Characterization of Cementitious Materials Undergoing Phase Change (153 Noyes (134)) - Oral - Abstract ID: 1330

Dr. Siwei Ma (Columbia University), Prof. Shiho Kawashima (Columbia University)

In this study, the effect of inorganic (nanoclay) and organic (diutan gum) admixtures on the structural build-up process of cement pastes will be discussed. Structural build-up is quantified using static yield stress and storage modulus, which are measured through shear rheological stress growth and small amplitude oscillatory shear (SAOS) tests, respectively. The results show distinctly different effects by the two admixtures on static yield stress and storage modulus. It will be discussed how this can be attributed to the two different structures of fresh cement pastes, i.e. floc structure and C-S-H structure, and different working mechanisms of the fine clay particles and natural polymers.

Cement-based 3D printed bioinspired architectured materials

Thursday, 20th June - 17:15: MS50 - Multi-Scale Control and Characterization of Cementitious Materials Undergoing Phase Change (153 Noyes (134)) - Oral - Abstract ID: 1365

Mr. Reza Moini (Purdue University), Prof. Jan Olek (Purdue University), Prof. Jeff Youngblood (Purdue University), Prof. Pablo Zavattieri (Purdue University)

There is a strong demand for new paradigms of design and development of high performance materials and structures where the main component is a brittle material. This is indeed the case for cementitious-based materials. On the other hand, there is a growing interest in Additive Manufacturing (AM) for cement-based materials. However, the intrinsic brittle behavior of these materials and the processing-induced interfaces represent major challenges. In our work, we make the case that additive manufacturing offers the opportunity to harness the role of interfaces, and we do that by exploring bio-inspired architectures as a way of controlling and diversifying the mechanical response of brittle cement paste elements. By natural selection, *Nature* has evolved efficient strategies to synthesize materials that often exhibit exceptional mechanical properties that significantly break the trade-offs often achieved by man-made materials. In fact, most highly biomineralized materials have high content of brittle minerals, contain a large population of defect and weak interfaces and yet they exhibit superior performance. In particular, I will discuss how Nature employs weak interfaces and clever architectures to achieve higher toughness without sacrificing stiffness and strength in comparison with typical engineering material. We then employ direct ink writing (DIW) to print elements in a layer-by-layer deposition process to evaluate the role of material behavior, interfaces and bioinspired architectures on the mechanical response.

An innovative technique to design gusset plates using heat treatment

Thursday, 20th June - 16:00: MS47 - Applications of Material-Level Architecture in Earthquake Engineering (Baxter Lecture Hall (296)) - Oral - Abstract ID: 91

Mr. Hossein Mohammadi (McMaster University), . Tracy Becker (University of California, Berkeley), Prof. Hatem Zurob (McMaster University)

Gusset plates are key components in the seismic performance of concentrically braced frames. Poor performance of gusset plates can lead to change in failure mechanism away from brace buckling towards gusset plate or beam and column connection failure. Current design practice uses either a fold line or an elliptical clearance to permit the gusset plate rotation during brace buckling. While the first method can result in overly large plates, the second can lead to damage to the welds and gusset plate near the surrounding frame. Here, a new design approach is proposed by locally changing the mechanical material properties of the gusset plate. Starting with a high strength steel gusset plate, a yield path is defined through using a controlled heat treatment to lower the yield strength, forcing the inelastic deformation to occur in the yield path. Not only does this result in smaller gusset plate dimensions, but also reduces the potential damage to welding at the gusset-to-frame connection. Using strength and ductility properties from heat treatment tests of material coupons, proposed design procedures for the heat treated gusset plates are developed and the design methodology is outlined. Performance of the gusset plates designed from normal, high strength, and heat treated high strength steel plates are compared through finite element analysis, showing benefits of the heat treated gusset plates especially when their reduced size in considered.

Novel Heat-treated Braces for enhanced Seismic Performance and Structural Efficiency of Concentrically Braced Frames

Thursday, 20th June - 16:15: MS47 - Applications of Material-Level Architecture in Earthquake Engineering (Baxter Lecture Hall (296)) - Oral - Abstract ID: 710

Dr. Machel Morrison (North Carolina State University)

This study develops an innovative technique for enhancing the seismic performance and economy of concentrically braced frames (CBFs). The technique involves heat-treating the mid-section of the brace (up to one brace depth away from the brace to gusset plate connection) by subjecting this region to high temperatures followed by controlled cooling. The proposed heat-treatment reduces the yield and tensile strength, while increasing the ductility, work hardening ability and notch toughness of ASTM A500 steel in hollow structural sections (HSSs). These changes in mechanical properties have several desirable effects for CBFs. First and foremost, material overstrength can be lowered. Consequently, the size of capacity protected elements such as beams, columns, connections and possibly foundations can be reduced, making CBFs more economical. Second, the improved material work hardening ability reduces the susceptibility of heat treated braces (HTBs) to strain localization (at mid-length plastic hinges), and the improved material ductility and notch toughness delays the onset of rupture and by consequence, increases deformation capacity. Third, reinforcement of the slotted connection between the HSS brace and gusset plate as currently required by AISC 341 is no longer needed, since this connection is capacity protected by the reduced strength of the interior portion of the HTB. Results from a series of material tests and numerical studies will be presented to demonstrate the performance of the technique.

Seismic Retrofit of Reinforced Concrete Wall Piers Using Various Carbon Fiber Geometric Forms

Thursday, 20th June - 16:30: MS47 - Applications of Material-Level Architecture in Earthquake Engineering (Baxter Lecture Hall (296)) - Oral - Abstract ID: 123

Ms. Vanessa McEntee (University of Utah), Mr. Bhaskar Kunwar (University of Utah), Dr. Chris Pantelides (University of Utah)

Seismic deficiencies of reinforced concrete bridge wall piers have created a need for innovative rehabilitation methods. Carbon fiber reinforced polymer composites were applied to retrofit various deficiencies including inadequate flexural and transverse reinforcement and short lap splice length. Two 9 ft tall, 4 ft wide, and 1 ft thick reinforced concrete wall piers with inadequate reinforcing details were tested under cyclic loads. The first was tested in the as-built condition and the second was seismically retrofitted using three geometric forms from the same carbon fiber material. The first fiber element was a jacket, consisting of woven fibers externally wrapped in the hoop direction of the wall; the jacket was used to confine the concrete and the lap spliced bars at the wall base. The jacket was used in conjunction with horizontal fiber anchors placed through the wall thickness (second fiber element) to improve the bond of jacket to concrete and enhance the shear friction mechanism of the lap spliced bars; the horizontal anchors were formed using fiber bundles. The third fiber composite element consisted of fiber bundles used as vertical anchors to create a positive connection between footing and wall, thus resisting tension from flexure. In order to verify the contribution of horizontal fiber anchors, twelve single anchors with various diameters were embedded in concrete blocks and tested in shear under monotonic and cyclic loads. The seismic retrofit method was successful by using a single fiber material formed into three elements to increase its effectiveness in achieving the retrofit goals.

Plastic hinge relocation in RC beams through rebar heat treatment

Thursday, 20th June - 16:45: MS47 - Applications of Material-Level Architecture in Earthquake Engineering (Baxter Lecture Hall (296)) - Oral - Abstract ID: 664

Mr. Heramb Mahajan (North Carolina State University), Dr. Machel Morrison (North Carolina State University), Prof. Tasnim Hassan (North Carolina State University)

The existing design detailing procedure in the ACI Code leads to rebar congestion in the beam-column joints when Gr. 60 rebar is used. To avoid the rebar congestion, the Gr. 80 rebar is proposed as potential candidate. Extensive research is being done on Gr. 80 rebar to study the rebar performance in RC beam and column under seismic loading. The Gr. 80 rebar have high yield and tensile strengths but low ductility compared to Gr. 60 rebar and hence may result in premature rebar buckling and fracture at the plastic hinge location. Heat treatment of Gr. 80 rebar reduces yield and ultimate strengths, but increases ductility. Hence, heat treatment of Gr, 80 rebars is investigated in relocating plastic hinge location and enhancing seismic performance of RC beams and columns. In addition, rebar heat treatment ensures the strong column-weak beam design philosophy. For application of this heat treatment performance enhancement concept, Gr. 80 rebar strength and ductility are experimentally investigated with different heat treatment parameters. The data obtained from study were used in optimizing the heat treatment methodology for Gr 80 rebar. The material properties for optimized heat treatment are determined and used in determining constitutive model parameters to simulate the monotonic and cyclic responses of RC beam with the heat treated rebar in the plastic hinge. The simulation responses demonstrate performance enhancement of RC beams through successful relocation of the plastic hinge and delay in rebar buckling.

Behavior of Foam-Filled HSS under Cyclic Loading

Thursday, 20th June - 17:00: MS47 - Applications of Material-Level Architecture in Earthquake Engineering (Baxter Lecture Hall (296)) - Oral - Abstract ID: 508

Mr. Malcolm Ammons (University of Michigan), Mr. Christian Flores Carreras (University of Michigan), Prof. Jason McCormick (University of Michigan)

Steel structures subjected to severe ground shaking dissipate energy by utilizing a structural fuse concept, whereby sacrificial members undergo significant plastic deformation to minimize damage elsewhere in the structure. In the case of steel special moment frames, plastic hinges form at the column bases and beam ends. Alternatively, when the lateral load resisting system (LLRS) is comprised of braced frames, plastic hinges are typically formed at the brace ends and at the center of the brace. In each of the aforementioned cases the performance of the LLRS can be severely compromised due to local buckling. To mitigate this deficiency, a lightweight, high damping polyurethane foam is introduced into the voids of hollow structural section (HSS) beams and bracing members. Two experimental programs are undertaken with filled beam and brace members to evaluate the ability of the foam to inhibit local buckling and stabilize the behavior in regions where significant inelastic deformation is expected. The members are subjected to large cyclic loads. The presence of the foam in rectangular HSS beams is able to inhibit local buckling and provide enhanced energy dissipation compared to that of equivalent size empty beams. Similarly, the foam fill is able to reduce the severity and impede the onset of local buckling at the mid-length of circular HSS braces, ultimately leading to a prolonged fracture life. The results suggest that the inclusion of foam fill can increase design flexibility by allowing for HSS with a larger width-thickness ratio to be utilized.

A novel technique involving heat treatment for plastic hinge relocation in steel building beam-column connections

Thursday, 20th June - 17:15: MS47 - Applications of Material-Level Architecture in Earthquake Engineering (Baxter Lecture Hall (296)) - Oral - Abstract ID: 702

Dr. Machel Morrison (North Carolina State University), Mr. Doug Schweizer (Thornton Tomasetti, Inc), Dr. Shahriar Quayyum (Applied Research Associates, Inc.), Prof. Tasnim Hassan (North Carolina State University)

This study develops and experimentally validates a novel technique involving heat treatment for relocating plastic hinges in steel moment frame beam-column connections. Through heat-treating the beam flanges in the desired plastic hinge location of a wide flange beam, yield and ultimate strengths of the material are reduced. Consequently, yielding and plastic hinge formation is promoted in the heat-treated beam section. Plastic hinge relocation away from the connection mitigates against brittle connection failures and thereby enhances seismic performance. Design of the heat-treated beam-column connection (called HBS connection) was performed through detailed finite element analysis and material testing. Welded flange-welded web (all welded), welded flange-bolted web, and extended end plate connections are analytically and experimentally evaluated to demonstrate the seismic performance enhancement of HBS connections. The experiments demonstrated yielding and plastic hinge development in the heat-treated regions without any weld or near weld fracture even at 6% interstorey drift. Strength degradation due to beam local buckling initiating and propagating in the heat-treated region was the observed failure mechanism. Detailed analyses of strain and beam deformation data will be presented to demonstrate the mechanism of the HBS connection seismic performance enhancement.

Some New Directions in Modeling Granular Flows

Friday, 21st June - 08:30: Plenary 5 (Beckman Auditorium (1,136)) - Oral - Abstract ID: 1421

Prof. Ken Kamrin (MIT)

Despite their ubiquity in nature, granular materials have proven historically elusive to model. To predict a flow, one can attempt to track every grain with discrete particle methods, but many geotechnical and industrial systems are too large for this and a continuum model is desired. However, granular media display unusual behaviors that complicate the continuum treatment: one example is that they can behave like solid, flow like liquid, or separate into a "gas". In recent years, several technological advancements have made it possible, now more than ever, to rise above these challenges. This talk will discuss continuum modeling that can transcend these apparent phases, as well as a Material Point Method (MPM) implementation, which allows the model to be carried out in real geometries to fluid-like levels of deformation. This approach serves as a scaffold for the developments discussed next: hybrid continuum-discrete modeling and, time-permitting, multiphase continuum modeling of wet granular materials. The hybrid methodology handshakes an MPM-continuum implementation with a discrete particle representation in regions where the continuum approach may not hold. The spatial split between continuum and discrete zones is adaptive, allowing a user-defined "oracle" to decide how to divvy the geometry each time-step. Lastly, we adopt the recent "MPM-on-MPM" approach to simulate fluid-saturated granular mixtures as two coupled continua, both represented with MPM. We present a particular constitutive model which is shown to be predictive in systems of simple grains in water, allowing a seamless transition between dense slurry flows and rapidly flowing suspensions.

Simulation of Two Spatial Dimensions Wind Velocity Time Histories as Non-Gaussian Stochastic Waves

Friday, 21st June - 10:30: MS83 - Computational Methods for Stochastic Engineering Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 255

Prof. Michael Haijun Zhou (Shenzhen University), Mr. Qi Wen (Shenzhen University), Prof. George Deodatis (Columbia University), Prof. Michael Shields (Johns Hopkins University)

A methodology is proposed for efficient and accurate modeling and simulation of correlated two spatial dimension non-Gaussian wind velocity time histories at an arbitrarily large number of points.The spectral representation method (SRM) is a widely-used method for the simulation of fluctuating wind speed fields. To solve the computational challenges of the Cholesky decomposition involved in the spectral representation method, a frequency-wavenumber (FK) spectrum based on SRM was proposed recently. The method can be used for the efficient simulation of Gaussian wind fields in one or two spatial dimension. In this paper, the FK spectrum based on SRM is extended to simulate non-Gaussian wind velocities as a non-Gaussian stochastic wave in two spatial dimensions. The non-Gaussian wave is characterized by its frequency-wavenumber (FK) spectrum and marginal probability density function (PDF). This allows the non-Gaussian wind velocities to be modeled at a virtually infinite number of points along the length and height of the structure. The compatibility of the FK spectrum and marginal PDF according to translation process theory is secured by using an extension of the Iterative Translation Approximation Method introduced by the third and fourth authors. This method does not need to generate any sample functions in the iterative process, and improves the iterations efficiency significantly. To enhance the computational efficiency with respect to the threefold summation over the one-dimensional frequency domain and the two-dimensional wavenumber domain，the Fast Fourier Transform is used. Numerical examples are provided demonstrating that the simulated non-Gaussian wave samples exhibit the desired spectral and coherence characteristics.

Simulation of non-Gaussian processes for non-linear stochastic systems

Friday, 21st June - 10:45: MS83 - Computational Methods for Stochastic Engineering Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 531

Mr. Lohit Vandanapu (Johns Hopkins University), Prof. Michael Shields (Johns Hopkins University)

Studying the dynamic response of non-linear stochastic systems has always been of interest to engineers. But, the response of a non-linear system is highly sensitive to the input stochastic excitation. So, developing an accurate expansion for the simulation of stochastic processes has been studied for many decades and methods such as Spectral Representation (SRM) and Karhunen-Loeve (K-L) Expansion have been well established. Under stationarity assumptions, both SRM and KLE can only be used to model Gaussian processes and Gaussian processes alone cannot represent the wide range of stochastic processes in nature like wind gusts, shoaling ocean waves etc. which are known to exhibit non-Gaussianity. Many methods such as translation process theory have been applied to induce the desired properties from an underlying Gaussian process but these methods do not take higher-order spectra into consideration. Recently, the Bispectral Representation Method, which is derived by modifying the expansion of Spectral Representation has been introduced to precisely match third-order spectra along with the second-order spectra of the input excitation. But, implementing the expansion in its current form is computationally prohibitive and scales poorly for higher-dimensional stochastic expansion. We present a Fourier based implementation, which dramatically reduces the computational cost and makes simulation of higher-dimensional processes tractable. A brief application of the proposed methodology to a non-linear bridge deck model along with comparison with other methodologies is presented, which illustrates the sensitivity of a nonlinear systems to choices in non-Gaussian process modeling.

Neural agent for structural analysis: a novel approach

Friday, 21st June - 11:00: MS83 - Computational Methods for Stochastic Engineering Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 532

Mr. Xihaier Luo (University of Notre Dame), Prof. Ahsan Kareem (University of Notre Dame)

Differential equations play a prominent role in the analysis of various physical systems as they represent them in a rigorous mathematical form. A wide range of numerical approaches such as the finite element method (FEM), isogeometric analysis (IGA), etc., have been henceforth developed to obtain a solution to these differential equations by dividing a continuous domain into a set of discrete subdomains, resulting in simultaneous equations. Propagating and quantifying design uncertainties in such a discretized domain can be very challenging considering it requires repeated evaluations of complex functions with high dimensionality. Inspired by the latest development of computer vision, a ConvNet based machine learning framework is presented as an alternative to solving and learning engineering systems governed by differential equations in this paper. Specifically, underlying physical principles involved in the differential formulation are directly integrated into the objective function of a constrained non-convex optimization problem. It is noteworthy that the proposed surrogate is capable of learning the intrinsic input/output mapping relationship via only using the input data, resolving the dilemma of limited data that practitioners often encountered in model training. Examples with emphasis on solid mechanics are provided to demonstrate the effective usage of the proposed method as an attractive alternative to conventional FEM and IGA based schemes.

Uncertainty propagation through high-fidelity non-linear dynamic systems driven by stochastic excitation

Friday, 21st June - 11:15: MS83 - Computational Methods for Stochastic Engineering Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 941

Mr. Bowei Li (University of Michigan), Dr. Seymour Spence (University of Michigan)

Modern performance-based design is centered on estimating performance in terms of system-level probabilistic metrics such as expected repair costs or downtime. This implies the need to propagate uncertainty through structural systems that generally exhibit significant non-linearity in their response. The need to account for both record-to-record variability as well as system uncertainties makes this process computationally challenging. This is especially true if simulation-based methods, such as Monte Carlo simulation, are to be used for the uncertainty propagation. To overcome this, a method is introduced in this paper for efficiently propagating uncertainty through high-fidelity finite element models of uncertain non-linear dynamic systems subject to stochastic excitation. The proposed framework is based on defining a physics-based parametric reduced-order model of the high-fidelity system. By combining the reduced order model with polynomial chaos and nonlinear autoregressive with exogenous input models, a metamodeling strategy is defined for rapidly estimating solutions to the original non-linear system. To illustrate the accuracy and efficiency of the approach, a probabilistic performance assessment based on Monte Carlo simulation is carried out on a full scale steel frame with inelasticity modeled through distributed plasticity. The frame is subject to both stochastic excitations as well as parameter uncertainty in the damping and stiffness.

High performance computing strategies for efficient Wiener path integral based stochastic response analysis of diverse dynamical systems

Friday, 21st June - 11:30: MS83 - Computational Methods for Stochastic Engineering Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 561

Mr. Ketson Roberto Maximiano dos Santos (Columbia University), Mr. Apostolos Psaros (Columbia University), Mr. Ioannis Petromichelakis (Columbia University), Prof. Ioannis Kougioumtzoglou (Columbia University)

The computational efficiency of the Wiener path integral (WPI) technique for determining the stochastic response of diverse dynamical systems is enhanced herein by exploiting recent advances in high performance computing strategies, such as parallel processing schemes and graphics processing units (GPUs) technology. Specifically, according to the standard brute-force numerical implementation of the WPI technique, the solution of a boundary value problem (BVP) is required for determining a single point of the system joint response PDF. In this regard, for an m-DOF system with $2m$ stochastic dimensions ($m$displacements and m velocities), the effective PDF domain is discretized into *points; thus, yielding BVPs to be solved numerically for evaluating the joint response PDF. Clearly, this approach renders the associated computational cost prohibitive for relatively high-dimensional systems. Although there have been recent advances based on sparse PDF representations and compressive sampling tools for reducing drastically the above cost [1], an alternative remedy is pursued in this paper by exploiting the structure of the related BVPs, each corresponding to a specific point of the PDF domain. Notably, these BVPs have identical structure, but different boundary conditions; thus, rendering their solution by parallel processing strategies a promising choice. Several numerical examples are considered for assessing the performance of the proposed solution strategies, including comparisons with pertinent Monte Carlo simulation data.*

[1] A. F. Psaros, I.A. Kougioumtzoglou, I. Petromichelakis, Sparse representations and compressive sampling for enhancing the computational efficiency of the Wiener path integral technique, Mechanical Systems and Signal Processing, 111 (2018) 87–101

Wiener path integral based response determination of structural systems subject to stochastic excitations modeled via fractional order filters

Friday, 21st June - 11:45: MS83 - Computational Methods for Stochastic Engineering Dynamics & SHM; Part 2 (Ramo (371)) - Oral - Abstract ID: 777

Ms. Maria Katsidoniotaki (Columbia University), Mr. Apostolos Psaros (Columbia University), Dr. Alberto Di Matteo (Università degli Studi di Palermo), Prof. Ioannis Kougioumtzoglou (Columbia University), Dr. Antonina Pirrotta (Università degli Studi di Palermo)

The Wiener path integral (WPI) technique has proved to be a reliable tool for determining the stochastic response of a diverse class of dynamical systems subject to various kinds of excitations modeled as non-Gaussian, non-white and non-stationary stochastic processes [1]. Nevertheless, in many cases the need for increasingly sophisticated modeling of excitations has led recently to the utilization of fractional calculus, which can be construed as a generalization of classical calculus yielding enhanced modeling capabilities. An indicative example relates to a recent enhancement, based on a fractional-order filter, of the widely used in earthquake engineering Kanai-Tajimi seismic excitation power spectrum for circumventing certain limitations of the original standard model [2]. Motivated by the above developments, the WPI technique is extended herein to account for stochastic excitations modeled via fractional-order filters. Several numerical examples are considered, while comparisons with relevant Monte Carlo simulation data demonstrate the reliability of the technique.

[1] Psaros A. F., Brudastova O., Malara G., Kougioumtzoglou I. A., "Wiener Path Integral based response determination of nonlinear systems subject to non-white, non-Gaussian, and non-stationary stochastic excitation." Journal of Sound and Vibration 433 (2018): 314-333.
[2] Alotta, G., M. Di Paola, and A. Pirrotta. "Fractional Tajimi–Kanai model for simulating earthquake ground motion." Bulletin of earthquake engineering 12.6 (2014): 2495-2506.

Efficient bridge lifetime assessment by traffic load model updating and Subset Simulation

Friday, 21st June - 10:30: MS89 - Bayesian Inference in System Identification: Efficient Algorithms and Applications (Steele 102 (130)) - Oral - Abstract ID: 309

Dr. Stephen Wu (The Institute of Statistical Mathematics), Dr. HeQing Mu (South China University of Technology), Mr. Han-Teng Liu (South China University of Technology)

We demonstrate a proof-of-concept study on efficient bridge lifetime assessment using limited amount of traffic load data. Conventional approach fits a standard distribution, such as a normal distribution, with observed traffic load effect in a given period. Then, the distribution is used to predict future traffic load effect, leading to the final lifetime assessment of a bridge. As the reliability estimation of a bridge depends heavily on the rare traffic load effect events, the conventional approach is inefficient and inaccurate for practical purposes. We propose a more effective use of the traffic load data using a better bridge reliability assessment framework. Our framework involves two steps: (1) a traffic load simulation model trained by real data, and (2) reliability estimation of the bridge based on the inferred traffic load model. A reliable simulation model can guarantee the supply of sufficient data for accurate reliability assessment. To further improve the efficiency of our algorithm, we employ the popular subset simulation method to estimate extremely small failure probability values. The proposed framework is validated the simulated examples.

Bayesian system identification based on an adaptive sequential Markov chain Monte Carlo method

Friday, 21st June - 10:45: MS89 - Bayesian Inference in System Identification: Efficient Algorithms and Applications (Steele 102 (130)) - Oral - Abstract ID: 467

Dr. Jia-Hua Yang (Department of Disaster Mitigation for Structures, College of Civil Engineering, Tongji University), Dr. Heung Fai Lam (Department of Architecture and Civil Engineering, City University of Hong Kong)

This paper studies the problem of system identification, i.e., identifying accurate mathematical models of dynamic systems based on measured data. To explicitly address uncertainties due to measurement noise and modeling errors, system identification is formulated as a Bayesian inference problem. The objective is to identify the posterior PDF of uncertain model parameters conditional on measured data. A newly developed adaptive sequential Markov chain Monte Carlo method is applied to identify the complicated posterior PDF in a high-dimension parameter space. By adaptively constructing sampling in multiple levels, the proposed method can efficiently handle unidentifiable problems, where the posterior PDF is distributed in the neighborhood of an extended and usually highly complex manifold of the parameter space that cannot be calculated explicitly. This feature is important as in practice measured data is limited and unidentifiable problems are common. Experimental case studies show that the proposed method can reasonably quantify the posterior uncertainties and can handle damage detection for unidentifiable problems.

EVALUATING THE NON-LINEARITY OF RAILWAY BALLAST USING BAYESIAN FRAMEWORK

Friday, 21st June - 11:00: MS89 - Bayesian Inference in System Identification: Efficient Algorithms and Applications (Steele 102 (130)) - Oral - Abstract ID: 610

Mr. Mujib Olamide Adeagbo (Department of Architecture and Civil Engineering, City University of Hong Kong), Dr. Heung Fai Lam (Department of Architecture and Civil Engineering, City University of Hong Kong)

Non-linearity in the mechanical properties of engineering materials with discrete particles is well-established. Hence, for proper evaluation of the stiffness and resilience of the ballast layer in railway tracks, it is essential to adequately represent this phenomenon in structural models. For structural health monitoring of railway tracks, misrepresenting or neglecting the non-linearity phenomenon will result in over- or under-estimation of the stiffness and stress to which the ballast under a sleeper section is subjected; leading to an inefficient track health evaluation. The investigations reported in this paper were carried out on an indoor rail track panel under laboratory conditions, by an impact hammer test. To ensure that the developed model is able to capture the real behavior of damaged ballast, ballast damage was artificially simulated under a section of the sleeper using smaller-size ballast. A simple model of the track was utilized, by modelling individual sleeper as a beam on a continuous non-linear spring series, which represents the ballast. For model updating purpose, a MCMC- based Bayesian algorithm was employed to identify the model parameters and quantify their uncertainties, using acceleration data collected at thirteen sensors installed along the considered sleeper. Six well-known empirical models for rigid/plastic materials are considered in modelling the behavior of the non-linear spring series; and the Bayesian model class selection method is used to evaluate the most plausible model class for capturing the mechanics of the ballast particles. The selected model class will be useful in future research works on more accurate ballast damage methodologies.

A Bayesian method for sequential compressive sensing

Friday, 21st June - 11:15: MS89 - Bayesian Inference in System Identification: Efficient Algorithms and Applications (Steele 102 (130)) - Oral - Abstract ID: 618

Prof. Yong Huang (Harbin Institute of Technology), Prof. Jim Beck (California Institute of Technology), Prof. Hui Li (Harbin Institute of Technology)

Bayesian compressive sensing has attracted substantial interest in recent years for reliably and robustly reconstructing sparse high-dimensional signals from much smaller number of compressive sensing measurements. However, online tracking of sparse changing signals is not well understood. The focus in this study is the sparse Bayesian learning framework to impose sparseness in the signal models, but, in addition,we would like our model to capture the evolution of the sparse signal changeswith shared "common sparseness", i.e., the sparse signal changes between twosuccessive time instants are also sparse. To this end, we present a hierarchical Bayesian model for the problem of sequential compressed sensing and develop a method to recursively estimate the marginal posterior distribution of the signal model parameter vector for each time, where the two sparseness constraints mentioned above are also effectively incorporated. We will show our model of the sparse dynamic system can be represented as aconditionally-linear Gaussian state space model for the signal model parametervectors, leading to some interesting analytical properties of the method, as many quantities of interest can be calculated by using Kalman filtering equations. The measurement and state prediction error parameters (noise parameters) will be learned solely from the available data up to the current time and so this method can resolve the well-known instability problem of Kalman filter due to arbitrary assignment of the noise parameters. Finally, illustrative examples will be presented.

Particle Filtering Strain-Based Crack Localization

Friday, 21st June - 11:30: MS89 - Bayesian Inference in System Identification: Efficient Algorithms and Applications (Steele 102 (130)) - Oral - Abstract ID: 647

Mr. Charilaos Mylonas (ETH Zurich, D-BAUG, IBK), Prof. Eleni Chatzi (ETH Zurich)

Vibration-based techniques often fall short of the task of precise damage localization. That is due to the fact that localized damages have a limited effect on global modal characteristics. On the other hand, the smallest of cracks, cause localized strain concentrations with predictable spatial configurations. Therefore strain is potentially a much more effective measure for localizing cracks.

The strain effect around the cracks is load orientation dependent. In this work, we focus on the fact that varying linearly independent load conditions will produce different strain patterns around the crack. Building upon our related recent work, we propose a methodology to incorporate, rather than correct for, the varying load conditions in the crack localization problem. An often overlooked but of central role issue of particle filtering is the choice of proposal distribution. In this work, we propose a method to learn a good proposal distribution for the crack detection problem directly from simulated data, through emerging deep learning techniques.

Operation modal identification of a two-coupled wall structure following a Bayesian approach

Friday, 21st June - 11:45: MS89 - Bayesian Inference in System Identification: Efficient Algorithms and Applications (Steele 102 (130)) - Oral - Abstract ID: 667

Dr. Jun Hu (Department of Architecture and Civil Engineering, City University of Hong Kong), Dr. Heung Fai Lam (Department of Architecture and Civil Engineering, City University of Hong Kong), Mr. Yimin Lin (Department of Architecture and Civil Engineering, City University of Hong Kong)

This paper presents a comprehensive study on ambient vibration test and modal identification of a two-coupled wall structure. The building consists of two student residence halls with different heights. The two residence halls are not straightly aligned, and are rigidly connected by a corridor. With only six sensors, a multi-setup measurement plan was carefully planned to obtain the time-history data. To avoid the disturbance of test on the normal operation of the building, the measurement was mainly carried out inside the three staircases of the structure. Two additional setups were set on the 9/F of the building to capture the torsional behavior the building as well as to connect the mode shape information in different staircases. The fast Bayesian FFT method was adopted to extract the modal parameters from ambient vibration test data. Based on the obtained measurement data, several horizontal modes were identified. The identified modal parameters are analyzed and discussed in details. This study provides valuable experience and information for practical implementation of Bayesian modal identification method.

Obstruction-Invariant Indoor Occupant Localization Using Footstep-Induced Structural Vibration

Friday, 21st June - 10:30: MS94 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 681

Mr. Mostafa Mirshekari (Carnegie Mellon University), Mr. Jonathon Fagert (Carnegie Mellon University), Dr. Shijia Pan (Carnegie Mellon University), Prof. Pei Zhang (Carnegie Mellon University), Prof. Hae Young Noh (Carnegie Mellon University)

Step-level indoor occupant localization is important in many smart building applications including space utilization and healthcare. Current sensing approaches for occupant localization (including vision-based, pressure-based, and mobile-based) have limited success due deployment constraints including privacy, sensor density or on-body devices. To overcome these limitations, we have introduced sensing occupants through footstep-induced floor vibrations in our prior work. These footsteps result in floor-vibration waves which travel through the floor and reach different sensors at different times. Our prior work uses this Time-Difference-Of-Arrival (TDoA) of the waves between sensor pairs to locate the occupants. This approach, although accurate in open spaces, is not reliable in cluttered indoor settings where obstructions such as walls or furniture are present because of the waveform distortions caused by these obstructions.

In this work, we characterize the effects of obstructions on wave propagation to enable accurate footstep-induced vibration-based occupant localization in cluttered indoor settings. The main challenge is that when the wave passes through an obstruction, its waveform distorts which results in errors in TDoA estimation and, consequently, in occupant localization. One of the main sources of this distortion is that the obstruction-induced attenuation rate of the wave varies across different frequency components. We 1) decide whether the wave has passed through an obstruction by characterizing the frequency-dependent attenuation, and 2) choose the frequency components which are less distorted by the obstruction for localizing the footsteps. We validate our approach through both controlled (i.e., lab settings) and uncontrolled experiments using weights, furniture, and walls as obstructions.

Vibration source characterization for human gait health monitoring using footstep-induced floor vibrations

Friday, 21st June - 10:45: MS94 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 845

Mr. Jonathon Fagert (Carnegie Mellon University), Mr. Mostafa Mirshekari (Carnegie Mellon University), Dr. Shijia Pan (Carnegie Mellon University), Prof. Pei Zhang (Carnegie Mellon University), Prof. Hae Young Noh (Carnegie Mellon University)

We present a method for characterizing vibration sources on building floor structures to separate phases of human gait for gait health monitoring. Detailed inter-foot gait information (i.e. heel vs. toe floor interaction, contact time, etc.) is critical for diagnosis of gait disorders, diseases (e.g. Cerebral Palsy), and for elderly fall risk assessment. By characterizing the frequency content of footstep-induced structural floor vibrations, we can passively acquire detailed inter-foot gait information in a sparse and non-intrusive manner. This enables monitoring in home environments, which improves on current approaches (including direct observation and sensing techniques) with operational restrictions such as dense sensor deployment and line of sight requirements. Our intuition is that footsteps generate vibrations in the floor structure, and these vibrations contain information about the footstep-floor interaction and gait characteristics. The primary research challenge addressed in this work is that floor vibration signals are a mixture of responses from the heel contact of one foot and the toe push-off of the opposite foot, making isolation of individual effects difficult. We overcome this challenge by modeling the heel and toe floor interactions as independent excitation sources, characterizing the frequency spectrum of each source, and sequentially performing change point detection to isolate each spectral component. We then use these separated signals to estimate detailed inter-foot gait information. We validate our approach by conducting real-world walking experiments with multiple people in different structures across several walking styles and speeds.

Model Updating for Performance Assessment of a Building in Mexico City Using Post-Earthquake Ambient Vibration Measurements

Friday, 21st June - 11:00: MS94 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 760

Dr. Pei Liu (Beijing Jiaotong University/Tufts University), Mr. Mario Ortega (University at Baffalo), Dr. Babak Moaveni (Tufts University), Dr. Andreas Stavridis (University at Baffalo), Dr. Richard Wood (The University of Nebraska-Lincoln)

This study is focused on Bayesian finite element model updating of a 16-story building in Mexico City after the 2017 Puebla earthquake on 19 September 2017 with a magnitude of 7.1. A group of the authors visited the building and collected ambient vibration measurements in October 2017 and January 2018 following the earthquake. The building was instrumented with 20 sensors measuring its ambient acceleration response in two horizontal directions in opposite corners. A two-stage Bayesian model updating method, including the fast Bayesian FFT modal identification approach and the Bayesian inference, is used for model parameter estimation. Modal parameters statistics including their most probable values and uncertainties are identified in Stage I. The estimated most probable values and uncertainties are used in Stage II for inferring the structural parameters. A global optimization method based on subset simulation is proposed to be used to find the most probable values of the model parameters. The posterior covariance matrix of the model parameters is approximated as the inverse of the Hessian matrix evaluated at the most probable values. The updated model parameters are compared with the observed damage to evaluate the performance of implemented updating approach for performance assessment.

Quantifying and Managing Uncertainties in Subsurface Infrastructure Mapping and Assessment

Friday, 21st June - 11:15: MS94 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 1081

Dr. Dylan Burns (University of Vermont), Mr. Dan Orfeo (University of Vermont), Mr. Yan Zhang (University of Vermont), Mr. Mauricio Pereira (University of Vermont), Prof. Tian Xia (University of Vermont), Prof. Dryver Huston (University of Vermont)

Subsurface infrastructure includes buried utilities, tunnels and foundations. Even though much of this infrastructure is vital to modern society, much of the information regarding location and condition is uncertain. The uncertainty drives up the costs and delays routine construction, emergency repairs and urban planning. The digitization of subsurface infrastructure information through combinations of digital 3-D mapping, geophysical sensors, internet of things sensors and internal robots provides a way forward in quantifying and reducing this uncertainty. This presentation will describe the use of geophysical sensors, such as ground penetrating radar, low-frequency magnetic sensing and acoustic pipe locating, coupled with above-ground 3-D surface maps from optical sensors for localization to create 3-D maps of subsurface infrastructure with the intent of dramatically reducing the location uncertainty. Ground truth measurements from construction operations and comparisons with conventional utility maps provide data for uncertainty quantification. Similarly, but more uncertain, is the condition assessment of the subsurface infrastructure. Concerns include pipe material, pipe wall thickness, leaks, propensity to fracture, and the source of missing water. Presented will be data on some of the uncertainties in the condition assessment of the subsurface infrastructure and the use of sensors and related digital tools to reduce the uncertainty.

A Hierarchical Bayes Inversion Method for Characterization of Soil Properties Using Surface Wave Measurements

Friday, 21st June - 11:30: MS94 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 593

. Mehdi M. Akhlaghi (Tufts University), Dr. Babak Moaveni (Tufts University), Dr. Laurie G. Baise (Tufts University)

In this paper, a hierarchical Bayesian inversion framework is developed for site characterization using the surface wave measurements. To achieve this objective, synthetic sensor data is calculated using the general wave propagation theory. The sensor data is polluted with random noise to simulate the real-life scenario. Dispersion curves and H/V spectral ratios are calculated using the noisy synthetic sensors. The computed dispersion curves and H/V spectra together with their estimation uncertainties are used for the site characterization through the proposed inversion process. The hierarchical Bayesian inversion process will then provide the optimal values of soil parameters at different depths and their estimation uncertainties. The updating soil parameters and error functions (including phase velocity error function and eigenfrequency error function) are assumed to follow a Gaussian distribution and mean and covariance matrix of the probability distribution are updated as hyperparameters. This framework lets us consider the noise in the sensors and the uncertainties in the model which makes it a more realistic approach in dealing with actual sensor measurements and simplified modeling assumptions in practical applications.

Sparse Bayesian Learning and Model Reduction for Robust Structural Damage Identification

Friday, 21st June - 11:45: MS94 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification; Part 2 (Kerckhoff 119 (174)) - Oral - Abstract ID: 601

Prof. Jian Li (University of Kansas), Dr. Parisa Asadollahi (University of Kansas), Prof. Yong Huang (Harbin Institute of Technology)

Structural damage to civil engineering structures is intrinsically a local phenomenon and generally occurs at a limited number of locations. Such a prior knowledge of the sparse nature of damage can improve damage identification results. In the meantime, the ability to account for uncertainties is also critical to achieving reliable results. The uncertainties may come from measurement noise, modeling errors, and limited sensing information. To this end, Sparse Bayesian Learning (SBL) that employs the concept of Automatic Relevance Determination (ARD) to automatically promote sparseness in the posterior distributions of damage parameters is employed to identify and quantify structural damage using limited and incomplete modal information. In particular, to alleviate the ill-conditioning in the estimation of system modal parameters due to limited sensors as well as the unmeasurable rotational Degree of Freedoms (DOFs), model reduction techniques such as static condensation and iterated improved reduced system (IIRS) technique are employed to condense out the unmeasured DOFs from the system model, ensuring convergence in system modal parameter estimation. Subsequently, a two-stage SBL-based damage detection algorithm is proposed, in which the first stage estimates system modal properties with the incomplete modal data, and the second stage identifies the damaged elements by promoting model sparseness through SBL. The proposed method is validated through the finite element model of a long-span cable-stayed bridge using simulated noisy modal data.

Increasing Resiliency and Durability of Bridge Columns with UHPC

Friday, 21st June - 10:30: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 78

Mr. Dovlet Akyniyazov (University of Southern California), Dr. Bora Gencturk (University of Southern California), Mr. Hadi Aryan (University of Southern California)

Ultra-high performance concrete (UHPC) is characterized by very high compressive strength (exceeding 150 MPa), high toughness and reduced porosity (or high durability). In this study, UHPC is proposed to improve multi-hazard performance; namely, resistance to chloride attack and seismic loading of bridge columns. Two large-scale columns, one conventional reinforced concrete and another reinforced UHPC are built and tested under simulated seismic loading. Their performance is compared in terms of stiffness, strength, ductility and energy absorption. Additional material testing is performed to characterize the mechanical and durability properties of both materials. In addition to the conventional cylinder compression and split tensile tests, direct tension testing of dog bone shaped specimens and fracture energy tests of prisms are performed. Durability properties are measured using chloride penetration and electrical resistivity tests.

Resilience Assessment: Methods and Implementation

Friday, 21st June - 10:45: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 175

Prof. Elsayed Elsayed (Rutgers University)

In this presentation, we consider a critical system with dependencies between multiple units and interdependencies where there are bidirectional links between several units. We intend to investigate a concept of a generic method for resilience assessment under natural hazards and manmade hazards (such as cyber-attack). The aim is to address critical units in the system and approaches to improve its resilience via redundancy when applicable and allocation of proper resources during the recovery process to achieve an acceptable functioning threshold of the overall system. The analytical method is composed of three major components: 1. Development of a failure distribution function that considers multi-hazards at different threat levels to determine the severity of the interruption of operations and represent the infrastructure as network with nodes and arcs 2) Development of a resilience importance measure for each node and arc in the network by considering the effect of its failure on the overall system performance 3) Development of models for failure recovery to attain a specified threshold functioning of the system's nodes and arcs to achieve the overall system recovery level.

Temporal Network Model for Resilience-based Management of Mega-Infrastructure Construction Projects

Friday, 21st June - 11:00: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 237

Mr. Ahmed Gondia (McMaster University), Prof. Wael El-Dakhakhni (McMaster University)

Construction sites of infrastructure mega-projects are inherently risky working environments as they accommodate a wide-ranging assortment of contractors with tasks that are cross-disciplinary, interdependent and successive. Without proper coordination, errors and/or delays could propagate through these contractors' complex series of interdependent work scopes hindering project performance (e.g. through time over-run and surpassing original budgets), thus giving rise to claims and disputes. The aim of this paper is to utilize temporal network theory to model the interrelated nature of the numerous contractors interacting within construction project sites in order to facilitate the coordination and adaptation of their interdependent work tasks both spatially (i.e. based on physical site location) and temporally (i.e. as the project progresses), thus ensuring the overall project resilience to interdependence-induced risks. First, work scope interdependencies of contractors working concurrently in various site locations are modeled through a series of network topologies. Second, temporal networks are generated to represent the variance of these interdependencies over the entirety of the project lifecycle. Third, further dynamic analyses are undergone to identify critical contractors with the highest influences on disrupting work flows at different project time stages. Fourth, preventive measures are taken against the cascade of interdependence-induced work flow disruptions across the networks of contractors. Finally, key project performance indicators, tracked throughout intermittent time stages, are correlated with the temporal networks' topologies to assess interdependence-induced project vulnerability, and subsequently enhance project resilience.

Quantifying Resilience of Power Infrastructure Systems, One "R" at a Time

Friday, 21st June - 11:15: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 465

Mr. Eric Goforth (McMaster University), Dr. Mohamed Ezzeldin (McMaster University), Prof. Wael El-Dakhakhni (McMaster University), Dr. Lydell Wiebe (McMaster University)

Power infrastructure is the backbone on which all nations critically rely to ensure the functionality of most other infrastructure systems. Weather-related hazardous events regularly cause catastrophic damage to power infrastructure, disrupting the critical power service provided to communities, with estimated costs between $18 to $33 billion annually from 2003-2012. Although several research studies have focused on determining power grid resilience metrics under different hazardous weather events, only a limited number of studies have adopted Multi-Agent Simulation (**MAS**) as a method to quantify power infrastructure resilience. The four "R's" of resilience are *Robustness*, *Redundancy*, *Resourcefulness*, and R*apidity*. To demonstrate the applicability of MAS to quantifying resilience, this paper will show how it can be implemented as a computational and visualization tool to quantify the resourcefulness demand of power infrastructure under hazardous event scenarios. This work incorporates a case study in Ontario, Canada, where a hazardous weather event is modeled, and the resourcefulness demand metric is tracked to determine the resources required to restore the transmission infrastructure function. This study is a first step towards using artificial intelligence and intelligent system simulation tools to quantify the resourcefulness demand of power infrastructure based on the impacts of hazardous events.

Data Analytics Applications for Power Infrastructure Resilience under Meteorological Hazards

Friday, 21st June - 11:30: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 682

Ms. May Haggag (McMaster University), Dr. Ahmad Siam (McMaster University), Prof. Wael El-Dakhakhni (McMaster University), Prof. Hassini Elkafi (McMaster University)

Increased severity and frequency of climate change-induced hazards including hydrological-, meteorological-, and climatological hazards is affecting the resilience of critical infrastructure systems (CIS) globally. Canadian insurers are facing natural hazard-induced claims at the rate of approximately $1-billion annually, whereas it was closer to $400-million annually in the previous decade. Moreover, annual national liabilities of the Disaster Financial Assistance Arrangements have increased from around $100-million annually in late 1990s to $500-million in 2009-10 and reached approximately $2-billion in 2013-14. To maintain their basic functionalities, Canadian cities have to maximize the resilience of their CIS in the face of natural hazards. In this context, resilience can be defined as the ability of city's CIS to bounce back to their initial performance following hazardous events. Unfortunately, these systems are highly interdependent, which further complicates their response and increases their vulnerability. In their previous work, the authors proposed a framework to quantify city resilience by implementing machine learning techniques. The framework focused on historical power outages, outlined their different causes, and showed that meteorological hazards are the main cause of power outages in North America. Subsequently, the aim of this paper is to integrate meteorological hazards data with electric power infrastructure in an attempt to quantify system vulnerability, and thus enhance its resilience under such hazards. This paper is considered as a step in integrating future meteorological hazards, based on climate change models, with electric power infrastructure performance metrics, in an attempt to maximize power infrastructure resilience and mitigate interdependence-induced risks to other CIS.

Challenges Facing Additive Construction to Fabricate Rapid Resilient Structures

Friday, 21st June - 11:45: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 1 (Firestone 384 (76)) - Oral - Abstract ID: 718

Dr. Hunain Alkhateb (The University of Mississippi), Dr. Hatem Almaseid (The University of Mississippi), Mr. Hashem Almashaqbeh (The University of Mississippi), Prof. Ahmed Al-ostaz (The University of Mississippi), Dr. Jennifer Edmunson (ESSCA Technical Fellow in Science and Optics Jacobs Technology/NASA-Marshall), Mr. Michael Fiske (Jacobs Space Exploration Group/NASA-Marshall)

Besides the extraterrestrial applications, semi-autonomous construction is becoming an emerging technology that is facilitating opportunities in the construction industry by reducing labor costs and materials waste and increasing the reliability of rapid infrastructure construction. Robotic arms have been used to automate casting of concrete into formwork and computer-controlled gantry cranes, similar to Additive Construction with Mobile Emplacement (ACME) systems at Marshall Space Flight Center (MSFC), have been adapted to deposit material in layer upon layer fashion. Automated construction (AC) optimization goals include: 1) building taller wind towers to access higher energy winds, 2) enabling cost-effective design strategies by precise control of materials, 3) facilitating intricate architectural designs, and 4) providing tools for repairing structural elements in hard to reach areas, such as during deep space missions. In a human-made or a natural disaster event, additive construction can provide shelter to in-need communities; this technology will become the primary emergency rescue application that will deliver reliable relief aid in extreme events around the world. In the very near future, it will become the go-to technology for providing resilient infrastructures during and after disastrous events. In this study, we are addressing some of the challenges facing the AC technology for assembling rapid resilient structures.

21st-Century Hurricane-Induced Flood Hazards and Mitigation for Jamaica Bay, New York

Friday, 21st June - 10:30: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 2 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 884

Prof. Reza Marsooli (Stevens Institute of Technology), Prof. Ning Lin (Princeton University), Ms. Rennie Jones (Princeton University), Prof. Guy Nordenson (Princeton University)

Low lying areas surrounding Jamaica Bay – a large lagoonal estuary in New York City – accommodate some of the most populous coastal communities in the nation, yet they are highly vulnerable to flooding especially due to tropical cyclones (TCs) as exemplified during Hurricane Sandy in 2012. In the coming decades, the level of vulnerability of these communities to flood hazards is expected to increase in response to sea level rise (SLR) and changes in the intensity and frequency of TCs. This study investigates the impacts of SLR and TC climatology change on flood hazards in Jamaica Bay and its floodplains. We utilize a probabilistic approach to estimate flood return periods in Jamaica Bay for the late-20th, mid-21st, and late-21st centuries (under the emission scenario RCP8.5). The return periods are estimated using the extreme value theory and combining probabilistic estimates of SLR and synthetic TC storm tides simulated by a basin-scale hydrodynamic model. We implement a high-resolution local-scale hydrodynamic model to simulate flooding over the bay's floodplains. Changes in the extent of flooding and the height of wind waves are estimated for different scenarios of SLR. We also propose and evaluate a series of tidal and storm surge barriers to protect the densely populated neighborhoods located on the east side of the bay.

Risk-based Robust Decision Making for Climate Adaptation of Deteriorating Coastal Bridges

Friday, 21st June - 10:45: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 2 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 911

Dr. David Yang (Lehigh University), Prof. Dan Frangopol (Lehigh University)

Coastal bridges are susceptible to substantial threat from corrosion and hurricanes. Future climatic and socioeconomic changes can further amplify this threat due to the increasing frequency and intensity of hurricanes as well as growing exposure and consequences to adverse events. Future conditions of these changes involve deep uncertainties such as the complexity of climatic and socioeconomic systems and the ambiguity of future policy scenarios. In order to perform decision-making under deep uncertainty, a novel approach is proposed to identify the critical scenarios of bridge and environmental conditions that could lead to unacceptable life-cycle risk. Various factors including temperature increase, sea level rise, and hurricane frequency and intensity are considered using the methodologies originated from robust decision making. By using Latin hypercube sampling, the entire space of relevant factors and their associated life-cycle risks are explored. An unacceptable risk level is derived from the threshold reliability index of existing structures and the associated failure consequences. Based on the simulation of bridge risks in different future scenarios, advanced analysis tools including feature scoring, scenario discovery, and dimensional stacking are utilized to identify driving forces of bridge vulnerabilities under climate change. The implications associated with the obtained results on decision-making about climate adaptation are also discussed.

Quantification of Community Resilience against Hurricanes through a Distributed Simulation Platform

Friday, 21st June - 11:00: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 2 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 931

Mr. Ahmed Abdelhady (University of Michigan), Dr. Seymour Spence (University of Michigan), Prof. Jason McCormick (University of Michigan)

Resilience quantification is increasingly recognized as a fundamental way to provide a rational basis for planning mitigation strategies that reduce the risks from natural hazards. Realizing how hurricanes have been one of the costliest natural hazards affecting the United States over the past four decades, this work presents a framework to probabilistically quantify resilience of residential communities subjected to hurricanes. After setting resilience goals and their related metrics, direct damage caused by the hurricane is estimated using an engineering-based vulnerability model. The vulnerability model estimates damage due to excessive dynamic wind pressure and impact of windborne debris. Mapping between the level of damage and estimates of building functionality as well as recovery times is achieved using a set of specified performance limit states. This leads to the identification of the recovery path for each building which can then be aggregated to determine the community recovery path. The framework uses a distributed simulation platform, based on Lightweight Communications and Marshalling (LCM) libraries, to model the interdependencies in the damage estimation process. The use of distributed simulation leads to a modifiable and extensible computational platform that enables a seamless collaboration between researchers from different fields and backgrounds. A case study consisting in a typical Florida residential community is presented. By embedding the framework within a Monte Carlo simulation strategy, probabilistic measures associated with the resilience metrics are quantified. This provides a means for decision makers to compare current community resilience with target levels, identify gaps, and set strategies to improve community resilience.

Fragility assessment of power distribution system for resilience hardening

Friday, 21st June - 11:15: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 2 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1162

Mr. Jintao Zhang (University of Connecticut), Mr. William Hughes (University of Connecticut), Dr. Wei Zhang (University of Connecticut), Dr. Amvrossios Bagtzoglou (University of Connecticut)

To address the challenge of power grid asset management and different resilience options, business and engineering constrains such as limited availability of capital, equipment, workers, etc., efficient strategies need to be established to prioritize these resilience hardenings options. In the present study, a data-informed fragility assessment approach is proposed to integrate key parameters and heterogeneous data from multiple sources. At first, based on the database for the physical structures of pole-wire system, finite element models are established as well as their key random parameters and distributions. Secondly, deterministic and empirical fragility functions as well as heuristic and expert judgements are established. Different resilience interventions, stemming from different interdependent disciplines, such as tree trimming, hardening of pole-wire structural systems, improvement of distribution system design, etc., are quantified with performance-based metrics. Sensitivity analysis is performed to evaluate the effects of different fragility curves, such as the physics-based fragility curves, data-driven based fragility curves, and data-informed fragility curves. The training data of various weather data as well as power outage data are based on the various storm events in the state of Connecticut including hurricanes, snow storms and other storm events. After including various failure modes, that might be triggered from various events, such as break of wires, fracture of poles, short circuit from fallen tree branches, etc., cost-based optimization and decision-making are performed to prioritize the resilience options.

Risk assessment of port structures

Friday, 21st June - 11:30: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 2 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 1169

Mr. Marco Maniglio (Politecnico di Torino), Dr. Georgios Balomenos (McMaster University), Prof. Jamie Padgett (Rice University), Prof. Gian Paolo Cimellaro (Politecnico di Torino)

Ports are often in areas prone to storm surge and flooding from severe storms as well as climate change effects, such as sea level rise. Although vulnerability of ports subjected to earthquakes has been widely studied, models that support risk assessment from coastal hazards, including hurricanes, are lacking. This study presents a methodology for fragility analysis of wharf/pier structures typical in port facilities that are subjected to hurricane-induced storm surge and wave loading. Such models enable future risk assessment of these structures when exposed to current or projected storm conditions. The proposed framework utilizes Monte Carlo simulation to estimate variability in loads, geometrical configurations, material properties and capacities associated with different failure modes. A detailed study focuses on aging and deterioration models, considering uniform and pitting corrosion and modifications in materials strength,given several exposure conditions under consideration. Then different statistical learning methods are applied to predict structural behavior and to derive parameterized fragility functions for ready application in regional risk assessment. Finally, the proposed framework is applied to case studies in the Houston Ship Channel, with simulated storm scenarios and realistic metrics.

Extreme Storm Surge Return Period Prediction Using Tidal Gauge Data and Estimation of Damage to Structures from Storm-Induced Wind Speed in South Korea

Friday, 21st June - 11:45: MS68 - Hurricane Hazards, Risk, and Adaptation in a Changing Environment; Part 2 (Gates-Thomas Hall Auditorium 135 (88)) - Oral - Abstract ID: 795

Mr. Sang Guk Yum (Columbia University), Prof. George Deodatis (Columbia University)

Global warming can be expected to have brought consequences into nature and human society directly. The most negative effect of global warming is the rising sea level related to the large typhoons which can cause flooding. This study researches two topics. The first topic is to develop a statistical model to predict the return period of the storm surge related to typhoon Maemi, 2003 in South Korea. To estimate the return period of the typhoon, Clustered Separated Peaks over Threshold (CSPS) has been used and Weibull distribution is used for the peak storm surge height's fitting. The estimated return period of typhoon Maemi's peak total water level is 389.11 years (95% CI 342.27-476.2 years). The second aim is related to the fragility curves of properties to estimate the damage from typhoon Maemi in 2003. In this research, an insurance company provides their loss data caused by the wind speed of typhoon Maemi in 2003. The damage ratios in the loss data and wind speeds are used as the main factor for constructing fragility curves to predict the levels of damage of the properties. With the damage ratios, wind speeds and GIS spatial data, this study constructs the fragility curves with four different damage levels (Level I-Level IV). The findings and results of this study can be basic new references for governments, the engineering industry, and the insurance industry to develop new strategies to cope with climate change.

Adaptive Polynomial Dimensional Decomposition Based on f-index for Stochastic Topology Optimization

Friday, 21st June - 10:30: MS107 - Advances in Computational Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 894

Prof. Xuchun Ren (Georgia Southern University)

Adaptive algorithm for polynomial dimensional decomposition (PDD) often involves importance measure for truncation parameters. For moment-based uncertainty analysis, a well-known importance measure is the Sobol index, which represents the contribution of an component function to the total variance. When applying to reliablility analysis, the adaptive algorithm based on Sobol index may produce inefficient or inaccurate truncation due to it reflects only the second moment not the probability density function (PDF) of the random output. This article present an adaptive algorithm for PDD based on -*index reflecting change of the PDF functions. Numerical examples indicate that the new method developed provides computationally efficient solutions.*

Sensitivity analysis and parameter optimization for acoustic cloaking in coupled fluid – structure systems

Friday, 21st June - 10:45: MS107 - Advances in Computational Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 1398

Mr. Harisankar Ramaswamy (University of Southern California), Mr. Saikat Dey (Naval Research Laboratory), Prof. Assad Oberai (University of Southern California)

Development of efficient computational techniques for computing the sensitivity of the quantity of interest with respect to material and geometric parameters is important in design optimization. In this work, we use adjoint equation based finite element formulation to compute the sensitivity for a coupled fluid – structure acoustic system, there by laying the ground work for solving the cloaking problem for such systems. The solution to the forward problem is obtained by solving the elasticity equations in the solid domain and the Helmholtz equation in the fluid domain in the presence of time harmonic excitation. Viscous effects in the solid and the fluid are modeled by considering complex elastic moduli. Both forward and adjoint problems are implemented in Multiphenics, an open source finite element package. The solution of the primal and adjoint problems is verified using the method of manufactured solutions, and the computation of the sensitivity is verified using the so-called Taylor test. Finally, some simple examples of cloaking problems are presented to demonstrate the applicability of this approach.
Keywords – Fluid-Structure Acoustics, Finite Element Method, Sensitivity analysis, Topology Optimization, Acoustic Cloaks, Multiphenics.

Implicit SPH for incompressible fluid simulations in LS-DYNA

Friday, 21st June - 11:00: MS107 - Advances in Computational Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 885

Dr. Edouard Yreux (LSTC)

An implicit SPH formulation for incompressible fluid simulations is presented. This method was recently developed in LS-DYNA for fluid-structure impacts, such as water wading simulations for the automotive industry, and is based on a traditional projection scheme. Intermediate velocities are first predicted based on external and viscosity forces contribution, and a Poisson equation is then solved to obtain pressure forces such that incompressibility is maintained up to a given tolerance. Various numerical examples are presented to illustrate the capability of the method to handle relatively large models in a reasonable time, and with acceptable memory requirements.

Limitations of Nonlinear Analytical Models for Computational Substructures for Real-Time Hybrid Simulation

Friday, 21st June - 11:15: MS107 - Advances in Computational Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 583

Ms. Elif Ecem Bas (University of Nevada, Reno), Dr. Mohamed Moustafa (University of Nevada, Reno)

Hybrid Simulation(HS) is a well-established testing method that has been used for decades to evaluate the seismic response of structural components and full systems.However, extending HS capabilities to wide range of applications under seismic or other hazards can pose new challenges.One potential application of HS is selecting the best retrofit strategies.For instance, conventional HSS braces or Buckling Restrained Braces(BRBs) can be used as seismic retrofit components.In an HS setting, existing buildings could be represented with the computer model and braces could be the experimental substructure.However, older buildings might exhibit lower strength or limited ductility and could go nonlinear with the retrofit.This example among others highlights the need for robust ways of incorporating nonlinear computational models into HS frameworks.The real challenge is when the tested substructures are rate-dependent or there is a need for real-time HS(RTHS) along with the nonlinear computational substructures.The objective of this study is to evaluate the computational limitations when the computational models involve nonlinear material behavior.A parametric study is conducted to evaluate computational performance and limitations when nonlinear analytical models are used for RTHS.Steel frames with a varying number of bays/stories,are used and subjected to earthquake loading.Nonlinear columns and beam are modeled numerically,and a small-scale brace is tested physically using a compact HS setup at the UNR.Different computational models with different levels of nonlinearity and DOFs are used to evaluate the computational time for each time step along with any convergence issues for a wide range of solvers, and the findings are summarized under various earthquake scales.

Multiscale Computational Modeling of Bio-Inspired Impact-Resistant Composites

Friday, 21st June - 11:30: MS107 - Advances in Computational Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 958

Mr. Chengping Rao (Northeastern University), Prof. Yang (Emily) Liu (Northeastern University)

The hierarchical structure of the bio-inspired composites can be designed and optimized to exemplify the material's fracture toughness and impact resistance. In this study, we focus on the Bouligand structure in the dactyl club of the smashing mantis shrimp, which is capable of withstanding repetitive high-energy impact from its prey without catastrophic material failure. The Bouligand structure is characterized by a helicoidal arrangement of strong fibers in a weak matrix, an architecture which has high impact resistance and energy absorbance. It is crucial to understand the fundamental resistance mechanism of such an advanced material, in order to inspire and improve the design of the next generation of impact-resistant composites for protection systems such helmets and body armors. To this end, a bottom-up multiscale computational approach is proposed, which explicitly models the hierarchical Bouligand microstructure at the microscale, for predicting the macroscopic mechanical behaviors of bio-inspired composites under high-speed impact loads. The effect of the microstructural arrangements, such as the fiber volume fraction, interlayer spacing and the layer-to-layer pitch angle, on the nonlinear behavior and fracture mechanism of the helicoidal composite is investigated through multiscale analysis. The proposed multiscale modeling framework can be used to aid the design and optimization of the helicoidal bio-inspired composites for lighter, tougher and stronger materials that won't fail under extreme loading conditions.

Simulating Three-dimensional Hydraulic Fracturing within a GFEM Framework

Friday, 21st June - 11:45: MS107 - Advances in Computational Mechanics; Part 2 (107 Downs (71)) - Oral - Abstract ID: 1265

Mr. Nathan Shauer (University of Illinois at Urbana-Champaign), Prof. Carlos Duarte (University of Illinois at Urbana Champaign)

This presentation reports on recent advances of an adaptive Generalized Finite Element Method (GFEM) for the simulation of multiple 3-D non-planar hydraulic fracture propagation near a wellbore. In order to reduce operational cost, hydraulic fractures are often created in stages where multiple fractures are propagated at the same time. This can lead to complex fracture geometries due to interactions and realignment with the *in-situ* stresses. As a result, it is estimated that the majority of the gas and oil production comes from only 20 to 30% of the stages. Computational methods able to predict the near wellbore tortuosity and pressure drop can play a key role in improving the performance of multistage fracturing. The GFEM is particularly appealing for simulating problems with fractures since it does not require the finite element mesh to fit fracture faces. Furthermore, analytical asymptotic solutions are used to enrich the GFEM approximation near fracture fronts, leading to more accurate solutions than in the standard FEM. In this work, the rock is assumed to behave as an isotropic 3-D elastic medium and the fluid inside of the fracture is modeled with the lubrication theory. Fracturing fluid leak-off is considered with Carter's model. Conservation of mass is shown to be well satisfied even though mesh adaptivity is performed in order to capture the multiscale features and singularities of the solution. The proposed methodology is verified against analytical solutions and validated with experimental results for both planar and non-planar fracture geometries.

Application of the Work Potential Theory to the Material Characterization of Concrete

Friday, 21st June - 10:30: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 1356

Dr. Kenneth Walls (University of Alabama at Birmingham), Dr. Kevin Schrum (University of Alabama at Birmingham)

This work investigates the applicability of Schapery's Work Potential Theory (WPT), a constitutive viscoelastic continuum damage model, to concrete over a wide range of loading conditions. The WPT is based on the premise that the amount of work applied to a material is equal to the sum of the recoverable work (via recoverable strain energy) and the energy lost by permanent damage (such as plasticity and cracking). The damage in a structure depends on previous damage states. Therefore, the WPT is ideally suited for evaluating the residual capacity of a concrete structure after being subjected to extreme loading conditions, such as impact or blast. Knowing the parameters that govern the strength capacity of the concrete, such as aggregate size, the WPT can calculate the extent of damage from a single loading event, which can then be used to determine how much energy the structure can absorb on subsequent impacts. This work will extend the WPT to concrete by using data obtained from the the U.S. Army Engineer Research and Development Center (ERDC) to identify relevant damage parameters.

Numerical Approaches for Calculating the Shape and Velocity of an Explosively Formed Projectile (EFP)

Friday, 21st June - 10:45: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 545

Mr. John Puryear (ABSG Consulting Inc.), Mr. Darrell Barker (ABSG Consulting Inc.)

Determining the depth of penetration of an explosively-formed projectile (EFP) into a target requires accurate calculation of both its shape and peak velocity. Penetration depth correlates with specific momentum, a function of presented shape, mass and velocity.

Formation of an EFP entails volumetric expansion of the explosive and extensive plastic flow of the metal liner. Accordingly, two numerical approaches that permit material flow were examined: Arbitrary Lagrangian Eulerian (ALE) and Eulerian finite difference. The ALE calculation was performed in LS-DYNA®, and the Eulerian finite difference calculation was performed in CTH. The approaches were applied to a copper EFP described by Hertel[1], and Hertel's measurements are the basis for comparing the numerical approaches.

For comparison of the EFP shapes calculated by the two approaches, the Jones-Wilkins-Lee (JWL) equation of state (EOS) was used in both calculations for the LX-14 high explosive backing the liner. In addition, both calculations included the Johnson-Cook constitutive model combined with the Gruneisen EOS for the liner and EFP casing.

In this presentation, the approaches for calculating the EFP shape and peak velocity are described. The calculated results are compared to measurements from Hertel. Possible sources for the inaccuracy of the shape calculated using ALE are discussed. Finally, the refinement details included in available equations of state for the LX-14 and their effect on peak velocity are discussed.

[1] Hertel, Eugene S. Jr. SAND92-1879 "A Comparison of the CTH Hydrodynamics Code with Experimental Data." Sandia National Laboratories, Albuquerque, NM, September 1992.

Channeling and shielding effects on wave loading of structures

Friday, 21st June - 11:00: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 761

Prof. Michael Motley (University of Washington), Mr. Andrew Winter (University of Washington), Prof. Marc Eberhard (University of Washington)

Over the past two decades, many significant tsunami events, including Sumatra in 2004, Japan in 2011, and Sulawesi in 2018, have caused widespread devastation to the built environment. To combat this engineers have attempted to improve design provisions, particularly in ASCE 7-16, where a new tsunami load chapter and commentary have been added. However, there is still a need to gain a more general understanding of the variations in flow conditions and fluid loading on a structure that are caused by the presence of neighboring structures. A series of experiments to assess the effects of shielding and channeling caused by surrounding structures was conducted at the NHERI Coastal Wave/Surge and Tsunami Experimental Facility. Results showed that shielding and channeling have significant effects on the flow, including large local pressures acting on subcomponents of the structure. Using the computational fluid dynamics (CFD) solver OpenFOAM, this work presents a parametric study of the effects of the surrounding built environment on a model structure and how changes to the built environment affect structural demands. The model was validated against the experimental results and extended for more general cases. Results show that the CFD approach allows the designer to predict localized pressures and corresponding three-dimensional forcing profiles on a structure or structural component. The datasets is used to develop a force prediction model to modify common hydrodynamic force predictions based on shielding and channeling effects.

A Comparison of NMAP, EPIC and CTH for Modeling Fragment Simulating Projectile Impact on Steel Plates

Friday, 21st June - 11:15: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 784

Dr. Paul Sparks (U.S. Army Engineer Research and Development Center), Mr. Daniel Rios-Estremera (U.S. Army Engineer Research and Development Center), Mr. David Roman-Castro (U.S. Army Engineer Research and Development Center), Dr. Jesse Sherburn (U.S. Army Engineer Research and Development Center), Dr. William Heard (U.S. Army Engineer Research and Development Center)

Protective structures are typically designed to achieve a certain level of protection (LOP) to shield personnel or key assets from fragmenting weapon effects. The penetration of the weapon casing fragments have a high probability of perforating or striking a structure when operating in urban environments where proximity is an inevitable disadvantage. The produced fragments can be represented by a fragment simulating projectile (FSP). This investigation examines the structural response of steel plates when impacted by FSP's with striking velocities in the ordnance regime. The ballistic data produced from these experiments will be compared to three different numerical methods: Nonlinear Meshfree Analysis Program (NMAP) which is a meshless based code which employs reproducing kernel particle methods (RKPM) in a semi-Lagrangian framework, Elastic-Plastic Impact Code (EPIC) which is a Lagrangian finite element code with smooth particle hydrodynamics (SPH) options and CTH which is an Eulerian shock physics based wave code. These numerical codes are advantageous for modeling penetration and perforation problems that predict deformation and fragmentation of the material. The accuracy of each numerical code is assessed and validated against the experimental data. The inherent strengths and weakness of each of the models will be discussed.

Keywords: Projectile Impact, Steel Plates, Constitutive Modeling, Penetration Modeling

* Permission to publish was granted by Director, Geotechnical and Structures Laboratory.

A stable, efficient, locking free hexahedral element for problems in non-linear dynamics

Friday, 21st June - 11:30: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 1267

Dr. Brian Giffin (Lawrence Livermore National Laboratory)

A new fully integrated 8-node hexahedral solid finite element is proposed for general use in non-linear quasi-static and dynamic problems. The element formulation is derived from a mixed/enhanced assumed strain principle, where the chosen enhancements for alleviating volumetric and shear locking are treated separately, leading to increased computational efficiency, as well as improved stability of the element in quasi-static problems. Nonetheless, for use in highly dynamic problems (such as impact), supplementary stabilization of the element is required. To this end, a novel stabilization strategy is proposed which avoids the use of non-physical parameters, and preserves the locking-free behavior of the element. An efficient implementation of the element is developed for the non-linear finite element code DYNA3D, and a number of example problems are shown to demonstrate the superior accuracy and stability of the element for problems involving highly dynamic processes.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

ON THE OPTIMAL DESIGN OF STRESS WAVE ATTENUATORS FOR MITIGATING TRANSIENT IMPULSIVE LOADINGS

Friday, 21st June - 11:45: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 1 (269 Lauristson (104)) - Oral - Abstract ID: 484

Dr. Reza Rafiee-dehkharghani (University of Tehran), Prof. Amjad Aref (University at Buffalo), Prof. Gary Dargush (University at Buffalo)

According to wave propagation theories, the stress wave characteristics change as the wave passes through various discontinuities in the structure. Such discontinuities include domain boundaries, abrupt change in material properties, and general change of the geometry, including the cross section. This concept can be harnessed to design the structures for stress wave attenuation purposes. This paper describes an optimization procedure for the design of collinear and non-collinear stress wave attenuators using the concept of longitudinal waves in rods and flexural waves in Timoshenko beams. The wave propagation analysis in the structures is performed using the finite element method (FEM) as finding the analytical solutions for wave propagation in layered structures with multiple discontinuities is very cumbersome. For optimal design of the structures, a heuristic optimization methodology is used due to the nature of the problem and lack of gradient information. This methodology is based on genetic algorithms (GA), and uses a finite element code in its fitness function. The results of the optimization procedure show that layered collinear structures can be utilized for attenuating the amplitude of transient loadings with high frequencies; however, for small frequencies, the stress wave attenuation in collinear structures is insignificant, while non-collinear structures are rather effective for attenuation purposes.

Experimental study and XFEM fracture analysis on reinforced concrete wedge splitting specimens

Friday, 21st June - 10:30: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 121

Mr. Aiqing Xu (Department of Civil and Environmental Engineering, University of California, Los Angeles), Ms. Xiaoyan Man (Department of Civil and Environmental Engineering, University of California, Los Angeles), Prof. Woody Ju (Department of Civil and Environmental Engineering, University of California, Los Angeles), Prof. Shaowei Hu (Materials & Structural Engineering Department, Nanjing Hydraulic Research Institute)

In this paper, the experimental study and XFEM fracture analysis on reinforced concrete wedge splitting specimens were conducted to study the influences of initial crack-depth ratios on the fracture mechanics parameters of reinforced concrete wedge splitting specimens, and the restraint of steel bars on crack propagation. Our experimental and numerical results indicate that the reinforced concrete wedge splitting specimens can continue to bear external loads after the unstable failure of concrete, and that its bearing capacity is related to the initial crack-depth ratios. For the specimens with larger initial crack lengths, the number of reinforcements should be appropriately increased to improve their bearing capacities and crack resistance. The initial cracking load P_{ini} and unstable fracture load P_{un} of the specimens gradually decrease with the increase of initial crack-depth ratio. Through the increase of initial crack-depth ratios, the critical effective crack length a_c increases linearly, and the subcritical crack propagation length Δa_c shows a decreasing trend. The initial fracture toughness K_I^{ini} is affected by the initial crack-depth ratio, but the unstable fracture toughness K_I^{un} is independent of the ratio. Moreover, when the value of initial crack-depth ratio is 0.3~0.4, K_I^{ini} and K_I^{un} can be regarded as material constants. The fracture parametric results of the XFEM model are in good agreement with the experimental values, which provides an effective approach to study the fracture characteristics of reinforced concrete structures.

Microstructural Damage Characterization and Its Effect on Structural Degradation of Concrete under Freeze-Thaw Action

Friday, 21st June - 10:45: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 196

Dr. Yijia Dong (Hohai University), Prof. Chao Su (Hohai University), Prof. Pizhong Qiao (WSU), Prof. Lizhi Sun (UC Irvine)

Concrete structures in cold region are exposed to cyclic freezing and thawing environment, during which deformation and fracture properties of concrete degrade due to internal damage. In recent years, internal microstructural damage has been observed by three-dimensional X-Ray CT techniques but its mechanical influence to the fracture property is unknown. To gain a deep understand of fracture behavior of concrete damaged by freeze-thaw cycles, the deformation and fracture processes of concrete samples damaged by freeze-thaw cycles in 3-point bending tests were modeled and simulated using micromechanics-based finite element method. Two level meso-to macro-scale finite element model was developed based on X-Ray CT images and realistic micro cracks due to freeze-thaw cycles was taken into account. The load-deflection curves and fracture energies were compared with experimental results and showed satisfactory consistency. Simulation results demonstrated that microcracks are the main reason of decrease of fracture properties.

Localizing gradient damage model with micro inertia for dynamic fracture

Friday, 21st June - 11:00: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 280

Dr. Leong Hien Poh (National University of Singapore)

A localizing gradient damage model with micro inertia effect is proposed for the dynamic fracture of quasi-brittle materials. The objective is to achieve mesh independent solutions, and to avoid spurious effects associated with the conventional nonlocal enhancement. The proposed localizing gradient damage model closely resembles the conventional gradient enhancement, albeit with an interaction domain that decreases with damage, complemented by a micro inertia effect. The tensile loading of a Polymethyl Methacrylate plate is considered. It is shown that the proposed model effectively captures the experimentally observed transition of crack profiles as the loading rate increases, i.e. from a straight crack propagation, to sub-branching, and finally to macro branching. Numerical results in terms of crack patterns, crack velocities, and fracture energies are in good agreement with the experimental data.

Characterization of Composite Material Interfacial Properties Through Multiscale Modelling

Friday, 21st June - 11:15: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 645

Dr. Vincent Iacobellis (University of Toronto), Prof. Kamran Behdinan (University of Toronto)

Fracture in composite materials due to transverse loading is often the result of debonding at the interface between matrix and the reinforcing inclusions. During transverse loading this material interface is subjected to high local stress levels that increase the tendency for damage nucleation to occur near the bonding site. In this study, the interfacial properties across a polymer-graphite interface are carried out using a combined concurrent-hierarchical multiscale modeling approach. Using the bridging cell concurrent multiscale method, which couples atomistic to continuum scales, the work of adhesion and interfacial stress are obtained. These parameters are then fit to a bilinear cohesive zone model of the material interface and used to model material debonding in a composite microstructure RVE. The stiffness, strength, and stress distribution are calculated from this RVE model and compared to experimental results in the literature. Furthermore, the effect of volume fraction and relative spacing of the reinforcing material on the type of crack initiation and propagation from material interface into the matrix is studied.

A micromechanical aspect on damage of an innovative asphalt pavement material featuring high-toughness, low-viscosity nanomolecular resin and its numerical simulations

Friday, 21st June - 11:30: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 85

Mr. Hao Zhang (University of California, Los Angeles), Prof. Woody Ju (University of California, Los Angeles)

To significantly enhance the durability and service life of asphalt pavements, researchers at UCLA have proposed an innovative asphalt pavement material system by adding a low viscosity, high toughness nanomolecular dicyclopentadiene (DCPD, $C_{10}H_{12}$) resin as a microstructural caging binder or reinforcement. After the DCPD resin is infiltrated, cured and hardened under controlled conditions, it will occupy most air voids and form a continuous network of micromechanical "cages" that locally confine asphalt-aggregates, thus considerably increasing the asphalt pavement load bearing capacity under repeated traffic stresses (fatigue and wheel rutting), dramatically enhancing the compressive, shear and tensile loading strengths, effectively anchoring pothole patches with original peripheral pavement walls and pavement sub-bases, minimizing water infusion and favourably serving as a barrier for alligator cracks initiations and propagations.

In this presentation, a three-dimensional micromechanical framework is developed based on micromechanics and continuum damage mechanics to predict the effective elastic- and viscoelastic-damage behaviors of the innovative nanomolecular resin material system under the splitting tension test (ASTM D6931). The theoretical micromechanical predictions are then compared with properly designed laboratory experiments as well as three-dimensional numerical simulations. Furthermore, the behaviors and superior performance of the innovative pavement material system under the high-cycle four-point bending fatigue test (ASTM D7460 and AASHTO T321) and Hamburger rutting test (AASHTO T324) are presented to illustrate the dramatic improvement of its damage resistance capability over currently used pavement materials (Superpave D2 mix).

Mechanics and Mechanisms of Slow Crack Propagation in Brittle Hydrogels

Friday, 21st June - 11:45: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 1 (Lees-Kubota (118)) - Oral - Abstract ID: 1342

Ms. Kimberley Mac Donald (California Institute of Technology), Prof. Guruswami Ravichandran (California Institute of Technology)

Several experiments have reported significant roughening of crack surfaces in brittle hydrogels following slow crack propagation (O(0.1 - 1 mm/s)). These experiments used post-mortem imaging to characterize the extent of roughening as a function of crack speed. Toughening mechanisms including plastic deformations have been suggested as causes of this roughening. We conduct in-situ 2D and 3D imaging using confocal microscopy at an internal plane of very slow crack propagation events (O(0.01 mm/s)) in a thin brittle hydrogel as well as pre- and post-propagation volumetric images of the cracked specimen. We seek to better understand the mechanisms at play in these slow crack roughening events by observing both crack propagation and renucleation. Additionally, we study the crack tip region and crack shape to infer the fracture toughness of the gel. Observations suggest that toughening mechanisms are at play in these surface roughening events and lead to crack arrest followed by renucleation at a “weak” point on the crack surface. We hypothesize that there are two interconnected events at play: The crack is slow enough that the gel “sees” the stress concentrations at the crack tip and water is forced out of the gel while there is also time for viscous elastic and plastic processes to occur.

The Dynamic Failure and Safety Protection of Long-Span Spatial Structures Subjected to Blast Loads

Friday, 21st June - 10:30: MS29 - Advances in Experimental, Analytical and Computational Wind Engineering (103 Downs (50)) - Oral - Abstract ID: 358

Dr. Jialu Ma (Institute of Engineering Mechanics, CEA), Prof. Guibo Nie (Institute of Engineering Mechanics, CEA), Prof. Xudong Zhi (School of Civil Engineering, Harbin Institute of Technology), Prof. Lingxin Zhang (Institute of Engineering Mechanics, CEA), Prof. Feng Fan (School of Civil Engineering, Harbin Institute of Technology)

Long-span spatial structures are always the landmarks in the worldwide because of their special usage functions. Especially, they are treated as emergency shelters after the occurrence of those extreme disasters. Therefore, it is importance to study the dynamic failure and safety protection of long-span spatial structures subjected to blast loads. In this paper, the finite element model (FEM) of a single-layer reticulated dome was created. The structural dynamic responses with the blast loads were simulated by ANSYS/LS-DYNA. A series of key parameters of structure and loading were combined respectively. The effects of these parameters were systemically investigated. The dynamic response and failure of the single-layer reticulated domes were numerically compared and summarized. Different failure types were defined and introduced. Based on the features of numerical simulations, a new kind of energy-consumption devices, composed with composite materials, were designed. Finally, the energy-consumption devices were simulated. The results show that the new devices could effectively consume the extra energy imported by dynamic loading, which is helpful for using to the safety protection of long-span spatial structures when it subjected to extreme loads.

Design of an active fin system to mitigate tall building responses using cyber-physical testing in the wind tunnel

Friday, 21st June - 10:45: MS29 - Advances in Experimental, Analytical and Computational Wind Engineering (103 Downs (50)) - Oral - Abstract ID: 1098

Mr. Michael Whiteman (University of Maryland), Dr. Pedro Fernandez-Caban (University of Maryland), Prof. Brian Phillips (University of Maryland), Prof. Forrest Masters (University of Florida), Prof. Jennifer Bridge (University of Florida), Dr. Justin Davis (University of Florida)

The wind-induced response of tall and slender structures is typically dominated by vortex-induced vibrations normal to the mean wind flow. Vortex-induced vibrations occur when the shedding frequency of these vortices approaches the natural frequency of the building, which usually leads to resonant amplification in the cross-wind direction (i.e., lock-in phenomenon). Aerodynamic modification (i.e., tailoring) of the building geometry is an efficient technique to significantly suppressing vortex-induced vibrations in tall buildings. The use of minor aerodynamic features (e.g., corner softening) can positively impact the flow around the building which may lead to considerable reductions in the wind-induced response. In the absence of dependable analytical models, this study proposes a cyber-physical framework to accurately characterize and enhance the aerodynamic design of tall building envelope systems in a boundary layer wind tunnel (BLWT). The approach makes use of an aeroelastic tall building specimen equipped with an active fin system (AFS). The AFS consists of twelve individually controlled fins installed at three different heights of the four corners of a nominally square (in plan) building. The angles that the fins make with respect to the building are adjusted using small stepper-motors to adapt to changes in wind direction and wind speed. A stochastic optimization algorithm is integrated into the cyber-physical framework to optimize fin angles and seek candidate solutions that will reduce the building response and disrupt vortex-induced vibrations for given wind conditions. BLWT testing is carried out at the University of Florida Natural Hazard Engineering Research Infrastructure (NHERI) Experimental Facility.

Computational Modeling in Dynamic Analysis of Multi-Rotor Wind Turbines (MRWTs)

Friday, 21st June - 11:00: MS29 - Advances in Experimental, Analytical and Computational Wind Engineering (103 Downs (50)) - Oral - Abstract ID: 1337

Dr. Reyhaneh Navabzadehesmaeili (University of Houston), Prof. John Niedzwecki (Texas A&M University), Prof. Luciana Barroso (Texas A&M University)

To compete with other companies in generating more power, there is a tendency to design and install larger wind turbine units such as 10 MW systems. However, increasing the size of rotors requires longer blades and taller support structures. Considering the fatigue, deflection and construction-maintenance concerns of larger structures, manufacturing larger modern wind turbines would not be a promising trend. Utilizing multiple smaller rotors mounted on one support structure, to increase the power generation along with providing efficient structural configuration, is an alternative approach. The idea mentioned as Multi-Rotor Wind Turbine (MRWT) system is a developing research attention. However, computational modeling of MRWTs according to the multi-body systems and multi-degree of freedom criteria seems challenging. Current study represents a building block (3-rotor) system to generate complex MRWT configurations. Consequently, a novel mathematical approach to derive the governing equations of motion (EOMs) for the system is presented. Lastly, the large deformation contribution to the dynamic behavior of the 3-rotor system is investigated by comparing the numerical solutions to the derived nonlinear EOMs and classic linear EOMs.

Construction Crane under Extreme Wind Hazards – Experimental Evaluation

Friday, 21st June - 11:15: MS29 - Advances in Experimental, Analytical and Computational Wind Engineering (103 Downs (50)) - Oral - Abstract ID: 97

Ms. Nafiseh Kiani (Florida International University), Prof. Youngjib Ham (Texas A&M University), Prof. Seung Jae Lee (Florida International University)

Construction sites are significantly vulnerable to extreme wind events due to high complexity associated with unsecured and unorganized construction resources such as temporary facilities, equipment and materials. A construction crane is the equipment that fails most frequently under extreme wind hazards, which may not only cause substantial direct damages to the construction projects, but also triggers a chain reaction of failures by generating wind-borne debris in jobsites. This cascading impact can propagate to neighboring infrastructure such as nearby buildings, which can result in significant economic losses and casualty. This study aims to experimentally investigate the behavior of cranes under extreme wind hazards to enhance the hazard preparedness in the construction environments and ultimately the community resilience. A set of aerodynamic wind tunnel testing is performed on a 1/50 scaled construction crane model in the NSF NHERI Wall of Wind (WOW) experimental facility that is capable of generating a range of wind speeds from Category 1 to 5 hurricanes on the Saffir-Simpson scale. Three types of jobsites are modeled with different surrounding densities, which enables to simulate construction cranes located in open terrain, suburb and urban areas respectively to consider the wind impact influenced by neighboring built environments. Wind directionality effects on the structural response are evaluated by rotating the WOW turntable during the test. This presentation will highlight the test results and findings.

Modeling ventilation in a slum house in Dhaka, Bangladesh

Friday, 21st June - 11:30: MS29 - Advances in Experimental, Analytical and Computational Wind Engineering (103 Downs (50)) - Oral - Abstract ID: 614

Mr. Yunjae Hwang (Stanford University), Dr. Laura Kwong (Stanford University), Mrs. Jenna Forsyth (Stanford University), Mr. Mahamudul Hasan (International Centre for Diarrhoeal Disease Research, Bangladesh), Mr. Sajjadur Rahman (International Centre for Diarrhoeal Disease Research, Bangladesh), Mr. Fosiul Nizame (International Centre for Diarrhoeal Disease Research, Bangladesh), Prof. Stephen Luby (Stanford University), Prof. Catherine Gorle (Stanford University)

According to UNICEF, approximately one million children die from pneumonia every year; it is the leading cause of death in children under 5. Previous research has found an association between the incidence of pneumonia and the presence of cross-ventilation in slum housing in Dhaka, Bangladesh. The objective of this research is to establish a validated computational model for predicting ventilation rates in low-income homes. This model will support the mechanistic understanding of future studies investigating ventilation and respiratory disease.

To achieve this objective we perform an uncertainty quantification study using two computational models with different levels of fidelity, and we conduct field experiments to validate the results. The low-fidelity model solves for the time-evolution of the volume-averaged air temperature in the house. Uncertainties in the model inputs are propagated through the model to predict a mean and 95% confidence interval for the air change per hour (ACH). The high-fidelity model is a computational fluid dynamics model that provides a solution for the three-dimensional flow and temperature field. It is used to determine spatial variability in the ventilation patterns and to investigate the validity of the assumptions in the low-fidelity model. The model results are validated against the field measurements, considering both instantaneous ACH measurements obtained using a tracer concentration decay technique, and time-series of air and wall temperatures obtained using thermistors and thermocouples. The results are interpreted to improve our understanding of the ventilation mechanisms and identify robust solutions that will work for a variety of weather and housing conditions.

Challenges and Opportunities in Multi-Hazard Engineering

Friday, 21st June - 11:45: MS29 - Advances in Experimental, Analytical and Computational Wind Engineering (103 Downs (50)) - Oral - Abstract ID: 170

Prof. Amal Elawady (Florida International University), Prof. Arindam Chowdhury (Florida International University), Prof. Ioannis Zisis (Florida International University), Prof. Peter Irwin (Florida International University)

Wind-induced effects on buildings and infrastructure located in the USA and around the globe have caused damages worth billions of dollars. To advance knowledge on various topics of wind engineering and develop wind damage mitigation techniques, the state-of-the-art large-scale experimental facility Wall of Wind (WOW) was developed at Florida International University (FIU), Miami, USA. The WOW powered by its 12-fan is capable of simulating hurricane winds at different wind speeds and up to 157 mph (Hurricane Category 5- Saffir-Simpson scale). Various Wind-Structural experimentation have been carried out at the WOW in order to assess wind loads on buildings, bridges and traffic signals, wind-driven rain (WDR) intrusion in buildings, and the capability of a building or its components to withstand high wind speeds. Due to its significant contributions to the wind engineering community, the WOW has been designated as an “Experimental Facility” (EF) under the Natural Hazards Engineering Research Infrastructure (NHERI) program of National Science Foundation (NSF). The capabilities, uniqueness, and resources at the 12 fan WOW EF enable researchers to perform cutting-edge research with the aim of preventing wind hazards from becoming community disasters. Facility enhancements that are underway, including automated roughness and the downburst simulator. More recently, the NHERI WOW is teaming up with the NHERI Lehigh Facility in order to develop algorithms to enable the usage of the Earthquake well developed technology “Real-Time Hybrid Simulations” in wind tunnel applications.

Image Based Probabilistic Analysis of the Microstructure of Pervious Concrete

Friday, 21st June - 10:30: MS75 - Cementitious Materials: Experiments and Modeling Across the Scales (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 161

Prof. Sarah Baxter (University of St Thomas), Prof. Katherine Acton (University of St Thomas), Prof. Rita Lederle (University of St Thomas)

Pervious concrete is a novel concrete material that can be used to mitigate problems associated with storm run-off and water pollution. Its most distinguishing characteristics are relatively high porosity and permeability.

Image analysis has played a significant role in the micromechanical modeling of pervious concrete. Using stereological techniques and statistical tools, features such as porosity, distribution of pore size, and spatial distribution of pores are extracted from thresholded grayscale images of the material. The metrics from these binary fields can then be used to simulate idealized microstructures with similar properties. A statistical analysis of the properties of the simulated microstructures gives insight into the variability of properties.

The choice of a threshold grayscale value, however, is somewhat subjective. Small changes in the threshold can cause significant differences in predicted porosity; thresholding also eliminates other information about the microstructure, including any distinction between the cement paste and aggregate phases of the concrete.

In this work, probabilistic metrics derived from non-thresholded, gray scale images of representative volume elements (RVE) are used to characterize the material microstructure. The image based random fields are more continuous than those from thresholded images; they distinguish between the composite's solid phases in addition to between the pore and solid phases. Image analysis results are compared/correlated to experimental measurements of porosity and permeability for a given mix design. The ultimate goal is to assess the accuracy of simulations, stemming from the image based probabilistic descriptors, in capturing porosity and permeability, as well as other microstructural, composite properties.

Computed Permeability from Pore Measurement of Cement Paste Subject to Freeze-thaw Cycles at Early Ages

Friday, 21st June - 10:45: MS75 - Cementitious Materials: Experiments and Modeling Across the Scales (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 226

Dr. Ya Wei (Tsinghua University)

Assessing the permeability of concrete subject to unexpected freeze-thaw cycles at early age is critical to ensure the durability and service life of concrete structures. However, measuring permeability of concrete has been a challenge. In this study, the permeability of cement paste is computed by using Katz-Thompson equation, general effective media (GEM) method, and Navier-Stokes method based on the pore parameters measured from the mercury intrusion porosimetry (MIP), the backscattered electron (BSE) imaging, and the X-ray CT techniques. The pastes are subject to freeze-thaw cycles at the age of 1 and 7 days followed by sealed curing until the age of 40 days. The water-to-cement (*w/c*) ratios of paste are 0.3 and 0.5, representing the high and low-strength concrete, respectively. The measured pore characteristics and the calculated permeability are then compared to that of the control samples. The measurable pore size range of each technique is quantified, and the applicability of each computing method for permeability is discussed. The results of this study provide the insight into the feasibility of measuring techniques and the predicting method, particularly for cementitious materials subject to freeze-thaw cycles.

Modeling the effect of microstructure on ultrasonic wave propagation

Friday, 21st June - 11:00: MS75 - Cementitious Materials: Experiments and Modeling Across the Scales (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 658

Mr. Raj Gopal Nannapaneni (University of Houston), Dr. Kalyana B.Nakshatrala (University of Houston), Prof. Konrad J.Krakowiak (University of Houston)

In this talk, we discuss the influence of microstructural properties like porosity and pore size distribution on the ultrasonic wave propagation; as such a characterization gives a much broader understanding of the materials. Our study is a combination of numerical modeling and experiments on cementitious systems. In this talk, we present a modeling framework based on a lumped parameter system approach, which offers a clear advantage in modeling the evolving pore space by simple tuning of stiffness and mass in the pore regions. We discuss the calibration of stiffness and mass of the lumped parameter system from the elastic properties and density of the material in continuum using the energy equivalence of unit cells in discrete and continuum. Computations are carried out on a representative volume element (RVE) with periodic boundary conditions. The governing equations under these lumped parameter systems with periodic boundary conditions form a system of ordinary differential equations (ODEs) with an algebraic constraint arising from the periodic boundary conditions and thus resulting in a system of differential-algebraic equations (DAEs). We employ v-continuity of the periodic constraints, the v-form of the Newmark average acceleration to solve the wave propagation problem. Due to these choices, we have a numerical modeling framework that does not exhibit numerical dissipation and is unconditionally stable. We also present the results of measured parameters like transient time and velocity, from numerical simulations for different combinations of porosity and pore size distribution. We perform Monte-Carlo simulations to get a statistical estimate of the measured parameters.

Chemical and mechanical interactions between soft hydrogels as a water reservoir with a cementitious matrix

Friday, 21st June - 11:15: MS75 - Cementitious Materials: Experiments and Modeling Across the Scales (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 783

Prof. Ali Ghahremaninezhad (University of Miami), Dr. Khashayar Farzanian (Yale University)

Hydrogels consist of a polymeric network dissolved in a solvent and their chemical and mechanical responses are sensitive to external stimuli such as temperature, pH, concentration of salt solution, electric field etc. The use of hydrogels with a large absorption capacity in the infrastructure applications is an emerging line of research aimed at improving the durability of cement-based materials. Applications include mitigating autogenous shrinkage cracking in cement-based materials with low water to cement ratios. Cement-based materials consist of a complex microstructure and exhibit variations in their physicochemical characteristics. Therefore, understanding the behavior of hydrogels in such an environment is critical in the optimum design of cement-based materials containing hydrogels.

We report an experimental investigation into the mechanical and chemical interactions of hydrogels in an alkaline environment. The swelling/deswelling and deformation behavior of the hydrogels and their dependence on alkali ions and their concentration in the solution were studied. The effect of mechanical stress on the behavior of hydrogels was elucidated and discussed. The uniaxial tensile test was used to evaluate the mechanical properties of hydrogels. The effect of pore structure of a cement-based matrix on the deswelling of the hydrogel was examined. It was observed that the hydrogel response was strongly influenced by the concentration and type of the alkali counterions as well as mechanical stress. Alkali counterions were shown to affect the mechanical properties of hydrogels. The results from this study provide valuable insight into the underlying mechanisms governing the behavior of hydrogels in a cement-based matrix.

Reversible water uptake/release by hydrates governs the thermal expansion of cement paste — A multiscale poromechanical analysis

Friday, 21st June - 11:30: MS75 - Cementitious Materials: Experiments and Modeling Across the Scales (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1159

Dr. Hui Wang (Tongji University), Prof. Christian Hellmich (Vienna University of Technology), Prof. Yong Yuan (Tongji University), Prof. Herbert Mang (Vienna University of Technology), Prof. Bernhard Pichler (Vienna University of Technology)

Quasi-instantaneous thermal expansion of mature cement pastes is governed by the relative humidity within their air-filled porosity and by the decrease/increase of this internal relative humidity resulting from a temperature decrease/increase. The latter is shown to result from quasi-instantaneous water uptake/release by cement hydrates, using multiscale poromechanics and a three-scale representation of mature cement pastes. Partially saturated gel and capillary pores are envisaged to be connected and spherical, with pore size distributions following exponential distributions. Effective pore pressures are quantified based on (i) the pressure of the fluids filling the pores and (ii) the surface tension at the interface between the pore and the surrounding solid matrix. The Mori-Tanaka scheme is used for the scale transition from effective pore pressures to eigenstrains at the cement paste level. In addition, mass conservation of water is explicitly accounted for. Downscaling macroscopic thermal expansion coefficients allows for identifying the molecular water uptake/release characteristics of the hydrates. These characteristics are independent of the initial water-to-cement mass ratio, as shown in the context of predicting the thermal expansion coefficients of different mature cement pastes, with w/c-ratios ranging from 0.50 to 0.70, see also http://doi.org/csgw.

Cement cohesion from structuring of ions and restructuring of water

Friday, 21st June - 11:45: MS75 - Cementitious Materials: Experiments and Modeling Across the Scales (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1238

Mr. Abhay Goyal (Georgetown University), Dr. Katerina Ioannidou (LMGC), Dr. Roland Pellenq (Massachusetts Institute of Technology), Prof. Emanuela Del Gado (Georgetown University)

Reducing the environmental impact of cement production is central to reducing greenhouse gas emissions of the construction industry. However, any modification of cement is hindered by an incomplete understanding of the setting process due to its complexity at the nano- and meso-scales. During setting, the precipitation and non-equilibrium aggregation of charged particles into a percolating, porous network is responsible for the overall mechanical properties. But what is the origin of adhesion between these particles? Previous studies suggest that spatial organization of multivalent ions can lead to attraction between highly charged surfaces, but the role of the solvent is largely overlooked. The solvent itself can also exhibit a great deal of structure due to confinement and strong electrostatic forces. To investigate these effects, we combine a primitive model for ions and surfaces with an explicit representation of water. We find that the presence of water proves to have a strong impact on the ordering of ions and greatly enhances the strength of attraction between two surfaces. By identifying quantitatively the link between chemistry and cohesive forces in cement, these results may open new paths for designing stronger cements, more durable and more sustainable.

Structural Building Monitoring

Friday, 21st June - 10:30: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1235

Mr. Nathan Hicks (Silman)

The presentation will explore the importance of vibration and movement monitoring, during construction, to protect historic buildings and structures. Case studies will show how our firm has used monitoring on a variety of historic projects from Thomas Jefferson's Rotunda to 100 year old smokestacks to the Virginia General Assembly Building. While monitoring is often overlooked it can play an integral role especially when considering that historic building materials, such as unreinforced masonry, are often more sensitive to movement and vibrations. The talk will focus on how to put together a monitoring plan and best practices for monitoring equipment, monitoring frequency/duration and monitoring thresholds. Finally the presentation will look at what the future of monitoring might look like, including the potential for laser scanning.

Multimodal Data Fusion and Analysis for Heritage Structures

Friday, 21st June - 10:45: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 828

Dr. Dominique Rissolo (University of California, San Diego), Mr. Vid Petrovic (University of California, San Diego), Dr. Michael Hess (University of California, San Diego), Mr. Eric Lo (University of California, San Diego), Mr. Dominique Meyer (University of California, San Diego), Mr. Christopher Mcfarland (University of California, San Diego), Dr. Falko Kuester (University of California, San Diego)

Mainstream three-dimensional data-capture techniques, such as terrestrial laser scanning and SfM photogrammetry, are commonly used for architectural documentation and visualization as well as for HBIM and FEA applications. The Cultural Heritage Engineering Initiative at UC San Diego has been refining a unique point-based visual analytics engine that enables a range of 2D and surface and subsurface 3D data from diagnostic imaging modalities to be integrated into a point-data scaffold. The resulting digital surrogates of buildings, monuments, or architectural elements can be annotated or manipulated by a variety of user-scripted tools. The goal is to simultaneously and seamlessly interact with 3D point-clouds and meshes as well as with 2D thermal and hyper-spectral images, which can be layered, draped, or projected on point-clouds. Recent developments include real-time dynamic recall and rapid evaluation of images used to derive geometry via SfM. Experimental machine-learning tools are being applied to point-cloud segmentation and subsequent classification of building materials as well as to damage detection and monitoring.

Lapped scarf joint with inclined faces and wooden dowels intended for tensile loads: analysis and design

Friday, 21st June - 11:00: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 100

Ms. Suzy Bishara (CTU)

The object of the thesis is to design a lapped scarf joint with inclined faces that would be suitable in use for repairing timber beams. The new portion of the beam would be attached to the old intact part of the beam. The joint would have inclined faces and would be held together using wooden dowels. In this case there would be nine wooden dowels in order to optimize the behavior of the joint under tensile stresses. Experimental tests will be performed for tension and bending. In addition, a numerical model will be developed using ANSYS and will be validated with the experimental model.Upon validation of the numerical model, an additional numerical test would be done for compression.

The stresses will be evaluated along specific sections of the beam to determine the stresses produced under different load applications. The Von Mises stresses are obtained and used to produce Mohr circle diagrams to characterize the type of stress present at various nodes.

This study is part of a progression of previous studies that have investigated lapped scarf joints, which would be introduced and used for comparison accordingly. The ultimate outcome is to provide understanding for the behavior of lapped scarf joints with wooden dowels and be able to reproduce such joints for different cases, using different beam sizes and determining the adequate dowel design for sufficient support. Design diagrams for use in constructions are assessed.

Hazard Mitigation and Rehabilitation using a Deterministic Approach

Friday, 21st June - 11:15: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 392

Mr. Melvyn Green (Melvyn Green & Associates)

ABSTRACT

Hazard Mitigation and Rehabilitation using a Deterministic Approach

Melvyn Green, Structural Engineer. F SEAOC, F ASCE, F APTI

According to the US Department of Energy, about 94% of US commercial buildings are four stories or less in height. A large percentage of these are of brick and stone construction. This group of buildings (as well as apartment and industrial buildings) often comprise the major historic resource buildings in many communities. Such buildings also pose a well-documented risk from earthquakes and extreme winds in many areas of the world.

To mitigate this risk building code provisions have been developed. They are based on the development of empirical methods but also on a major test program, and experience. Because construction and materials are not as homogenous as they might be in theory. Thus, some analytical and modeling methods may not be appropriate.

The development of this approach and its implementation will be presented. In addition, several example will be provided including a conservation of brick and mortar materials and site issues including archeological requirements.

Also included will be a description of major masonry materials and assemblies including brick, stone, adobe, and tile. The discussion will also note the issues of “risk adverse” engineers and how this has a negative effect on heritage structures.

Ultrasonic tomography: non-destructive evaluation of the weathering state on a marble obelisk, considering the effects of structural properties

Friday, 21st June - 11:30: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1259

Prof. Siegfried Siegesmund (University of Goettingen), Mrs. Johanna Menningen (University of Goettingen), Dr. Daryl Tweeton (GeoTom, LCC), Mr. Markus Träupmann (University of Goettingen)

The use of ultrasonic methods for a non-destructive investigation of immovable, high-ranking cultural heritage made of natural stone, has developed into the state-of-the-art testing. This routinely applied transmission method gives no detailed information concerning the internal structures. Onsite measurements have been executed in a tomographic approach for a marble obelisk in the Neuer Garten, Potsdam (Germany) to characterise the weathering conditions. Detailed decay mapping has been performed on a scale of 1:1, to prove the validity of this data. The rock properties for the same marble variety were examined under laboratory conditions to gain data on their directional dependence, influencing factors like water content and artificial weathering behaviour. These results were used to cross check the ultrasonic measurements onsite and the tests under laboratory conditions, to obtain a reliable interpreta- tion. The ultrasonic velocity distributions measured under defined conditions, revealed a possible anisotropy between 9 and 30%, which is a basic input parameter for the calculated tomograms. The synthetic tomograms clearly show the great impact of anisotropy considering the velocity distribution modelled for the measured planes. Based on the laboratory data, an amount of 20% anisotropy was applied to the tomograms, which improved the ability to distinguish the velocity variation due to deterioration from that caused by rock fabric. The results demonstrate that the rock fabric and its anisotropy need to be considered for interpreting the tomographic investigation. Before an adequate assertion can be made, the above influences must be considered as a basis for conservation purposes.

Simplified expression for determination of horizontal reactions in segmental, parabolic, and catenary arches

Friday, 21st June - 11:45: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 1 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1125

Prof. Branko Glisic (Princeton University)

Arch made revolution in ancient times, and since then it was frequently used as the main structural member in several types of structures. Numerical methods, such as finite element modeling and discrete element modeling, have been developed to calculate reactions and internal forces in arches under various loading conditions. While these methods were demonstrated as excellent tools for detailed structural analysis, they might be time consuming and somewhat tedious to apply for conceptual design or quick verification where only ballpark estimates of reactions and internal forces are needed (i.e., for “back-of-the-envelope” calculation). For that purpose, approximate and simplified, yet accurate, closed-form expressions would enable not only fast calculation, but also an easy creation of parametric studies. This paper develops and presents novel simplified closed-form expression for calculation of horizontal reactions in linear-elastic arches with three typical structural systems – hingeless, two-hinged, and three-hinged, and with three typical symmetric shapes with constant cross-section – segmental, parabolic, and catenary. The expression is applicable to arches under self-weight, and, with some restrictions, when loaded with uniformly distributed load along the span (e.g., due to deck with constant cross-section). Surprisingly, it was concluded that the horizontal reactions do not depend significantly on arch shape or even on number of hinges, but they mostly depend on load intensity, span, and equivalent angle of embrace. Moreover, a linear relationship between horizontal reactions of the three structural systems was found. Finally, brief parametric study related to shape was performed, yielding new insights and better understating of arches.

What would it take to build on Mars?

Friday, 21st June - 10:30: MS105 - Extraterrestrial soil mechanics: 50 years after Apollo 11 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1197

Prof. José Andrade (Caltech)

The human race is currently actively exploring our solar system and will need to develop infrastructure outside of our planet. In this contribution, we will explore what would it take to build infrastructure on Mars –a key location for human exploration– where there is not direct access to common construction materials used on Earth, and where the most abundant and accessible material is regolith. The need to build on the red planet will drive the development of new materials and autonomous construction systems. These developments necessitate an urgent push to understand the physical and chemical properties of regolith. Specifically, celestial soil mechanics can shed light into the mechanical behavior of these materials by relying on physics-based approaches and new tools such as artificial intelligence. In this contribution, we will outline some of the new developments in simulating the mechanics of regolith using physics-based models, as well as machine learning techniques, and how these could be relevant to building new worlds.

The Stinger: A Geotechnical Sensing Package for Robotic Scouting on a Small Planetary Rover

Friday, 21st June - 10:45: MS105 - Extraterrestrial soil mechanics: 50 years after Apollo 11 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1100

Mr. Zachary Mank (Honeybee Robotics), Dr. kris zacny (Honeybee Robotics), Mr. Joseph Palmowski (Honeybee Robotics), Mr. Daniel Hastings (Honeybee Robotics), Mr. Nick Traeden (Honeybee Robotics), Mr. Alex Wang (Honeybee Robotics), Mr. Philip Beard (Honeybee Robotics), Mr. Jameil Bailey (Honeybee Robotics), Mr. Thomas Thomas (Honeybee Robotics), Mr. Michael Yu (Honeybee Robotics), Mr. Paul Chow (Honeybee Robotics), Mr. Leo Stolov (Honeybee Robotics), Mr. Jared Atkinson (Honeybee Robotics), Mr. Arno Rogg (NASA Ames Research Center), Mrs. Maria Bualat (NASA Ames Research Center), Dr. Terry Fong (NASA Ames Research Center)

Flawless operation of mobility systems, excavation, mining and In Situ Resource Utilization (ISRU) operations, regolith transport, and many other activities critically depend on knowledge of the geotechnical properties of the soil in a given area. To meet this need, Honeybee has developed the Stinger as a planetary geotechnical instrument. The system combines an Apollo-based penetrometer approach for measuring bearing strength with a Lunokhod approach for measuring shear strength.

The Stinger system consists of a vertical feed z-stage, a mechanism head, and a probe, and is designed to be mounted to a rover such as the KREX-2 rover developed by IRG at NASA Ames Research Center. The probe tip is designed after the cone of a static cone penetrometer to allow continuous bearing strength measurement. A shear vane is also initially housed inside the cone tip of the probe and can be deployed at any depth of interest up to 50 cm to conduct a shear test. When the shear vane is extended, the cone-vane is then rotated to measure the shear strength of the soil. Multiple shear tests can be conducted at various depths at a single test site. This combination of measurements can then be used to calculate Cone Index, Shear Index, and Friction Index and develop a regolith property profile for a vertical cross-section. Test data collected with a Stinger prototype shows very good correlation with data from stand-alone cone penetrometer and shear vane data in multiple different lunar and Martian simulants.

Discrete element modelling of low gravity sample collection and transfer operations for Enceladus surface acquisition

Friday, 21st June - 11:00: MS105 - Extraterrestrial soil mechanics: 50 years after Apollo 11 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 1217

Mr. Dario Riccobono (Politecnico di Torino), Dr. Scott Moreland (Jet Propulsion Laboratory, California Institute of Technology), Dr. Paul Backes (Jet Propulsion Laboratory, California Institute of Technology), Prof. Giancarlo Genta (Politecnico di Torino)

Saturn's moon Enceladus represents one of the most promising places in the Solar System that might potentially host the life beyond Earth. The Cassini mission strongly suggested the presence of hydrothermal activity and observed material from the subsurface ocean being ejected by plumes and then settling on the surface. Moreover, the low radiation environment would help preserving the chemical composition of samples deposited on the surface. A potential future mission landing on the surface of Enceladus would have the goal of collecting surface samples for in-situ analysis. On the other hand, the low surface gravity of Enceladus (1% of Earth's gravity) represents a unique challenge for sample handling. This study focuses on the analysis of tool-soil interaction in a gravity environment like the one found on Enceladus. The Discrete Element Method was chosen to investigate the material's flow while performing unconstrained sample collection and transfer operations.

RESPONSE TO STATIC AND IMPULSIVE LOADS OF DNA-1A LUNAR REGOLITH SIMULANT

Friday, 21st June - 11:15: MS105 - Extraterrestrial soil mechanics: 50 years after Apollo 11 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 736

Ms. Valentina Marzulli (Institute for Multiscale Simulation, Friedrich-Alexander-Universität Erlangen-Nürnberg), Dr. Francesco Cafaro (DICATECh, Politecnico di Bari), Prof. Thorsten Poeschel (Institute for Multiscale Simulation, Friedrich-Alexander-Universität Erlangen-Nürnberg Germany)

Deepening the mechanics of extraterrestrial soils is extremely challenging for the entire scientific community, since a thorough knowledge of such materials is requested for dealing with the forthcoming colonization of celestial bodies (i.e. Moon, Mars). An extensive experimental campaign has been carried out on the lunar regolith simulant DNA “De NoArti”, in order to determine its mechanical properties, mainly in loose states and at low pressures, both in dry and in wet conditions. Since the use of the lunar regolith for earthwork related to the moonbase construction involves both static and impulsive loads, like those resulting from mobilization of earth pressure and from impacts of micrometeoroids, the experimental investigation also focused on the response of the material to impulsive loads. In particular, the force generated at the base of the simulant layer by a low kinetic energy impact has been measured and related to the properties of the material.

Planet Rover Wheels Loading Test Applied to Its Regolith Strength/Property Estimation

Friday, 21st June - 11:30: MS105 - Extraterrestrial soil mechanics: 50 years after Apollo 11 (Salvatori Seminar Room (45)) - Oral - Abstract ID: 192

Prof. Jiliang Li (Purdue University Northwest), Dr. Jinyuan Zhai (Purdue University Northwest)

Any successful planet exploration such as Moon or Mars exploration is essentially geotechnical exploration which is important for any construction and building structures on either the Mars or Moon. One of the immediate and critical task is efficiently and properly characterizing the moon or Martian surface materials properties such as the Mars surface regolith elastic and plastic strength parameters under rover's own wheels' loading pressure.

Drilling below Mars surface and seismic wave reconnaissance could provide further more insightful information of Mars structures. Martian surface deformation profiles under Rover's wheels own loading pressure could conveniently provide invaluable information. The camera and video images taken are invaluable but not enough. Equally important and invaluable are the recorded analysis of the Mars surface profiling before being run over by the rover and after the rover run across the land. Deformation profile recorded and collected could provide some fast and appropriate estimation of the Mars soil strength parameters based on a strip loading test method developed. Measurement and recording the Martian surface materials deformation profiles under the rover's wheels own loading pressure is important. Though they are only surface materials, properly study and documenting different area's surface regolith strength parameters will be critical for future mankind's construction and building of survival and living structures on Mars.

Anisotropic Shear Behavior at Snakeskin Inspired Surfaces

Friday, 21st June - 10:30: MS2+3 - Bio-Inspired interfaces, Bio-Inspired Burrowing, Drilling and Excavation (147 Noyes (84)) - Oral - Abstract ID: 270

Mr. Kyle O'Hara (University of California, Davis), Dr. Alejandro Martinez (University of California Davis)

Design procedures in geotechnical engineering do not consider directionality dependence on the strength and stiffness of soil-structure interfaces. Multifunctional geotechnical systems may be developed based on interfaces that generate higher shear resistances in one loading direction than another. These interfaces with anisotropic frictional properties can be modeled after a biological adaptation present in many snake species. When snakes shear soil during forward movement (i.e. caudal direction) they generate less shear resistance than when they shear soil during backward movement (i.e. cranial direction). Previous research on the monotonic shear behavior between sand and snakeskin-inspired surfaces has shown that dilation plays a key role in the observed frictional anisotropy, where cranial shearing induces larger soil dilation and mobilizes a larger shear strength. This paper presents the results of a series of interface shear tests on snakeskin-inspired surfaces subjected to cyclic shearing under constant stiffness and constant load boundary conditions. The experimental trends clearly show the dependence of strength, stiffness, and dilatancy degradation on the shearing direction and boundary conditions. When the surfaces are displaced in the caudal direction, the response is similar to that mobilized by a smooth surface (i.e. with a small roughness magnitude). On the other hand, when the surfaces are displaced in the cranial direction, the response is similar to that mobilized by a rough surface (i.e. with a large roughness magnitude). The results presented herein provide evidence of the associated load transfer mechanisms, where caudal shearing induces interface frictional interactions while cranial shearing also induces passive resistances.

Bioinspired glass fiber reinforced polymer composites to improve machinability

Friday, 21st June - 10:45: MS2+3 - Bio-Inspired interfaces, Bio-Inspired Burrowing, Drilling and Excavation (147 Noyes (84)) - Oral - Abstract ID: 698

Dr. Claudiane Ouellet-Plamondon (ETS Montreal)

The diversity of function in biological materials arises from a variety of structure from base substances. For example, plant leaves featuring superhydrophobic coating have micro and nanostructure hierarchical textures. The best-known example of natural superhydrophobic coating is the lotus leaf (*Nelumbo nucifera*) characterized by a surface formed by papillose epidermal cells covered with epicuticular wax tubules. In this work, we are interested in improving the machinability of glass fiber reinforced polymer (GFRP) composites to reduce the heat produced during cutting and the wear of milling tools. The anisotropic and heterogeneous nature of the composite materials makes the cutting very difficult. Plates of 16 plies unidirectional laminates were prepared to understand the effects of additives: microparticles of wax, clay, with and without a wetting agent. The plates were made by infusion with a previously modified epoxy resin. The modification of the resin consists in adding the additives following a precise protocol of mixing and sonication. The quality of the cut, the cutting conditions and the mechanical performance were then analyzed. The contact angle of the cutting surface was also measured to determine the surface energy. The wax particles significantly decrease the cutting temperature for the trimming process. The wax particles also decreasing the roughness. Finally, the combined effect of wax and clay results in the lower temperatures and cutting forces. The synergy between the clay and the wax particles added the epoxy demonstrates the importance of creating a hierarchical structure. The bioinspired approach is promising for improving GFRP machining.

A DEM study of the interaction between multiple anchors of a bio-inspired probe

Friday, 21st June - 11:00: MS2+3 - Bio-Inspired interfaces, Bio-Inspired Burrowing, Drilling and Excavation (147 Noyes (84)) - Oral - Abstract ID: 301

Ms. Yuyan Chen (University of California Davis), Dr. Alejandro Martinez (University of California Davis), Dr. Jason DeJong (University of California Davis)

This paper provides the results of Discrete Element Modeling (DEM) simulations of a self-burrowing in-situ testing probe that uses bio-inspiration from organisms such as trees, earthworms, and caecilians. This bio-inspired probe consists of a radially-expanding segment (i.e. anchor) that generates a reaction force to advance the probe and an axially-elongating segment (i.e. tip) that forces the tip to advance while measuring the soil penetration resistance. Previous research using cavity expansion theory by the authors has shown that dense sandy soil will pose the biggest challenge for self-penetration. Thus, it is possible that one single anchor may not be able to mobilize the reaction force required to penetrate through dense coarse-grained soils. This DEM study investigates the interaction between two expanding segments (i.e. anchors) within the shaft of the bio-inspired probe in terms of altered states of stress and soil deformations. These simulations test the following four hypotheses: (i) the leading anchor mobilizes larger reaction force than the trailing one due to a shadowing effect, (ii) as the distance between the anchors is increased the difference in mobilized reaction force decreases, (iii) the difference in mobilized reaction between the leading and trailing anchors becomes greater as the soil density is increased, and (iv) as the anchor is further expanded a larger fraction of the reaction force is generated through bearing capacity. The results presented in this paper will guide the design and development of the anchorage system of a field-scale self-burrowing probe prototype.

Effect of Rotation on Seed's Self-Burial Process: Insights from DEM Simulations

Friday, 21st June - 11:15: MS2+3 - Bio-Inspired interfaces, Bio-Inspired Burrowing, Drilling and Excavation (147 Noyes (84)) - Oral - Abstract ID: 886

Mr. Yong Tang (Arizona State University), Prof. Junliang "Julian" Tao (Arizona State University)

Seeds of some flowering plants such as *Erodium* and *Pelargonium* can burry itself into the ground for future germination. The self-burial behavior is realized due to hygroscopic coiling and uncoiling of the awns. It is hypothesized that the rotating motion due to the changing of the helical structure of the awn reduces penetration resistance of the seed via breaking the local force chains in soil. In this study, this hypothesis is tested using a DEM model, which allows to investigate the interaction between a penetrator and the granular material at different scales. The DEM model was first calibrated and validated using existing laboratory triaxial test data of Ottawa sand. A cone was then penetrated into the calibrated soil sample with different rotational speeds. It was observed that the rotational movement can significantly reduce the penetration resistance; and the reduction becomes more pronounced at higher rotational speed. From particle scale analysis, the force chain and coordination number of the soil sample was investigated and comparisons were made among cases, which shed light on the fundamental mechanism of the reduction effect. Furthermore, attempt was also made to simulate the rotational penetration through coiling and uncoiling of the awn to study the self-burial mechanism.

Impact of shell-opening of a model razor clam on the evolution of force chains in granular media

Friday, 21st June - 11:30: MS2+3 - Bio-Inspired interfaces, Bio-Inspired Burrowing, Drilling and Excavation (147 Noyes (84)) - Oral - Abstract ID: 888

Dr. Nariman Mahabadi (Arizona State University), Mr. Sichuan Huang (Arizona State University), Prof. Junliang "Julian" Tao (Arizona State University)

The razor clams periodically alternate inflating the shelled body and the muscular foot during locomotion. It is hypothesized that inflation of the shelled body not only forms a firm anchor for the foot penetration, but also affects the soil packing and stress around the foot, which results in the penetration resistance reduction and energy saving. This study utilizes the combined techniques of photoelasticity, image processing and 2D discrete element method modeling to investigate the mechanical interplay between a dynamic penetrating razor clam model and the surrounding particle packing. A simplified penetrator model composed of an expandable rectangular body and a protrusible triangular foot is designed and incorporated into a transparent cell containing thousands of photoelastic disks. Several time sequential images are taken during the model penetration. An image processing algorithm is developed to detect the evolution of grain contact forces (orientation and magnitude of contact forces) during the body expansion and foot penetration of the model. Meanwhile, a 2D DEM model with similar conditions (including boundary condition, chamber size, penetrator dimension, particle size and position) to the experiment setup is developed. The force chain network and corresponding displacement field during the simulation are monitored and compared with the experimental results. Results from this study show that the body expansion affect the foot penetration by introducing structure disturbance into the particulate environment around the foot. Also, the proposed hybrid experimental-numerical model can provide a reliable prediction-calibration model for soil-penetrator interaction mechanisms.

The self-propulsion of a helical swimmer in granular matter

Friday, 21st June - 11:45: MS2+3 - Bio-Inspired interfaces, Bio-Inspired Burrowing, Drilling and Excavation (147 Noyes (84)) - Oral - Abstract ID: 1319

Mr. Jose Valdes (Universidad Nacional Autonoma de Mexico), Dr. Roberto Zenit (Universidad Nacional Autonoma de Mexico), Dr. Elsa de la Calleja (Universidad Nacional Autonoma de Mexico), Ms. Veronica Angeles (Universidad Nacional Autonoma de Mexico)

The motion of helicoidal swimmers moving in a pool filled with granular medium is studied experimentally. The horizontal displacement through granular beads is measured considering geometrical modifications of the swimmer, the size and frictional properties of the media. We found three main parameters which affect the swimming performance: the body diameter, the wave length, and the helix angle. The swimming speed scales with the rotation speed, ωR. The size of particles does not affect the swimming speed significantly; the swimming speed is reduced when the particle's angle of repose increases. It was found that a maximum swimming speed is achived when the helix angle is close to 55 degrees. The experimental data are compared with predictions of the granular resistive force theory, which was extended to be applicable for a swimmer with a rigid helical tail. The agreement was satisfactory.

Fourier series-based discrete element method for irregular-shaped particles

Friday, 21st June - 10:30: MS35 - Computational Geomechanics; Part 4 (142 Keck (72)) - Oral - Abstract ID: 390

Prof. Qiushi Chen (Clemson University), Dr. Zhengshou Lai (Sun Yat-sen University)

The Fourier series is ideally suited to describe particles of irregular shape. This paper aims to develop a Fourier series-based Discrete Element Method (FS-DEM) for computational mechanics of irregular-shaped particles. To begin with, the Fourier series-based method for particle geometric description and coordinate representation is introduced. In this method, a particle shape is implicitly determined by FS coefficients, which remain constants and are independent of the particle position or kinematics. Focusing on the FS-based method, contact detection and resolution algorithms are then developed to identify contacts and resolve contact geometric features for both particle-particle or particle-boundary contact cases. The FS-DEM framework for computational mechanics of irregular particles is finally completed with recourse to conventional contact behavior, law of motion, and movement integration. The accuracy and efficiency of the FS-DEM framework is verified via three numerical tests. An Overlapping Discrete Element Cluster-based commercial DEM code, PFC, is adopted to perform benchmark simulations. Results indicate that the proposed FS-DEM framework provides another flexible, accurate and efficient approach to model irregular particles.

Large Deformation Poroplasticity Modeling for Landslide and Soil Penetration Problems

Friday, 21st June - 10:45: MS35 - Computational Geomechanics; Part 4 (142 Keck (72)) - Oral - Abstract ID: 416

Prof. Craig Foster (University of Illinois at Chicago), Mr. Seyed Milad Parvaneh (University of Illinois at Chicago), Prof. Sheng-Wei Chi (University of Illinois at Chicago)

Soil penetration and landslides are highly complex processes that involves large deformation plasticity, material separation and contact, viscous motion and other effects. Accurate modeling of such processes is not easily handled within the finite element context. While modeling the soil with discrete elements is possible, it can become extremely expensive computationally.

Meshfree methods offer an alternative approach that can be very effective for large deformation and material separation. These methods combine the motion of discrete particles that allow material separation and contact with greater efficiency of continuum formulations. The Reproducing Kernel Particle Method is used in this research to handle the contact and material separation.

The focus of this presentation will be on the constitutive model used for the soil in these models. The solid model is a large deformation viscoplasticity model. The model has a hyperbolic tension/shear surface and an elliptic compression cap. The tension surface facilitates material separation, while the tensile and shear strength degrade with plastic deformation. Work in progress includes modifying the frictional strength of the material with volume change. The compression caps captures pore collapse and grain crushing under penetration. The volumetric response is tied directly to the porosity, so that the model can readily be implemented in a poromechanical framework. Rate dependence is necessary to accurately capture high strain-rate effects in both penetration and landslide events. A Duvaut-Lions model is used and can capture the transition to viscous fluid-like behavior and back to solid.

The model is placed in a saturated poromechanical framework.

Multiscale poromechanics: double porosity, transverse isotropy, and non-Darcy flow

Friday, 21st June - 11:00: MS35 - Computational Geomechanics; Part 4 (142 Keck (72)) - Oral - Abstract ID: 445

Dr. Qi Zhang (Stanford University), Prof. Jinhyun Choo (The University of Hong Kong), Prof. Ronaldo Borja (Stanford University)

Fluid flow in isotropic porous media with one porosity scale is a well understood process and a common scenario in numerous simulations published in the literature. However, there exists a class of porous materials that exhibit two porosity scales with strong permeability contrast, for example, aggregated soils and sedimentary rocks. In this presentation, we shall refer to the larger and smaller pores of sedimentary rocks as the micro-fractures and nanopores, respectively. Due to preferentially oriented micro-fractures in the rock, fluid could flow predominantly in the direction of the discontinuities, resulting in an anisotropic flow pattern at the larger scale. We idealize such material as a transversely isotropic medium with respect to fluid flow. In addition, the nanopores of sedimentary rocks such as shale are so small in size that Darcy's law may not hold at this scale. Here we will present a hydromechanical model for generic materials with two porosity scales that accommodates both transverse isotropy at the larger scale and non-Darcy flow at the smaller scale to illustrate their impacts on the overall fluid flow patterns.

On the strength of transversely isotropic rocks

Friday, 21st June - 11:15: MS35 - Computational Geomechanics; Part 4 (142 Keck (72)) - Oral - Abstract ID: 512

Mr. Yang Zhao (Stanford University), Dr. Shabnam Semnani (Stanford University), Mr. Qing Yin (Stanford University), Prof. Ronaldo Borja (Stanford University)

Accurate prediction of strength in rocks with distinct bedding planes requires knowledge of the bedding plane orientation relative to the load direction. Thermal softening adds complexity to the problem since it is known to have significant influence on the strength and strain localization properties of rocks. In this study, we use a recently proposed thermoplastic constitutive model appropriate for rocks exhibiting transverse isotropy in both the elastic and plastic responses to predict their strength and strain localization properties. Recognizing that laboratory-derived strengths can be influenced by material and geometric inhomogeneities of the rock samples, we consider both stress-point and boundary-value problem simulations of rock strength behavior. Both plane strain and 3D loading conditions are considered. Results of the simulations of the strength of a natural Tournemire shale and a synthetic transversely isotropic rock suggest that the mechanical model can reproduce the general U-shaped variation of rock strength with bedding plane orientation quite well. We show that this variation could depend on many factors, including the stress loading condition (plane strain versus 3D), degree of anisotropy, temperature, shear-induced dilation versus shear-induced compaction, specimen imperfections, and boundary restraints.

Determination of slide direction for three-dimensional slope stability

Friday, 21st June - 11:30: MS35 - Computational Geomechanics; Part 4 (142 Keck (72)) - Oral - Abstract ID: 565

Dr. Murray Fredlund (SoilVision - Bentley), Mr. Haihua Lu (SoilVision - Bentley), Mr. Yukuai Wan (Hohai University), Prof. Gilson Gitirana (Universidade Federal de Goias)

Three-dimensional analyses are becoming more common in Geotechnical Engineering practice. This is largely thanks to the development and verification of rigorous theoretical basis, the analysis of case histories, and the availability of efficient and more friendly computational tools to construct and manipulate complex geometry. The Limit Equilibrium Method (LEM) and plastic analysis based on the shear strength reduction (SSR) technique have been the most common approaches. The results obtained using both methods are comparable. However, each approach presents different theoretical and practical limitations and advantages. Among the main limitations of the early 3D Limit Equilibrium Methods is that the direction of the slide needs to be assumed. Some alternatives have been proposed to extend the LEM theory in order to overcome this limitation. This paper presents a review of some of these approaches and a detailed comparison. Special attention is given to the Gao method and to brute force analyses. A number of simple asymmetric and more complex real geometries have been considered. The results how that the Gao method is able to predict the slide direction and provides the minimum factor of safety, at a lower computational cost.

The coupled DEM-FVM method for complex fracturing of tight rocks under thermal and hydraulic stimulation

Friday, 21st June - 11:45: MS35 - Computational Geomechanics; Part 4 (142 Keck (72)) - Oral - Abstract ID: 700

Dr. Jiaoyan Li (Idaho National Laboratory), Dr. Yidong Xia (Idaho National Laboratory), Dr. Hai Huang (Idaho National Laboratory)

Hydraulic fracturing (HF) is a permeability enhancement process primarily used in shale source extraction and geothermal recovery. Despite its popularity, HF is challenging to monitor and control at field scales. Among the numerical methods developed for predictive simulations of HF, the discrete element method (DEM) manifests an inherent capability of capturing fracture initiation and propagation, and evolution of complex fracturing patterns without much sophisticated numerical schemes. However, the problem sizes and phenomena that most DEM simulators can handle are bounded by either their computing capacity or physical modeling capability. To overcome many observed constraints, this work introduces a distributed-memory parallel DEM method that couples a finite volume method (FVM) for simulation of coupled hydro-thermal-mechanical phenomena in tight rocks. A remarkable feature in this coupled DEM-FVM method is that it creates a dual-mesh topology in tetrahedral meshes for establishing a two-way coupling between DEM and FVM, in which a cell-centered FVM solves porous flow and heat transport following the Darcy's law, and a vertex-based DEM handles mechanical responses and fracturing in rock matrix. The developed method is implemented in an MPI based parallel code to allow massive parallel computing on HPC clusters. Benchmark problems of practical interest will be presented to validate the developed method. In addition, scaling test results on HPC clusters will be reported to demonstrate the capacity and efficiency of the code to solve problems at unprecedented sizes.

Assessment of Applicability of Micromechanics-based Homogenization Schemes in Cement-based Materials via Digital Image Correlation

Friday, 21st June - 10:30: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 365

Dr. Siming Liang (Tsinghua University), Dr. Ya Wei (Tsinghua University)

Cement-based material is a heterogeneous and multiscale material with aging-dependent microstructure and mechanical properties, which makes it difficult to predict the mechanical properties accurately. Up to date there have existed many micromechanics-based homogenization schemes to predict the effective mechanical properties of cement-based materials, however, it is still an open question which of the micromechanics-based homogenization schemes is suitable for cement-based materials. This study combines the numerical calculation and experimental measurement to assess the applicability of micromechanics-based homogenization schemes in the prediction of mechanical properties of cement-based materials. The relationship between the local microscopic strain and overall macroscopic strain in the commonly-used homogenization schemes including the dilute scheme, the Mori-Tanaka scheme, and the self-consistent scheme is first recalled. Then the digital image correlation technique is employed to quantify the development of the strain distribution within each phase in a concrete specimen during the loading stage. The relationship between the local microscopic strain within each phase and the overall macroscopic strain will be established based on the measured strain results, which will be used to verify the theoretical one in different homogenization schemes. Several influencing factors including the volume fraction of aggregate, the *w*/*c* ratio, and the curing age of concrete are examined. The findings obtained in this study will provide better understanding of the applicability of micromechanics-based homogenization schemes in cement-based materials, which can contribute to predicting accurately the mechanical properties of cement-based materials with suitable homogenization scheme.

Dynamic Strain Aging of C45 steel over a wide range of temperatures and strain rates

Friday, 21st June - 10:45: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 405

Dr. Yooseob Song (Louisiana State University, Baton Rouge, Louisiana), Dr. George Voyiadjis (Louisiana State University, Baton Rouge), Dr. Alexis Rusinek (Lorraine University)

In this paper, a modified constitutive relation to model the dynamic strain aging (DSA) phenomenon observed on metals in a certain range of strain rates and temperatures is proposed based on the previous model of Voyiadjis-Abed. The main cause of DSA is known as the interaction between mobile dislocations and diffusing solute atoms and it usually takes place beyond a certain critical strain in a specific range of temperature depending on the strain rates applied. Experiments were performed using a C45 steel for a large range of temperatures from 298 K to 923 K under quasi-static loading. For C45 steel, a stress increase was observed in the experiments according to the temperature variation. A phenomenological model cannot capture this stress increase when dynamic strain aging is active. A physically based Voyiadjis-Abed model is modified in the present work by means of the Weibull distribution which is also derived using a physically based mechanism of evolution of the dislocation density. In addition, the proposed model is very flexible to implement and easy to incorporate into existing finite element codes. Observing the comparison of the proposed model with experiments in term of behavior and hardening, the proposed model addresses accurately the DSA material phenomenon for all range of temperatures, temperature sensitivity, stress level and hardening with plastic deformation increase.

Modelling and characterizing the adhesion of grooved interface between shotcrete and geopolymer by FEM and Wedge Split method

Friday, 21st June - 11:00: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 926

Mr. Zhaopeng Yang (University of Science and Technology Beijing), Prof. Linbing Wang (V)

This paper presents results of a research project to increase the fracture resistance of the interfaces between geopolymer coatings and shot concrete by fabricating grooves in the concrete base. To substantially advance the initial fracture toughness of the geopolymer strips, franc 3d simulation was carried out to partition the mixed fracture mode and determine the initial stress intensity factor (SIF). The wedge split experiments were carefully conducted to compare the interface adhesion capacity among all different specimens. The average energy release rate (ERR) was calculated by integrating the Pv-CMOD diagram to quantify the interfacial fracture toughness. Both the simulation and experiment results indicate that the highest interface fracture toughness was reached by the diagonal grooves among all others.

Integrated Modeling and Experimental Process Observations to Improve Asphalt Mix Design

Friday, 21st June - 11:15: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 827

Prof. Linbing Wang (V)

Traditional asphalt mix designs use experimental parameters to judge whether the mixes are satisfactory or not. However the material performances and usually not linear and one or a limited number of parameters may not reflect the overall performances of the mixes. This presentation will focus on an integrated modeling and experimental observation method to use data of the entire experimental process to better interpret the experimental data for improving mix designs.

Analytical analysis of ground settlement induced by construction of a curved shield tunnel

Friday, 21st June - 11:30: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 915

Dr. Pengfei Li (Beijing University of Technology)

This paper presents a series of analytical solutions of ground settlement induced by construction of a curved shield tunnel. Firstly, a calculation model of ground settlement due to ground loss was established based on the three-dimensional image theory. This model can take the parameters of “integrative gap at shield tail” (IGST) and over-cutting gap in a curved tunnel into account. Secondly, a theoretical formula of ground displacement induced by force per unit area exerted at the space surface was deduced by the rewritten of Mindlin solutions. According to this theoretical formula, analytical solutions of ground settlement were proposed due to construction loads, such as additional thrust, friction force and grouting pressures. Thirdly, a case study was conducted to analyze the axial ground surface settlement, the transversal ground surface settlement and the subsurface settlement. The results show that the ground settlement above the axis of the curved tunnel is not different from that of the straight-line tunnel. However, the transversal settlement troughs of the curved tunnel are nonsymmetrical about the tunnel axis, which is unlike the straight-line tunnel. The peak of ground settlement caused by IGST has a tendency of offset towards the inner side of the curved tunnel. Finally, a validation of the proposed model was performed by comparing the analytical results to the numerical results as well as the monitoring results. The theoretical results conformed well to those monitored results, which are of practical guiding significance to the construction of a curved shield tunnel.

Mesoscale Coupled Chemo-Mechanical Modelling of Concrete Damage Subject to Combined SA and F-T Degradation

Friday, 21st June - 11:45: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 1 (153 Noyes (134)) - Oral - Abstract ID: 957

Prof. Yang Lu (Boise State University), Mr. Md Aminul Islam (Boise State University)

Combined degradation in heterogeneous microstructure, like concrete, is a very complicated process, which involves the interactions between porous media moisture migration, heat transfer, phase change, and deformation. Concrete structures are subject to damage due to Sulfate Attack (SA) and Freeze-Thaw (F-T) in cold regions containing ample amount of sulfate species. Existing studies have considered heat-moisture migration and hydro-mechanical coupling. However, the synergistic damage effects study is still in lack. Combined degradation and damage cases are common in concrete service conditions. The combined effect of SA and F-T is a multiscale/multiphysics degradation phenomena of concrete that involves complicated chemical reactions, heat transfer, phase transition of water inside the porous media of concrete. Due to the complexity, existing experimental and modeling approaches are unsuited to assess these coupled degradation effects comparing to single dominant degradation mode, i.e. SA or F-T. This research, for the first time, presents a theoretical model addressing the coupled degradation effects to capture the complex chemo-mechanical damage behaviors using the classical theory of phase change, a diffusion-reaction process, and a cohesive damage model. This coupled mathematical model can be applied in assessing the effect of the pore-size distribution (PSD), the hysteresis of solidification and melting of water in concrete pores, and the change of porosity due to SA and F-T, especially the factors that are difficult to evaluate by current experimental methods. The developed model is also capable of precisely predicting the service life and damage tolerance of cementitious materials due to these combined environmental impacts.

Atomic Picture of Calcium Carbonate Precipitation by Molecular Dynamics Simulations

Friday, 21st June - 10:30: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 685

Ms. Qi Zhou (University of California, Los Angeles), Prof. Mathieu Bauchy (University of California, Los Angeles), Mr. Tao Du (Harbin Institute of Technology)

The precipitation of calcium carbonate plays an important role in nature. Further understanding the atomic mechanism and driving force behind the carbonation reaction could be key to facilitate the capture of $CO_2$by mineralization. Here, based on molecular dynamics simulations, we investigate the early-age precipitation of an amorphous calcium carbonate gel. We show that the gelation reaction manifests itself by the formation of some calcium carbonate clusters that grow over time. Interestingly, we demonstrate the existence of some local atomic stress in calcium carbonate gels—wherein Ca and C atoms exhibit a state of local tension and compression, respectively. We find that this internal stress gets released upon gelation and drives the carbonation reaction.

Machine Learning-Aided Development of Empirical Force-Fields

Friday, 21st June - 10:45: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 706

Mr. Han Liu (University of California, Los Angeles), Mr. Zipeng Fu (University of California, Los Angeles), Ms. Yipeng Li (University of California, Los Angeles), Ms. Nazreen Sabri (University of California, Los Angeles), Prof. Mathieu Bauchy (University of California, Los Angeles)

The development of reliable, yet computationally efficient interatomic forcefields is key to facilitate the modeling of glasses. However, the parametrization of novel forcefields is challenging as the high number of parameters renders traditional optimization methods inefficient or subject to bias. Here, we present a new parametrization method based on machine learning, which combines *ab initio* molecular dynamics simulations and Bayesian optimization. By taking the examples of silicate glass and chalcogenide glass, we show that our method yields new interatomic forcefields that offers an unprecedented agreement with *ab initio* simulations. This method offers a new route to efficiently parametrize new interatomic forcefields for disordered solids in a non-biased fashion.

New insights into the response to indentation of glasses from peridynamic simulations

Friday, 21st June - 11:00: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 743

Mr. Yuzhe Cao (Department of Civil and Environmental Engineering, University of California, Los Angeles), Prof. Mathieu Bauchy (Department of Civil and Environmental Engineering, University of California, Los Angeles)

Understanding the response of glasses to indentation (e.g., permanent densification or shear flow) is critical to developing new ultrahard glasses for cover screen applications. However, the linkages between the compositions of glasses and their response to indentation remain unclear. Here, we conduct some peridynamic simulations to model the nanoindentation of silicate glasses with varying compositions. We show that the propensity for shear flow vs. permanent densification strongly depends on glass composition—wherein silicate glasses with a low packing density and low Poisson's ratio (e.g., silica) favor permanent densification, whereas more compact silicate glasses with higher Poisson's ration (e.g., calcium aluminosilicate) favor shear flow deformations. By offering a realistic description of indentation-induced deformations in glasses, the peridynamic technique could facilitate the design of novel glasses with enhanced mechanical properties.

Modeling of the effects of surface tension in nano-composites with spherical and circular material surfaces

Friday, 21st June - 11:15: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 193

Prof. Sofia Mogilevskaya (University of Minnesota), Dr. Volodymyr Kushch (Institute for Superhard Materials of the National Academy of Sciences), Prof. Anna Zemlyanova (Kansas State University)

The concept of surface tension is important in modeling of various nano-sized phenomena where the influence of the surface becomes more significant due to the high surface-area-to-volume ratio. To model nanomaterials, new continuum theories of the mechanical surfaces have emerged, e.g. those by Gurtin and Murdoch (1975, 1978) and Steigman and Ogden (1997, 1999). In these theories, the material surface possesses constant residual surface tension as well as elastic properties.

Inclusion of surface tension in the model introduces additional difficulties, especially in three-dimensional setting. In this talk, we present new displacements representations that allow for straightforward analytical treatment of problems involving spherical and circular material surfaces that possess constant surface tension. The representations are useful in deriving closed-form expressions for the local elastic fields and effective moduli of a macroscopically isotropic composite materials containing spherical and circular inhomogeneities with the interfaces described by the complete Gurtin-Murdoch and Steigmann-Ogden models.

Nanolayered Attributes of Calcium-Silicate-Hydrate Gels

Friday, 21st June - 11:30: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1048

Dr. Mohammad Javad Abdolhosseini Qomi (UC Irvine)

Calcium-Silicate-Hydrates (C-S-H) gel, the main binding phase in cementitious materials, has a complex multiscale texture. Despite decades of intensive research, the relation between C-S-H's chemical composition and mesoscale texture remains experimentally limited to probe and theoretically elusive to comprehend. While nanogranular texture explains a wide range of experimental observations, understanding the fundamental processes that control particles' size and shape are still obscure. This paper strides to establish a link between the chemistry of C-S-H nanolayers at the molecular level and formation of C-S-H globules at the mesoscale via the potential-of-mean-force (PMF) coarse-graining approach. We propose a new thermo-mechanical load cycling scheme that effectively packs polydisperse coarse-grained nanolayers and creates representative C-S-H gel structures at various packing densities. We find that the C-S-H nanolayers percolate at approx 10 packing fraction, significantly below the percolation of ideal hard contact oblate particles and rather close to that of overlapping ellipsoids. The agglomeration of C-S-H Nanolayers leads to the formation of globular clusters with the effective thickness of approx 5 nm, in striking agreement with small angle neutron and X-ray scattering measurements as well as nanoscale imaging observations. The study of pore structure and local packing distribution in the course of densification shows a transition from a connected pore network to isolated nanoporosity. Furthermore, the calculated mechanical properties are in excellent agreement with statistical nanoindentation experiments, positioning nanolayered morphology as a finer description of C-S-H globule models. Such high-resolution description becomes indispensable when investigating phenomena that involve internal building blocks of globules.

Understanding thermo-mechanical properties of cross-linked C-S-H

Friday, 21st June - 11:45: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 1 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1049

Mr. Ali Morshedifard (University of California, Irvine), Dr. Mohammad Javad Abdolhosseini Qomi (UC I)

In the US, more than 60% of single-family residential houses are estimated to be under-insulated (Pew, 2009). Innovative materials can potentially lower the cost and fast-track rectification of such problems. In this talk, we propose cross-linking C-S-H using organo-silanes (xCSH) as a viable method of reducing thermal conductivity of cementitious materials. By utilizing tools from computational physics we show that xCSH has a significantly reduced thermal conductivity. Physical origins of this reduction are also investigated. Moreover, by studying fracture toughness, we demonstrate a ductile behavior which is highly desirable in construction materials. We also show that elastic properties are not significantly affected by incorporation of organo-silanes which would otherwise hamper their widespread industrial use. These findings have been partially demonstrated experimentally and we hope that future refinement of both experiments and simulations can result in a commercially viable material for construction industry.

Nonconservative loads of the follower type and related Hopf bifurcations in elastic structures

Friday, 21st June - 13:00: Plenary 6 (Beckman Auditorium (1,136)) - Oral - Abstract ID: 497

Prof. Davide Bigoni (University of Trento)

Tangentially follower loads in the sense introduced by Ziegler (1952) open the way to Hopf bifurcations (referred also as flutter instability) in elastic structures. These bifurcations display a series of unexpected mechanical behaviours, such as a lowering of the instability load associated to an increase of dissipation and the so-called 'Ziegler paradox', in which a vanishing small viscosity is shown to produce a strong and finite decrease in the flutter load evaluated without keeping damping into consideration. The follower loads have been for fifty years considered almost impossible to be realized in practice, so that all the unexpected mechanical features associated to them were believed to be mathematical curiosities, rather than real mechanical behaviours. Bigoni and Noselli have shown how to realize from friction a Ziegler type load on a double pendulum and have documented a Hopf bifurcation in an elastic structure. We report recent results showing how to realize a follower load acting at the end of a rod (Bigoni et al. 2018). These results demonstrate the detrimental effect of the dissipation on stability and open the way to a new understanding of flutter in elastic solids.

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An efficient algorithm to test the observability of rational nonlinear systems with partially measured inputs

Friday, 21st June - 14:00: MS80 - Structural Identification and Damage Detection; Part 3 (Ramo (371)) - Oral - Abstract ID: 690

Mr. Xiaodong Shi (University of Oxford), Prof. Manolis Chatzis (University of Oxford), Dr. Kristof Maes (KU Leuven, Department of Civil Engineering), Prof. Martin Williams (University of Oxford)

Accurately estimating the system parameter values, and tracing the evolution of state variables and inputs of a system is becoming more feasible due to recent developments in system identification methods and sensor technology. However, for a system identification campaign to be successful, the sensor setups should be chosen so that the states, the parameters and the inputs of interest can estimated or traced, i.e. are observable. Theoretical observability methods have been developed under the typical assumption that all inputs are known. Yet this assumption is rarely met in practice, as for example the loads on a wind turbine or a bridge are impractical to measure. A recent work by the authors relaxed this assumption, allowing for studying the observability of systems with partially measured inputs and outputs affected by direct feedthrough.

The symbolic nature of the computations involved in observability methods limits their implementation to systems with a small number of degrees of freedom. This paper proposes an efficient method to test the observability of rational nonlinear systems with partially measured inputs. An algorithm suggested by the authors for systems with partially measured inputs and direct feedthrough is paired with a computational efficient scheme for calculating Lie derivatives. Semi-numerical implementation of the method is achieved through the use of complimentary system to the observability matrix. The efficiency of the method is demonstrated through suitable examples.

Global Sensitivity Analysis for the Design of Nonlinear Identification Experiments

Friday, 21st June - 14:15: MS80 - Structural Identification and Damage Detection; Part 3 (Ramo (371)) - Oral - Abstract ID: 317

Mrs. Alana Lund (Purdue University), Prof. Shirley Dyke (Purdue University), Prof. Wei Song (University of Alabama), Prof. Ilias Bilionis (Purdue University)

One of the fundamental challenges in nonlinear system identification is the determination of the identifiability of a system, which may vary with respect to different input excitations. Global sensitivity analysis techniques provide a unique perspective on this problem that is well-suited to informing the design of identification experiments. These methods use Monte Carlo sampling to decompose the variance in the response of a model into contributions from the variation of its respective parameters, which are termed their sensitivities. When used with a specific system input, this process results in the assignment of sensitivity histories to the parameters, which indicate the degree of information concerning the parameters that is available in the system response over time. In this study we establish the utility of global sensitivity analysis as an indicator of identifiability through the experimental identification of a nonlinear energy sink device. The experimental identification results are generated using the unscented Kalman filter and compared with sensitivity histories generated using a Sobol' sensitivity analysis on the system model. The results demonstrate how global sensitivity analysis can be used as a method to pre-select experimental excitations for nonlinear system identification.

Vibration-based monitoring of systems featuring operational and environmental variability

Friday, 21st June - 14:30: MS80 - Structural Identification and Damage Detection; Part 3 (Ramo (371)) - Oral - Abstract ID: 763

Mr. Konstantinos Tatsis (ETH Zurich), Dr. Vasilis Dertimanis (ETH), Prof. Eleni Chatzi (ETH Zurich)

The major difficulties associated with vibration monitoring of in-service systems, such as wind turbines, lie in the environmental and operational effects which exert a strong influence on the dynamic properties of such systems. Within this context, the problem of response prediction for condition diagnostics and control application becomes an intricate task which needs to be based on estimation methods able to account for system variability. To overcome this issue, this work proposes a two-step Bayesian framework for input-state and parameter estimation of time-varying systems. The proposed approach employs a time-series model in order to firstly track the evolution of modal properties and subsequently deliver them to a modally reduced-order model for joint input-state estimation on the basis of a limited number of vibration measurements. The latter is carried out using an output-only Bayesian filter and the entire framework is demonstrated on a simulated case study by means of the estimated response at critical validation points.

Influence of Local Nonlinearities on Global System Dynamics and Nonlinear System Identification

Friday, 21st June - 14:45: MS80 - Structural Identification and Damage Detection; Part 3 (Ramo (371)) - Oral - Abstract ID: 843

Dr. Keegan Moore (University of Nebraska-Lincoln), Dr. Lawrence Bergman (University of Illinois at Urbana-Champaign), Dr. Alexander Vakakis (University of Illinois at Urbana-Champaign)

This research explores two recent investigations into the effects of local nonlinearities on global system dynamics and the identification of local nonlinear attachments. The first study discusses the characteristic nonlinear system identification (CNSI) procedure, which is a data-driven approach for modeling the dynamics of local nonlinear attachments. The CNSI method is unique in that relies entirely on measured response data, measured mass properties and requires no prior knowledge of the dynamics of the structure. The output of the CNSI technique is a reduced-order model, incorporating both nonlinear stiffness and nonlinear damping models, for the nonlinear physics governing the response of the attachment. The CNSI technique is demonstrated using the experimentally measured response of a linear structure with a smooth nonlinear attachment. The second study investigates the influence of local nonlinearities on the global dynamics of a model airplane under broadband loading. The experimental study reveals that the local nonlinearities drastically affect the global dynamical response of the model plane by inducing low-to-high frequency energy transfers in the modal space. These energy transfers significantly enhance the overall dissipative capacity of the plane, without any additional damping. Accordingly, this study promotes a new concept for passively enhancing the inherent dissipative capacity of a complex structure through the addition of local nonlinear attachments.

Value of information assessment of structural health monitoring through optimal stochastic control

Friday, 21st June - 15:00: MS80 - Structural Identification and Damage Detection; Part 3 (Ramo (371)) - Oral - Abstract ID: 1280

Mr. Charalampos Andriotis (Pennsylvania State University), Dr. Kostas G. Papakonstantinou (Pennsylvania State University), Prof. Eleni Chatzi (ETH Zurich)

Sequential decision-making under uncertainty for determining optimal lifetime strategies for deteriorating engineering systems and infrastructure entails two fundamental sets of control actions. The first includes the various structural interventions, e.g. replacements, repairs or rehabilitations, which can directly modify the existing properties of the system. The second refers to the sought observational schemes, e.g. inspection visits or monitoring plans, which are essential for updating our existing knowledge about the state of the system. Decisions about the latter have to rely on quantifiable measures of efficiency and be made in an objective manner, considering the Value of Information (VoI) of different observational strategies over the entire life-cycle of the system and for all possible future states and maintenance scenarios. In this work, we present general solutions for quantifying the VoI of different inspection plans and structural health monitoring alternatives, using Partially Observable Markov Decision Processes (POMDPs) to assess the expected life-cycle cost of the underlying stochastic systems. POMDP formulations are articulated for different structural settings with the same availability of intervention actions but with varying inspection and monitoring options, enabling practical and adept VoI estimates through the computed optimal control policies for each setting. Solutions are derived using point-based solvers which can very efficiently approximate the POMDP value functions, through Bellman backups at reachable points of the belief state space. The suggested methodology is successfully applied and demonstrated in various stationary and non-stationary structural environments, with both infinite and finite planning horizons, featuring single- or multi-component deteriorating engineering systems.

An intelligent wireless monitoring system for near-real-time condition assessment of civil infrastructures under sudden events

Friday, 21st June - 15:15: MS80 - Structural Identification and Damage Detection; Part 3 (Ramo (371)) - Oral - Abstract ID: 1014

Mr. Yuguang Fu (University of Illinois at Urbana-Champaign), Mr. Tu Hoang (University of Illinois at Urbana-Champaign), Dr. Kirill Mechitov (University of Illinois at Urbana-Champaign), Prof. Billie F. Spencer (University of Illinois at Urbana Champaign)

Many damage scenarios for civil infrastructure involve sudden events, such as strong earthquakes and bridge collisions. Due to their unpredictable nature, many of these events go unnoticed or unreported. But their consequence could be catastrophic, resulting in damage/failure in a matter of seconds or hidden damage that accelerates structural degradation. Efficient structural health monitoring (SHM) is thus critical to not only detect the events but also enable rapid structural condition assessment to ensure safety. Traditional monitoring systems using wired sensors are very expensive, ranging from $5K to $20K per channel. Wireless sensors offer tremendous opportunity to reduce cost, which however remains elusive for sudden event monitoring. Particularly, most wireless sensors are duty-cycled to preserve limited battery power; and hence, they may miss the events if they are in power-saving sleep mode. In this paper, an intelligent wireless monitoring system is developed to realize cost-effective sudden event monitoring, which consists of ultralow-power on-demand hardware prototypes, reactive time synchronization, high-throughput real-time data acquisition, a GUI and online condition assessment algorithms for near-real-time data visualization and processing. The developed system can be automatically turned on/off to collect high-fidelity (24-bit) data when it detects the start/stop of an event, with minimal power budget (~350μs) and low response latency (~0ms). The capabilities of the developed system are validated through laboratory experiments, demonstrating that the proposed solution is able to capture high-fidelity synchronized data under sudden events and enable near-real-time structural condition assessment.

Performance-based Durability Assessment of RC Structures under Marine Atmospheric Environment

Friday, 21st June - 14:00: MS88 - Modeling Deterioration of Structures and Infrastructure (Steele 102 (130)) - Oral - Abstract ID: 108

Mr. Hongyuan Guo (The Hong Kong Polytechnic University), Prof. You Dong (Hong Kong Polytechnic University)

Reinforced concrete (RC) structures under marine atmospheric environment generally suffer from chloride ingress, which could cause reinforcement corrosion and impair structural serviceability and safety during the service life. Performance-based engineering, as a novel approach to design structures with predictable and defined performance, has attracted increasing interests within durability engineering. In this paper, a modular and performance-based durability engineering for RC structures under marine atmospheric environment is proposed considering exposure analysis, deterioration, repair analysis, and impact analysis. The effects of climate change on the performance-based durability engineering are also assessed. To begin with, an environmental model is developed considering global warming, seasonal and daily variation of temperature, humidity and surface chloride content. Additionally, a comprehensive deterioration analysis model is developed to account for the two-dimensional chloride transport and non-uniformity of corrosion. Then, a calculation method of time-dependent reliability is proposed to compute the reliability index. Moreover, the impact/consequence analysis (e.g. financial cost and downtime) is performed to aid the decision-making process of RC structures considering durability issues. The effects of steel bar configuration and non-uniform corrosion on time-dependent reliability, the maintenance scheme, financial cost, and downtime are also investigated.

Sample-based life-cycle analysis and optimization of deterioration engineering systems

Friday, 21st June - 14:15: MS88 - Modeling Deterioration of Structures and Infrastructure (Steele 102 (130)) - Oral - Abstract ID: 866

Mr. Zhenqiang Wang (Colorado State University), Prof. Gaofeng Jia (Colorado State University), Prof. Paolo Gardoni (University of Illinois at Urbana-Champaign)

For a complete life-cycle analysis of deterioration engineering systems for guiding intervention activity such as repair or replacement, it is critical to model and incorporate the deterioration processes and associated uncertainties. However, general simulation-based approach for evaluating life-cycle performances typically entails many evaluations of the system model, and optimization of life-cycle performance would entail significant computational challenges. To address these challenges and facilitate efficient selection of intervention criterion for optimal life-cycle performance, an efficient sample and kernel density estimation (KDE) based approach is proposed. To evaluate life-cycle performances such as availability, total cost, and benefits of operating the system, renewal-theory life-cycle analysis (RTLCA) is adopted where state-dependent stochastic models are integrated to model the effects of multiple deterioration processes and their interactions. Stochastic simulation is used to estimate the time-variant performance indicators needed to inform intervention activities for the life-cycle analysis. To efficiently estimate and optimize the life-cycle performances (i.e., select optimal value for the intervention criterion), the proposed approach artificially treats the intervention criterion as uncertain random variable with uniform distribution. It then requires simulation of only one set of samples, based on which KDE is used for efficient approximation of the relevant probability density functions in RTLCA for any selected value of intervention criterion. Since only one set of samples is needed, the proposed approach has great computational efficiency. As an illustration, the proposed approach is used to optimize the life-cycle performance of an example reinforced concrete bridge subject to deterioration due to corrosion and seismic loads.

Deterioration modeling of glass fiber reinforced polymer composite structures/systems

Friday, 21st June - 14:30: MS88 - Modeling Deterioration of Structures and Infrastructure (Steele 102 (130)) - Oral - Abstract ID: 210

Dr. Zhiye Li (Stanford University), Prof. Michael Lepech (Stanford University)

The material degradation of civil infrastructure is the synergistic result in various physical, chemical, UV and other mechanisms of deterioration. It will exacerbate creep and fatigue and reduce the accuracy of the current physical based life cycle assessment tool. When engineer and architects want to take advantage of new construction material, e.g., polymer-based composite and smart materials, lacking long-term historical data will prevent experience based design tool to give reliability assessment result. In this circumstance, the multiphysics model coupled with deterioration models and fracture mechanics will be crucial to access the safety and resilience of new material structure/systems.

In this study, the multiphysics model aims to understand moisture and UV degradation of FRCs subject to climate and environmental changes and then to integrate the model of degradation into afterward damage, e.g., creep and fatigue. From existing literature, moisture effects and UV exposure are investigated and the mechanisms of deterioration of composite materials are identified. These mechanisms are computationally modeled using COMSOL® multi-physics modeling software using geometries and element properties that are provided by the manufacturer of composite plates which are used for the San Francisco Museum of Modern Art (SFMOMA).

The benefit of this effort is to prove the concept of the physical-based SIMSS framework which integrating multiphysics and multiscale considerations. This model will give a prediction considering more physical elements at the micromechanics level of Sustainable Integrated Materials, Structures and Systems (SIMSS) paradigm such as climate change, environmental change, fire-resistant, and seismic-resistant design.

Computational Modeling the Effect of ASR Damage on the Shear Strength of Reinforced Concrete Beams

Friday, 21st June - 14:45: MS88 - Modeling Deterioration of Structures and Infrastructure (Steele 102 (130)) - Oral - Abstract ID: 219

Mr. Hadi Aryan (University of Southern California), Dr. Bora Gencturk (University of Southern California), Ms. Clotilde Chambreuil (ENS Paris Saclay)

A detailed nonlinear finite element (FE) model is created for shear strength analysis of reinforced concrete beams with minimum shear reinforcement. The FE model is extensively validated using the experimental data from shear tests including shear load versus deflection, shear deformation, maximum crack width, and concrete and reinforcement strains. Three cases of alkali-silica reaction (ASR) were identified for the concrete expansions of 0.05%, 0.15%, and 0.3%. Corresponding degradation in the mechanical properties of concrete including compressive strength, tensile strength, elastic modulus, and fracture energy was calculated based on empirical data. The reduced mechanical properties of concrete were implemented in the FE model to investigate the effect of ASR. Shear analysis was performed on the reference model and the ASR models. Results showed that the degradation of concrete properties due to ASR expansion up to 0.3% can reduce the shear strength of the beam by 25%.

Improved bridge deterioration prediction using Bayesian updating considering incomplete data

Friday, 21st June - 15:00: MS88 - Modeling Deterioration of Structures and Infrastructure (Steele 102 (130)) - Oral - Abstract ID: 846

Ms. Min Li (Colorado State University), Prof. Gaofeng Jia (Colorado State University)

Bridge inspection is critical for effective bridge preservation. Estimation of the time that a bridge or bridge component stays in a specific condition rating can help select appropriate inspection intervals. For this purpose, statistical models of the time-in-condition rating (TICR) for bridge or bridge elements serve as good candidates. Typically, these models are calibrated using existing inspection data. Existing research tends to trim a large portion of the inspection data that are deemed incomplete. However, there is a lot of useful information in these data (e.g., upper or lower bounds for the TICR values). This type of information should also be incorporated to establish better estimation of the TICR and more appropriate inspection intervals. This work uses a statistical model to characterize the TICR and develops a Bayesian framework for calibration of the model parameters incorporating all the data in existing inspection database. Modification of the likelihood function in the Bayesian framework is developed to explicitly accommodate both complete and incomplete condition inspection data. Maximum likelihood estimation is then used to establish point estimates for the model parameters. Overall, the framework can fully utilize all the existing inspection data and guide more informed decision on selecting inspection intervals. The developed framework is applied to establish the statistical models of TICR for different types of bridges in Colorado using NBI data. Comparison between models using only complete inspection data and those using all the data demonstrates the need to explicitly incorporating the incomplete inspection data.

Deterioration models including real-time damage accumulation within shock occurrences

Friday, 21st June - 15:15: MS88 - Modeling Deterioration of Structures and Infrastructure (Steele 102 (130)) - Oral - Abstract ID: 800

Mr. Leandro Iannacone (University of Illinois at Urbana-Champaign), Prof. Paolo Gardoni (University of Illinois at Urbana-Champaign), Prof. Gaofeng Jia (Colorado State University)

Modeling the deterioration of engineering systems is a critical part in their Life-Cycle Analysis. The current literature usually distinguishes between gradual deterioration processes, continuously acting on the system (such as corrosion and fatigue) and shock deterioration processes, acting at specific moments in time (such as earthquakes and floods). In particular, shock processes are usually modeled by considering the overall effect on the system as a discrete quantity at the end of the shock occurrence. However, although the time frame over which they operate is much shorter than the one for gradual deterioration processes, shock deterioration phenomena are still a result of continuous processes. With the recent development of formulations making use of Stochastic Differential Equations (SDEs) to model deterioration processes, a more accurate analysis of the effect of a shock deterioration process within the shock occurrence itself is made possible. The purpose of this work is to use the aforementioned formulations to accurately analyze the real-time damage accumulation within an earthquake occurrence. This will allow to investigate the effect of important factors that could not be included using traditional methods, such as the specific ground motions associated with an earthquake. The proposed procedure will then be applied on a sample bridge subject to a set of ground motions over time.

Efficient Evidence Estimation for Bayesian Model Selection

Friday, 21st June - 14:00: MS94+23 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification, Robustness of infrastructures (Kerckhoff 119 (174)) - Oral - Abstract ID: 982

Dr. Subhayan De (University of Colorado, Boulder), Prof. Erik Johnson (University of Southern California), Prof. Steve Wojtkiewicz (Clarkson University)

Multiple models are often available to describe physical phenomena. Bayesian model selection helps select the model(s) that best explain the phenomena (i.e., the measured data) using Bayes' theorem. However, the main computational challenge for Bayesian model selection is to estimate the 'evidence' or marginal likelihood, which is typically a multidimensional integral over the whole space of the parameters of the model. A standard Monte Carlo (MC) approach to estimate this integral requires the evaluation of the forward models many times. Hence, for large-scale and complex models this MC approach is too computationally expensive. To alleviate this computational burden, in this study, a probability integral transform is used to convert the multidimensional evidence integral into a one-dimensional integral. Then, the approach uses an adaptive scheme based on iso-likelihood contours for estimating this integral using quadrature rule and sampling methods (e.g., importance sampling, stratified sampling, and Markov Chain Monte Carlo sampling). Two numerical examples are used to illustrate the proposed approach. The first example, flow past a cylinder with uncertainty present in the inlet flow velocity, shows that the proposed approach produces accurate results compared to MC sampling. The second example evaluates models of an 11-story base-isolated building with an uncertain hysteretic isolation layer, all subjected to historical earthquake excitation, to demonstrate that the proposed approach reduces the computational cost by approximately half when compared to a standard MC approach.

Digital Twins for Operational Monitoring and Rapid Post Earthquake Assessment of Civil Infrastructures

Friday, 21st June - 14:15: MS94+23 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification, Robustness of infrastructures (Kerckhoff 119 (174)) - Oral - Abstract ID: 1185

Dr. Hamed Ebrahimian (SC Solutions, Inc.), Dr. Farid Ghahari (University of California, Los Angeles), Prof. Ertugrul Taciroglu (University of California, Los Angeles)

The current advancements in computational structural mechanics techniques on one hand, and model updating and uncertainty quantification methods, on the other hand, have provided new opportunities to address the challenges that infrastructure owners face in managing their aging inventories. High-fidelity linear/nonlinear Finite Element (FE) models can be used to simulate the response of structural systems in operational condition and during catastrophic events. Nevertheless, the application of mechanics-based modeling techniques for structural assessment and diagnosis is limited. This is mainly due to the large uncertainties associated with forward FE models, including model parameters and loading uncertainties. Grounded on Bayesian inference method, a stochastic model updating approach will be presented for joint model and load identification. Referred to as the Digital Twin, the trained (or updated) FE model can be used for damage diagnosis and to disseminate actionable information for decision making. The application of Digital Twins for operational monitoring and post-earthquake assessment of bridges will be shown in this presentation. For operational monitoring, the FE model updating is integrated with computer vision techniques, which identify the vehicle locations from the raw traffic camera recordings, and synchronize the vehicle location with the measured acceleration responses of the bridge. The obtained information will be used for joint finite element (FE) model and vehicular load identification. For post-earthquake assessment, the measured acceleration response of the bridge is used to estimate jointly the model parameters and the time history of the foundation input motions (FIMs).

Surrogate Modeling with Physics-guided Neural Networks

Friday, 21st June - 14:30: MS94+23 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification, Robustness of infrastructures (Kerckhoff 119 (174)) - Oral - Abstract ID: 1006

Dr. Jinwoo Jang (Florida Atlantic University), Dr. Daniel Bartilson (Columbia University), Dr. Andrew Smyth (Columbia University)

The full-scale simulations of high fidelity computational models are fundamentally and practically important to deeply understand various dynamic and structural systems. However, the high dimensionality and complexity of those models require to deal with the expensive computation cost to run forward simulations of high fidelity models. The computational cost can exponentially increase when it is required to repeat the simulations many times, particularly in the study of uncertainty quantification and inverse problems. Surrogate models can be developed to replace the full simulation of computational models and to predict the outputs of computational models at a lower computational cost.

This work forces on the development of a more effective and robust neural networks model as a mean of replacing heavy computational model simulations. The sensitivity-based parameterization technique will be applied to a full-scale computational model to find physically meaningful clusters of structural components. Then, the learned knowledge about the relationship in the similarity of parameters' effects on model outputs between computational model elements will guide the spare connection of a neural network model structure. A physics-guided neural network model will be more robust and effective in terms of model complexity and predictive performance.

Nonlinear Finite Element Model Updating of a Dynamically Tested Two-Story RC Building

Friday, 21st June - 14:45: MS94+23 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification, Robustness of infrastructures (Kerckhoff 119 (174)) - Oral - Abstract ID: 1111

Dr. Seyedsina Yousefianmoghadam (University at Buffalo), Dr. Andreas Stavridis (University at Baffalo), Dr. Babak Moaveni (Tufts University)

This study discusses the model updating of a two-story masonry-infilled RC building in El Centro, California using the response obtained during dynamic tests. The building was deteriorated due to major earthquakes and it was further damaged by removing perimeter masonry infills at three stages. The building exhibited non-linear behavior due to forced vibrations which was recorded through an array of 97 sensors. This data has been used to validate nonlinear strut model of the damaged structure, which combines the ASCE 41-17 assessment guidelines with a novel hysteretic rule used to model the cyclic behavior of the masonry infills. The parameters governing the evolution of the hysteretic behavior of infills are updated to obtain a reference model representing the condition of the structure prior to the tests. This is achieved by minimizing the error between the dynamic response of the building during the forced-vibration tests and that of the model. The reference model is then updated using the experimental results in each stage of damage to assess the capability of the model-updating approach in identifying and localizing the damage.

The Components-Modeling-Method Based Numerical Analysis on the Structural Response of Planar Multi-Storey Steel Frame under Disproportional Collapse Scenario

Friday, 21st June - 15:00: MS94+23 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification, Robustness of infrastructures (Kerckhoff 119 (174)) - Oral - Abstract ID: 449

Prof. Yiyi Chen (State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University), Dr. Zhiyang Xie (State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University)

Numerical model based on the local damage mechanism is usually an option to simulate potential ductile fractures initiated in stress-concentration region, whereas the extremely fine mesh grid would accordingly cause large computational expense. In present study, a components –modeling-method based is proposed to deal with the local failure including ductile fractures simply and with satisfied accuracy. Two simplified connections models, for the conventional welded as well as bolted beam-to-column connections respectively, have been established, and its accuracy and efficiency are validated by comparison with the experimental results. Based on these models, the effects of the local failures on the structural response have been investigated under different horizontal boundary conditions. The numerical analysis results indicate that, with the vertical displacement increasing, the vertical loading resistance of the beams over removed column would be gradually shifted to the catenary mechanism if the connections possessing high ductility. In that case the horizontal restraint stiffness of the remaining structure adjacent to the column removed spans would have significant influence on the redistribution of vertical gravity load and the subsequent structural response. For the lower floors where the column loss occurs, the stronger horizontal stiffness of adjacent frame region would enhance the catenary mechanism of beams over removed column, while that positive effects would rapidly decay towards the upper floors due to the decrease of horizontal stiffness. This phenomenon would cause the additional vertical load passing through the undamaged mid-column so as to impose the additive demands on the connections in the lower floor.

Global Stability Analysis of Moment Resisting Frame Building in Post-Earthquake Fire Scenarios

Friday, 21st June - 15:15: MS94+23 - Integration of Physics-based Models with Data for Model Identification, Updating, and Uncertainty Quantification, Robustness of infrastructures (Kerckhoff 119 (174)) - Oral - Abstract ID: 968

Mr. Prabodh Dahal (The University of Mississippi), Dr. Chris Mullen (The University of Mississippi)

The advancements in seismic analysis and design approaches have surely made improvements to avoid the structural failure and collapses, however, secondary hazards associated with the earthquake are being prime concerns in today's world of structural engineering. Fire is one of the hazards associated with the earthquake which is likely to cause severe damage to the structure, lives and properties.

The stability of moment resisting frame building (Steel and Concrete) at global level with respect to post-earthquake fire is analyzed in this work. The buildings located on the seismic zone are first analyzed for the earthquake loads, and later are investigated for the effect of fire and again the effect due to the aftershock is investigated. The damage induced by earthquake is distributed damage. The damaged system is analyzed later with the added localized damage caused by the fire which gives different insights for the robustness of moment resisting building frame system.

Non-linear dynamic analysis is performed for the earthquake. Then, the damage pattern associated with fire with the prime consideration of fire in different parts, intensity of fire, fire spread and thermal gradient across the members is taken and applied to the disturbed system. And, again the system is analyzed for the aftershock associated with the previous earthquake. The different failure modes owing to the lateral stability and overall stiffness loss pattern are investigated for several mainshock-fire-aftershock patterns, ultimately.

A Conceptual Framework for City Resilience Index Classification for Climate Change

Friday, 21st June - 14:00: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 875

Mr. Mostafa Naiem (McMaster University), Prof. Wael El-Dakhakhni (McMaster University), Dr. Ahmad Siam (McMaster University), Prof. Paulin Coulibaly (McMaster University)

In the past decades, the United States of America and Canada have witnessed a continuous increase in the frequency and magnitude of climate change-induced natural disasters. These events include droughts, floods, wild fires, and most recently, tornadoes. In 2016, climate change induced damage was estimated to be $8.6 billion in Canada, while in the United States of America, floods are becoming one of the costliest and highest in occurrence of all climate change induced hazards, costing an average of $8 billion dollars annually. Also, hurricanes such as hurricane Sandy cost over $67 billion dollars of total damage, while more recently. hurricane Florence resulted in an estimated damage of $5 billion so far. It is thus clear that the effect of climate change is already costing North Americans billions of dollars annually, at an increasing rate. Given the effect of these events on cities, there is yet to be a clear methodology to quantify a city's resilience in the face of such hazards, that also takes into account the interdependence of different infrastructure networks. Although there have been multiple frameworks in literature, none has been comprehensive for a large-scale city. As such, this paper will introduce a framework for city's resilience index classification for climate change. In addition, a case study for city resilience index classification will be addressed for one of the climate change consequences (flooding) in Lake Ontario. The paper is considered a first step towards a full update for the resiliency concept due to climate change induced

Development of analytical framework for objective resilience of corroded steel bridges

Friday, 21st June - 14:15: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 903

Mr. George Tzortzinis (University of Massachusetts, Amherst), Mr. Brendan Knickle (University of Massachusetts, Amherst), Dr. Simos Gerasimidis (University of Massachusetts, Amherst), Mr. Alexander Bardow (Massachusetts Department of Transportation), Dr. Sergio Breña (University of Massachusetts, Amherst)

An essential component of community resilience management is the evaluation of its infrastructure. In the framework of resilience estimation, the physical deterioration of the assets should be carefully considered, since American infrastructure is classified in poor to fair condition, with many of its elements approaching the end of their service life (ASCE 2017). The existing damage and deteriorating conditions act as a source of uncertainty and may promote an overly optimistic pre-hazardous resilience network estimation. This work provides an effective tool for functionality assessment of deteriorated steel bridges under normal loading conditions. The proposed methodology emerges from real corrosion data. Initially the current deterioration condition of steel bridges was explicitly studied through MassDOT inspection reports of structures that had experienced beam end corrosion. The analytical model was validated using experimental data obtained from full scale loading tests on beams with natural corrosion. The use of the proposed methodology eliminates the practitioners need for detailed finite element analyses and introduces a useful tool for objective resilience. This tool can assist in improving both failure prognosis and decision making on rehabilitation and upgrades to steel bridges, thus preventing larger consequences for the transportation network.

Consideration of Post-Earthquake Fire scenarios for the Objective Infrastructure Resilience

Friday, 21st June - 14:30: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 966

Dr. Chris Mullen (The University of Mississippi), Mr. Prabodh Dahal (The University of Mississippi)

It is quite difficult to quantify the parameters that governs the objective resilience of the infrastructural facilities. Different approaches are undertaken to develop the indices for assessing the resiliency of the structural system. Considering a specific hazard can be the good practice to assess the robustness of infrastructural facilities, however achieving resilience is not solely dependent on how strong/robust a system is. Resourcefulness, Redundancies and recovery are also equally important.

The parameters governing the resilience of moment resisting building frame system are studied in this work. One of the primary hazard –earthquake, and associated secondary hazard- fire, are examined for the associated infrastructural resilience. The structural failure and collapses prevention are quite improved with the advancement in seismic design approaches, however, the fire has been found to cause severe damage even in the system sustaining large earthquake.

The global stability of the overall building system is investigated with different cases of mainshock-fire-aftershock patterns. Prime consideration is for the distributed damage due to the earthquake and localized damage due to the fire. Different fire extinguishing systems and other non-structural elements associated with fire are taken into consideration. Their vulnerability in case of earthquake and post-earthquake fires are also considered to get a big-picture idea for identifying different indices for the infrastructure resilience. A framework to assess the objective resilience of the building in post-earthquake fire scenario in developed that can be a vital contribution to quantify the different resilience indices.

RAIL NEUTRAL TEMPERATURE MONITORING USING NON-CONTACT PHOTOLUMINESCENCE PIEZOSPECTROSCOPY: A FIELD STUDY AT HIGH-SPEED RAIL TRACK

Friday, 21st June - 14:45: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 876

Prof. Hae-Bum Yun (University of Central Florida), Dr. Kyoung-Chan Lee (Korea Railroad Research Institute), Dr. Sung Ho Hwang (Korea Railroad Research Institute)

A novel non-contact stress sensing method using the photoluminescence piezospectroscopy (PLPS) method was applied in full-scale field test at high-speed rail tracks. The fluorescence spectra of the aluminum oxide (a-Al_2O_3) were collected from different locations on bare thermite weld surface for about 1.5 days. Prominent a-Al_2O_3signals (i.e., R1/R2 peaks) were observed with the very short measurement time of 0.01 second, which is preferable in mobile sensing applications. The kernel spectrum estimation (KSE) method was developed as a postprocessing technique to determine R1/R2 peak locations accurately. The R1/R2 time histories showed strong correlation with those of strain gauges mounted on the rail near the thermite welds. The piezospectroscopy coefficients were determined at -30.01 cm^{-1}/GPa for R1 and -32.11 cm^{-1}/GPa for R2, calibrated with the strain gauge measurements. Prior to the field test, a laboratory test was conducted to determine the R1/R2 zero-stress states using a pulverized thermite weld sample. The zero-stress state was determined at 14,404.99 cm^{-1} for R1 and 14,434.09 cm^{-1} for R2. Using these parameters, rail neutral temperature was determined at full-scale high-speed tracks based on the absolute rail stress measured with PLPS without additional field calibrations.

Seismic Resilience of Fully Integrated Hospital Clusters Subjected to Mainshock-Aftershock Sequences

Friday, 21st June - 15:00: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 1389

Prof. Hussam Mahmoud (Colorado State University), Mr. Emad Hassan (Colorado State University)

Modeling the recovery process of a community's infrastructure after the occurrence of extreme events is now at the forefront of research. Estimating post-disaster recovery of either single or multiple infrastructure in a community requires proper flow and interaction of information of the physical, economic and social components of the involved sectors. Understanding this recovery process is essential, particularly for critical infrastructure, such as a hospital, which is vital for a community's well-being. In this study, a full functionality and recovery process of a hospital cluster is quantified and assessed using a newly developed framework. The hospital functionality assessment encompasses both quantity and quality of the hospitalization service. The quantity of the hospitalization service is presented as a function of the number of staffed beds, which is expressed as a combination of the staff, space and supplies availability while the quality measured by the patient waiting time. The demand on the hospitals, estimated based on a newly developed patient-driven model, which considers patient constraints, patient-to-hospital connection, hospital availability in addition to hospital cluster interaction. The hospitals dependency on other infrastructure during the recovery process and the interaction between different hospitals is modeled. Socioeconomic data related to hospital operation and recovery after the earthquake are used for the assessment. The presented framework accounts for limitation in resources such as the repair crews within the community, expected economic return for each hospital, and interdependencies between the different lifelines including the investigated hospitals.

Investigating the Social Resilience of Urban Regions in Response to Natural Hazards

Friday, 21st June - 15:15: MS61 - Multihazards considerations for Objective Infrastructure Resilience; Part 2 (Firestone 384 (76)) - Oral - Abstract ID: 1323

Dr. Farrokh Namjooyan (Science and Research Branch, Islamic Azad University), Dr. Fariborz Tehrani (California State University, Fresno)

This presentation aims to investigate a case study on the social resilience of an urban region in response to a potential earthquake event, as an example of a natural hazard. The social resilience is an essential factor to determine the ability and the capacity of the community for crisis management. The case study covers the District 12 of Tehran municipality, a historic district with nearly 250,000 population, including 14 major communities in a 91 square kilometer area. This district hosts high impact buildings such as the grand bazaar; and numerous government buildings, national museums, and international embassies. The proposed methodology employs an objective descriptive-analytic approach. Data mining involved development and deployment of a questionnaire using Cochran relationship to gather information from 384 samples. In addition, presented methodology incorporated regional documents and maps in comparison with similar experiences in other cities to extract vulnerability and resiliency maps. Statistical analyses confirmed the reliability of data obtained from the questionnaire based on Cronbach's alpha (0.812). Results indicated a significant relationship between the social dimension of the resilience and the level of earthquake resilience for the selected region, that is a Pearson correlation of 0.567 with the significance level in the alpha region of 0.01 and the confidence level of 0.99. Results also identified objective rankings of various communities within the region, including the best and the worst performing communities in respect to their social dimension for earthquake resiliency. This ranking is essential for urban planning efforts based on objective resilience of communities.

Real-time hybrid simulation framework for multi-axial platforms

Friday, 21st June - 14:00: MS16 - Recent Advances in Real-time Hybrid Simulation (107 Downs (71)) - Oral - Abstract ID: 323

Mr. Amirali Najafi (University of Illinois at Urbana-Champaign), Prof. Billie F. Spencer (University of Illinois at Urbana Champaign)

Shake table testing has been widely used for evaluation of the performance of structures under earthquake loading. Shake table facilities are however generally expensive to build and operate. There are also size and weight limitations associated with the shake table capacity. The real-time hybrid simulation (RTHS) method is an alternative to dynamic shake table testing. RTHS involves substructuring of a full structure into numerical and experimental sub-components. The experimental execution is in real-time to allow for dynamic and rate-dependent behavior.

Multi degree of freedom RTHS serves as an alternative to multi-axial shake table testing. Multi-axial platforms like Load and Boundary Condition Boxes (LBCB), serve in prescribing three-dimensional loads and boundary conditions. Implementation of the RTHS methodology on multi-axial platforms has proven difficult due to challenges of kinematic coupling, system identification, sensitivity calibration and actuator control design. Stability problems are likely to occur, unless these challenges are addressed and appropriate compensation is provided on the actuator dynamics.

In this presentation, a real-time hybrid simulation framework is introduced for multi-axial platforms. This RTHS framework addresses challenges of actuator dynamic compensation, kinematic transformation, system identification and numerical integration.

Development of real-time hybrid simulation system for a bridge deck section model in a wind tunnel

Friday, 21st June - 14:15: MS16 - Recent Advances in Real-time Hybrid Simulation (107 Downs (71)) - Oral - Abstract ID: 363

Mr. Youchan Hwang (Seoul National University), Prof. Oh-sung Kwon (University of Toronto), Prof. Ho-Kyung Kim (Seoul National University), Dr. Un Yong Jeong (Gradient Wind Engineering Inc.)

Various experimental approaches have been used to estimate the self-excited forces and aeroelastic response of bridge deck. The so-called flutter derivatives, identified from the prescribed harmonic motion tests, are widely utilized for the modeling self-excited forces. The aeroelastic motion is usually reproduced on a spring-supported test setup, in which the measurement of the wind-induced forces is not feasible. Accordingly, current experimental practices are not suitable to measure the wind-induced forces and the aeroelastic response in one test. This limitation can be overcome by introducing a state-of-the-arts hybrid simulation technique in wind tunnel test.To address these challenges, this paper proposes a real-time hybrid simulation system that combines the traditional 2D wind-tunnel test and a numerical model consisting of a basic equation of motion. This system consists of a bridge deck section model, an instrumentation that measures the wind-induced force and inertial force of the model, and a real-time program that controls the motor by solving the equation of motion based on the measured forces and compensate actuator delay. Because this approach does not require assumption in representing wind-structure interaction, it is expected that the method allows reproducing real vibration due to the actual wind load. In this approach, the displacement and the load can be also obtained in real-time which can be used to improve understanding on wind-structure interaction. The research is in progress. A free vibration test is performed to validate the accuracy of the control system and the results are compared against the numerical predictions.

Real-time Hybrid Simulation in Aerospace Applications

Friday, 21st June - 14:30: MS16 - Recent Advances in Real-time Hybrid Simulation (107 Downs (71)) - Oral - Abstract ID: 462

Dr. Xiuyu Gao (MTS Systems Corporation), Dr. Shawn You (MTS Systems Corporation), Mr. Arlin Nelson (MTS Systems Corporation)

The advancement of real-time hybrid simulation technology needs more applications in other industries besides civil structural testing. This study shows some recent development and validation work in aerospace structural testing. The model assisted compensator (MAC) is developed in MTS, which is intended to improve the performance of test systems with large number of actuators and the challenges of strong dynamic cross-couplings. MAC is a model-in-the-loop testing technique that uses a real-time model to predict the responses of the test article, then the servo-controller can use these responses as outer-loop compensation signals to improve the test speed and accuracy. MAC is validated on a shell/wing type of structure, which shows superior behaviour in dealing with cross-couplings with multiple structural modes. In another type of application, real-time hybrid simulation is applied to test the aircraft landing gear oleo strut. Simscape Multibody is used to model the dynamics of numerical subsystems, while the physical oleo tested on a loading frame. The oleo dynamics is highly complex and nonlinear with steep changes of force due to breakout of the pre-charged load; the large friction; and the flow change due to varying metering pins. The existence of large oleo stiffness terms makes the system extremely sensitive to the delay caused negative damping effect. Moreover, the drop test procedure generates impact load that need to be accommodated by the hybrid system. The first real-time hybrid simulation of landing gear drop test is performed successfully by MTS.

Real-Time Hybrid Simulation for Damper Performance Evaluation under Wind Load

Friday, 21st June - 14:45: MS16 - Recent Advances in Real-time Hybrid Simulation (107 Downs (71)) - Oral - Abstract ID: 794

Prof. Wei Song (University of Alabama), Dr. Teng Wu (University at Buffalo)

Dampers have been widely used in controlling the wind-induced vibration of flexible structures, such as high-rise buildings and long-span bridges. Typically, damper performance is evaluated by using reduced-scale wind tunnel tests, which bringing in higher uncertainties comparing to its corresponding full-scale field implementation.

To address this concern, a real-time hybrid simulation (RTHS) has been proposed for evaluating damper performance in reducing wind-induced response on flexible structures. It effectively integrates the full-scale numerical model of damping devices with reduced-scale wind-tunnel testing environment via the use of actuators and sensors. The proposed RTHS is capable to provide accurate evaluation of damper performance in reducing wind-induced responses. In this paper, a tuned mass damper (TMD) model is integrated with a wind-tunnel tested building model to demonstrate the capability of the proposed RTHS. The accuracy of the evaluation is shown by the comparison between the response of the overall system and that obtained from the RTHS.

Real-time Hybrid Simulation of Highly Nonlinear Devices Using the Particle Filter

Friday, 21st June - 15:00: MS16 - Recent Advances in Real-time Hybrid Simulation (107 Downs (71)) - Oral - Abstract ID: 858

Mr. Johnny Condori (Purdue University), Dr. Amin Maghareh (Purdue University), Prof. Shirley Dyke (Purdue University)

In the last decades Real-Time Hybrid Simulation (RTHS) has been applied successfully to linear structural systems, and with restrictions and limitations to nonlinear problems. In RTHS we use commonly measured signals from the Physical substructure to feed the control approach implemented in the computational domain, and Kalman Filter techniques are readily available for filtering out noise high frequencies and send these filtered signals to the control scheme, otherwise the test would go unstable. However, this approach is not suitable when experimenting with highly nonlinear physical specimens. In this study, using a Bayesian approach, a nonlinear estimator is designed by adopting a Particle Filter (PF) algorithm that processes the measured signals from a nonlinear physical specimen. As a case study, a nonlinear spring coupled with a hydraulic actuator model plays the role of the actual plant (physical domain), and a nonlinear algebraic function is used as an approximation (a nominal plant), which is implemented in the PF estimator to spread the particles into the next time step. Then, we take advantage of the measured displacement and force signals to compute the relative likelihoods of each particle; finally, resampling is conducted to generate the posterior probability density functions of the states that are fed back to the controller. A set of virtual simulations demonstrates that the PF estimator is superior to conventional filters for RTHS experimentation with highly nonlinear physical substructures.

Design of a Controller for Physical Substructures in Stochastic Real-Time Hybrid Simulations

Friday, 21st June - 15:15: MS16 - Recent Advances in Real-time Hybrid Simulation (107 Downs (71)) - Oral - Abstract ID: 625

Mr. Nikolaos Tsokanas (ETH Zurich), Prof. Bozidar Stojadinovic (ETH Zurich)

Real-time hybrid simulation is a method to obtain the response of a system subjected to dynamic excitation by combining loading-rate-sensitive numerical and physical substructures. The interfaces between physical and numerical substructures are usually implemented using closed-loop-controlled actuation systems. In current practice, the parameters that characterize the hybrid model are deterministic. However, the effect of uncertainties may be significant.

Stochastic hybrid simulation is an extension of the deterministic hybrid simulation where the parameters of the model are treated as random variables with known probability distributions. The results are probability distributions of the structural response quantities of interest. The arising question is to what extent does the actuation control system affect the outcomes of stochastic hybrid simulations. This question is most acute for real-time hybrid simulations.

The response of a benchmark stochastic prototype to random excitation will be computed. Then, a part of the prototype will be replaced by a hybrid model whose substructure interfaces are actuated in closed-loop control. A controller that guarantees robustness and stability of the interfaces will be designed. The parameters of this hybrid model will be treated as random variables in repeated real-time hybrid response simulations to the same random excitation. The difference between the prototype and hybrid model responses will be used to determine if the controller design has an effect on the simulation outcomes, to predict such effects, and to propose guidelines for real-time controller design such that it has a predictable effect.

Keywords: stochastic hybrid simulation, dynamic response, uncertainty modeling, controller design

Compatible Second-Order Finite Elements for Use in Explicit-Dynamic Simulations That Facilitate Hex-Dominant Meshing

Friday, 21st June - 14:00: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1054

Mr. Robert Browning (U.S. Army Engineer Research and Development Center), Dr. Kent Danielson (U.S. Army Engineer Research and Development Center), Dr. David Littlefield (University of Alabama at Birmingham)

Hexahedral (hex) elements continue to be preferred for high-rate explicit-dynamic finite element analysis. However, generating an all-hex mesh for complex geometries can be extremely time-consuming and thus cost-prohibitive. This has fostered the development of hex-dominant meshing techniques where the geometry is predominantly filled with hexes, and then difficult regions are meshed with tetrahedral (tet) elements, with appropriate transition elements joining them. The total number of elements in the mesh can also be greatly reduced by using second-order (as opposed to first-order) elements, since curvature can be captured and flexure modeled with a single element through the thickness of a structural member. However, care must be taken with explicit-dynamic codes to identify a robust set of second-order element shape functions suitable for mass lumping. Thus far, a 27-node hex, a 15-node tet, and a 21-node wedge element (an extruded triangle) have been successfully implemented into meshing and finite element analysis software. Recently, a 19-node second-order pyramid element was developed that will offer further flexibility for hex-dominant meshing. The pyramid element is suitable for mass lumping and is compatible with the other second-order elements, thus providing a well-rounded set of element shapes for meshing complex volumes. This presentation will provide an overview of the compatible set of elements and their respective shape functions, as well as results of benchmarking the performance of a hex-dominant mesh against an all-hex mesh. Permission to publish was granted by Director, Geotechnical & Structures Laboratory.

Simulation of Post-Event Capacity for Reinforced Concrete Structures

Friday, 21st June - 14:15: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1201

Mr. Andrew Groeneveld (U.S. Army Engineer Research and Development Center), Mr. Robert Browning (U.S. Army Engineer Research and Development Center), Dr. Wesley Trim (U.S. Army Engineer Research and Development Center)

The Advanced Fundamental Concrete (AFC) model is a robust constitutive model originally developed at the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) for simulating penetration of projectiles into concrete. The model is very efficient and includes a three-invariant failure surface and nonlinear loading and unloading in hydrostatic compression. To date, it has primarily been used for simulating the response of concrete to highly dynamic loads such as impacts and explosions. To determine whether a structure will perform adequately following an extreme event, it is useful to assess its quasi-static residual capacity.

The performance of the AFC model for simulating quasi-static loads was examined. Tests on normal-strength concrete panels were modeled using a VUMAT implementation of AFC in the commercial finite-element code Abaqus/Explicit. Explicit dynamic simulation results correlated well with experimental data; however, care must be taken to avoid numerical error in the VUMAT calculations. It was found that a model that performs well for short-duration dynamic simulations may be unstable for quasi-static simulations.

Finally, an example calculation with both dynamic and quasi-static loading is demonstrated. A reinforced concrete column was subjected to a transient high-pressure (blast) loading, followed by quasi-static compression to assess its residual capacity. This calculation demonstrates the capability for residual capacity assessment. However, more work is needed, particularly in the area of experimental data for validation.

Implementation of MCEER TR 14-0006 Blast Load Curves in LS-DYNA® and Benchmark to Commonly Practiced Blast Loading Application Methods

Friday, 21st June - 14:30: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1223

Mr. Devon Wilson (Arup North America Limited), Ms. Deborah Blass (Arup North America Limited), Mr. Sam Noli (Arup North America Limited), Ms. Kendra Jones (Arup North America Limited)

A tool has been developed to explore implementation of the blast load curves derived by J. Shin, A. Whittaker, A. Aref and D. Cormie in the MCEER Technical Report 14-0006 (2014). The MCEER proposed blast load curves capture the effects of high explosives near the face of the charge, where the traditionally-used Kingery and Bulmash (KB) empirical data is not applicable. Although not a replacement for a proper computational fluid dynamics assessment, designers can use simplified methods such as this tool to provide rough order of magnitude assessments prior to performing more complex hydrocode methods.

*The ultimate intention of this tool is to supplement the capability of the current LS-DYNA method, *Load_Blast_Enhanced (LBE), which can then be used to compliment more complex Arbitrary Lagrangian Eulerian (ALE) methods. It is not intended for this tool to replace more sophisticated hydrocode methods.*

*The MCEER proposed curves for incident and reflected peak overpressures and impulses have been compared to *Load_Blast_Enhanced in range for validation before investigating the tool in the out-of-range values. The tool was developed to apply the polynomials into a calculation of load application in LS-DYNA based on the charge weight, standoff and angle of incidence geometry of the model.*

While the MCEER research provides values for calculating the pressures and impulse as angle of incidence varies, there exists a gap in published reflection coefficients for scaled distances below 0.16 m/kg$^{1/3}$. A method for extrapolating the blast load curves has been assessed and future research based on the findings is proposed.

REFINEMENTS TO A CONTACT METHOD FOR MULTI-MATERIAL EULERIAN HYDROCODES

Friday, 21st June - 14:45: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 1362

Dr. David Littlefield (University of Alabama at Birmingham)

Realistic and accurate modeling of contact for problems involving large deformations and severe distortions presents a host of computational challenges. Due to their natural description of surfaces, Lagrangian finite element methods are traditionally used for problems involving sliding contact. However, problems such as those involving ballistic penetrations, blast-structure interactions, and vehicular crash dynamics, can result in elements developing large aspect ratios, twisting, or even inverting. For this reason, Eulerian methods have become popular. However, additional complexities arise when these methods permit multiple materials to occupy a single finite element.

Multi-material Eulerian formulations in computational structural mechanics are traditionally approached using mixed-element thermodynamic and constitutive models. These traditional approaches treat discontinuous pressure and stress fields that exist in elements with material interfaces by using a single approximated pressure and stress field. However, this approximation often has little basis in the physics taking place at the contact boundary and can easily lead to unphysical behavior. In previous work we have presented an approach that is a significant departure from traditional Eulerian contact models by solving the conservation equations separately for each material and then imposing inequality constraints associated with contact to the solutions for each material. One limitation of the original model was that it could not be applied to 'self-contact' scenarios, such as when a thin body folds over and contacts itself. We have generalized our approach in this work, so that it is now applicable to self-contact. Computational examples are shown to demonstrate the veracity of this new development.

Progressive Collapse Fragility Analysis and Progressive Collapse Potential Assessment of RC Spatial Frames with Infilled Walls

Friday, 21st June - 15:00: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 612

Prof. Mingming Jia (School of Civil Engineering, Harbin Institute of Technology), Prof. Dagang Lu (School of Civil Engineering, Harbin Institute of Technology)

The progressive collapse performance of the RC spatial frame with infilled walls were researched based on progressive collapse fragility and progressive collapse potential. The finite element analysis model of a two-bay and six-story RC spatial frame with infilled walls was built in the OpenSEES. The structural dynamics responses with removing components were obtained by nonlinear dynamic analysis, which were compared with the experimental results to validate the accuracy of finite model and simulation method. The structure did not collapse when two columns in the first floor were removed, which showed large progressive collapse potential. Considering of the uncertainties of the structure, the improved Latin Hypercube Sampling (LHS) method based on the finite element model was adopted to random structural analysis. The structural progressive collapse fragility was obtained from random Static Pushdown Analysis (PDA) and Vertical Incremental Dynamic Analysis (IDA) methods. The RC spatial frames with infilled walls show smaller progressive collapse failure probability and larger progressive collapse resistance capacity than those of the bare frame. The influence of infilled walls on the progressive collapse performance of RC spatial frames was evaluated with comparison of structural progressive collapse potential, and the progressive collapse resistance capacity of RC spatial frames was improved greatly with the function of infilled walls.

Challenges in Modeling Contact in Explicit High-Velocity Impact Computations

Friday, 21st June - 15:15: MS15 - Advances in Simulation for Extreme Dynamic Loading of Structures; Part 2 (269 Lauristson (104)) - Oral - Abstract ID: 978

Mr. Dominic Wilmes (Karagozian & Case, Inc.), Dr. Casey Meakin (Karagozian & Case, Inc.), Mr. Joe Magallanes (Karagozian & Case, Inc.)

Contact approaches available in commercial, explicit finite element analysis codes can often fail to accurately reproduce the expected physics in high-velocity impact problems. Traditional contact treatments, including the penalty method, can introduce noise into the calculation while never truly satisfying the contact constraint condition. In problems where relative velocities approach the sound speed of the materials involved in the calculation, contact noise can blur shock fronts and improperly chosen contact constraints can contribute to numerical instabilities and/or non-physical behaviors. Additionally, these methods often admit significant penetration at high velocities which push the boundaries of detailed contact search algorithms, as they only approximate the contact constraint. This contribution seeks to highlight a selection of contact algorithms which are designed to more accurately treat the contact constraint, leading to increased stability and accuracy in high-velocity impact problems. These chosen methods are implemented in an in-house finite element code and are benchmarked against a more traditional, penalty-based contact scheme. Several examples are used to illustrate the computed differences between each contact treatment, as well as the computational cost associated with each algorithm.

Multi-scale random media modeling of concrete

Friday, 21st June - 14:00: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 994

Prof. Jie Li (Tongji University), Dr. Hankun Liu (Sichuan Institute of Building Research), Prof. Xiaodan Ren (Tongji)

In the present paper, a multi-scale random media model is proposed based on the indentation tests for each constituent of concrete including hydrated cement paste (HCP), aggregate and interfacial transition zone (ITZ). Firstly, systematic indentation tests are performed for each constituent of concrete at the nano- and micro- scales. Following the random field theory, each constituent of concrete materials is modeled as a random field. The scale of fluctuation is investigated based on the results of indentation tests. At the nano-scale, the scales of fluctuation for HCP and ITZ both turn to be roughly 20 micrometers, but that of aggregate is much larger. At the micro-scale, the scale of fluctuation of HCP and aggregate stays from 167 to 569 micrometers. Then the pointwise parameter estimation and model verification are performed for each constituent of concrete, and the one-dimensional (1-D) probabilistic density function (PDF) of the random field is obtained based on the proposed maximum possibility criterion. The probability distributions of the indentation modulus and hardness for each constituent of concrete are identified based on the statistical analysis. By introducing the reconstruction technique, concrete materials could be reconstructed as the random medium at the nano- and micro- scales. With the local averaging theory, the reduce factor for mechanical properties between the nano- and micro- scales is studied and it is shown that the experimental reduce factor agrees well with the theoretical one.

A Computational study of the micro-mechanics underlying ballistic impact towards designing a class of better ballistic composites

Friday, 21st June - 14:15: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 1288

Mr. Ramachandran Varun Raj (Eindhoven University of Technology), Prof. Ron Peerlings (Eindhoven University of Technology), Prof. Vikram Deshpande (University of Cambridge)

Composites reinforced with Ultra High Molecular Weight Polyethylene (UHMWPE) fibers – possessing a highly oriented molecular chain structure – exhibit superior performance under ballistic loading attributable to the high specific strength of these fibers. During ballistic penetration, the interplay between different failure modes is uniquely influenced by a combination of composite properties. In order to tap into the full potential of these composites, a deeper understanding of the underlying penetration mechanics is sought. As a first step in this direction, an unclamped infinite UHMWPE beam under ballistic impact was analyzed using dynamic finite element simulations and the onset of different failure modes was identified. A micro-mechanically motivated homogenized ply level model using orthotropic elasticity and crystal plasticity was formulated to capture the anisotropic interactions between the fibers and the matrix. Fiber strength, matrix strength and fiber topology were varied by adjustments in the constitutive law for each simulation and the corresponding dominant failure initiation mode was mapped as a function of these properties to construct impact maps. Two fiber topologies were studied based on manufacturing feasibility - a fiber system (circular fibers) and a strength equivalent tape system (continuous microstructure, with no individual fibers discernible). The impact map results indicate an improved ballistic resistance to failure in tape systems as compared to the equivalent fiber systems. Extending the study to capture failure mode propagation and switching, a viscous damage model is incorporated into ply-level constitutive model in order to capture quasi-brittle fiber failure within plies at high strain-rate loadings.

A novel multi-scale model for predicting the thermal damage of hybrid fiber reinforced concrete

Friday, 21st June - 14:30: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 69

Dr. Yao Zhang (Tongji University), Prof. Woody Ju (University of California, Los Angeles)

Abstract: A multi-scale micromechanical model is proposed to predict the damage degree of hybrid fiber reinforced concrete (HFRC) under or after high temperatures. The thermal degradation of HFRC is generally composed of the damage of the cement paste caused by thermal decomposition and thermal incompatibility, the deterioration of aggregates and fibers, and the interfacial damage between aggregates and the matrix. In this multi-scale model, four levels of HFRC structures are considered when the thermal damage degree is derived; namely, the equivalent calcium silicate hydrate (C-S-H) product level, the cement paste level, the concrete level and the HFRC level. At the cement paste level, thermal decompositions of C-S-H product and calcium hydroxide are taken into account. In addition, a dimensionless parameter of the crack density is introduced to represent the thermal cracking of the matrix. At the concrete level, the interfacial damage of aggregates is simulated by a spring-interface model, in which the interfacial parameters are assumed to be functions of temperature. Moreover, at the cement paste level and the HFRC level, a sub-stepping homogenization method is adopted to determine the effective properties. Comparisons between previously published experimental data and predictions and discussions illustrate the feasibility of the proposed multi-scale model in predicting thermal damage of concrete and HFRC.

Key words: HFRC, thermal damage, interfacial damage, multi-scale thermal damage model, thermal decomposition

Effective elastoplastic damage mechanics for fiber reinforced nanocomposites with evolutionary fiber debonding

Friday, 21st June - 14:45: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 74

Mr. Yinghui Zhu (University of California, Los Angeles), Prof. Woody Ju (University of California, Los Angeles)

A nanomechanical evolutionary damage framework is presented to predict the effective elastoplastic damage behavior of continuous fiber reinforced nanocomposites. Under uniformly distributed transverse load in the longitudinal direction, debonding is considered at the interface between randomly distributed, unidirectionally aligned circular-fibers and surrounding matrix. By assuming uniform interface debonding along fibers, the effective properties are investigated under the plane strain condition. Further, the interface energy effect is incorporated in this model as nanosized fibers are studied. Three bonding modes, the perfectly bonded, partially debonded and completely debonded fibers, are considered at the same time and their corresponding probabilities are simulated by Weibull's distribution function. Based on the evolutionary effective interface debonding angle, the partially debonded isotropic fibers are regarded as equivalent to perfectly bonded orthotropic fibers, and the completely debonded fibers become voids. For the equivalented four-phase nanocomposite, the interface energy effect is assumed to induce interface stress on the zero-thickness membrane-type interface, and the stress discontinuity equations through interface are formulated in accordance with the equilibrium conditions on the idealized interface. Subsequently, effective elastic stiffness is derived from the discontinuity equations. Furthermore, to characterize the elastoplastic behavior, we assume that reinforcement phases are elastic and matrix phase is elastoplastic. An effective yield function is then proposed to estimate the effective elastoplastic responses of the fiber reinforced nanocomposite. Finally, prediction of elastoplastic damage behavior for a two-phase fiber reinforced nanocomposite is presented as illustration, where the size effect due to interface energy is notable.

Micromechanical damage formulation and experimental testing for internal freeze-thaw damage of porous concretes

Friday, 21st June - 15:00: MS20 - Multiscale Behavior of Damage and Failure Mechanics; Part 2 (Lees-Kubota (118)) - Oral - Abstract ID: 106

Mr. Tien-Shu Chang (University of California, Los Angeles), Prof. Woody Ju (University of California, Los Angeles)

In cold climates, freeze-thaw action is one of the major reasons jeopardizing mechanical properties of contemporary concrete infrastructures, such as bridge columns, bridge decks, concrete dams and concrete pavements. In these concretes, the cracks and voids generated by the cyclic freeze-thaw events not only reduce the effective strength of the concretes but also increase the rate of corrosion of the rebars due to the exposure to the air. In this study, a rigorous formulation in observance of the local form of the second law of thermodynamics is proposed to predict the damage evolution and homogenized stress of concretes due to freeze-thaw actions. Based on the fundamental concepts in strain-based continuum damage mechanics developed by Ju (1989), it is further extended that the thermal effects and crystallization pressure are considered in our novel formulation. An elastic-damage tangent moduli tensor is derived for the implementation of finite element simulation. The delayed damage evolution model is for the first time correctly applied to the freeze-thaw damage of concretes. The corresponding computational algorithm is proposed and the results of damage evolution and homogenized stress are compared with the literature. Experimentally, the freeze-thaw resistance of the fiber-reinforced phase change material concrete (FRPCM concrete) is particularly studied. An innovative freeze-thaw machine featuring automated freeze-thaw actions is constructed to address the common problems of the commercial freeze-thaw machines.

Transport phenomena and swelling behavior in compacted granular systems: A multiscale, multi-physics modeling approach

Friday, 21st June - 14:00: MS72 - Mechanics and Physics of Granular Materials; Part 4 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 1019

Mr. Pedro Martins (Purdue University), Prof. Marcial Gonzalez (Purdue University)

Imbibition and drainage of a fluid in granular media play a crucial role in all aspects of their behavior. For example, granular infrastructure materials are structurally compromised by their exposure to cycles of rain-freeze-thaw. In contrast, compacted powders for pharmaceutical applications rely on imbibition, swelling and disintegration phenomena to control drug release profiles. Microstructure plays a central role in the transport phenomena and swelling behavior of these granular system. Our work focuses on low-porosity microstructures that originate from the manufacturing process of powder compaction. Specifically, we study the coupled effects of fluid transport through the interconnected pore space, fluid absorption from particle to particle and from pore to particle, particle swelling, development of internal stresses, and eventually breakage of solid bridges formed during compaction. Out multiscale, multi-physics modeling approach utilizes (i) our particle mechanics approach (PMA) to model the compaction process up to porosities close to 0 using generalized loading-unloading contact laws for elasto-plastic spheres with bonding strength, (ii) a dynamic network model of two-phase, pressure-driven flow within the pore structure obtained from a Laguerre tessellation of the PMA solution, (iii) a discrete Fikian-type absorption transient solver to model fluid transport across interparticle contact interfaces and across particle-pore interfaces determined form the PMA solution, and (iv) empirical rules for particle swelling and softening, and solid-bridge weakening, as a function of fluid content to solve for mechanical equilibrium using the PMA. Experimental efforts to calibrate these models, and the elucidation of optimal strategies for coupling different time- and length-scales, are underway.

Structural signature of the onset of granular creep flow in rotating drum systems

Friday, 21st June - 14:15: MS72 - Mechanics and Physics of Granular Materials; Part 4 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 447

. Liuchi Li (Caltech), Prof. José Andrade (Caltech)

Understanding the micro-structure of granular flow in heterogeneous systems is vital for establishing predictive models but has received little attention. Via experimentally validated 3D discrete element simulations, we investigate the internal structure of stationary surface flow developed in rotating drum systems. We identify a highly relevant micro-structural quantity $\delta \theta \coloneqq |\theta_c - \theta_f|$ defined as the deviation from the preferred direction of contacts (θ_c) to that of the force transmissions (θ_f). We show that its spatial variation signifies the transition not only from collisional flow to dense flow with location z_{crit1}, to which the corresponding Inertia number I recovers the critical value 0.1, but also from dense flow to creep flow with a deeper location z_{crit2} that coincides with the ending point of the exponentially-decaying velocity profile. When $z \leq z_{\text{crit2}}$ the $\mu(I)$ rheology in its invariant form holds, while for $z > z_{\text{crit2}}$ the $\mu(I)$ rheology breaks down and we find μ globally depends on $\delta\theta$.

On the effect of grain friction on characteristics of slip instabilities in a sheared granular fault gouge

Friday, 21st June - 14:30: MS72 - Mechanics and Physics of Granular Materials; Part 4 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 753

Dr. Omid Dorostkar (ETH), Prof. Jan Carmeliet (ETH)

In this work, we use three-dimensional Discrete Element Method (DEM) to simulate a sheared granular layer, with application to frictional stick-slip dynamics in a granular fault gouge. The granular fault gouge is compressed with a constant confining stress, and is sheared with a displacement control mechanism. Our results show that, particle friction can systematically change the timing and size of slip events: a fault gouge with high particle friction shows a more complex nucleation phase (stick phase), which contains frequent small slip events preceding the major event. The fault gouge with higher grain friction stores more elastic strain energy, which is released more often, as is evidenced in the kinetic energy signal. Using statistical analyses on a large number of slip events, we find that the average recurrence time and its variations decrease with particle friction. Our results suggest that a fault system with higher gouge grain friction produces more small slip events, but also contains a limited number of extreme events. We analyse the pseudo acoustic emission that is based on the monitoring of velocity signals of particles, and find higher temporal and more spatially distributed emission patterns for fault system with higher grain friction. Based on our micro- and macro-scale observations, we argue that fault gouge particle friction may affect the characteristics of seismic cycles and the complexities of nucleation phase in a way similar to the effect of fault roughness in absence of gouge.

Study of an athermal quasi static plastic deformation in a 2D granular material

Friday, 21st June - 14:45: MS72 - Mechanics and Physics of Granular Materials; Part 4 (310 Linde Lecture Hall (99)) - Oral - Abstract ID: 353

Dr. Jie Zhang (Shanghai Jiao Tong University)

In crystalline materials, the plasticity has been well understood in terms of dynamics of dislocation, i.e. flow defects in the crystals where the flow defects can be directly visualized under a microscope. In a contrast, the plasticity in amorphous materials, i.e. glass, is still poorly understood due to the disordered nature of the materials. In this talk, I will discuss the recent results we have obtained in our ongoing research of the plasticity of a 2D glass in the athermal quasi static limit where the 2D glass is made of bi-disperse granular disks with very low friction. Starting from a densely packed homogeneous and isotropic initial state, we apply pure shear deformation to the system. For a sufficiently small strain, the response of the system is linear and elastic like; when the strain is large enough, the plasticity of the system gradually develops and eventually the shear bands are fully developed. In this study, we are particularly interested in how to relate the local plastic deformation to the macroscopic response of the system and also in the development of the shear bands.

Scale model collapse analyses of freestanding multi-drum Pompeian columns

Friday, 21st June - 14:00: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 1333

Ms. Janille Maragh (Massachusetts Institute of Technology), Mr. Samuel Raymond (Massachusetts Institute of Technology), Mr. Eric Wong (Massachusetts Institute of Technology), Prof. John Ochsendorf (Massachusetts Institute of Technology), Prof. John Williams (Massachusetts Institute of Technology), Prof. Admir Masic (MIT)

From the catastrophic eruption of Mount Vesuvius in 79AD until its intentional excavation in 1748, the city of Pompeii had been covered by meters of pumice and volcanic ash, which restricted the exposure of the contained structures and art to air, moisture, and environmental events, leaving them in a well-preserved state for centuries. The free-standing multi-drum Pompeian columns found throughout the archaeological area are examples of such structures that are now at risk of damage, particularly in the event of seismic activity. This work presents the results of a study of three such columns from the Tempio di Apollo (Pompeii, Italy). Material Point Method (MPM) models were used to numerically predict the damage sustained by the columns' drums under several collapse conditions, which all yielded catastrophic results. The 3D models of the columns and their drums were used to numerically predict the most probable collapse mechanism of each column and the equivalent lateral ground acceleration necessary to cause it.These results were corroborated using 3D printed scale model physical studies in the form of tilt tests. The presented methodology and results show great promise in both the analysis of invaluable ancient masonry structures and the design of preservation strategies to protect them.

Diagnosis of damage on historic structures: Manifold learning and numerical methods for building pathology and diagnostics

Friday, 21st June - 14:15: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 474

Ms. Rebecca Napolitano (Princeton University), Dr. Wesley Reinhart (Princeton University), Mr. David Sroczynski (Princeton University), Prof. Branko Glisic (Princeton University)

Building pathology and diagnostics provides valuable insights into historic infrastructure which can inform not only necessary interventions but also preventative conservation. However, many existing methods for evaluating the origins and extent of damages are initially biased and/or computationally expensive. For instance, many works assume a singular initial loading condition during structural analysis which biases the results of the system. New methods which enable a user to quantitatively compare the results of many different loading scenarios to existing conditions have been developed in recent years. However, a main issue with these approaches is the computational power needed to analyze so many different loading conditions; additionally, a user still decides what initial conditions to implement, thus there is still bias present in the system. To address these limitations, an approach which leverages the power of manifold learning has been developed and tested on historic structures. Masonry walls were simulated under a range of loading conditions using discrete element modeling. Manifold learning can be applied to the resulting ensembles of crack patterns to infer damage pathways when the mechanism is unknown. Manifold learning produces an affinity matrix using the discrete element modeling simulations; the resultant affinity matrix can then be analyzed using spectral methods to discern the parameters which best describe the overall ensemble. The success of this method is measured against the results of experimental masonry walls in addition to other current methods to evaluate the efficiency and the effectiveness. Additionally, this method is applied to three historic case studies.

Calx Viva: technological insights into the production of ancient Roman concrete

Friday, 21st June - 14:30: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 542

Ms. Linda Seymour (MIT), Ms. Janille Maragh (MIT), Dr. James Weaver (Harvard), Prof. Admir Masic (MIT)

Roman concrete, a mixture of lime, volcanic ash, aggregate and water, is notable for its durability. The material has survived millennia in a variety of climate and seismic zones, yet little is understood about the exact mechanisms responsible for its longevity. Throughout Roman concrete structures, clasts of remnant lime persist distinct from the rest of the binding matrix. Little is known about these clasts from the conditions in which they form to the role they might play in the durability of the concrete. Here, we utilize high resolution characterization techniques including Raman spectroscopy, scanning electron microscopy and powder x-ray diffraction to understand the chemistry of the clasts and their fate in the long term evolution of Roman concrete. We provide new insights into the “hot mixing” production method that facilitates the formation of these clasts. The results of this research serve as a starting point for the design of antiqua-inspired construction materials, or materials that use the proven durability of ancient materials in order to design more durable materials of the future.

Structural Vulnerability of Roof Structures in Nepali Pagoda Temples Due to Load Path Discontinuity

Friday, 21st June - 14:45: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 537

Mr. Dilendra Maharjan (University of new), Ms. Maimuna Hossain (University of New Mexico), Ms. Maria del Pilar Rodriguez (University of New Mexico), Dr. Fernando Moreu (University of New Mexico)

The 2015 Nepal Earthquake proved to be detrimental for historic Nepali Pagoda temples. Most of the temples experienced varying degrees of damage, primarily in the roof structure. Nepali Pagoda temples are built in perfect symmetry. Yet, during the field visit, researcher observed most of the damages in roof structures were due to torsional failure. A unique feature of Nepali Pagoda temples is the discontinuous load path system of roof structures. After inspections of multiple temples, researches identified that load bearing walls are major lateral load resting members built up to the second tier of the temple. The roof (third tier) is supported by timber frames and brick masonry placed on top of the second-floor wooden joist. This type of design practice coupled with deteriorating roof could have led to the unusual behavior observed in the roof structures. To support this hypothesis from field observations the proposed experiment models the dynamic behavior of the temple to understand the seismic vulnerability. We investigate the possible causes of failure of the roof structures and aim to classify the different modes of failures. A simplified reduced scale model of the roof was built for a laboratory experiment and subjected to the 2015 Earthquake ground motion. This research studies issues related to the properties of deteriorating materials due to aging and in turn, the structural response.

Ontology-based Environment Integrating Cultural Heritage Structures and Earthquake Damage Data

Friday, 21st June - 15:00: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 339

Dr. Satwant Rihal (Cal Poly State University - San Luis Obispo), Dr. Hisham Assal (Cal Poly State University - San Luis Obispo)

This paper proposes the creation of an ontology to integrate the representation of cultural heritage structures with the damage data from earthquakes and other natural disaster events. The ontology will integrate many data sources to present a larger picture for researchers, designers, policy makers, building officials, and other types of users. The ontology will help turn the large volume of data into knowledge by connecting different data items from different sources and providing basic rules of inference to expand the knowledge, provide means to check the validity of some data, and to fill-in some of the missing information.

The ontology consists of four main areas of knowledge:structures, sites, regulations, and hazardous events. This ontology will serveas the medium for an integrated intelligent system to work with culturalheritage knowledge in the context of damage data from earthquakes and otherdisasters. The integrated environment will encompass data translators, whichwill access the variety of data sources and translate the data into theadequate ontology format. Data analysis tools will help determine the place ofeach data item in the ontology and resolve redundant information. The ontologyenvironment will enable the creation of intelligent tools for seismic assessmentof heritage structures. These tools encode the standard rules of earthquakeengineering practice using the ontology as the main description for the designobjects. The intelligent tools check the validity of proposed structuralsolutions and compliance with regulations and building codes.

Comparison of the Uplift Horizontal Acceleration of the Single-Nave Barrel Vault and the Rocking Frame

Friday, 21st June - 15:15: MS104 - Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures; Part 2 (Sharp Lecture Hall (134)) - Oral - Abstract ID: 319

Dr. Haris Alexakis (University of Cambridge), Prof. Nikolaos Makris (Southern Methodist University)

This paper compares the minimum horizontal acceleration that is needed to initiate uplift of the single-nave barrel vault and of the rocking frame which are the two most common masonry structural systems used to bridge a span. The paper concludes that regardless of the direction of the rupture of the buttresses, the single-nave barrel vault uplifts with a seismic coefficient, ε, that is always smaller than the slenderness of the buttresses, s=b/h. In contrast, the rocking frame always uplifts with a seismic coefficient, ε=b/h, regardless of the mass of its prismatic epistyle; therefore, the rocking frame has a superior seismic performance than the single-nave barrel vault.

IMPROVED CONVERGENCE OF FORWARD AND INVERSE SOFT TISSUE MODELS

Friday, 21st June - 14:00: MS4 - Computational Biomechanics: From Cell, Tissue, to Organ-Level Modeling (147 Noyes (84)) - Oral - Abstract ID: 345

Dr. Ankush Aggarwal (University of Glasgow), Dr. Sanjay Pant (Swansea University), Dr. Yue Mei (Swansea University)

Soft tissues exhibit nonlinear and anisotropic mechanical behavior, which is modeled using exponential function in several constitutive models. In this talk, I will present methods that take into account this exponential nonlinearity to significantly improve the convergence of forward and inverse models.

For the forward model, I will start with a novel formulation that applies a transform on the discretized equations. For an exponential nonlinearity, this transformation is its inverse, i.e. log. This leads to a small modification in the residual vector, which can be implemented in any existing finite element solver and allows us to take 10 to 100 times larger load steps [1].

For the inverse model, I will present two different scenarios – displacement controlled (DC) and force controlled (FC). In DC case, a displacement or strain is applied and force or stress is matched to calculate the elastic parameters. Inversely, in FC case, a force or stress is applied and displacement or strain is matched to calculated the elastic parameters. For the DC case, I will show that using a “log-norm” improves the convergence as well as sensitivity of the solution to data noise. Whereas, for the FC case, a nonlinear parameter transformation with regular L_2 norm improves the convergence [2].

Lastly, I will generalize these approaches to computation wherer type of nonlinearity is unknown. Thus I will present improved versions of Newton-Raphson and Gauss-Newton methods.

[1] Mei, Hurtado, Pant, and Aggarwal. CMAME, 337:110-127, 2018

[2] Aggarwal. BMMB, 16(4):1309–1327, Aug 2017.

A New Robust 3D Constitutive Model for the Passive Properties of Left Ventricular Myocardium

Friday, 21st June - 14:15: MS4 - Computational Biomechanics: From Cell, Tissue, to Organ-Level Modeling (147 Noyes (84)) - Oral - Abstract ID: 511

Mr. David Li (The University of Texas at Austin), Dr. Reza Avazmohammadi (The University of Texas at Austin), Mr. Samer Merchant (University of Utah), Dr. Tomonori Kawamura (University of Pennsylvania), Dr. Edward Hsu (University of Utah), Dr. Joseph Gorman (University of Pennsylvania), Dr. Robert Gorman (University of Pennsylvania), Dr. Michael Sacks (University of Texas at Austin)

Myocardium exhibits complex fully 3D behavior that demands a comprehensive 3D constitutive formulation in order for its mechanical properties to be captured in a computational model. Despite promising initial success, current modeling efforts have not yet been rigorously applied to 3D datasets to yield the most robust estimates of material parameters. To this end, we collected a structural-mechanical dataset from ovine myocardium specimens in full 3D, consisting of triaxial mechanical testing and fiber structure measured with diffusion tensor imaging. We first used a model for myocardium introduced by Holzapfel and Ogden to fit a set of optimally selected loading paths and determined model parameters using inverse finite element simulations and nonlinear least-squares regression. However, the model was unable to fully capture the mechanical anisotropy in all loading paths. Hypothesizing that the myocardium exhibits further modes of coupling, we determined that multiple additional coupling terms were required by the model in order to fit the optimal paths. Further examination of the model revealed that the optimal loading paths cause both relative stretching and shearing of fiber families, which could be explained by interactions between myofibers and the surrounding collagen matrix. Specifically, the substantial relative shearing drove the need for the extended terms. This extended constitutive model has particular relevance in the simulation of myocardium in non-physiological states like myocardial infarction. Ultimately, development of more robust models in this manner will make them better suited for clinical evaluation of myocardium and for simulating treatment of cardiac diseases.

Oscillating Solitary Waves Supported by a Strain-Cued Strain Transformation and a Strain-Gradient-Cued Motility Transformation Can Segment an Initially Homogeneous Cell Population

Friday, 21st June - 14:30: MS4 - Computational Biomechanics: From Cell, Tissue, to Organ-Level Modeling (147 Noyes (84)) - Oral - Abstract ID: 557

Dr. Brian Cox (none)

We show that segmentation is possible in a system that relies entirely on strain cues to transmit positional and timing information. The strain-cue theory offers an alternative to Turing-like models of segmentation, e.g., the clock-and-wavefront mechanism based on varying concentrations of interacting molecules. We consider two strain-induced transformations that act within a population of migrating cells: a critical strain gradient triggers a surge in the motility of a cell and, subsequently, a critical strain amplitude triggers a strain transformation in the cell. A solitary-wave-like strain pulse is created. If the strain transformation acts alone (no motility transformation), the strain pulse propagates at fixed velocity with an approximately rectangular shape and a fixed amplitude (a strain-based "wavefront"). When a motility transformation precedes the strain transformation, the pulse can develop a cyclic variation: the location where the strain transformation is triggered no longer advances at fixed velocity but exhibits a series of jumps at regular time intervals (a strain-based "clock"). The jumps create a periodic strain imprint on the cell population, the possible genesis of a segmented pattern of cell phenotype. Once patterned, the cell population will very likely generate periodic variations in the concentrations of chemical factors, as observed, for example, during somitogenesis. However, the variations in chemical factors need not sustain the initial symmetry-breaking of the homogeneous population (i.e., need not act as the clock in the "clock and wavefront" model of segmentation); symmetry-breaking can be effected solely by strain and strain-gradient cues, with patterns in chemical factors arising subsequently.

A multi-scale model to determine in-situ heart valve interstitial cell contractile behaviors in native and synthetic micro-environments

Friday, 21st June - 14:45: MS4 - Computational Biomechanics: From Cell, Tissue, to Organ-Level Modeling (147 Noyes (84)) - Oral - Abstract ID: 787

Dr. Michael Sacks (University of Texas at Austin)

Mechanical forces are known to regulate valve interstitial cell (VIC) functional state by modulating their biosynthetic activity, translating to differences in tissue composition and structure, and potentially leading to valve dysfunction. While advances have been made toward the understanding of VIC behavior ex-situ, the VIC biomechanical state in its native extracellular matrix (ECM) remains largely unknown. We thus developed a novel integrated numerical-experimental framework to estimate VIC mechanobiological state in-situ was developed. Flexural deformation of intact valve leaflets was used to quantify the effects of VIC stiffness and contraction at the tissue level. Flexure is both a relevant deformation mode of the cardiac cycle and highly sensitive to layer-specific changes in VIC/tissue interactions. As a first step, a tissue-level bilayer model that accurately captures the bidirectional flexural response of AV intact layers was developed. Next, tissue micromorphology was incorporated in a macro-micro scale framework to simulate layer-specific VIC-ECM interactions. The macro-micro AV model enabled the estimation of changes in effective VIC stiffness and contraction in-situ that are otherwise inaccessible through experimental approaches alone. We also utilized 3-D hydrogel encapsulation, which is an increasingly popular technique for studying VICs. Cell contraction was elicited through chemical treatment and we applied a modified version of our multi-scale model. The resulting cell force levels were comparable to native in-situ results. Overall, the developed numerical-experimental methodology can be used to obtain VIC properties in-situ. Our approach can lead to further understanding of VIC-ECM mechanical coupling under pathophysiological conditions and the investigation of possible treatment strategies.

In-vitro measurement of nonlinear tissue elasticity with acoustic radiation force

Friday, 21st June - 15:00: MS4 - Computational Biomechanics: From Cell, Tissue, to Organ-Level Modeling (147 Noyes (84)) - Oral - Abstract ID: 869

Mr. Danial Panahandeh-Shahraki (Department of Civil, Environmental and Geo- Engineering, University of Minnesota, Twin Cities, MN 55455), Dr. Siavash Ghavami (Department of Radiology, Mayo Clinic College of Medicine & Science, Rochester, MN 55905,), Dr. Viksit Kumar (Department of Physiology and Biomedical Engineering, Mayo Clinic College of Medicine & Science, Rochester, MN 55905), Dr. Matthew W. Urban (Department of Radiology, Mayo Clinic College of Medicine & Science, Rochester, MN 55905), Mrs. Azra Alizad (Department of Radiology, Mayo Clinic College of Medicine & Science, Rochester, MN 55905), Prof. Mostafa Fatemi (Department of Physiology and Biomedical Engineering, Mayo Clinic College of Medicine & Science, Rochester, MN 55905), Prof. Bojan Guzina (Department of Civil, Environmental and Geo- Engineering, University of Minnesota, Twin Cities, MN 55455)

C-Elastography (CE) is a recently developed technique to non-invasively map the nonlinear elasticity of soft tissue. The main objective of this work is to evaluate the performance of CE in differentiating masses within breast tissue. This method is based on a recent finding that the magnitude of the acoustic radiation force (ARF) in tissue-like solids is related linearly to a third-order modulus of elasticity, *C* – responsible for the coupling of deviatoric and volumetric constitutive responses. Accordingly, estimation of the ARF magnitude (from the ARF-induced shear waves) is a key to estimating nonlinear modulus *C* within the focal region of the ultrasound beam generating the ARF. In this vein, the CE technique deploys a combination of ultrasound motion sensing and 3D elastodynamic simulation to estimate the magnitude of ARF and thus the nonlinear modulus *C*. In this study, we developed a 3D elastodynamic finite element (EFE) model of the ARF experiment in tissue-mimicking phantoms to determine (i) the "background" shear modulus from the phase of the ARF-generated shear waves; (ii) the ARF magnitude from the shear wave amplitude, and (iii) the modulus *C* from the knowledge of the ARF. Since ultrasound focusing inherently confines the ARF to a small region, CE opens a gate for measuring *C* within O(mm^3) volumes. In-vitro measurements have been performed on normal breast tissue embedded in tissue-mimicking phantoms. The corresponding *C*-Elastograms indicate marked (and sharp) C- contrast at push points acting on the breast tissue. Acknowledgement: NIH-Grant EB23113.

The Effects of Mechanical Stress on the Collective Cell Behavior on Micropatterned Substrates

Friday, 21st June - 15:15: MS4 - Computational Biomechanics: From Cell, Tissue, to Organ-Level Modeling (147 Noyes (84)) - Oral - Abstract ID: 1173

Ms. Habibeh Ashouri Choshali (Worcester Polytechnic Institute), Ms. Heather Cirka (Worcester Polytechnic Institute), Mr. Zachary Goldblatt (Worcester Polytechnic Institute), Prof. Nima Rahbar (Worcester Polytechnic Institute), Prof. Kristen Billiar (Worcester Polytechnic Institute)

Acto-myosin machinery of the cell creates contractile forces which results in stress and strain fields within the cell aggregate. Recent evidences propose that the mechanical stresses regulate collective cell behavior including cell migration, cell differentiation, apoptosis and cell proliferation [1-3]. However, it still remains unclear what is the exact mechanical signal that leads to local tissue pattern formation. This work explores the effect of substrate shape, stiffness and cell monolayer inhomogeneity on the collective cell behavior both numerically by finite element modeling (FEM) and experimentally by measuring the traction forces. It is observed that the maximum principal stress predicted by FEM in the cell layer, is inversely proportional to the patterns of proliferation. The results suggest a non-constant material property for the cell monolayer in a way that the contractility decreases when moving towards the center of the cell layer.

References

[1] Nelson, Celeste M., et al. "Emergent patterns of growth controlled by multicellular form and mechanics." Proceedings of the National Academy of Sciences of the United States of America 102.33 (2005): 11594-11599.

[2] Li, Bin, et al. "Spatial patterning of cell proliferation and differentiation depends on mechanical stress magnitude." Journal of biomechanics 42.11 (2009): 1622-1627.

[3] He, Shijie, et al. "Dissecting collective cell behavior in polarization and alignment on micropatterned substrates." Biophysical journal 109.3 (2015): 489-500.

Adaptive Mesh-Refinement for Poromechanics Problems of High-Order Continua: A Configurational Force Approach

Friday, 21st June - 14:00: MS35 - Computational Geomechanics; Part 5 (142 Keck (72)) - Oral - Abstract ID: 902

Prof. Seon Hong Na (McMaster University), Prof. Wai Ching Sun (Columbia University)

Mechanical and hydraulic behaviors of many geological materials, such as clay, limestone, and sedimentary rock are inherently anisotropy and size-dependent. This size-dependence can be exploited to formulate high-order models that circumvents the pathological mesh dependence in the softening regimes. However, the onset of deformation band and other forms of strain localization may still lead to sharp displacement and pore pressure gradients that must be resolved properly to maintain accuracy. To resolve this issue, we derive a new configurational force for dissipative fluid-infiltrating porous materials that exhibit gradient-dependent plastic flow. This configurational force takes account of the energy flux due to the gradient terms and hence is a suitable remeshing criterion for higher-order continua. In addition, a Lie algebra internal variable mapping is used such that the history-dependent behaviors for the new configuration can be captured in the new equilibrate state. Our numerical results indicate that the proposed method enables one to resolve sharp gradient without an initial fine mesh. This salient feature is important for simulating hydro-mechanical coupling behaviors in the post-bifurcation regimes.

Simulation of Compaction Bands in Porous Rock Based on X-Ray CT Measurements

Friday, 21st June - 14:15: MS35 - Computational Geomechanics; Part 5 (142 Keck (72)) - Oral - Abstract ID: 1020

Mr. Ghassan Shahin (Northwestern University), Prof. Cino Viggiani (Université Grenoble Alpes / Laboratoire 3SR), Prof. Giuseppe Buscarnera (Northwestern University)

Compaction localisation in idealized numerical analyses is often triggered by introducing weak zones into the simulated specimen. In natural rocks, however, the onset of localization is affected by the natural heterogeneity of the material. Advances in material characterization such as X-ray micro-tomography can therefore be an asset for an objective assessment of compaction banding patterns. Here a strategy is proposed to integrate measurements from computerized tomography (CT) with deformation analyses based on the finite element method (FEM). Specifically, a CT-FEM mapping scheme is proposed by using the concept of representative elementary volume (REV) to associate each integration point in the numerical domain to a material volume in the physical specimen. This strategy allows the determination of the state variables at each integration point directly from a counterpart volume in the CT-image. The proposed scheme has been applied to reproduce the deformation response of a specimen of porous carbonate rock. A numerical replica has been used to examine the role of spatial heterogeneities and boundary conditions on the onset and propagation of compaction bands. The study revealed that, in addition to material heterogeneity, friction at the boundary is a crucial factor in determining the spatial patterns of compaction localization. Specifically, with low boundary friction compaction bands are systematically triggered in the most porous portions of the specimen, while above a certain value they always initiate at the boundaries. These results suggest that accounting for system heterogeneities is a mandatory step to objectively predict rock compaction patterns in the natural environment.

A Meshfree Large-strain Computational Framework for Modeling Liquefaction-induced Deformations

Friday, 21st June - 14:30: MS35 - Computational Geomechanics; Part 5 (142 Keck (72)) - Oral - Abstract ID: 1065

Prof. J. S. Chen (UC San Diego), Mr. Zhijian Qiu (University of California San Diego), Dr. Haoyan Wei (University of California San Diego), Prof. Ahmed Elgamal (University of California San Diego), Dr. Jinchi Lu (University of California San Diego)

During earthquakes, liquefaction and associated deformations cause extensive damage and destruction. Modeling of such failure processes remains challenging, as conventional numerical modeling methods suffer from mesh distortions. In this paper, a stabilized and nodally integrated meshfree approach is developed and employed, aiming to simulate complex damage mechanisms and extreme flow-like material deformations in multiphase geomaterials. To this end, an equal-order reproducing kernel approximation pair in conjunction with fluid pressure projection is adopted in the mixed meshfree formulation, which eliminates spurious pressure oscillations caused by the inf-sup condition violation. By adopting the implicit gradient approximation, the gradients of strain and fluid flux fields are conveniently added into the mixed formulation to eliminate spurious low-energy modes of nodal integrations at low computational cost. In addition, a set of modified test functions is introduced to ensure variationally consistency, leading to a convergent and stable meshfree formulation for multiphase porous media. Under this computational framework, a calibrated UCSD soil constitutive model is integrated and implemented to capture the soil liquefaction and cyclic mobility mechanisms. Illustrative simulation is presented and discussed. Finally, the effectiveness of the developed meshfree approach for simulating liquefaction-induced lateral deformations is validated by comparing to experimental observations.

Recent Advances in Hydraulic Fracturing of Shale, Water and Gas Permeability, and Crack Branching

Friday, 21st June - 14:45: MS35 - Computational Geomechanics; Part 5 (142 Keck (72)) - Oral - Abstract ID: 1104

Mr. Saeed Rahimi-Aghdam (Northwestern University), Prof. Zdenek Bazant (Northwestern University), Dr. Viet Chau (Los Alamos National Laboratory), Dr. Esteban Rougier (Los Alamos National Laboratory), Dr. Hari Viswanathan (Los Alamos National Laboratory), Dr. Gowri Srinivasan (Los Alamos National Laboratory), Mr. Hoang Nguyen (Northwestern University), Dr. Satish Karra (Los Alamos National Laboratory), Mr. Hyunjin Lee (Northwestern University)

Recent advances in the simulation of hydraulic fracturing (aka fracking, frac) and the formulation of the associated fracture mechanics are presented. The classical fracture mechanics, as well as the current commercial softwares, predict vertical cracks to propagate without branching from the perforations of the horizontal well casing, which are typically spaced at 10 m or more. However, to explain the gas production rate at the wellhead, the crack spacing would have to be only about 0.1 m, which would increase the overall gas permeability of shale mass about 10,000x. This permeability increase has generally been attributed to a preexisting system of orthogonal natural cracks, whose spacing is about 0.1 m. But their average age is about 100 million years, and a recent analysis indicated that these cracks must have been completely closed by secondary creep of shale in less than a million years. In the present analysis it is considered that the tectonic events that produced the natural cracks in shale must have also created weak layers with nano- or micro-cracking damage. It is numerically demonstrated that the seepage forces together with a greatly enhanced permeability along the weak layers, with a greatly increased transverse Biot coefficient, must cause the fracking to engender lateral branching and the opening of hydraulic cracks along the weak layers, even if these cracks are initially almost closed. Extensive finite element simulations based on recently developed anisotropic spherocylindrical microplane constitutive law, demonstrate these findings.

Finite Element Analyses of Granular Assembly Under 1D Confined Compression Incorporating Computed Tomography Imaging and Damage Mechanics

Friday, 21st June - 15:00: MS35 - Computational Geomechanics; Part 5 (142 Keck (72)) - Oral - Abstract ID: 1110

Ms. Anne Turner (University of Arkansas Little Rock), Mr. Aashish Sharma (University of Tennessee, Knoxville), Dr. Dayakar Penumadu (University of Tennessee, Knoxville), Dr. Eric Herbold (Lawrence Livermore National Laboratory)

Fracture of individual grains within a granular assembly affect the strength and deformation behavior of granular materials under large stress states. Interparticle forces, leading to contact stresses and ultimately fracture initiation, are influenced by particle morphology. A numerical method that incorporates both particle fracture and morphology can provide a more accurate model of a granular material's macro-scale response. In this research, a numerical approach utilizing high resolution x-ray computed tomography (CT) to incorporate grain morphology and an explicit finite element code which includes damage mechanics for simulating grain fracture is used to analyze an assembly of Ottawa sand particles subjected one-dimensional confined compression. First, single grain crushing tests of sand particles are simulated and compared to experimental results in order to obtain fracture properties, such as the stress at which fracture initiates and fracture energy. Then a granular assembly of CT imaged Ottawa sand particles is analyzed under one-dimensional confined compression with and without incorporating damage mechanics to investigate the initiation of particle fracture and its effect on the stress-strain behavior of the assembly. This approach can then be applied to modeling granular assemblies under other types of loading, considering the effect of individual particle shape and fracture on the assembly's deformation response through well calibrated numerical simulations.

Anisotropic Critical State Hypoplastic Constitutive Model for Granular Soils

Friday, 21st June - 15:15: MS35 - Computational Geomechanics; Part 5 (142 Keck (72)) - Oral - Abstract ID: 361

Mr. Dong Liao (Zhejiang University), Prof. Zhongxuan Yang (Zhejiang University)

Inherent anisotropy is commonly observed in soils and the mechanical behaviour of soil is significantly influenced by its fabric anisotropy. Hypoplasticity has been received increasing acceptance in the constitutive modelling for soils, in which many salient features such as non-linear stress-strain relations, dilatancy, and critical state failure, etc., can be described by asingle tensorial equation. However, within the framework of hypoplasticity, modelling the fabric anisotropy remains challenging, as the fabric and its evolution are mostly vaguely assumed without sound basis. Based on the newly developed anisotropic critical state theory (ACST), a fabric tensor, which describes the internal structure of sand, is introduced into hypoplastic model, and it always evolves towards its critical state value during loading process. Then a state parameter signifying the interplay between the fabric and the stress state is defined, to reflect the effect of fabric and its evolution on the dilatancy and strength of the soils. A modification is also undertaken to improve the undrained performance of hypoplastic model. The modified hypoplastic model can simulatethe experimental tests of anisotropic sand under different stress paths (differentintermediate principal stress or rotation of principal stress axial directions) and soil densities.

Effects of internal curing on permeability properties of cement mortar: simulation and experimental analysis

Friday, 21st June - 14:00: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1057

Dr. Qingli Dai (Michigan tech), Mr. Ruizhe Si (Michigan Technological University)

The transport properties of the internal cured cement mortar was investigated by simulation and experimental test in this study. The internal cured mortar samples were prepared by introducing the lightweight aggregates as the internal curing agent. The water cement ratio of the prepared samples with/without internal curing was fixed at 0.45. The X-ray Computed Tomography techniques was employed to obtain the image data of the microstructure of samples at micro-scale. Then the images were processed to separate the pore phase from the solid phase and stacked to reconstruct the three-dimensional micro-structure of the prepared mortars. The transport properties of the mortars was simulated by the permeability-solver computational program. The digital data of the three-dimensional structure of the prepared mortars was import into the program for porosity, pore connectivity, and permeability analysis. The burning algorithm was used to analyze the connectivity of the pores. The finite difference method and compressibility relaxation algorithm was used to simulate the water transport. The permeability of the mixtures was calculate according to the Darcy's Law. The transport properties of the samples with/without internal curing was evaluated by the numerical model at two different curing ages (60 hours and 80 hours). The results showed that the internally cured samples have the lower permeability than the samples without internal curing. The permeability of the internal cured sample decreased with the curing ages. The autogenous shrinkage cracks can be mitigated by using the internal curing technique. The calculated permeability values were generally consistent with the laboratory test data.

Effects of realistic tire–pavement contact stresses on pavement nonlinear responses

Friday, 21st June - 14:15: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1119

Prof. Maryam Shakiba (Virginia Tech), Ms. Angeli Gamez (University of Illinois at Urbana-Champaign), Prof. Imad Al-qadi (University of Illinois at Urbana-Champaign), Prof. Dallas Little (Texas A&M University, College Station)

Realistic tire–pavement interface contact areas and stresses were incorporated into the Pavement Analysis. The analysis includes the complex thermo-viscoelastic–viscoplastic–viscodamage responses of the pavement. The application of realistic tire loading is necessary to calculate accurate pavement responses. We used a database of tire contact areas and stresses obtained from tire finite element simulations. The database includes tire interface characteristics with pavements for various applied loads, tire inflation pressures, vehicle speeds and scenarios of different rolling simulations. A parametric study was conducted to investigate the effect of simulations of tire contact stresses that match field measurements on viscoelastic and viscoplastic pavement responses. Pavement responses are greatly affected using realistic tire loading contact stresses and contact geometry as compared to simplified contact models. The impact on rutting and damage predictions cannot be ignored if reliable projections of pavement performance are to be made. This study confirms the importance of considering realistic three- dimensional contact stresses to design and analyze pavements.

Numerical Modeling of Frictional Contact between a Blunt Tool and Quasi-brittle Rock

Friday, 21st June - 14:30: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1172

Dr. Yaneng Zhou (Louisiana State University), Prof. George Z. Voyiadjis (Louisiana State University)

Frictional contact is an important component of rock cutting with a blunt cutter. There has been a gap in knowledge of frictional contact between experimental tests conducted on quasi-brittle rocks and previous numerical and analytical analyses on elastoplastic rocks. The average contact stress between a sliding wear flat and a rock is generally overestimated in previous studies without considering material length scales. This study analyzes the contact stress using an elasto-plastic-damage model that accounts for the material length scales of quasi-brittle materials. The constitutive model developed for quasi-brittle materials is implemented in the commercial finite element software ABAQUS as a user-defined material model. The average contact stress in frictional contact on a quasi-brittle rock is predominantly governed by two dimensionless parameters: an elastoplastic parameter η and a brittleness number ξ. The dimensionless elastoplastic parameter η contrasts the magnitude of a characteristic elastic contact stress to a yield strength of a material, and the brittleness number ξ is the ratio of a geometrical length scale to a material length scale. The average contact stress generally increases with the dimensionless elastoplastic parameter η and then levels off at a limit value, and it generally decreases with the brittleness number ξ. This study reduces the gap in previous studies to some extent by introducing the brittleness number ξ in frictional contact. The current numerical results of the average contact stress are generally consistent with typical experimental results conducted on quasi-brittle rocks despite limitations in the finite element modeling.

Wave and Static Moduli of Elasticity of Concrete Materials

Friday, 21st June - 14:45: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1179

Mr. Dongxu Liu (UC Irvine), Prof. Pizhong Qiao (WSU), Dr. Zhidong Zhou (WSU), Prof. Lizhi Sun (UC Irvine)

Nondestructive ultrasound-based methods have been applied to evaluate the mechanical properties of concrete materials. While the wave modulus of elasticity of concrete is frequently reported higher than the static counterpart, the microstructural mechanisms are poorly understood. In this study, computational micromechanics is conducted to investigate the effects of aggregates and porosity on both the effective wave modulus of elasticity and static modulus of elasticity, based on concrete microstructures obtained X-ray micro-tomography. It is demonstrated that the existence of microstructural-level porous defects plays a more significant role on the elastic properties of concrete when compared with the aggregates. It is confirmed that the higher wave modulus of elasticity of concrete than the static one is caused by the existence of crack-like porosity. It is further concluded that the decrease of static modulus of elasticity is more significant than the one of wave modulus of elasticity.

Behavior of Saturated Cohesionless Soils to High Speed Cone Penetration

Friday, 21st June - 15:00: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 1180

Prof. Chung Song (University of Nebraska-Lincoln), Mr. Binyam Bekele (The University of Nebraska-Lincoln)

PCPT (Piezocone Cone Penetration Test) technique is widely used to explore soil conditions quickly and accurately. The typical penetration speed, called the international reference speed, is 2 cm/s. With this speed, however, the excess pore pressure for cohesionless soils is practically zero, and usage of excess pore pressure is quite limited for these soils.

By increasing the penetration speed, PCPT allows less time for excess pore pressure dissipation during penetration, and measurable excess pore pressure will be observed. The result may be utilized to enhance soil classification capability, predict soil permeability, and predict undrained behavior of cohesive soils that is extremely important in Earthquake engineering. This study conducted numerical simulations based on coupled theory of mixtures and further incorporating dynamic inertia effect of the PCPT. The study also compared the published data at higher penetration rate for cohesionless soils.

Use of APT Performance Data to Enhance Asphalt Mix Design

Friday, 21st June - 15:15: MS51 - Multiscale Characterization and Modeling of Infrastructure Materials; Part 2 (153 Noyes (134)) - Oral - Abstract ID: 927

Ms. Chunru Cheng (University of Science and Technology Beijing), Prof. Linbing Wang (V)

Asphalt mix design is typically developed based on laboratory testing and specifications based on lab tests. The road performances, however, are not considered adequately in the mix design process. This presentation focuses on integration of the performance data from accelerated pavement testing to improve asphalt mix design procedures and specifications.

Engineering thermal and viscoelastic properties of calcium-silicate-hydrates (C-S-H) via organic-inorganic crosslinking.

Friday, 21st June - 14:00: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1091

Mr. Amir Moshiri (University of Houston), Mr. Ali Morshedifard (UC Irvine), Dr. Mohammad Javad Abdolhosseini Qomi (UC I), Prof. Konrad J.Krakowiak (University of Houston)

Concrete provides high load-bearing capacity and long-term structural performance, while ensuring cost effectiveness. However, due to the intrinsic inorganic nature of calcium-silicate-hydrate (C-S-H), as well as its multi-scale porous microstructure, it suffers from low tensile strength and toughness. Similarly, the inorganic framework of C-S-H dictates its low thermal conductivity, which sets back the application of concrete in building envelopes. With the average thermal conductivity ~ 1 W/mK, C-S-H is considered to already achieve its lowest thermal conductivity state, called “glass limit”. This limit cannot be overcome using common chemical modifications to C-S-H chemistry, which proved to be ineffective. In this work, we explore new pathway to engineer thermal and viscoelastic properties of cement-based materials starting from the molecular level. Our original approach combines organic and inorganic chemistry to cross-link galleries of C-S-H with organic molecules of different C-chain size. With experimental techniques such as X-ray diffraction, 29Si and 13C NMR, electron microscopy and ICP spectrometry, we study atomistic details of crosslinked C-S-H and the impact of crosslinking on its texture. We show that incorporation of organic component within C-S-H structure is feasible, and the size of [CH2]-n chains is responsible for change in the size of the unit cell, as well as physical properties of cross-lined C-S-H. Finally, we examine the impact of organic molecules on the thermal and mechanical properties of cross-linked C-S-H, at the nano and micro-scales, via indentation and heat-flow meter techniques. Results of the ongoing experimental campaign will be discussed during the presentation

Unsaturated Hygro-Thermo-Poromechanics Based on RVE with Diverging Pores Shaped to Simulate Both Capillary and Hindered Adsorbed Water

Friday, 21st June - 14:15: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1383

Mr. Hoang Nguyen (Northwestern University), Mr. Saeed Rahimi-Aghdam (Northwestern University), Prof. Zdenek Bazant (Northwestern University)

A model for a representative volume element (RVE) simulating hygro-thermo-poromechnics for an unsaturated materials such as hardened cement paste or concrete is developed. For each loading direction, the RVE contains a concave, suitably diverging, pore with transition form hindered to freely exposed adsorbed water and a capillary meniscus of varying curvature. A homogenization scheme is formulated, using the Eshelby's tensor for concave pore shapes and the Mori-Tanaka scheme for random orientation pores. The coupled hygro-thermo-mechanical behavior is based on effective pressure in unsaturated pore calculated from the Gibbs free energy contributions of capillary water and free and hindered absorbed water. The model is validated by data on sorption isotherms, on drying tests of loaded and load-free concretes, on shrinkage tests, and on hygrothermic coefficient. The model facilitates the development of general unsaturated poromomechanical constitutive equation, including the Biot coefficient and Biot modulus.

Multiscale Poromechanics of Wet Cement Paste

Friday, 21st June - 14:30: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1204

Dr. Katerina Ioannidou (CNRS / Laboratoire de Mécanique et Génie Civil / Université de Montpellier), Mr. Tingtao Zhou (Massachusetts Institute of Technology), Prof. Franz Ulm (Massachusetts Institute of Technology), Prof. Martin Bazant (Massachusetts Institute of Technology), Dr. Roland Pellenq (Massachusetts Institute of Technology)

Capillary effects such as imbibition-drying cycles impact the mechanics of granular systems over time. A multiscale poromechanics framework was applied to cement paste, that is the most common building material, experiencing broad humidity variations over the lifetime of infrastructure. First, the liquid density distribution at intermediate to high relative humidities is obtained using a lattice gas density functional method together with a realistic granular model of cement hydrates. The calculated adsorption/desorption isotherms and pore size distributions are discussed and compare well to nitrogen and water experiments. The standard method for pore size distribution determination from desorption data is evaluated. Then, the integration of the Korteweg liquid stress field around each cement hydrate particle provided the capillary forces at the nanoscale. The cement microstructure was relaxed under the action of the capillary forces. Local plastic deformations of the cement nano-grains assembly were identified due to liquid-solid interactions. The spatial correlations of the non-affine displacements extend to a few tens of nm. Finally, the Love-Weber method provided the homogenized liquid stress at the micronscale. The homogenization length coincided with the spatial correlation length of plastic events. Our results on the solid response to capillary stress field suggest that the micronscale texture is not affected by mild drying, while nanoscale plastic deformations still occur. These results pave the way towards understanding capillary phenomena induced stresses in heterogeneous porous media ranging from construction materials, hydrogels to living systems.

Two models based on local microscopic relaxations to explain long-term basic creep of concrete

Friday, 21st June - 14:45: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1287

Dr. Matthieu Vandamme (Ecole des Ponts Paris Tech)

Cement-based materials creep (i.e., deform over time when under constant mechanical stress) over decades. This study is dedicated to find out whether two models used to explain creep of metallic alloys, which rely on the idea of a creep originating from local activated processes (which we interpret as local microscopic relaxations) can explain the long-term creep of cement-based materials. The two models, called exhaustion model and work-hardening model, differ by how the activation energies are distributed and evolve over the creep process.

We show that the two models capture equally well several phenomenological features of long-term basic creep of cement-based materials, namely its logarithmic evolution over time, a linear dependence of the creep strains on the applied stress, and how the viscoelastic Poisson's ratio evolves over time. The models also provide a plausible explanation for why the indentation technique makes it possible to quantitatively characterize the long-term logarithmic kinetics of creep in minutes, while this kinetics is reached after days at the macroscopic scale. The reason put forward is that the magnitude of the stresses below the indenter probe is much larger than for macroscopic creep experiments.

Moisture induced crossover in the thermodynamic and mechanical response of hydrophilic biopolymer

Friday, 21st June - 15:00: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1347

Mr. Chi Zhang (ETH Zurich), Dr. Benoit Coasne (CNRS), Dr. Robert Guyer (Los Alamos National Laboratory), Dr. Dominique Derome (Empa), Prof. Jan Carmeliet (ETH)

The understanding of the thermodynamic and mechanical responses of hydrophilic biopolymers upon moisture adsorption is important in attempts to utilizing natural sustainable resources, e.g. wood. In this study, molecular dynamic simulation is used to investigate the influence of moisture on the properties of softwood hemicellulose xylan, i.e. arabinoglucuronoxylan (AGX), a hydrophilic biopolymer. A moisture induced crossover behavior is found in many thermodynamic and mechanical properties of AGX, such as heat of adsorption, heat capacity, thermal expansion, elastic moduli and Poisson's ratio. The further study of water population and polymer-water contact area leads to the identification of a double-layer adsorption occurring along the amorphous polymeric chains. The saturation of the first layer of water and the quick growth of the second adsorption layer of water, a nanometer scale structural feature, is seen as the main mechanism of the crossover behavior of the system. Besides the volume fraction of two water layers and polymer, many properties of the system can be predicted by simple rules of mixture (RoM). Our findings may have implications concerning the influence of moisture on hydrophilic polymers.

Hygromechanical hysteretic behavior of wood cell wall - studied by molecular dynamics

Friday, 21st June - 15:15: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 2 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 1293

Dr. Dominique Derome (Empa), Mr. Chi Zhang (ETH Zurich), Mr. Mingyang Chen (ETH Zurich), Dr. Benoit Coasne (CNRS), Prof. Jan Carmeliet (ETH)

The interaction of the composite polymeric material, that is the layer S2 of wood cell wall, with water is known to rearrange its internal structure, make it moisture sensitive and influence its physical properties. As the origin of moisture-induced processes is found in this S2 layer, we study the coupled effects of water sorption on hygric and mechanical properties of different polymeric components. Our aim is to understand all the ramifications of this intricate nanocomposite, with the specific aim of upscaling the results to cellular and macroscopic scales. In order to study the behavior of S2 layer, we analyse the different configurations of cellulose microfibril aggregates and S2 matrix using Molecular Dynamics (MD) simulations. These atomistic simulations are used to mimic water adsorption and desorption in amorphous cellulose, make observations on hysteresis and relate the hygromechanical behavior as observed from the breaking and reforming of hydrogen bonds. An experimental campaign, based on AFM investigations, provides complementary insights.

Uncertainty Quantification of Modal Parameters from Combined Deterministic-Stochastic Subspace State-Space System Identification

Friday, 21st June - 16:00: MS80+92 - Structural Identification and Damage Detection, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 981

Mr. Tianhao Yu (University of Southern California), Prof. Erik Johnson (University of Southern California)

Estimating modal parameters is essential in modal-based structural health monitoring and damage detection. Among various strategies for identifying dynamic system models, subspace-based system identification stands out since it requires neither iterations nor prior parameterizations. Despite a plethora of literature on the subspace-based system identification itself, the uncertainty quantification of modal parameters obtained from it remains a rather new topic of investigation.

In the previous studies, the uncertainty in estimated modal parameters was quantified based on the assumption that the statistics of the inputs and the outputs are known (Reynders et al., 2008; Mellinger et al., 2016). However, this is not the case in reality, when the measured inputs or outputs are combinations of deterministic and stochastic components, which are inseparable.

To solve this real-world problem, this paper proposes that the statistics of inputs and outputs could be obtained by making use of the identified residues from system identification, assuming that the model order is sufficiently high to limit modelling errors and that the nonlinearity in the system is negligible. This is a natural way of approaching this problem because, when the modelling error and nonlinearity are taken away, a strong correlation should be expected between the noise terms in state-space model and the noises embedded in the data-acquisition process. This proposition is first verified on a lumped-mass stick model by means of Monte-Carlo sampling and then tested with experimental data from a base-isolated building tested in Japan's E-defense Lab.

Vibration-based estimation of offshore monopile foundation stiffness

Friday, 21st June - 16:15: MS80+92 - Structural Identification and Damage Detection, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 130

Dr. Anela Bajric (University of Oxford), Prof. Manolis Chatzis (University of Oxford), Prof. Ross Mcadam (University of Oxford), Prof. Byron Byrne (University of Oxford)

Output only methods are used for the identification of in-situ properties of structures. However, when applied to offshore wind turbines these methods typically focus on the identification of the superstructure and assume simplified characteristics, such as cantilevered fixity, for the foundation. The ability to identify the foundation properties of as-built offshore wind structures offers significant value to wind farm operators and is critical for the validation of design methods, maintenance management and model updating for lifetime assessment and extension. A method is presented for identifying the stiffness associated with the foundation by introducing a reduced order physical representation of the system. The reduced physical representation enables identification of the lateral and rotational stiffness of a macro-element foundation model from vibrations at a limited number of measurement locations. Preliminary results of the identified system parameters are demonstrated through synthetic accelerations of an offshore wind turbine, with a foundation stiffness representative of a design in realistic soil conditions. These results show that a limited number of acceleration measurements at arbitrary sensor locations can identify the macro-element stiffness associated with offshore mononpile foundations in uncertain soil conditions.

Output-only particle filtering for structural system identification

Friday, 21st June - 16:30: MS80+92 - Structural Identification and Damage Detection, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 722

Dr. Saeed Eftekhar Azam (University of Nebraska–Lincoln), Prof. Daniel Linzell (University of Nebraska–Lincoln)

Particle filters are a well-established approach for state estimation in highly nonlinear systems disturbed by non-Gaussian measurement and process noise. Since particle filters are centered on numerical quadrature of stochastic integrals, they could become computationally intensive as dimensionality of the system increases. When possible, the ensemble of quadrature points is rendered more efficient by application of Kalman filters or a Markov Chain step. The unscented particle filter is known to be one of the most accurate forms of these filters when the number of quadrature points is known to be significantly less than those needed for a generic particle filter. One of the most striking properties of an unscented particle filter is its applicability to general nonlinear and non-Gaussian systems without need for calculation of the Jacobian. It also has been theoretically proven that an unscented particle filter has a better convergence rate than an extended particle filter. The standard version of an unscented particle filter requires a priori knowledge of external inputs, information that is often impractical to obtain for structural systems. A novel framework is presented herein for application of particle filters to structural system identification where state-space equations include direct feedthrough. A dual Kalman filter was adopted for estimating unknown external inputs needed for the unscented particle filter. Extensive numerical experiments on shear-type structures were completed to subsequently prove method feasibility.

Sparsity-Promoting Acceleration Sensor Placement for Estimator Design in Civil Structures

Friday, 21st June - 16:45: MS80+92 - Structural Identification and Damage Detection, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 1124

Ms. Kali Gustafson (University of Minnesota), Dr. Lauren Linderman (University of Minnesota)

Advancements in structural health monitoring and control have shown promising results for better protecting infrastructure. Sensor networks aid in updating dynamic models and limiting the vibration response under dynamic loading. However, the vast scale of civil systems makes it impossible to measure all degrees of freedom. Therefore, a limited number of measurements are leveraged to obtain a full set of displacement and velocity (state) measurements through state estimation. Sparse feedback, which limits the information as well as the number of sensors for feedback, requires the selection of essential measurements. The exact sensor placement problem considers all possible combinations of sensors, which presents computational challenges for high degree of freedom systems. Through the nine-story nonlinear benchmark structure, the Kalman filter alternating direction method of multipliers (kfadmm) algorithm is shown to systematically balance measurement sparsity and estimator error covariance in acceleration sensor selection. The method does not require knowing the number of sensors a priori. The best number of sensors for a given application can be determined after looking at the increase in the cost function as sensors are removed from the system. Compared to the exact method and the sequential sensor placement method, the kfadmm sensor selection approach results in similar sensor choices at only slightly higher estimation error. Moreover, covariance weightings are observed to impact sensor selection. When the model is trusted more than the measurements, the n^{th}-floor sensor matters most; however, when the measurements are trusted more than the model, the first-floor sensor controls the estimator design.

Optimal Protective Measures for Coastal Infrastructure Subjected to Hurricane Induced Storm Surge and Sea Level Rise

Friday, 21st June - 17:00: MS80+92 - Structural Identification and Damage Detection, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 1363

Ms. Yuki Miura (Columbia University), Prof. Kyle Mandli (Columbia University), Prof. George Deodatis (Columbia University)

A general methodological tool is introduced to determine a set of optimal protective measures for coastal infrastructure subjected to a combination of hurricane induced storm surge and sea level rise. The solution is obtained through an optimization scheme accounting for a prescribed budget. A number of protective measures are considered including sea walls, artificial sand dunes, artificial islands and reefs, sealing of individual components of the infrastructure, etc. Optimality is defined as maximum reduction of overall losses over a prescribed multi-year window (accounting for the cost of the protective measures), compared to the base scenario of doing nothing. The optimal solution involves different protective measures implemented with spatial and temporal variation. Losses are considered both to the above- and below-ground infrastructure. The methodology combines a novel and extremely fast computational tool to estimate flooding and corresponding infrastructure losses using Geographical Information Systems, with the more accurate (and computationally much more expensive) GeoClaw software co-developed by one of the authors. To verify the accuracy of the proposed methodology, its results are compared to actual available data from the 2012 Hurricane Sandy.

Sensor Data Visualization using Augmented Reality and Database

Friday, 21st June - 17:15: MS80+92 - Structural Identification and Damage Detection, Advances in Computational Methods for Rapid Uncertainty Quantification and Robust/Performance-Based Design of Civil Structures/Systems Exposed to Natural and Man-Made Hazards (Ramo (371)) - Oral - Abstract ID: 971

Mr. Marlon Aguero (University of New Mexico), Ms. Soamiya Chavez (University of New Mexico), Mr. Dilendra Maharjan (University of New Mexico), Mr. David Mascarenas (Los Alamos National Laboratory), Dr. Fernando Moreu (University of New Mexico)

Abstract: The application of sensors in structural health monitoring (SHM) is of utmost importance, as they record the behavior of structures and help structural engineers to make and prioritize informed decisions about necessary repairs or maintenance procedures. However, many of the sensors that are currently used require further processing of information obtained in the field later at the office or the decision-making headquarters. This approach to SHM delays decision making. Wireless sensors networks (WSN) are designed to analyze the data and present decisions remotely, however there is still a gap between remotely operated WSN and industry decisions. In general, industry relies on inspectors decisions. If WSN could inform inspectors, industry decisions would be improved by data. The application of Augmented Reality (AR) tools, such as HoloLens, permits direct interaction with the real world for engineers and enables visualization and integration of SHM with inspectors at the field. For example, HoloLens make it possible to visualize information coming from the sensors in a graphic form in real time. This presentation shows how to enable effective communication between the sensors and the HoloLens. The communication involves sending information from the sensors to a database in real time in a reliable way.

Bayesian Finite Element Model Updating for A Long-Span Suspension Bridge Utilizing Hybrid Monte Carlo Simulation

Friday, 21st June - 16:00: MS89+88+84 - Bayesian Inference in System Identification: Efficient Algorithms and Applications, Modeling Deterioration of Structures and Infrastructure, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 590

Mr. Jianxiao Mao (Southeast University), Prof. Hao Wang (Southeast University)

Bayesian model updating techniques have been widely investigated and utilized in finite element model (FEM) updating due to their advantages in quantifying system uncertainties. In this case study, a long-span suspension bridge, Runyang Suspension Bridge (RSB), with its main span of 1,490m, is taken as the research object. Based on the identified modal properties from field tests, Bayesian model updating algorithms, i.e., Metropolis-Hastings (MH)and Hybrid Monte Carlo (HMC), are utilized to update the initial FEM of RSB. To reduce the computation burden of the updating process, a Kriging model is established using the experimental datasets generated using Latin hypercube sampling method. Subsequently, the relation between the acceptance rate and step size of the two sampling algorithms are investigated. The step size which guarantees the acceptance rate larger than 70% is selected for Bayesian model updating. Results show that HMC is more efficient than MH. The corresponding burn-in length of HMC is smaller than 20,000, while that of MH is larger than 200,000. For a fixed step size, the acceptance rate of MH will decrease with the increase of the length of target chain. However, the HMC could still achieve satisfied acceptance during the updating process. Results could provide references for FEM updating and model-updating-based status evaluation of similar long-span bridges.

Long-term Evolution of Systems Modeled by Partially Observable Markov Decision Processes

Friday, 21st June - 16:15: MS89+88+84 - Bayesian Inference in System Identification: Efficient Algorithms and Applications, Modeling Deterioration of Structures and Infrastructure, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 1105

Mr. Shuo Li (Carnegie Mellon Univ), Prof. Matteo Pozzi (Carnegie Mellon University)

When the operation and maintenance (O&M) of an infrastructure component are modeled as a Partially Observable Markov Decision Process (POMDP), the time evolution of the component's state under the optimal policy cannot be easily predicted. Questions about this evolution, on the other hand, can be relevant for describing the long-term system's behavior. For example, one can ask when and how frequently the process will visit some critical states.This paper illustrates how to predict relevant features of the time evolution of a controlled infrastructure component modeled as a POMDP. We address questions as: "is a critical state even reachable?", "what is the probability of reaching that state within a time period?" Answering these questions is challenging as, in a POMDP, the condition state is not directly observable. We apply the grid method and the policy evaluation method with finite state controllers to address these problems, and we discuss their computational complexity. Outcomes of these analyses can provide the decision makers with deeper understanding of the long-term system reliability and suggest them revising the control policy.

Unscented Kalman Filtering with State Interval Constraints for Joint Seismic Input and Parameter Estimation of Nonlinear Structural Models

Friday, 21st June - 16:30: MS89+88+84 - Bayesian Inference in System Identification: Efficient Algorithms and Applications, Modeling Deterioration of Structures and Infrastructure, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 819

Mr. Jixing Cao (Tongji University/Department of Disaster Mitigation for Structures), Prof. Haibei Xiong (Tongji University/Department of Disaster Mitigation for Structures), Dr. Farid Ghahari (University of California, Los Angeles), Prof. Ertugrul Taciroglu (University of California, Los Angeles)

State parameters and input excitations are crucial information in damage identification and performance assessment of structure. In many practical applications, input excitation measurements are either spatially incomplete, or completely unavailable. While for certain cases—namely when the unknown input is white noise—output only identification can be carried out with standard techniques, the input is non-stationary for many situations such as strong ground shaking or extreme wind events. A novel approach is presented here that employs a Bayesian technique for joint state and parameter estimation. The proposed approach combines truncated probability density functions (TPDF) technique and unscented Kalman filtering (UKF), and allows the estimation of the unknown time-invariant model parameters and the unknown input excitation simultaneously using sparsely available structural response measurements. The TPDF method enables the consideration of interval constraints for state estimation; and the UKF filter is augmented for estimating the unknown input. In the estimation process, the unmeasured response and model parameters are not included explicitly in the state equation and no additional regularization or analytical linearization is required. This feature of the proposed method makes it easy to incorporate complex nonlinear FE models in a state space. The proposed method is examined and validated through shake table testing of a model building at different damage states. The method provides comprehensive damage diagnosis capabilities at different length scales, ranging from global (structural) to local levels (element, section, fiber). The validation results demonstrate the acceptable performance and robustness of the proposed algorithm.

Characterization of spatial heterogeneity in material properties using a probabilistic hybrid approach

Friday, 21st June - 16:45: MS89+88+84 - Bayesian Inference in System Identification: Efficient Algorithms and Applications, Modeling Deterioration of Structures and Infrastructure, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 984

Mr. Agnimitra Dasgupta (University of Southern California), Prof. Erik Johnson (University of Southern California), Prof. Steve Wojtkiewicz (Clarkson University)

Characterizing material spatial heterogeneity based on noisy strain or displacement measurements has important applications including material characterization and structural health monitoring. For accurate characterization, multiple complex modelling approaches may be used, each interpolating material properties from basis functions (that may vary in type and order) and associated weights (control points), modelled as random variables, that together together define a model class, which is a collection of models (possibly nested) that may be generated by sampling the control points. Determining the posteriors for all model classes is computationally expensive.

In this study, a probabilistic hybrid framework is used to identify the model class(es) that best describes the available data. First, model classes are falsified when their likelihoods fall below a likelihood bound determined using the false discovery rate (FDR). Then, the appropriate model class is chosen using Bayesian model selection. The quality of the final model class is then reevaluated to ensure that the selected model class reproduces, on average, the data within a specified likelihood.

This approach is illustrated using numerical experiments of a linear elastic dog-bone specimen subjected to uniform displacement at one edge. Spatial heterogeneity of material constitutive parameters is modelled using two-dimensional non-uniform rational B-splines (NURBS). The control points of the NURBS basis functions are assumed stochastic. The inference is then performed when noisy strain or displacement measurements are available. The model class that best describes the available data is then used to predict the spatial distribution of the material properties.

Bayesian model updating of a CRTS-II slab track system

Friday, 21st June - 17:00: MS89+88+84 - Bayesian Inference in System Identification: Efficient Algorithms and Applications, Modeling Deterioration of Structures and Infrastructure, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 146

Dr. Qin Hu (Huazhong University of Science and Technology)

The China Railway Track System (CRTS)-II slab track is one of the most popular track systems in the world. Due to the complexity of the geological and climatic condition along the Chinese high-speed railway, the infrastructure deterioration of the operating railway can be observed and the void damage of the cement-emulsified asphalt (CA) mortar layer is the most obvious. In many countries, railway damage detection still relies on visual inspection. However, such visual inspections are only able to identify the surface damage to the track geometry and rail twist problem. But the void damage of the CA mortar layer under the concrete slab, which can affect track stability, deteriorate riding quality and reduce the comfort of passengers, is extremely difficult to be detected through visual inspection. Therefore, to identify the substructure layer condition has become a current trend in the development of inspection techniques.

This paper reports the development of a Bayesian model updating method for identifying the model parameters of the slab track system based on laboratory experimental data. A three-dimensional finite element model was established using the software ABAQUS to obtain the dynamics response of the track structure. Comprehensive simulating studies have been conducted after obtaining the model parameters of the slab track system from the model updating results, which shows the proposed Bayesian model updating method is feasible in detecting the void damage of the CA layer and it is expected to provide effective technical support for the safety diagnosis of the slab track.

Distribution-Free Polynomial Chaos Expansion Surrogate Models for Efficient Structural Reliability Analysis

Friday, 21st June - 17:15: MS89+88+84 - Bayesian Inference in System Identification: Efficient Algorithms and Applications, Modeling Deterioration of Structures and Infrastructure, Stochastic Methods and Data-Driven Approaches in Computational Mechanics (Steele 102 (130)) - Oral - Abstract ID: 1120

Mr. HyeongUk Lim (The University of Texas at Austin), Prof. Lance Manuel (The University of Texas at Austin)

Polynomial chaos expansion (PCE) has been widely used to build surrogate models in lieu of complex stochastic high-dimensional reliability studies that can be prohibitively expensive using Monte Carlo simulation. PCE relies on the use of parametric distributions for associated variables and related basis functions. However, insufficient or imperfect information on some stochastic variables can limit its use; accepted parametric forms for variable distributions may not be justified such as with multimodal characteristics or mixed discrete-continuous support. Also, dependency structure among the random variables may be complex and make probabilistic transformation to independent variables needed for PCE cumbersome and may not even be defined explicitly. Nonlinearity in such probabilistic transformations can affect the accuracy of PCE surrogate models and slow convergence rates relative to truth system computation of different QoIs (quantities of interest). To address such challenges, a distribution-free PCE approach is proposed. Gram-Schmidt orthogonalization is undertaken in the proposed approach, which exploits a sequence of computed joint raw moments of the underlying random input variables in developing surrogate models. Using a few illustrative examples, we show how the proposed approach can offer a surrogate model-building alternative that can be efficient and accurate, especially against more traditional PCE approaches.

Uncertainty Quantification and Reliability Assessment of Pipelines Using Separation of Variables Methodology

Friday, 21st June - 16:00: MS96 - Advances in quantitative sustainability and resilience, physics-based, data-driven and uncertainty-informed modeling and prediction (Kerckhoff 119 (174)) - Oral - Abstract ID: 351

Dr. Omer Erbay (Simpson Gumpertz & Heger), Mr. Frederic Grant (Simpson Gumpertz & Heger), Dr. Juan Jimenez-Chong (Simpson Gumpertz & Heger), Mr. Peter Nardini (Simpson Gumpertz & Heger), Dr. Murat Engindeniz (Simpson Gumpertz & Heger)

Evaluating and improving the resiliency of aging infrastructure has become a critical task for the assessment of the overall resiliency of urban regions. Pipelines represent one of the primary components of the aging infrastructure because of their quantity and widespread geographical distribution and also their vital importance to the quality of urban life. Pipelines are not only a significant component of water utilities but also an important component in all energy utilities. When evaluating the condition of pipelines and performing asset management, the owners are challenged due to insufficient information about the reliability of these systems considering uncertainty in the parameters affecting their performance. This paper uses the separation of variables method, a systematic approach typically used in seismic fragility evaluation of nuclear facilities, to quantify reliability of pipelines. The focus is given to the structural performance of metal pipelines at their degraded state due to corrosion. The calculated uncertainties and reliabilities are compared to the same quantities obtained from Monte Carlo simulations. The paper also gives guidance on how to incorporate non-parametric uncertainties, such as expert opinion or modeling approaches, in the overall reliability assessment. This investigation shows that the uncertainty and performance reliability of pipelines can be effectively determined using the separation of variables methodology.

A close look at interdependencies for infrastructure disaster management: the implementation in PRAISys

Friday, 21st June - 16:15: MS96 - Advances in quantitative sustainability and resilience, physics-based, data-driven and uncertainty-informed modeling and prediction (Kerckhoff 119 (174)) - Oral - Abstract ID: 401

Dr. Wenjuan Sun (Lehigh University), Dr. Paolo Bocchini (Lehigh University), Dr. Brian Davison (Lehigh University)

Recent natural disasters have caused dramatic damage to infrastructure systems, drawing public attention on the Nation's capability to maintain and improve the continued service of critical infrastructures. As critical infrastructures are interconnected, damage in one system may lead to functionality disruptions and restoration delays in another. In this regard, both federal and state governments have called for efforts to develop computational frameworks and tools for assessing the disaster resilience of interdependent infrastructures. As part of these efforts, PRAISys (our simulation tool for Probabilistic Resilience Assessment of Interdependent Systems) is a comprehensive computational platform that aims to assess the disaster resilience of interdependent infrastructures with the consideration of uncertainties and generation of insights for informed decision-making. One of the critical features of PRAISys is the implementation of physics-based interdependency models at both component and system levels. This study describes the classification of infrastructure interdependency and the implementation of interdependency models in PRAISys. For demonstration, a case study is presented to assess the resilience of three infrastructure systems (i.e., power, communication, and transportation) under a hypothetical earthquake scenario in the Lehigh Valley, a two-county region in eastern Pennsylvania, USA. Simulation cases with different settings of interdependency are designed to evaluate the impact of interdependencies of different types on the damage and recovery of interdependent systems. A comparison of simulation results can indicate the interdependency type with the most adverse impact. By designing alternative strategies to alleviate this type of interdependency, more efficient plans of retrofit and restoration are possible for disaster management.

Probabilistic Inverse Framework to Identify Roughness Variables and Dynamic Characteristics of Vehicle Based on Smartphone's Measurement

Friday, 21st June - 16:30: MS96 - Advances in quantitative sustainability and resilience, physics-based, data-driven and uncertainty-informed modeling and prediction (Kerckhoff 119 (174)) - Oral - Abstract ID: 813

Mr. Meshkat Botshekan (University of Massachusetts Dartmouth), Dr. Mazdak Tootkaboni (University of Massachusetts Dartmouth), Dr. Arghavan Louhghalam (University of Massachusetts Dartmouth)

The increase in the need for travel and mobility on one hand and the significant maintenance cost of roadway networks on the other hand, require monitoring pavement conditions for optimum resource allocations. In addition, road surface condition controls ride quality and comfort, and affects greenhouse gas (GHG) emissions. Maintaining the roads in a good condition, and reducing pavements roughness as one of the key contributors to ride quality and GHG emission is crucial for a sustainable transportation system. Therefore, international roughness index (IRI) has been extensively used as a metric to monitor roadway network condition and to prioritize maintenance. However, evaluating IRI requires measuring road longitudinal profile via instrumented full-size vehicles making the process delicate and expensive. This calls for development of a framework to predict road roughness characteristics without the need to measure road roughness profile.

In this study we develop a framework that infers road roughness characteristics and dynamic properties of the vehicles from vertical acceleration recorded by passengers' smartphones. Roughness characteristics are inferred in the form of road roughness power spectral density (PSD) that can subsequently be used to estimate the expected value of IRI as well as other ride quality metrics. The framework uses a probabilistic inverse analysis method based on Bayesian inference along with various models for vehicle dynamics to infer the probability distribution for parameters of interest. The results are in good agreement with the reported vehicle and road characteristics.

Efficient Probabilistic Learning on Manifolds: Application to Oil Spills.

Friday, 21st June - 16:45: MS96 - Advances in quantitative sustainability and resilience, physics-based, data-driven and uncertainty-informed modeling and prediction (Kerckhoff 119 (174)) - Oral - Abstract ID: 1072

Dr. Ruda Zhang (University of Southern California), Prof. Roger Ghanem (University of Southern California)

Societal challenges often involve complex interaction across physical, social, and ecological systems, while their urgency may preclude mechanistic understanding and necessitate data-driven models that connect the component systems. Recent work (Soize and Ghanem, 2016. J. Comput. Phys.) has started to build high-dimensional joint probability models on sparse data sets by exploiting low-dimensional geometric structure of the data. Here we present a computationally efficient algorithm of manifold sampling that scales to large data sets, is easy to understand and implement, and unveils theoretical properties of the learned manifold in the context of non-parametric probability density estimation. We apply our technique to an integrated risk assessment of offshore drilling infrastructure, studying the exposure of ecosystems, coastal population, and economies to oil spills based on ocean circulation model output. Statistical inference on manifold-concentrated sample provides answer to three types of policy-making questions: predicting impact of future hazards; real-time estimation of event impact; and minimizing spatiotemporal risk for hazard prevention.

Development of surrogate models for steel plate shear wall systems for parametric analysis

Friday, 21st June - 17:00: MS96 - Advances in quantitative sustainability and resilience, physics-based, data-driven and uncertainty-informed modeling and prediction (Kerckhoff 119 (174)) - Oral - Abstract ID: 954

Mr. Nasar Khan (Indian Institute of Technology Gandhinagar), Prof. Gaurav Srivastava (Indian Institute of Technology Gandhinagar)

In recent decades, steel plate shear walls (SPSWs) have been considered as an innovative and convenient lateral load resisting system for resisting earthquakes and wind loads, especially in tall buildings, because of their high strength, considerable ductility, and significant energy dissipating capacity. A detailed analysis of such systems requires high-fidelity finite element simulations which can be very demanding on computational resources and time and typically, a large number of simulations are required for obtaining an optimal design. To address this issue, this current study develops several surrogate models for such systems using the uncertainty quantification framework of DAKOTA. Particularly, Data-fit, Gaussian-process, Taylor-Series data fit, Multi-variant Adaptive Regression splines and Moving least squares (MLS) have been used to develop surrogate models. Three primary design variables of shear walls: thickness, yield strength, and Young's modulus have been considered as inputs and four performance parameters: initial stiffness, the point of first yield, ultimate strength and ductility have been predicted. The surrogate models are compared for their efficacy using about 150 full finite element simulations of shear walls under different configurations. Furthermore, the developed models are used to predict the load-deflection response of SPSW systems.

Data-Driven Methods for Building Energy Consumption Efficiency under Climate Change

Friday, 21st June - 17:15: MS96 - Advances in quantitative sustainability and resilience, physics-based, data-driven and uncertainty-informed modeling and prediction (Kerckhoff 119 (174)) - Oral - Abstract ID: 1234

Ms. May Haggag (Mcmas), Dr. Ahmad Siam (McMaster University), Dr. Sharon McNicholas (McMaster University), Prof. Wael El-Dakhakhni (McMaster University)

Climate change amplifies the frequency and severity of natural disasters which include hydrological, climatological and meteorological hazards. These hazards adversely impact the performance of infrastructure systems. Building heating and cooling activities have been identified as key contributors to greenhouse gas emissions, and subsequently climate change. In this context, finding ways to decrease energy consumed by buildings heating and cooling activities can dramatically decrease the overall building energy consumption which has been a pressing global need in recent years. Subsequently, this study aims to predict building heating and cooling load requirements based on different design parameters in an effort to optimize such loads. In this respect, simulation of building energy consumption performance was used to obtain heating and cooling load dataset based on such parameters. Subsequently, several data analytics techniques were used to predict heating load requirements for buildings under eight specific design parameters. These techniques include multilinear regression, classification and clustering.This work presents a major step towards achieving more sustainable and energy efficient buildings that contribute to decreasing greenhouse gas emissions without compromising functionality and users' comfort.

Cross-mode Couplings for the Fatigue Damage Evaluation of Tri-modal Gaussian processes

Friday, 21st June - 16:00: MS26+27 - Relating microstructure to toughness: controlling damage and fracture, Modeling and Simulation of Material Damage (Lees-Kubota (118)) - Oral - Abstract ID: 23

Prof. Xiang Yuan Zheng (Tsinghua University), Mr. Shan Gao (Dalian University of Technology), Prof. Yi Huang (Dalian University of Technology)

In many engineering areas, the fatigue damage evaluation of structures subjected to random stress in the design stage is of great practical interest. The stress can be a single-mode, bimodal or multi-modal Gaussian process and traditional spectral methods focus on establishing a probabilistic model for the rainflow stress cycles to count the accumulation of damage. Recently, authors have developed a state-of-the-art bimodal spectral discretization method which crosses the border of traditional methods by introducing a coupling coefficient ξ to reflect the interaction between low- and high-frequency components. The present study extends this accurate bimodal method to solve the more complicated trimodal Gaussian problems. An assembly technique is developed to account for cross-mode couplings among low-, medium- and high-frequency components. Extensive comparisons with time-domain rainflow counting method and traditional spectral methods are conducted to validate the high level of accuracy and efficiency of this trimodal method. Moreover, via the proposed tri-modal method, for the first time the respective contributions of different frequencies and their couplings to the overall fatigue damage in a multi-modal situation can be so thoroughly differentiated. Case studies have evidenced the important role of cross-mode couplings in fatigue damage accumulation.

A mathematical framework to couple concrete material degradation with mechanical damage

Friday, 21st June - 16:15: MS26+27 - Relating microstructure to toughness: controlling damage and fracture, Modeling and Simulation of Material Damage (Lees-Kubota (118)) - Oral - Abstract ID: 221

Mr. Amit Jain (University of Southern California), Dr. Bora Gencturk (University of Southern California)

Degradation of the reinforced concrete (RC) structures is a major concern throughout the world. The degradation in RC structures can occur due to various reasons such as corrosion of the steel reinforcement, alkali-silica reactions (ASR), and thermal cycling, among others. Combined with mechanical loading, the degradation may lead to premature failures. Past literature has focused on separate investigations of degradation and mechanical loading. In this study, a mathematical framework is developed to couple mechanical damage with degradation. This framework entails the development of a three-dimensional concrete model that uses an isotropic damage index to independently account for the degradation in the elastic stiffness in both tension and compression loading. The model is implemented in the Multiphysics Object-Oriented Simulation Environment (MOOSE) developed by the U. S. Idaho National Laboratory. The study simulates the strain softening behavior of concrete in tension using the concept of fracture energy and characteristic length. The strain hardening behavior of concrete in compression is also considered. The model is validated for various uniaxial and multiaxial loading scenarios as well as for mesh independency and volumetric expansion. Prediction of the concrete crack location and crack width is also included in the model. The material model is applied to an RC beam to study the degradation due to corrosion of the steel reinforcement, which is quantified in terms of crack width and simultaneous loading to failure to quantify its degradation dependent load capacity.

A microcrack damage model using directional distribution density for Anisotropic Damage

Friday, 21st June - 16:30: MS26+27 - Relating microstructure to toughness: controlling damage and fracture, Modeling and Simulation of Material Damage (Lees-Kubota (118)) - Oral - Abstract ID: 413

Mr. Mitul Sisodiya (University of Colorado Boulder), Dr. Yida Zhang (University of Colorado Boulder)

Significant progress has been made in introducing damage either as a scalar or tensorial Internal State Variable in continuum models for quasi-brittle materials. The definition of damage variable can be purely macroscopical (i.e. stiffness degradation) or upscaled from micro-cracks and inclusions. However, the scalar or tensorial damage variables are approximations of the directional distribution density of micro-cracks. This approximation sometimes can lead to non-physical effects, such as negative probability of cracks along certain directions (Lubarda and Krajcinovic, 1993).

In this study, the information of micro-crack directional distribution directly enters the continuum model as an Internal State Function. We use tools from variational calculus to develop the general functional form of the constitutive law, so that the material response is a functional of the damage distribution function and stress state. Specifically, we start with developing the compliance change due to introduction of multiple non-interacting frictionless micro-cracks. Then thermodynamically consistent damage evolution and material response are rigorously derived using the principles of functional analysis under the framework of Hyperplasticity. Through such formulation, Damage can evolve in every direction according to the defined evolution law, allowing for accurate capturing of anisotropic behavior under multiple loadings in different directions. The present study focuses on developing a robust constitutive model for 2-D plane strain conditions. However, the general frame work may be easily extended to 3-D and more complex crack interaction models with little modification.

Lubarda, V. & Krajcinovic, D. (1993) Damage tensors and the crack density distribution. *International Journal of Solids and Structures* **30(20)**:2859-2877.

INTERACTION MECHANISMS IN BONDED ANCHOR SYSTEMS UNDER SUSTAINED LOAD

Friday, 21st June - 16:45: MS26+27 - Relating microstructure to toughness: controlling damage and fracture, Modeling and Simulation of Material Damage (Lees-Kubota (118)) - Oral - Abstract ID: 770

Mr. Ioannis Boumakis (Christian Doppler Laboratory for Life-Cycle Robustness in Fastening Technology University of Natural Resources and Life Sciences Vienna), Mr. Kresimir Nincevic (Christian Doppler Laboratory for Life-Cycle Robustness in Fastening Technology University of Natural Resources and Life Sciences Vienna,), Dr. Marco Marcon (Christian Doppler Laboratory for Life-Cycle Robustness in Fastening Technology University of Natural Resources and Life Sciences Vienna), Prof. Roman Wan-Wendner (Ghent University)

Bonded anchors find a wide range of applications in structural engineering, e.g. connecting different structural members, assembling precast elements, and attaching non-load components. The economic damage caused by the failure of a single anchor is several magnitudes higher than the cost of the anchor itself. Thus, their safe design requires a more accurate prediction of their long-term performance under sustained load. Current design and approval guidelines for the sustained load behavior are based on a semi-empirical approach. According to this, a simple power law is fitted to structural deformation data of bonded anchors installed in concrete and extrapolated to the life-time of the fastener. This approach is unable to account for the contribution of each material, i.e. concrete, steel, and polymer based mortars, potential stress redistributions in course of time, and evolving damage.. In this investigation, the contribution of each material to the entire system response is studied systematically. The creep response of concrete is predicted based on short-term and long-term material tests by a model that couples hydration, diffusion, and heat transport. The response of the adhesive is calibrated inversely in terms of a visco-elastic bond law utilizing available pull-out tests and sustained load anchor tests. The model is validated on sustained load tests of different geometries, with a very good predictive capacity. Finally, numerical parameter studies are presented that reveal the relationship between the evolving bond stress distribution and the interacting visco-elastic materials.

Restrained Shrinkage Cracking of Borehole Cement

Friday, 21st June - 17:00: MS26+27 - Relating microstructure to toughness: controlling damage and fracture, Modeling and Simulation of Material Damage (Lees-Kubota (118)) - Oral - Abstract ID: 425

Ms. Yige Zhang (University of Colorado Boulder), Prof. Mija Hubler (University of Colorado Boulder)

During hydration, the borehole cement sheath undergoes restrained shrinkage in the radial space bounded by the surrounding rock and well pipe. Since the sheath is expected to perform mechanically and provide sufficient sealing over time, it is important to understand the cracking behavior under these boundary conditions. This will allow cements to be designed to withstand this stress state and effective remediation methods to be developed for existing cracked subsurface infrastructure. This study experimentally models the radial stress state on the borehole cement sheath during restrained shrinkage to study the strain development and resulting crack formation. Previous studies have shown that the stiffness and geometry of the boundaries influence the cracking behavior of cement in similar ring tests. Digital image correlation (DIC) methods are applied to study these influences experimentally on a radial section scaled to match a typical borehole section. Additionally, insights are gained on the sequence of mechanisms driving crack development. A pressure vessel that can test well cement at full scale under elevated temperature and pressure will be used to study the restrained shrinkage of well cement in 3D case. By characterizing the location and extent of cracking in well cement structure, the remediation technique for borehole structure can be optimized.

Role of Interphase Properties on Mechanical Properties of Nacreous Structures

Friday, 21st June - 17:15: MS26+27 - Relating microstructure to toughness: controlling damage and fracture, Modeling and Simulation of Material Damage (Lees-Kubota (118)) - Oral - Abstract ID: 1171

Dr. Sina Askarinejad (University of Cambridge), Prof. Nima Rahbar (Worcester Polytechnic Institute)

Outstanding properties of nacre arises from the stacking structure and the nanoscale vital features in that structure. Moreover, problem-solving strategies of naturally growing composites such as nacre give us a fantastic vision to design, optimize and fabricate tough, stiff while strong composites. In order to provide the outstanding mechanical functions, nature has evolved complex and effective functionally graded interfaces. Particularly in nacre, organic-inorganic interface in which the proteins behave stiffer and stronger in proximity of calcium carbonate minerals provide an impressive role in structural integrity and mechanical deformation of the natural composite. This proximity layer is called interphase layer. Further research on the toughening mechanisms and the role of the interphase properties is essential as a guide on design and synthesize new materials. In this study, the well-known shear-lag theory was employed on a simplified two-dimensional unit-cell of the multilayered composite. The closed-form solutions for the displacements in the elastic components as a function of constituent properties can be used to calculate the effective mechanical properties of composite such as elastic modulus, strength and work-to-failure. The results solve important mysteries about nacre and emphasize on the role of organic-inorganic interface (interphase) properties. The effect of mineral bridges is also studied. Our results show that the properties of proteins in mineral bridges proximity are also significant especially in increasing the elastic modulus of the structural composite. Detailed relationships are presented to identify future directions for advanced material design and development.

A discrete element method with electromagnetic induced cohesion: dusts, powders and clays

Friday, 21st June - 16:00: MS36 - Constitutive Modeling and Advances in Computational Geotechnics (142 Keck (72)) - Oral - Abstract ID: 157

Mr. Daniel Bustamante (Universidad San Francisco de Quito USFQ), Prof. Alex Jerves (Universidad San Francisco de Quito USFQ)

Considering the electrification of granular media during natural and industrial processes such as the presence of ions in the interface of clay minerals, we introduce a new discrete element method (DEM) that adds the electrostatic interaction to the gravitational and mechanical forces governing the movement of 3D grains with arbitrary shapes. This new method is a computational approach inspired by the discrete numerical model of Cundall and Strack (in Géotechnique, 1979. https://doi.org/10.1680/geot.1979.29.1.47) and thus predicts the evolution of dry granular packings based on Newton's equations handling of individual grains. Since the electrical forces do not depend on the contact between the grains, but merely on the presence of distributed charges along their surfaces, the electrical interactions exist between each and every one of the grains that make up a medium. Therefore, to reduce the computational cost involved and justified by the fact that the electric force follows an inverse-square law, when evaluating the changes of force and momentum of each grain, only the electrical interactions with the closest neighbors are taken into account, neglecting the effects of the farthest grains. Finally, to verify the validity of this model, tests are carried out where the initial configuration and shapes of the grains supplied with surface charge density with random distribution is based on information directly taken from granular materials by means of combining 3D X-ray computerized tomography (3DXRCT) and mathematical functions such as level sets.

Micromechanical approach to model deformation response of granular materials using FEM considering meso-structure from X-ray computed tomography

Friday, 21st June - 16:15: MS36 - Constitutive Modeling and Advances in Computational Geotechnics (142 Keck (72)) - Oral - Abstract ID: 341

Mr. Mohmad Mohsin Thakur (University of Tennessee, Knoxville), Dr. Dayakar Penumadu (University of Tennessee, Knoxville)

The discrete nature of granular materials results in complex mechanical interactions such as non-affine deformations including slippage at grain contacts, force chain buckling and shear banding. Even until now, geomechanics community largely relies on triaxial testing as the basis for constitutive behavior at continuum scale. However, the continued evidence with the lack of suitable predictive models with reasonable number of parameters to capture phenomenological effects makes us believe that this problem is too complicated for any continuum-based approach. The urgent need is to incorporate mesoscale effects which are discrete and non-repeating in the numerical modeling, and hence FEM and X-ray CT imaging are explored concurrently. The X-ray CT images of Ottawa sand are transformed into a 3-D FEM mesh to solve a boundary value problem using actual grain and pore microstructure. The validity of the existence of representative elementary volume and its effect of the variation in size on stress-strain response is studied by simulating cubical specimens of different size for triaxial loading conditions. Furthermore, the variation in contact interaction properties such as limiting shear stress and elastic slip stiffness between the surface of grains is investigated. It was observed that contact properties are critical in predicting primary deformation modes such as sliding and rolling of grains in contrast to elastic compression of grains as observed in triaxial experiments at low/intermediate confining pressure. Additionally, development of force chains and shear bands on cylindrical specimen is presented with jamming/unjamming of force chains evident in kinetic energy and deviatoric stress oscillations

Lattice Element Method with refined beam theory for failure in cemented granular media

Friday, 21st June - 16:30: MS36 - Constitutive Modeling and Advances in Computational Geotechnics (142 Keck (72)) - Oral - Abstract ID: 774

Mr. Shahbaz Ahmad (Texas A&M University), Dr. Zarghaam Rizvi (Kiel University, Geomechanics and Geotechnics), Prof. Frank Wuttke (Kiel University, Geomechanics and Geotechnics)

In this paper, the lattice element method with embedded discontinuity is further extended to model the weak cemented granular media with refined beam theory. The more sophisticated and advance higher order Refined beam theory with higher order polynomial approximation instead of linear like Timoshenko beam for shear for accurate computation with a reduction in the dimensionality and convergent behaviour reduces the computation time and slender and stumpy member behaviour which arises due to Poisson random meshing technique. Two example are presented with a coarser and finer mesh and no significant mesh dependency on the system behaviour or failure pattern is recognised.

Generalized effective stress equation for soil

Friday, 21st June - 16:45: MS36 - Constitutive Modeling and Advances in Computational Geotechnics (142 Keck (72)) - Oral - Abstract ID: 1046

Prof. Chao Zhang (Hunan University), Prof. Ning Lu (Colorado School of Mines)

Since the early 2000s, suction stress has been conceptualized as a unitary way to quantify effective stress in soil, i.e., effective stress equal to total stress minus suction stress. Suction stress is the part of effective stress due to soil-water interaction. When soil is saturated, suction stress is the pore water pressure, whereas when soil is unsaturated, suction stress is a characteristic function of soil called the suction stress characteristic curve (SSCC). Two physicochemical soil-water retention mechanisms are responsible for the SSCC: capillarity and adsorption. These two mechanisms are explicitly considered to develop a closed-form equation for the SSCC and effective stress. The SSCC data from the literature for a variety of soils ranging from clean sand to silty and clayey soils are used to validate the equation, and indicate that the equation can well represent the data. Additional validation is achieved using experimental data of the soil shrinkage curves and the elastic modulus functions. The equation can be reduced to the Lu et al.'s previous closed-form equation for SSCC when capillarity dominates soil-water retention, can be reduced to the Bishop's effective stress equation when capillarity is the sole soil-water retention mechanism, and can be reduced to the Terzaghi's classical effective stress equation when soil is saturated.

Extending the Generalized Bounding Surface Model for Saturated Cohesive Soils to Non-Isothermal Conditions

Friday, 21st June - 17:00: MS36 - Constitutive Modeling and Advances in Computational Geotechnics (142 Keck (72)) - Oral - Abstract ID: 1128

Prof. Victor Kaliakin (University of Delaware), Dr. Meysam Mashayekhi (Federal Highway Administration (Turner-Fairbank Highway Research Center))

In its most general form, the Generalized Bounding Surface Model (GBSM) is a fully three-dimensional, temperature and time-dependent model that accounts for both inherent and stress induced anisotropy. To better simulate the behavior of saturated cohesive soils exhibiting softening, the model employs a non-associative flow rule. The microfabric-inspired rotational hardening rule developed for use with the model was guided by a thorough review of past modeling practice. Finally, the shape hardening function used in the GBSM simplified earlier versions without compromising the model's predictive capabilities.

Following a review of the various approaches that have been used to simulate the thermo-hydro-mechanical behavior of saturated cohesive soils, the GBSM was extended to account for non-isothermal conditions. This entailed a novel approach involving coupling terms in the scalar loading index. Thus, unlike all previous formulations for thermo-hydro-mechanical (THM) analyses, the outer (bounding) surface in stress invariants space was not a function of temperature. Instead, the thermal effects enter the formulation through thermoplastic stain components. In addition, separate projection centers are used for the mechanical and thermal portions of the response. This concept facilitates the inclusion of thermal history in THM simulations.

Following an overview of the GBSM and its extension to non-isothermal conditions, simulations under both drained and undrained conditions are compared with experimental results. Finally, the need for additional experimental results to better understand the THM response of saturated cohesive soils is discussed.

Practical aspects of seismic isolation using metafoundations: a case study

Friday, 21st June - 16:00: MS54 - Mechanical metamaterials for waves mitigation and control (153 Noyes (134)) - Oral - Abstract ID: 278

Mr. Panagiotis Martakis (ETH), Dr. Vasilis Dertimanis (ETH), Prof. Eleni Chatzi (ETH)

We attempt to evaluate the feasibility and the effectiveness of an innovative foundation, which relies on the concept of locally resonant metamaterials, from a practical point of view. The novel foundation integrates the well-established isolation system of lead rubber bearings in a layered structure form with reinforced concrete slabs, in order to tackle the inherent drawbacks of the bearing isolation. To this end, a realistic superstructure geometry is chosen, designed according to the current standards for isolated structures, and the driving parameters of the meta-foundation design are highlighted through a parametric analysis of the material properties, the geometry of the superstructure, the foundation and the soil. In order to illustrate the benefit of the proposed framework, a comparison with the response of conventional foundations is provided. The challenges on the design and the execution of the novel system are openly presented, putting the basis for further discussion on the feasibility of the proposed foundation concept for the seismic design of real structures.

Soil Structure Interaction and Structured Soils

Friday, 21st June - 16:15: MS54 - Mechanical metamaterials for waves mitigation and control (153 Noyes (134)) - Oral - Abstract ID: 187

Dr. Stephane Brule (FRESNEL), Dr. Sebastien Guenneau (FRESNEL), Dr. Stefan Enoch (AMU/INSTITUT FRESNEL)

The response of a structure to earthquake shaking is affected by interactions between three linked systems:the structure, the foundations, and the soil underlying and surrounding the foundation. Soil-structure interaction analysis evaluates the collective response of these systems to a specified ground motion.

Except for a few cases of study with full numerical modeling, a complete study of both the structure and foundations is rather complex and usually the problem is split into two canonical sub-problems: kinematic and inertial interactions. Kinematic interaction results from the presence of stiff foundation elements on or in soil, which causes motions at the foundation to depart from free-field motions. Inertial interaction refers to displacements and rotations at the foundation level of a structure that result from inertia-driven forces such as base shear and moment.

In addition to the research advances already made on the interaction of seismic waves with rigid elements in the ground or with holes, we have explored the possibilities of acting on the free surface displacement. In particular we have looked at the beneficial effects of a decrease of horizontal surface displacements in case of Rayleigh waves which directly affect the design of buildings. For that, we manage the artificial horizontal stratification of a given soil, initially homogeneous.

Numerical and experimental investigations on the wave mitigation properties of elastic metamaterials in bounded and non-periodic domains

Friday, 21st June - 16:30: MS54 - Mechanical metamaterials for waves mitigation and control (153 Noyes (134)) - Oral - Abstract ID: 524

Dr. Andrea Colombi (ETH Zurich), Mrs. Rachele Zaccherini (ETH Zurich), Dr. Vasilis Dertimanis (ETH), Prof. Eleni Chatzi (ETH Zurich)

Locally resonant metamaterials consisting of structured arrangements of repetitive resonant units have proven capable of controlling wave propagation across different wavelength scales. In the context of seismic and ground-borne vibration mitigation, the so-called metabarriers and metafoundations, constituted by a 3D periodic arrangement of meter-size resonators, have been recently investigated and proposed to protect critical infrastructures. In particular, the local resonances of the metamaterial open bandgaps in the dispersion diagram allowing waves to be reflected away from the building to shield. Often idealised as infinitely periodic structures, the band structure of the metamaterial is usually obtained from the elementary resonant unit-cell, exploiting the Floquet-Bloch theory. However, practical applications rarely meet this condition and require the metamaterial to be modelled in a more physically accurate way.

Here, the performance of the metamaterial in terms of attenuation and bandwidth are numerically investigated to the change of number, distribution and natural frequency of the cells within the metamaterial. 3D time domain simulations combining the metabarrier/metafoundation, the soil and the structure to shield are performed using SPECFEM3D, a spectral element software.

We experimentally investigate the potential of a small-scale resonant metabarrier, consisting of an array of horizontal resonators, buried under the surface of an unconsolidated granular medium. We analyse the interaction between the metamaterial and the surface shear waves, investigating the coupling between the resonators and the material inhomogeneity. Both numerical and experimental findings demonstrate wave attenuation around the resonant frequency of the metamaterial, thus proving the filtering effect of metamaterials in different soil conditions.

Dynamics of a metamaterial beam consisting of periodically-coupled parallel flexural elements

Friday, 21st June - 16:45: MS54 - Mechanical metamaterials for waves mitigation and control (153 Noyes (134)) - Oral - Abstract ID: 349

Ms. Setare Hajarolasvadi (University of Illinois at Urbana-Champaign), Prof. Ahmed Elbanna (University of Illinois at Urbana-Champaign)

Periodic systems have attracted a lot of attention in science and engineering due to the existence of band gaps in their frequency spectra. In this work, we study the flexural wave propagation in beams that are periodically connected in parallel and investigate how the contrast in the material and cross-sectional properties may affect the band structure of these systems and their dispersion properties. Results suggest that by changing the mass and stiffness ratios of the two beams, or by changing the inter-beam connection compliance, the band gap width, the lowest bandgap edge frequency, and the nature of the attenuation mechanism within the gap may be tuned. Furthermore, by considering a hierarchical system of periodically-connected beam elements with different individual unit cell sizes, we show how the interplay between scales may affect the overall dispersion properties of the system by opening and closing band gaps at different frequencies. The findings suggest that a modular design approach may lead to novel dispersion properties in beam structures. Finally, using a Frequency Response Function approach, we show that the aforementioned results hold in the limit of finite structures.

A systematic approach for engineering the dispersive behavior of periodic media

Friday, 21st June - 17:00: MS54 - Mechanical metamaterials for waves mitigation and control (153 Noyes (134)) - Oral - Abstract ID: 848

Mr. Heedong Goh (The University of Texas at Austin), Prof. Loukas Kallivokas (The University of Texas at Austin)

We are concerned with engineering the dispersion relation of a periodic medium as a means of controlling wave propagation. Specifically, we propose a systematic procedure to design the unit cell of a periodic medium to achieve a desired dispersive behavior, when, for example, a user-specified band gap or, alternatively, a target group-velocity profile is defined.

To describe the unit-cell design procedure, we use an inverse medium problem framework: we define a Lagrangian, consisting of an objective functional and the side-imposition of the underlying wave problem, where the latter is cast in terms of the Bloch eigenvalue problem. Then, the challenge is to define an appropriate objective functional so that it uniquely characterizes the desired dispersive behavior, and drives efficiently the design problem. In this presentation, we introduce two candidates for the objective functional: the discriminant of the eigenvalue problem and, alternatively, a misfit functional informed by a target group-velocity profile. Both functionals are real-valued and differentiable, and, thus, allow the use of a gradient-based procedure for arriving at the unit-cell design.

The proposed methodology can accommodate both topology and material design variables, or even discrete mass-spring-damper assemblies suitable for resonator designs. The methodology is demonstrated using scalar waves, yet it is generalizable to the vector case, since the associated eigenvalue problem is Hermitian. We demonstrate numerically, using time-domain simulations, the performance of various periodic structures with engineered dispersive behavior.

Multistable Architectures on Elastic Foundation for Tunable, Reversible Wave Propagation

Friday, 21st June - 17:15: MS54 - Mechanical metamaterials for waves mitigation and control (153 Noyes (134)) - Oral - Abstract ID: 977

Mr. Vinod Ramakrishnan (University of California, San Diego), Prof. Michael Frazier (University of California, San Diego)

Architected (meta)materials are remarkable for their extraordinary performance stemming from a cleverly designed, 3D-printed internal architecture. However, generally, once fabricated, there is little opportunity to adapt the internal architecture to changing requirements. In the context of elastic wave propagation, recent proposals have exploited instability and multistability within soft architectures to tune the dispersion characteristics, leading to one of two outcomes: (1) tuning is continuous and reversible, though reliant on the constant support of an external field or (2) tuning is among a finite number of discrete, stable configurations, though tuned states are energetically irreversible. In this presentation, we introduce a one-dimensional, spring-mass system representing a multistable architecture on elastic foundation with tunable wave propagation that is simultaneously stable (i.e., requiring no sustained external support) and reversible. Responding to the strain in the elastic substrate, the system switches among multiple stable configurations which locally alter the effective stiffness within the multistable architecture to tune the characteristic wave dynamics. This class of flexible, multistable metamaterial, inspired by the strain engineering in, e.g., ferroelectric thin films for tunable electronics, provides an attractive avenue for adapting dynamic performance to new requirements.

Predicting the Young's Modulus of Silicate Glasses using High-Throughput Molecular Dynamics Simulations and Machine Learning

Friday, 21st June - 16:00: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 609

Mr. Kai Yang (University of California, Los Angeles), Ms. Xinyi Xu (University of California, Los Angeles), Mr. Benjamin Yang (University of California, Los Angeles), Prof. Mathieu Bauchy (University of California, Los Angeles)

The development by machine learning of models predicting materials' properties usually requires the use of a large number of consistent data for training. However, quality experimental datasets are not always available or self-consistent. Here, as an alternative route, we combine machine learning with high-throughput molecular dynamics simulations to predict the Young's modulus of silicate glasses. We demonstrate that this combined approach offers excellent predictions over the entire compositional domain. By comparing the performances of select machine learning algorithms, we discuss the nature of the balance between accuracy, simplicity, and interpretability in machine learning.

Enhancing reactivity of light burned magnesia through morphological and microstructural modification

Friday, 21st June - 16:15: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 215

Dr. Abdullah Khalil (New York University Abu Dhabi), Dr. Rotana Hay (New York University Abu Dhabi), Prof. Kemal Celik (New York University Abu Dhabi)

Light burned magnesia is considered as the key material for future construction industry as its production is much more energy efficient as compared to conventional Portland cement. In addition, the unique ability of magnesia based cement to sequester atmospheric carbon dioxide and gain strength with time makes it an environment friendly construction material. The consolidation and strength gain mechanism in light burned magnesia is governed by its high reactivity that leads to accelerated reaction with water and brucite formation followed by absorption of surrounding carbon dioxide to form hydrated magnesium carbonates that are responsible for the microstructural densification and strength gain. Therefore, the high reactivity of light burned magnesia is the key towards its successful use as an alternative cementitious material for sustainable infrastructure. In this context, we aim to enhance the reactivity of light burned magnesia by reducing its particle size and modifying the microstructure through the classical method of ball milling. By using stainless steel jars and balls as the grinding media, we demonstrate that the reactivity of commercially available light burned magnesia continues to increase up to 12 hours of ball milling due to decrease in the particle size and crystallinity and an increase in the lattice distortion and the specific surface area. As compared to original light burned magnesia, the reaction time of ball milled magnesia was measured to be nearly half that promises profound effectiveness of the ball milling process to enhance the reactivity of light burned magnesia for construction and several other engineering applications.

Mechanistic Insight into the Formation of C-S-H Gel During Cement Hydration

Friday, 21st June - 16:30: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 236

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Cement hydration is a complex reaction process involving concomitant reactions of many mineral phases. C-S-H gels are the main hydration products of C_3S and C_2S, which are responsible for the strength development of concrete. The structure is analogue to a crystalline semi-tobermoritic layered structure with dreierkette-patterned (three tetrahedra repeating unit) linear chain of silicate (SiO_4) polymer. In order to fundamentally understand nucleation mechanism, it is necessary to investigate the polymerization mechanism of silicate at an atomistic level first and reveal structural change which is still not known completely. Atomistic simulation using Reactive Force Fields (ReaxFF), in combination with metadynamics (MetaD) can be an effective solution to study the chemical reaction pathways with sufficient accuracy and reasonable computing times. MetaD is a powerful technique for enforcing the chemical reaction by adding biased potential and reconstructing the free energy surface as a function of selected collective variables (i.e. distance, coordination number etc.). ReaxFF coupled with metaD have shown great potential and allowed to study the early hydration of C_3S. The present contribution aims to demonstrate the mechanistic insight into the polymerization (dimer, dreierkette and pentamer formation) of silicate including transition states at different temperature in pore solution as well as on the surfaces of C_3S. It will reveal proof for one of the two competing mechanisms of silicate polymerization during the hydration process. The Ca/Si ratio has a significant influence on the polymerization process. Therefore, a detail study of the polymerization of silicate with different Ca^{2+}concentration at constant temperature will be presented.

Influences of combinational distributions of various Ca/Si ratios and defects on the mechanical properties of calcium silicate hydrates

Friday, 21st June - 16:45: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 232

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Although cement as a durable building material has been widely used in construction environments. It still remains unclear on how their microstructures and chemical compositions at the molecular level affect the mechanical properties and time-dependent behaviors. The multiscale heterogeneities in the cementitious materials hinder the scientist from comprehensively understanding the mechanisms of the macroscopic phenomenon such as creeping and shrinkage. With various hydration extent, irregular porous void and impurities like ettringite, portlandite and sulfate hydrates, the study of the cement paste structure with accurate morphology from the molecular level to macroscale becomes challenging. In the light of determination of indentation modulus and hardness of Calcium-Silicate-Hydrate (C-S-H), the effect of random nanopores on strength and toughness performance has been recently explored. However, the defects at the nanoscale, for example, the intrinsic defective attribute of calcium silicate chains, including the mean length of chains and the calcium-to-silicon ratio (C/S), could strongly affect the mechanical properties of cement paste at the macroscale. In this study, we focus on using a molecular modeling approach to study how the combination of calcium silicate hydrates with various C/S ratio ranged from 1.5 to 1.9 would affect the mechanical properties. Molecular dynamics simulations are carried out to simulate the axial tensile tests. By analyzing atomic structures in different atomistic distributions, we reveal the relationships between the mechanical properties, including elastic modulus, toughness and ductility, and the water content and calcium-to-silicon ratio. Our results help us to bridge the atomistic structures of C-S-H with the mesoscopic material properties.

On the Allowable or Forbidden Nature of Vapor-Deposited Glasses

Friday, 21st June - 17:00: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 900

Mr. Zhe Wang (UCLA), Mr. Tao Du (Harbin Institute of Technology), Prof. Mathieu Bauchy (UCLA)

Vapor deposition can yield glasses that are more stable than those obtained by the more traditional melt-quenching route. However, it remains unclear whether vapor-deposited glasses are “allowable” or “forbidden,” that is, if they can be formed upon the extremely slow cooling of a melt or if they differ in nature from melt-quenched glasses. Here, based on reactive molecular dynamics simulation of SiO_2, we show, under certain conditions, vapor-deposited glasses can indeed be more stable than melt-quenched glasses. Importantly, we demonstrate that the allowable or forbidden nature of vapor-deposited glasses depends on the temperature of the substrate.

Water ageing effects upon the mechanical properties of E-glass fibre reinforced epoxy and its constituents

Friday, 21st June - 17:15: MS45 - The Link Between Composition, Structure, and Physical Properties of Materials; Part 3 (Baxter Lecture Hall (296)) - Oral - Abstract ID: 636

Dr. Gustavo Quino (University of Oxford), Dr. Vito Tagarielli (Imperial College London), Dr. Nik Petrinic (University of Oxford)

Some challenges arise when using composite materials in marine applications. Despite corrosion is not a problem, water exposure can induce detrimental effects upon the mechanical performance of the composites structures in the long term. This work aims to address the degradation of mechanical properties of composites due to water uptake (water ageing). As virtually no information of this type has been reported in the open literature to-date, the approach in this investigation, includes the analysis of the effects of water ageing upon each of the constituents of the composite i.e. E-glass fibres and epoxy resin, seeking to establish a link between the ageing of the individual constituents and the ageing of the composite.

Composite, single fibres, and resin specimens were immersed in a pure water bath at 50°C until reaching water saturation. Water absorption induced a significant drop in tensile strength and modulus of the pure resin [1] and the composite. Micro-mechanical experiments on single E-glass fibres revealed insensibility of the material to water ageing. A Hill-Mandel homogenisation approach was followed to associate the properties of the pristine and aged constituents to those properties measured in the composite.

These observations provide a basis for predictive numerical simulations that can capture the response of aged structures.

[1] G. Quino, A. Pellegrino, V. L. Tagarielli, and N. Petrinic, "Measurements of the effects of pure and salt water absorption on the rate-dependent response of an epoxy matrix," *Compos. Part B Eng.*, vol. 146, pp. 213–221, Aug. 2018.

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