

UC San Diego

JACOBS SCHOOL OF ENGINEERING  
Structural Engineering

# STRUCTURAL ENGINEERING

RESEARCH HIGHLIGHTS  
2018–2019



# WELCOME



On behalf of the approximately 500 undergraduate students, 200 graduate students, 26 researchers, 33 staff members, and 23 faculty members in the Department of Structural Engineering at the University of California San Diego, welcome! Structural engineering plays a critical role in fulfilling the basic needs of society for safe and

sustainable built environments and transportation means, and is an interdisciplinary field that provides exciting opportunities for solving problems at the forefront of research and practice.

Being the only Department of Structural Engineering in the country, we offer rich academic experiences to our students based around a rigorous set of core courses on engineering mechanics, materials engineering, engineering design, and computational analysis that lead toward upper-level focus sequences on civil structures, geotechnical engineering, structural health monitoring/nondestructive evaluation, or aerospace structures. The Department of Structural Engineering currently offers a BS degree in Structural Engineering, MS degrees in Structural Engineering, Structural Health Monitoring, and Geotechnical Engineering, and a PhD degree in Structural Engineering. The BS and PhD degrees in Structural Engineering permit specialization within the major thrust areas of the department: civil structures, geotechnical engineering, computational mechanics, aerospace structures, and structural health monitoring/nondestructive evaluation. Our MS degrees are geared toward building a solid background for careers in engineering practice or future PhD studies, and can be completed within three to four quarters. The Department is also initiating organized Co-Op and internship programs for BS and MS students leading to practical experiences for students and closer links with industry. A degree at any level from the Department of Structural Engineering is associated with a strong grasp of fundamentals honed through hands-on experimentation, numerical analyses, practical design concepts, and exposure to cutting-edge research that all form the basis for life-long learning. The top employers in our field consistently seek out our students, and many of our graduates are currently leaders in academia, engineering consulting, industry, and government laboratories.

Our world-class faculty members have a broad spectrum of complementary specialties with training in a range of traditional disciplines, including civil engineering, mechanical engineering, aerospace engineering, and engineering mechanics. This interdisciplinary set of backgrounds and emphasis on both theory and experimentation promotes discovery and innovation. Our research covers a range of structural materials and scales, from nano- and micro-structures consisting of

particle assemblies or biological structures to large-scale structures, like buildings, bridges, aircraft bodies, ship hulls, geotechnical structures, and marine and naval structures. The research of our faculty, researchers, and students has provided solutions to some of the most challenging problems in the field, including the development of new design and assessment methods to improve the earthquake resilience of buildings and civil infrastructure systems, maximizing the structural efficiency and minimizing the societal impact of a major earthquake event; advanced engineering and safety inspection methods for aircraft structures made of advanced composites; new materials and intervention methods to protect structures and human bodies against extreme loading like explosions and impacts; advanced sensing and non-destructive evaluation techniques to detect structural defects and monitor structural health; advanced computational methods to study and improve the aerodynamics of wind-turbine blades for green energy production, and to predict the response of structures to extreme load events; advanced visualization methods for the preservation of heritage structures; and the modeling of biological structures to understand the nature and help develop new treatment methods for diseases. Our research also addresses some of the emerging interdisciplinary challenges in the areas of systems engineering, structural optimization, data science, machine learning, additive manufacturing, new sensors, smart materials, micromechanics, geothermal energy recovery and storage, distributed renewable energy, and bioengineering. Our remarkable faculty members have received numerous awards and accolades, and many hold highly respected positions within their professional societies.

The unique talents of the students, staff and faculty members in the Department of Structural Engineering along with our vast experimental facilities have been major resources to private industries and governmental agencies that have also contributed to our consistently high ranking within our field. Our research has made direct impacts on standards and practice in structural engineering, geotechnical engineering, aerospace engineering, and materials engineering. The Department is committed to pursuing excellence in research and public service and providing the best possible education and training for our students to be leaders in their profession. It provides an open, inclusive and diverse environment for the faculty, researchers, staff, and students to achieve their best and fulfill their professional goals.

Sincerely,

**John S. McCartney**  
**Professor and Chair**  
**Department of Structural Engineering, UC San Diego**

# FACILITIES

Major assets of our department are our experimental, computational, and visualization facilities. The Structural and Materials Engineering (SME) Building, where the department is located, has well-equipped teaching and research laboratories for geomechanics (soils and rocks), advanced composite materials, aviation safety, structural health monitoring and non-destructive evaluation, and computer visualization. In addition, our Department is home to the world-class Charles Lee Powell Structural Engineering Laboratories, which have unique experimental facilities to study the performance of large-scale structural systems and components under extreme loading, including earthquake, impact, and blast loads. Between the Powell Laboratories and the SME Building, the Caltrans Seismic Response Modification Device (SRMD) is another unique test facility capable of real-time 6-DOF dynamic characterizations of full-scale bearing devices and dampers. The SRMD building also houses a 50 g-ton geotechnical centrifuge used for physical modeling of geotechnical systems realistic self-weight and earthquake loadings. The Englekirk Structural Engineering Center (ESEC), located 10 miles east of the main campus, has the world's largest outdoor shaking table for seismic testing of large-scale structures, a blast simulator, and a soil-structural interaction testing facility. In addition, ESEC has unique large-scale experimental setups for field testing of non-destructive evaluation methods that detect defects in train rails, and for field testing of underground geothermal energy storage methods. Through these facilities, students and visiting scholars have access to some of the most innovative and productive research infrastructure in the world.

## STRUCTURAL AND MATERIAL ENGINEERING (SME) BUILDING

The 183,000-square-foot building houses the Structural Engineering Department, Nano-engineering, a Medical Devices group, the EnVision Maker Studio and parts of the Visual Arts department. The building includes 62 research and instructional laboratories, 160 faculty, graduate student and staff offices, 12 Visual Arts studios distributed across all four building's floors, art exhibition and performance space, and Cymer Conference Center. Frieder Seible, the former Dean of the Jacobs School of Engineering, remarked, "The hope and aspiration for this building is that it is not a physical location for four seemingly disparate academic units, but that it will be transformational for our campus and how we collaborate in our research and education mission."

**THE ENGLEKIRK CENTER** In 2005, the Englekirk Structural Engineering Center opened as an expansion of the Powell Labs, equipped with the world's first outdoor shake table. It is adjacent to the country's largest Soil Foundation-Structure Interaction Testing Facility. The Blast Simulator, housed in the Center, is the world's first laboratory to simulate the effects of bombs without the use of explosive materials.



## CHARLES LEE POWELL STRUCTURAL RESEARCH LABORATORIES

The Charles Lee Powell Structural Research Laboratories are among the largest and most active full-scale structural testing facilities in the world. With its 50 ft. tall reaction wall and 120 ft. long strong floor, the Structural Systems Laboratory is equipped for full-scale testing of bridges, buildings and aircraft. The Structural Components Laboratory includes a 10 x 16 ft. shake table for realistic earthquake simulations. The main testing facility was dedicated in 1986. Throughout the years, additional facilities have been added as the scope and nature of Powell Labs research has expanded.



## SEISMIC RESPONSE MODIFICATION DEVICE (SRMD) TESTING LABORATORY

One of the world's largest shake tables, the six-degree-of-freedom shake table is used for the dynamic testing of full-scale base-isolation bearings, and dampers. Computer-controlled hydraulic actuators that can apply up to 12 million pounds of force during earthquake simulations power the SRMD.



# 8,900

Student enrollment  
at the Jacobs School  
of Engineering

# #17

Ranking among Civil  
Engineering Programs by  
2018 US News & World  
Report.

### 2018-19 RESEARCH HIGHLIGHTS

Editor

Jacqueline Vo

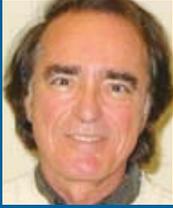
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### STRUCTURAL ENGINEERING DEPARTMENT

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La Jolla, CA 92093-0085  
structures.ucsd.edu

# WORLD-CLASS FACULTY



**ROBERT ASARO**

*Professor*

Composite design and manufacturing technologies for large scale structures and marine applications as well as the deformation, fracture and fatigue of high temperature intermetallics.



**ALICIA KIM**

*Professor*

Structural and topology optimization, multiscale and multiphysics optimization of structures and materials, optimization for composite materials, aerospace structures.



**JIUN-SHYAN (JS) CHEN**

*Professor*

Computational solid mechanics, multiscale materials modeling, modeling of extreme events.



**HYONNY KIM**

*Professor*

Impact effects on composite materials and structures with aerospace and other applications, multifunctional materials, nano-materials, and adhesive bonding.



**JOEL CONTE**

*Professor*

Structural Analysis and Dynamics, Structural Reliability and Risk Analysis, Earthquake Engineering.



**JOHN KOSMATKA**

*Professor*

Design, analysis, and experimental testing of light-weight advanced composite structures.



**AHMED-WAEIL ELGAMAL**

*Professor and Associate Dean*

Information Technology, Earthquake Engineering, Computational Geomechanics.



**PETR KRYSL**

*Professor*

Finite element computational modeling techniques for solids and structures, model order reduction in nonlinear mechanics, and computer and engineering simulations in multiphysics problems.



**VERONICA ELIASSON**

*Associate Professor*

Experimental mechanics within areas of shock wave focusing, shock wave dynamics, shock wave mitigation, high strain rate impact, fluid-structure interaction.



**FALKO KUESTER**

*Professor*

Scientific visualization and virtual reality, with emphasis on collaborative workspaces, multi-modal interfaces, and distributed and remote visualization of large data sets.



**CHARLES FARRAR**

*Adjunct Professor*

Analytical and experimental solid mechanics problems with emphasis on structural dynamics.



**FRANCESCO LANZA DI SCALEA**

*Professor*

Health Monitoring, Non-destructive Evaluation and Experimental Mechanics of Structural Components using novel sensing technology.



**TARA HUTCHINSON**

*Professor*

Earthquake and geotechnical engineering, performance assessment of structural/nonstructural components, and machine learning and computer vision methods for damage estimation.



**DAVID BENSON**

*Professor Emeritus*

Computational mechanics & computer methods for solving problems in mechanical engineering.



**KEN LOH**

*Professor*

Damage detection and localization, multifunctional materials, nanocomposites, scalable nano-manufacturing, smart infrastructure materials, structural health monitoring, thin films and coatings, tomographic methods, wearable technology.



**BENSON SHING**

*Professor*

Earthquake engineering, structural dynamics, inelastic behavior of concrete and masonry structures, bridge structures, finite element modeling of concrete and masonry structures, and structural testing.



**JOHN MCCARTNEY**

*Professor*

Geotechnical and geoenvironmental engineering, thermo-hydro-mechanical behavior of soils, design and analysis of thermally active geotechnical systems.



**MICHAEL TODD**

*Professor*

Structural health monitoring (SHM) strategies for civil/mechanical/aerospace systems, fiber optic and ultrasonic sensor solutions for SHM, nonlinear dynamics and mechanics, uncertainty and probabilistic modeling for SHM.



**GILBERTO MOSQUEDA**

*Professor*

Earthquake engineering, structural dynamics, seismic isolation and energy dissipation systems, seismic response of structural and nonstructural building systems, experimental methods including hybrid simulation.



**INGRID TOMAC**

*Assistant Professor*

Rock mechanics, geotechnical engineering, rock mass excavation and foundations, processes in rock fractures, flow and transport of dilute and dense-phase fluid-particle systems, thermo-poromechanics, advective-conductive heat flow and transport in geotechnical materials.



**YU GAO**

*Professor*

High-performance infrastructure materials, smart materials and structures, energy-related materials, failure analysis for engineering materials and structures.



**CHIA-MING UANG**

*Professor*

Earthquake engineering, seismic design of steel buildings and bridges.



**JOSE RESTREPO**

*Professor*

Seismic design of buildings for improved response during earthquakes.



**LELLI VAN DEN EINDE**

*Teaching Professor (LPSOE)*



**SHABNAM SEMNANI**

*Assistant Professor*

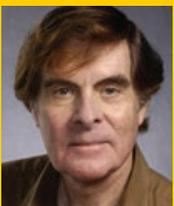
Characterization and modeling of heterogeneous geomaterials across scales, development of multi-scale and multi-physics models to link the microstructure and macroscopic behavior of these materials. Carbon sequestration, hydrocarbon recovery and geothermal energy production.



**GIANG ZHU**

*Associate Professor*

Ocean engineering, biomechanics.



**GILBERT HEGEMIER**

*Distinguished Professor Emeritus*

Earthquake engineering to retrofit bridges, roadways and buildings for improved public safety and structural performance.



**ENRIQUE LUCO**

*Distinguished Professor Emeritus*

Earthquake engineering, strong motion seismology, soil structure interaction.



**FRIEDER SEIBLE**

*Distinguished Professor Emeritus*

Design and retrofit of buildings and bridges for earthquake safety, new technologies to renew the nation's aging infrastructure, & bomb blast-resistant design of critical infrastructure.

# RESEARCH



## Seismic Design and Modeling of “Deep” Steel Columns

PROFESSOR CHIA-MING UANG

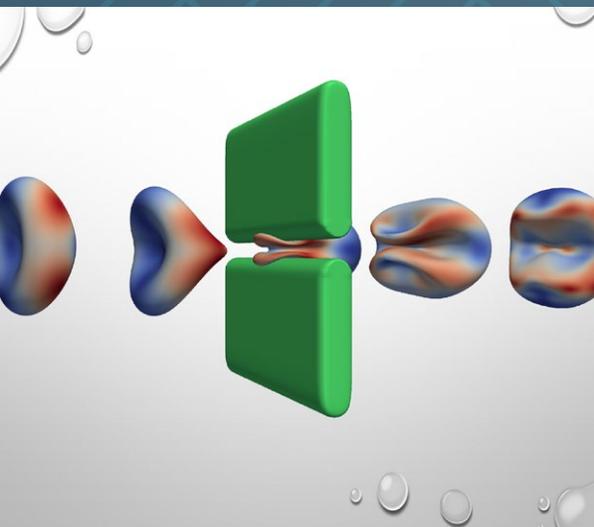
Steel special moment frame is widely used for multistory building construction in high seismic regions due to its excellent ductility capacity and architectural versatility. To control lateral deflection, design engineers also prefer to use “deep” columns to gain higher flexural stiffness. While a significant amount of research has been conducted on the cyclic performance of beams and beam-to-column connections, research on columns, especially deep columns, is very limited. This study showed that deep, slender columns were prone to local buckling and significant axial shortening, a phenomenon typically not captured in nonlinear finite element simulation. Column global buckling would occur when not only the member slenderness ratio was high but also more compact sections were used that caused significant strain hardening. Based on the test results, criteria that would limit the amount of local buckling to ensure sufficient column rotation capacities are in development. The implication of column shortening on the collapse vulnerability of multistory steel moment frame buildings is also been evaluated.



## Hydraulic/High Pressure Nitrogen Based Blast Simulator

PROFESSOR GILBERT A. HEGEMIER

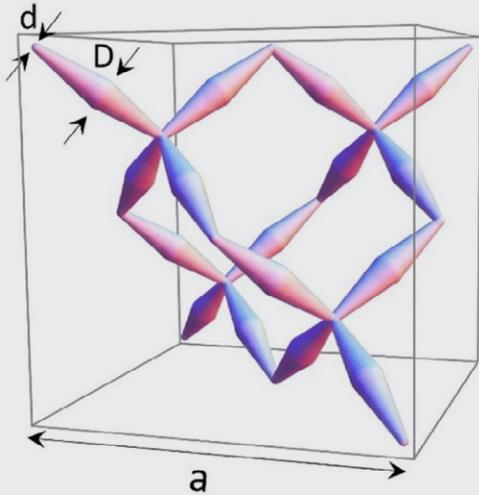
The UC San Diego blast simulator characterizes the response of civilian and military components and systems to terrorist explosive attack and high impact scenarios. It identifies threat mitigation and hardening optimization strategies using both retrofit and new construction methods and materials. The hydraulic/high pressure nitrogen based blast simulator simulates full-scale explosive loads up to 12,000 psi-msec without live explosives and without a fireball permitting structural responses to be seen as they occur. Energy deposition takes place in time intervals of 2 to 4 ms, the same as in a live explosive event. Impact scenarios with longer durations are also simulated. High-speed cameras with tracking software, and strain gages and accelerometers collect test data.



## Multiscale Simulation of Red Blood Cells in Circulation

PROFESSOR QIANG ZHU

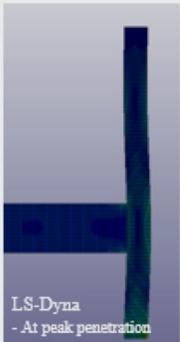
Since the size of red blood cells is comparable to those of micro-vessels and capillaries, in microcirculation blood cannot be treated as continuum fluid. In physiological conditions, red blood cells undergo tremendous deformation due to the combined effect of fluid forcing and constraints from various boundaries. We have conducted a multi-disciplinary study and created a high-fidelity multiscale model to relate cell deformations to the internal stress distribution inside the cell down to the molecular level. This model can be used to predict the structural stability and structural damage which leads to pathological conditions. Of particular interest is the in vivo mechanical performance of cells with mutations, diseases (e.g. malaria), or after storage (as happens in blood transfusion).



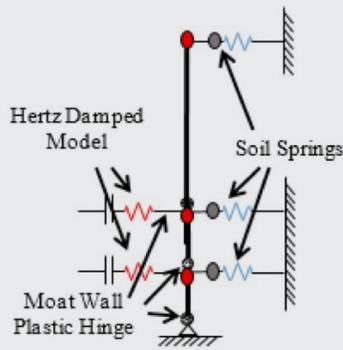
## Mechanical Response Of Confined Pentamode Lattices For Potential Use As Novel Seismic Isolation And Impact Protection Devices.

DR. GIANMARIO BENZONI WITH UNIVERSITY OF SALERNO

The ability of pentamode lattices to have both very soft and very stiff deformation modes suggests they are potentially suitable for use as seismic isolators. Unlike most other seismic isolators, where the response depends entirely on the properties of the materials used, the response of pentamode lattices depends mostly on their geometry. This is advantageous, as their response can be easily tuned by altering the geometry to control the vertical and horizontal stiffness for each application.



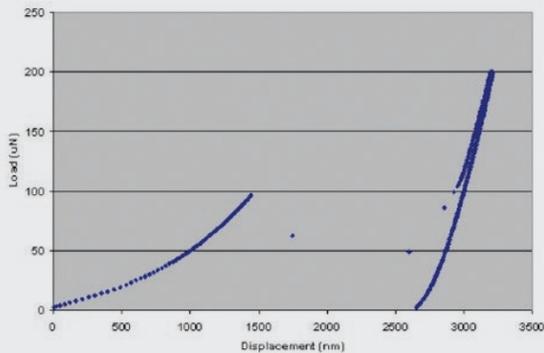
Finite element simulations of NPP base mat impact to moat wall and proposed macro model of moat wall for system level simulations



## Seismic Isolation of Nuclear Power Plants

PROFESSOR GILBERTO MOSQUEDA

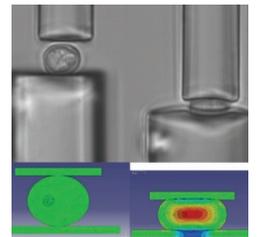
Seismic isolation is one of the most effective strategy to protect critical facilities including Nuclear Power Plants (NPPs) from the damaging effects of horizontal earthquake ground shaking. However, the behavior of the seismic isolation system under extreme earthquakes is not well understood and of significant safety concern. Recent research has focused on addressing the potential for impact of the isolated structure to the stop or moat wall after exceeding its clearance displacement limit. A moat wall model of the scale required for NPP applications was developed based on detailed simulations and previous experimental research. Simulation results indicate significant penetration into the moat wall is possible and the resulting increase in displacement demands on the isolation system should be considered in design.

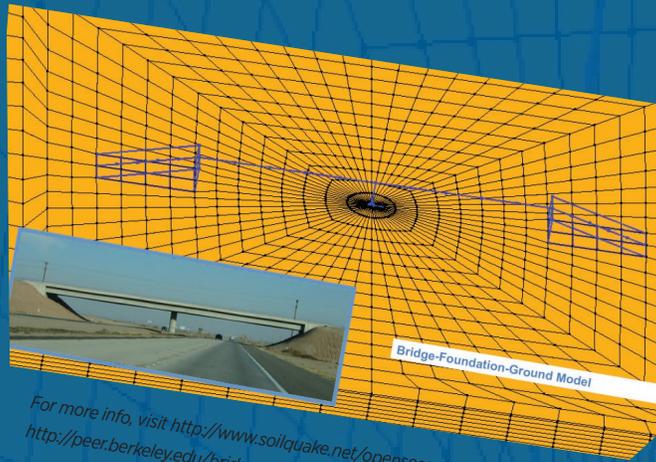


## Modeling the Nano-Mechanics Of Single-Cell Structures

PROFESSOR ROBERT J. ASARO

The cell wall of *S. cerevisiae* serves to protect the cell from thermal, oxidative and mechanical stresses and it is the target for anti-fungal drugs in pathogenic strains. It also serves as a model for cell wall formation in higher eukaryotes. Little is known about its mechanical properties due to the complex nature of its protein and polysaccharide components, and their interconnections. A multi-scale model describing the cell walls nano-mechanical response to AFM tip indentation and the whole cell's response to high hydrostatic pressure, nano-indentation and micro-manipulation compression experiments is under development.



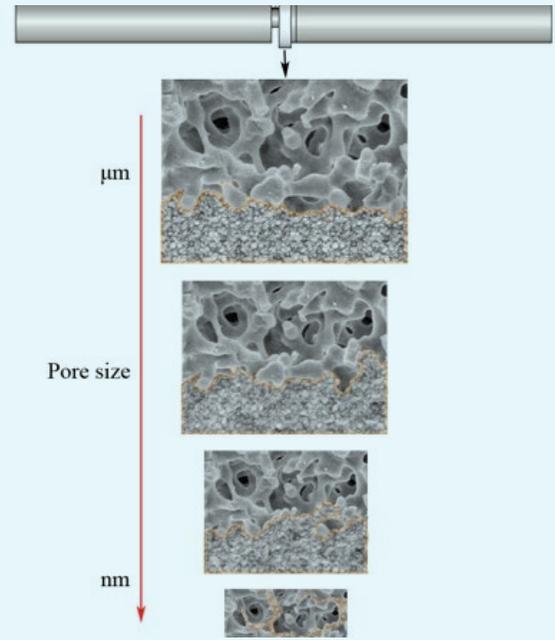


For more info, visit <http://www.soilquake.net/openseespj> and <http://peer.berkeley.edu/bridgepbee>

## Soil-structure Interaction and Performance-based Earthquake Engineering

PROFESSOR AHMED ELGAMAL

Three-dimensional (3D) nonlinear finite element simulations are becoming increasingly feasible for geotechnical applications. OpenSeesPL, created by J. Lu, A. Elgamal, and Z. Yang, is a versatile framework that uses a Windows-based graphical-user-interface (GUI) developed for 3D footing/pile-ground interaction analyses. Various ground modification scenarios may be addressed utilizing the 3D tool. Building on OpenSeesPL, a new GUI has been developed to combine nonlinear dynamic time history analysis of coupled soil-structure systems with an implementation of performance-based earthquake engineering (PBEE) for a single-column 2-span bridge configuration (research with Prof. K. Mackie, UCF). In this new interface, functionality is extended for analysis of multiple suites of ground motions and combination of results probabilistically using the Pacific Earthquake Engineering Research Center (PEER) PBEE framework. Definition of the bridge, the underlying ground strata, and the material properties are greatly facilitated via this integrated analysis and visualization platform.



## Stress Wave Mitigation In Porous Materials

PROFESSOR YU QIAO

Stress wave mitigation in porous materials, such as silica monoliths and PTFE foams, are investigated. As shown in Figure 1, a hat-shaped setup on the SHPB testing system is used to induce force on the porous silica monoliths with different average pore sizes, from a few nanometers to a few hundreds of microns. Under the same shear rate and the same shear displacement, if the pore size is as large as 100 microns, the local softening caused by cell collapse will promote the formation of shear banding along the direction of shear force, and the influence area encircled by orange line will be localized. Whereas if the pore size is small enough like tens of nanometers, local hardening ahead of the shear banding will happen, leading a large influence area and thus more energy will be absorbed by the porous materials.



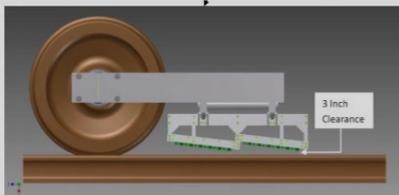
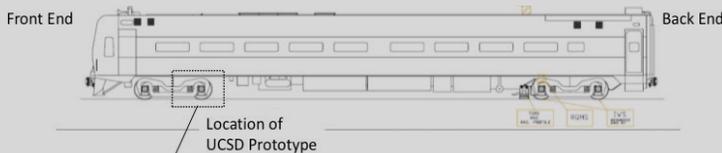
# High-speed Inspection of Railtracks by Passive Extraction of Acoustic Transfer Functions from Wheel-generated Dynamic Excitations

PROFESSOR FRANCESCO LANZA DI SCALEA

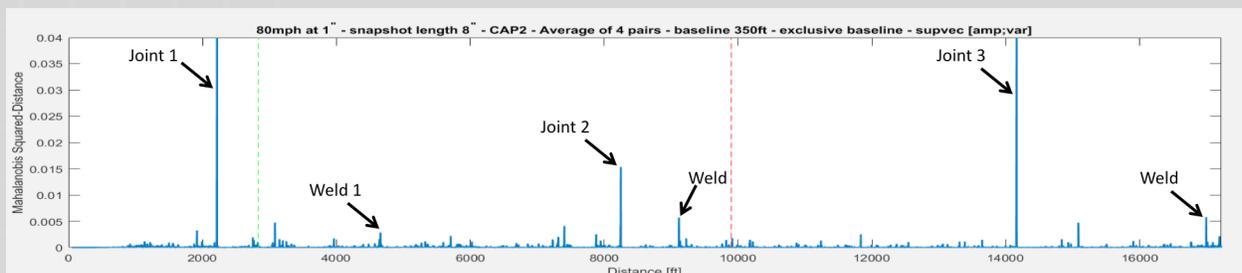
Internal defects in rails cause a number of train accidents worldwide, including derailments. Current rail inspection systems use ultrasonic transducers hosted in fluid-filled wheels to detect internal cracks before they reach critical size. These systems are operated at a maximum speed of 25-30 mph by dedicated inspection vehicles that need to be scheduled during normal train operations.

Under Federal Railroad Administration (FRA) funding, UCSD is working on a radically new method to inspect rails that can enable "smart trains" to conduct the inspection at regular traffic speeds (80 mph and beyond). The approach is based on the idea of passive reconstruction of an acoustic transfer function between two points of the rail by cross-correlating (and opportunely normalizing) apparently-random measurements of dynamic excitations

naturally occurring in the rail due to the rotating wheels of a traveling train. A system based on this idea was designed and constructed using pairs of non-contact air-coupled acoustic receivers. Special signal processing algorithms are being developed to increase the stability of the passively-reconstructed transfer function, i.e. minimize the variance and bias of the transfer function's estimate. A prototype has been tested at the Transportation Technology Center (TTC) in Pueblo, CO, the premiere testing facility in the country for railroad engineering research. For these tests, the UCSD prototype was mounted underneath the FRA DOTX216 test car. Very promising results were obtained at speeds up to 80 mph, with positive identification of rail discontinuities (joints, welds, defects) from changes in the passively-reconstructed transfer function solely using the train wheels as the dynamic excitation of the rail.



Passive-only rail inspection prototype mounted on DOTX216 car during field test at TTC.



Sample of inspection results at 80 mph test speed (TTCI RTT track)

# RESEARCH

## Mean-strain Methodology

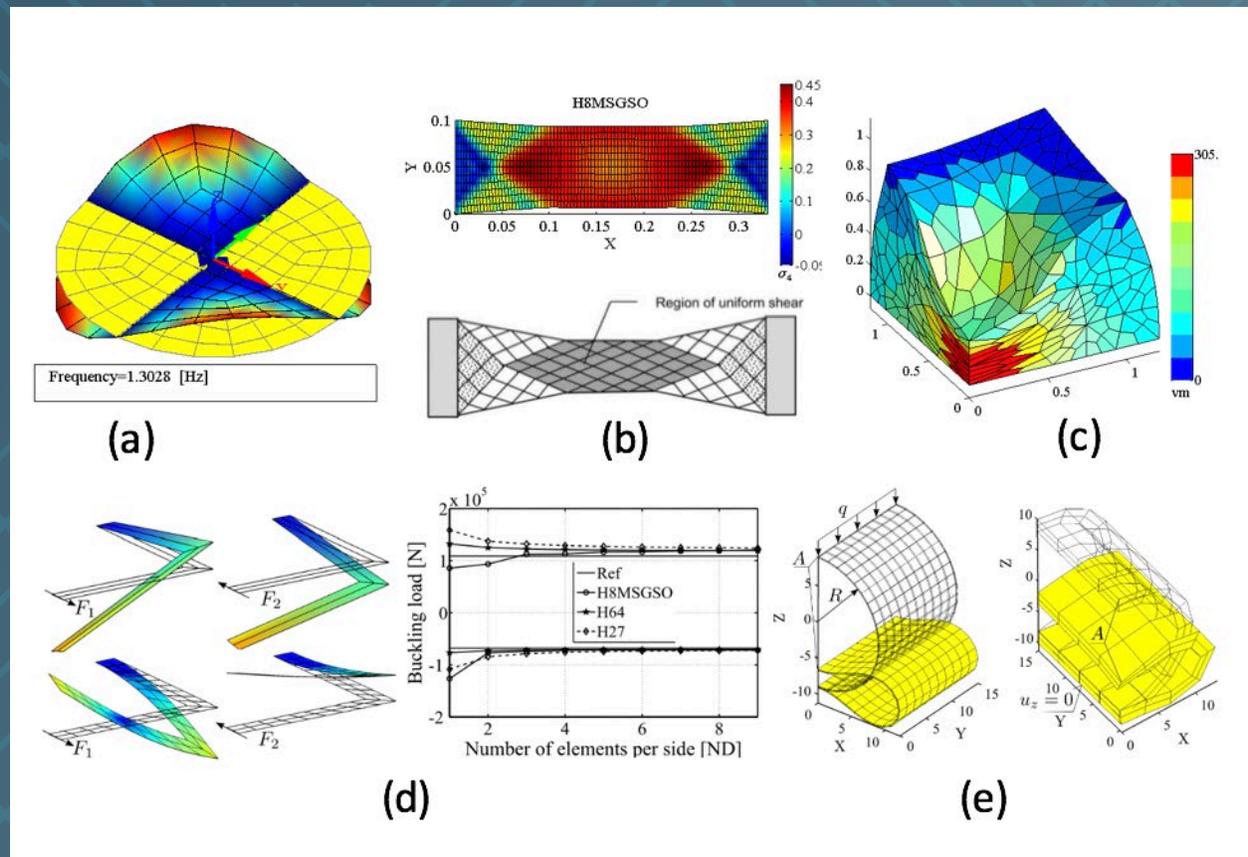
PROFESSOR PETR KRYSL

Methodology for stabilizing mean-strain hexahedron and tetrahedron finite elements for applications to anisotropic deformation in the infinitesimal- and finite-strain was described in several papers by Krysl et al. The approach is based on a sampling of the stabilization energy using the mean-strain quadrature and the "full" integration rule. This combination is shown to guarantee consistency and stability. The stabilization energy is expressed in terms of input parameters of the real material, and the value of the stabilization parameter is determined in a quasi-optimal

manner by linking the stabilization to the bending behavior of the elements.

The accuracy and convergence characteristics of the stabilized mean-strain formulations for both solid and thin-walled structures (shells) compare favorably with the capabilities of mean-strain and other high-performance hexahedral and tetrahedral elements described in the open literature and also with a number of successful shell elements.

Figure 1. Examples of the applications of the mean-strain methodology: (a) free vibration of thin structures, (b) deformation of anisotropic (composite) structures, (c) finite-strain compression of rubber-like materials, (d) buckling analysis of thin structures, (e) finite deformation of shell-like structures.

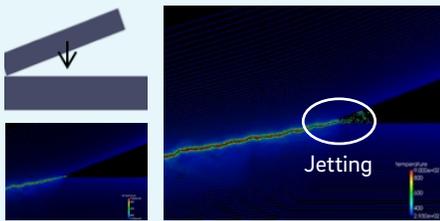


Krysl, P. (2015). "Mean-strain eight-node hexahedron with optimized energy-sampling stabilization for large-strain deformation." *International Journal for Numerical Methods in Engineering* 103(9): 650-670. Krysl, P. (2015). "Mean-strain eight-node hexahedron with stabilization by energy sampling." *International Journal for Numerical Methods in Engineering* 102(3-4): 437-449. Krysl, P. (2016). "Mean-strain 8-node hexahedron with optimized energy-sampling stabilization." *Finite Elements in Analysis and Design* 108: 41-53. Pakravan, A. and P. Krysl (2017). "Mean-strain 10-node tetrahedron with energy-sampling stabilization." *International Journal for Numerical Methods in Engineering* 109(10): 1439-1460. Pakravan, A. and P. Krysl (2017). "Mean-strain 10-node tetrahedron with energy-sampling stabilization for nonlinear deformation." *International Journal for Numerical Methods in Engineering* 111(7): 603-623.

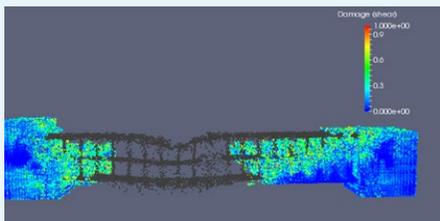
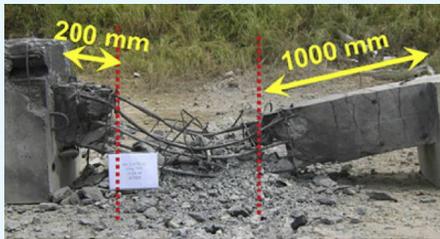
# Meshfree Method for Extreme Events Modeling

PROFESSOR J. S. CHEN

The complex multi-scale failure modes, damage evolution, and fragmentation resulting from high velocity contact-impact processes in solids and structures pose considerable difficulties in simulations using finite element methods. J. S. Chen is one of the original developers of meshfree methods for modeling material damage in fragment-impact processes. The in-house Nonlinear Meshfree Analysis Program (NMAP) developed by Chen's group has been successfully applied to the modeling of explosive welding process using the newly developed stabilized nodal integration and natural kernel contact algorithm as shown in the left figure. NMAP has also been applied to the modeling of reinforced concrete beam subjected to blast as shown in the right figure where the failure mechanisms and damage processes were properly captured by the proposed micro-crack informed damage model and implicit gradient regularization method.



Explosive welding situation

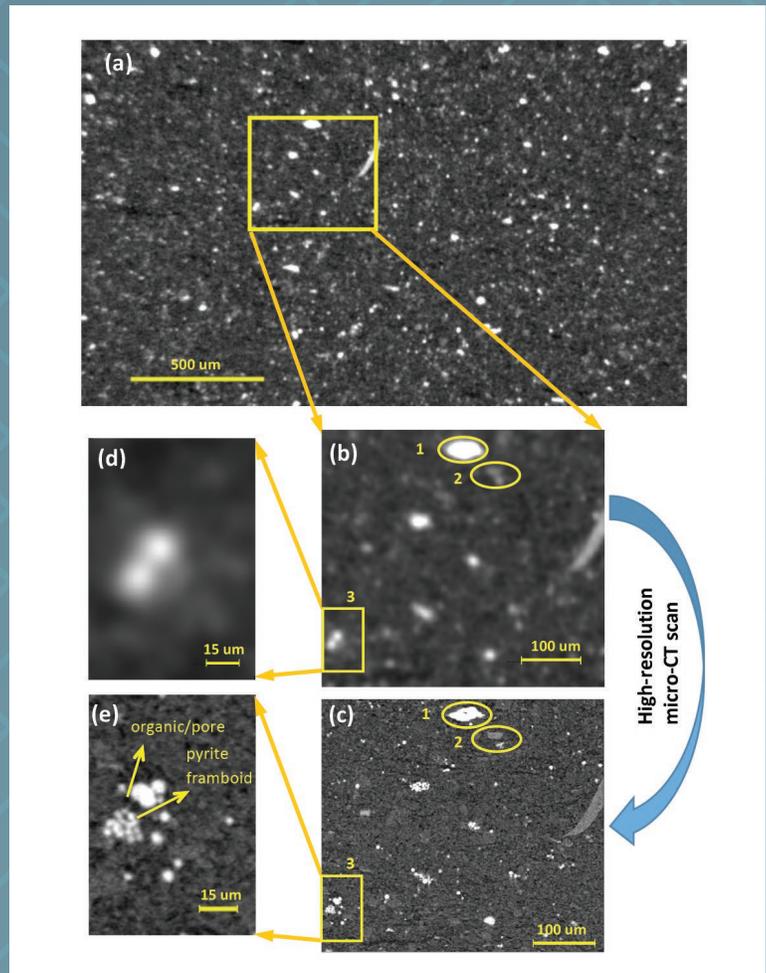


Reinforced concrete beam subjected to blast load

# Microstructure Characterization of Shale Through Multi-scale Imaging

ASSISTANT PROFESSOR SHABNAM SEMNANI

Shale is a highly heterogeneous material at multiple scales. A typical shale has a complex microstructure comprised of nanometer-scale pores and minerals mixed with macro-scale fractures and particles of varying size. Computational modeling of this complex and highly heterogeneous rock requires detailed characterization of heterogeneities and microstructure of the material using imaging and visualization techniques. Advances in high-resolution imaging capabilities have made it possible to image heterogeneous materials down to the nano-scale resolution. However, it is generally not feasible to image a large sample of shale at a high resolution over a large field of view (FOV), thus limiting a full characterization of the microstructure of this material. We have developed a statistical framework that uses high-resolution images to enhance low-resolution images obtained over a large FOV. The approach has been demonstrated using X-ray micro-tomography images of organic-rich Woodford shale obtained at different resolutions and FOV.



Multiscale imaging of shale. A single slice of shale with pixel size of 4.14  $\mu\text{m}$ , obtained using a low-resolution micro-tomography scan, is shown in (a), and the marked region is enlarged in (b). (c) Illustrates the same region shown in (b) obtained using a micro-tomography scan with a pixel size of 0.517  $\mu\text{m}$ . Region 3 marked in (b, c) is enlarged in (d, e), respectively, showing small pyrite particles, framboids, pores/organics, and matrix of low-density minerals and clay, which appear as a blurred range of gray values in the low-resolution image (after Semnani and Borja, 2017)

# Ultrasonic Phase Change Soft Robotics

PROFESSOR KEN LOH AND HAN-JOO LEE

Soft robotics have gained considerable interest due to their ability to deform freely and match the shape of virtually any surface it comes into contact. The soft material also provides higher degrees-of-freedom, which is essential for realizing next-generation bioinspired systems. The ARMOR Lab, funded by a National Science Foundation Project (grant no. 1762530) and in collaboration with Prof. H. Alicia Kim, is currently developing a unique method of soft actuation through ultrasonic atomization. Ultrasonic atomization is a method that generates small droplets of liquid by applying ultrasonic waves onto a layer of liquid (Figure 1). Soft actuation can then be achieved by sealing the structure in Fig. 1. Figs. 2(a) and 2(b) show an accordion-shaped structure that is purposefully designed for unidirectional extensional motion and actuation. During actuation (via ultrasonic atomization), small droplets of liquid evaporate much faster than its bulk form. After 45 s, the displacement increased by ~ 10 mm. Fig. 2(c) and 2(d) show a structure that bends as the air inside the structure expands. Similar testing condition resulted in a horizontal displacement of ~ 20 mm. The actuation rate can be controlled by adjusting the input voltage and frequency of the signal that excites the transducer. Additionally, repeating the test showed that the current actuation method is highly repeatable.

Actuation through ultrasonic atomization can potentially remove the need of heavy pumps in pneumatic systems and does not require tethered tubes since the ultrasonic wave can propagate through the structure itself. The project is currently funded by the National Science Foundation and future studies include modeling and fabricating structures that can achieve various functionalities and improving the efficiency of actuation.

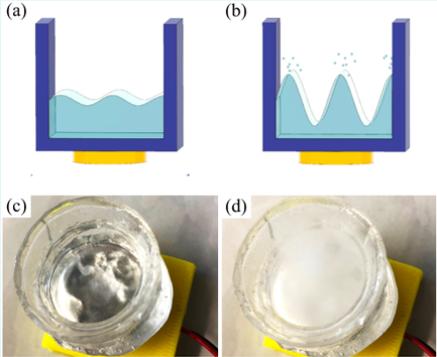


Fig. 1: Illustration and image of ultrasonic atomization

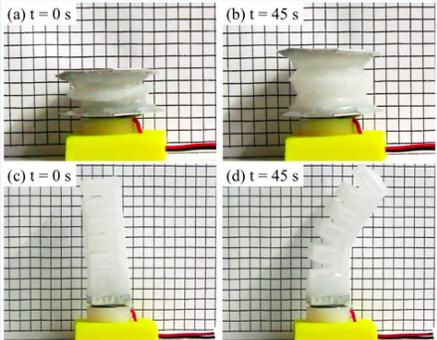


Fig. 2: Actuation of soft robotic structures

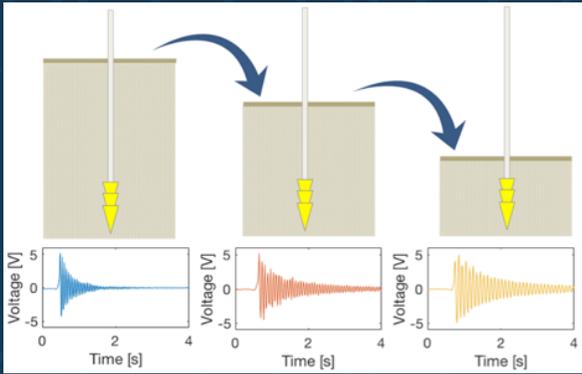


Fig. 1: The effect of scour on the piezo-rod's exposed length and subsequent output

# Buried Piezoelectric Sensing Rods for Scour Monitoring

PROFESSOR KEN LOH AND MORGAN FUNDERBURK

Hydrodynamic interaction between bridge piers and river water causes erosion at the base of the pier, known as scour, which can undermine structural integrity and ultimately lead to bridge failure. The ARMOR Lab, funded by the U.S. Army Corp of Engineers (under a project led by Prof. Michael Todd), is developing a scour monitoring system that can function even under the most extreme river conditions. A piezoelectric polymer was embedded inside of a flexible, water-resistant, cylinder that can be easily driven into the sediment around a pier. Due to the nature of piezoelectric materials, this sensor requires no external power, making monitoring completely passive. As the river flows, the cylindrical structure vibrates, and the sensor outputs a voltage in response to vibration of the rod. This voltage time history can be processed in the frequency domain, and the fundamental frequency of the cylindrical structure can be determined and correlated to the exposed length of the sensor. Changes in exposed length of the sensor is directly indicative of scour depth at that location (Fig. 1). By strategically placing these sensors, a topographical map of the riverbed surrounding the pier (and the scour hole, if any) can be estimated. Figure 2 shows prototype validation testing performed in a hydraulic flume at the National Taiwan University. Once water flow began, scour was gradually induced around the pier, and the frequency output from each sensor was monitored over time. The results of Fig. 3 show that the sensors have the capability to provide continuous and precise frequency tracking capabilities throughout different scour events. Future work will implement and test these scour sensors at a larger scale and in more realistic environments.

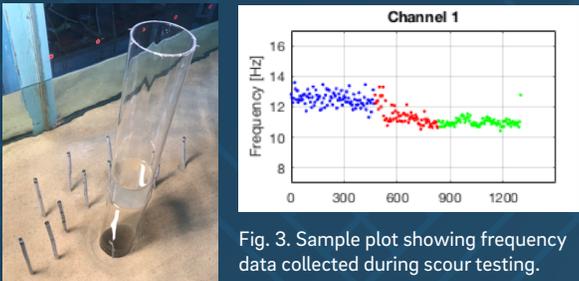


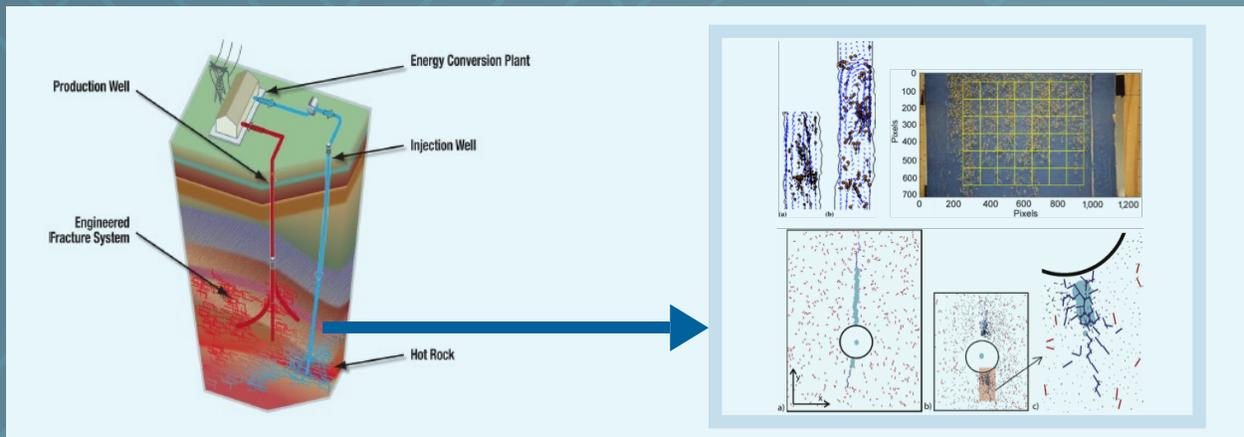
Fig. 3. Sample plot showing frequency data collected during scour testing.

Fig. 2. A circular pier with outfitted with scour sensors.

# The Emergent Field of Energy Geotechnics

ASSISTANT PROFESSOR INGRID TOMAC

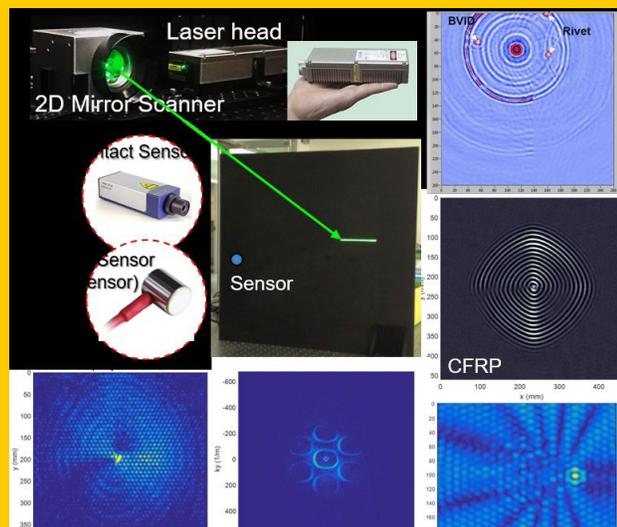
Energy geotechnics is an emergent field which relies on solving geomechanical problems for better extraction of renewable and sustainable energy from soils and rocks. Multi-scale and multi-physics problems are solved with aid of contemporary computational and experimental approaches, such as are Discrete Element Model coupled with computational fluid dynamics, micromechanical and laboratory scale experiments, Particle Image Velocimetry analysis of high speed camera images. Dr. Tomac team is putting experimental, theoretical and numerical effort to understand how dense-phase particulate fluid slurries flow in narrow, wavy, branched rock fractures. We will develop statistically supported theories for predicting placement of sand proppant in hydraulic fractures for efficient extraction of heat energy from deep enhanced geothermal systems (funded by NSF). Rock mass in 5 km deep geothermal reservoirs is subjected to coupled hydro-thermo-chemo-mechanical processes. Dr. Tomac and her team are developing novel failure and stress-strain theories for better predicting rock behavior during geothermal energy extraction.



## OPTIMAL DAMAGE DETECTION AND PROGNOSIS VIA ULTRASONIC SCATTERING

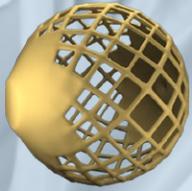
PROFESSOR MICHAEL TODD

Ultrasonic guided wave interrogation using piezoelectric arrays and full-field laser ultrasonic inspection has evolved into a very active research area. This research focuses on the detection, classification, and prognosis of damage using elastic waves as the interrogation mechanism. The novel approach in this work is the embedding of stochastic models to account for uncertainty of model/physical parameters, in order to derive an optimal detection process that supports predictive modeling with quantified uncertainty. Research is focusing on maximum likelihood estimates for detecting and localizing small scatterers in complex composite and metallic structures. Detection is accomplished using generalized likelihood testing, probabilistic imaging methodologies, and optimized data domain transformations.



# Multiscale and Multiphysics Design Optimization (M2DO)

PROFESSOR H. ALICIA KIM



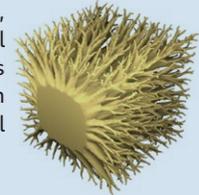
There is an increasing demand in minimizing cost associated with operation and manufacturing, weight while maximizing a structure's functional performance across all engineering sectors. With the recent advances in materials, manufacturing technology, digital engineering and model based engineering, we crystalize the benefits of these technologies in a structural design by developing high fidelity optimization methods and create novel and unintuitive multifunctional structures applicable to aerospace, marine, automotive, robotics, medical, built structures and materials.

Our current research is in design optimization of coupled multiscale and multiphysics problems and our primary interest is in developing Topology Optimization (TO) as it is capable to exploring the largest design space and provide the most creative and the best performing structures. Multiscale TO considers the simultaneous design of materials and structures crossing giga-resolution features. This allows the concept of an integrated material-structural system where multiple materials are specifically tailored to the structural functional requirements instead of simply selecting from existing materials. We have shown that our optimization will find the optimal material whether it is a specific microlattice or porous material, metamaterial, graded composite material or the traditional solid isotropic material and the

corresponding structural design for the optimal functionality or functionalities.

An expertise of the M2DO lab is the development of the state of the art level set topology optimization methods. A recent development in this area is the large-scale method, called VDB-LSTO. Inspired by the academy award winning VDB level set method, we formulated the new VDB-LSTO method that can solve orders of magnitude larger problems. Therefore, we are able to discover novel designs that cannot be obtained by the other existing methods.

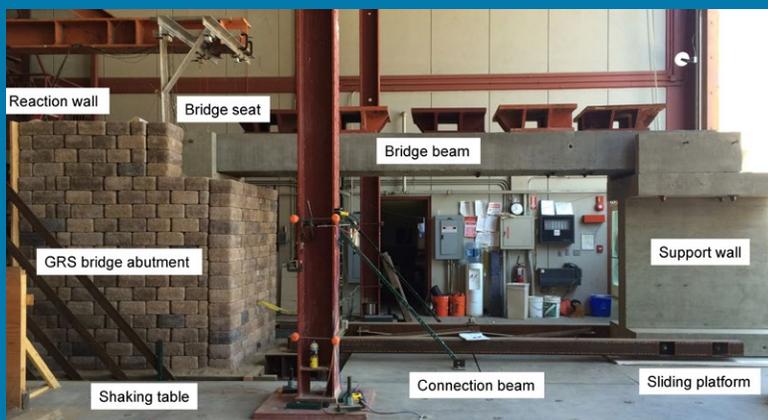
We are actively engaged in applying level set topology optimization to coupled multiphysics design problems. Modern complex systems have integrated multiple functionalities. For example, an aircraft wing has aerodynamic functionalities as well as the load carrying functionality and it is subjected to multiple failure mechanisms governed by structural mechanics and coupled aeroelasticity. Aircraft engine components are typically subject to three major physics, i.e. aerodynamics, thermodynamics and structural mechanics. Our research formulates such coupled multiphysics optimization for a wide range of complex structural system designs.



## Seismic Response of Geosynthetic Reinforced Soil Bridge Abutments

PROFESSOR JOHN MCCARTNEY

Geosynthetic reinforced soil (GRS) bridge abutments are widely used in transportation infrastructure, and provide many advantages over traditional pile-supported bridge abutments, including lower cost, faster and easier construction, and smoother transition between the bridge beam and approach roadway. However, the adoption of this technology in areas with high seismicity like California is pending until their seismic deformation response is better understood. The objective of an ongoing study funded by Caltrans and a FHWA pooled fund project is to characterize the seismic response of GRS bridge abutments using both shake table tests and numerical simulations. A series of five shaking table tests were performed by Yewei Zheng and the Powell Laboratory staff to investigate the seismic deformation response of half-scale GRS bridge abutments. The tests permit evaluation of the effects of bridge load, reinforcement spacing and stiffness, and shaking direction, and results show that reinforcement spacing and

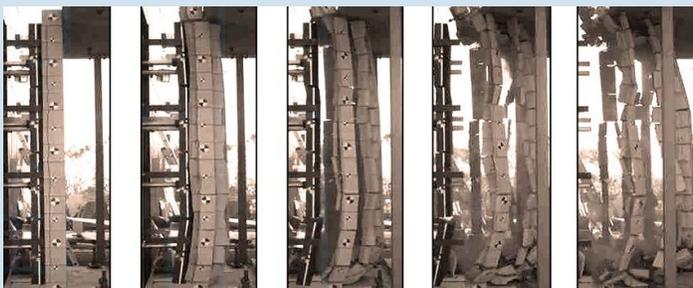


stiffness have the most significant effects on the deformation response. Shaking in the longitudinal direction also resulted in considerable facing displacements in the transverse direction, which indicates the importance of considering three-dimensional (3D) effects. The shaking table data is being used to validate 3D numerical simulations, which will be used to further understand the effects of different design details on the seismic deformation response of GRS bridge abutments that are needed to improve the seismic design guidelines for this type of structure.

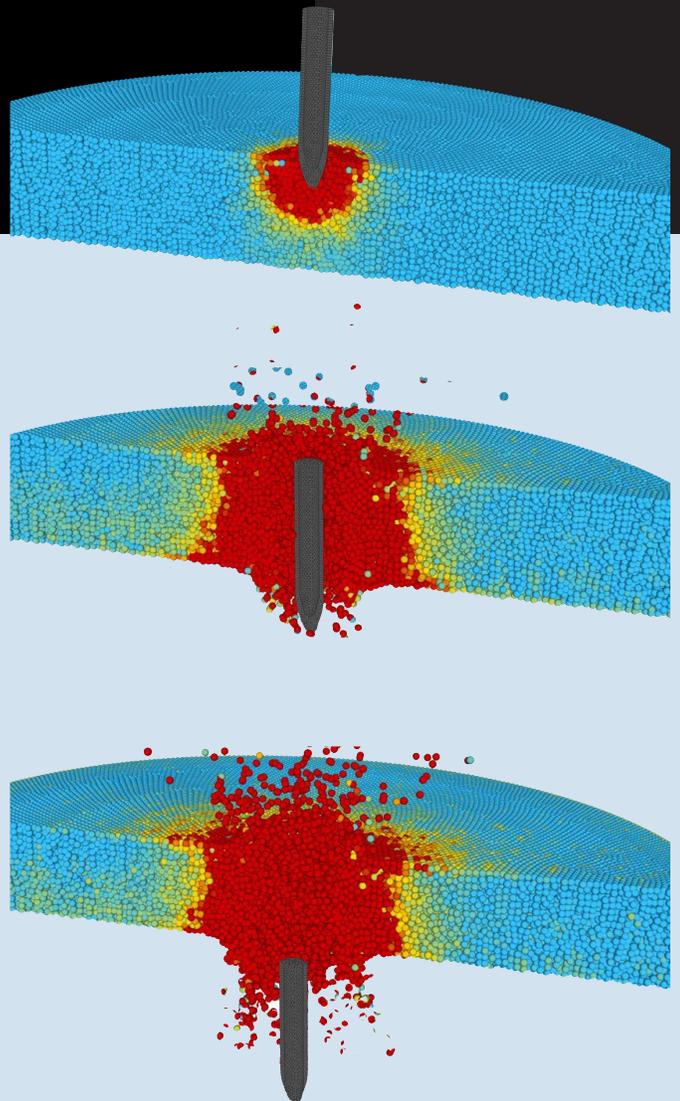
# CENTER FOR EXTREME EVENTS RESEARCH

**STRUCTURAL ENGINEERING R. ASARO, Y. BAZILEVS (ASSOCIATE DIRECTOR), J. S. CHEN (DIRECTOR), V. ELIASSON, G. HEGEMIER (ASSOCIATE DIRECTOR), T. HUTCHINSON, A. KIM, H. KIM, F. KUESTER, K. LOH, MECHANICAL AND AEROSPACE ENGINEERING V. NESTERENKO, A. P. PISANO, S. SARKAR, MATHEMATICS, R. BANK, L. T. CHENG, M. HOLST, RADIOLOGY, S. SINHA, SAN DIEGO SUPERCOMPUTER CENTER, A. MAJUMDAR, M. TATINENI**

Center researchers are world-renowned experts in experimental and computational methods, design optimization, sensor technology and multifunctional materials for extreme events. We leverage this expertise to develop better ways to protect entire built infrastructures, as well as bio-systems, from extreme events such as blasts from terrorist attacks and mining explosions, car crashes, sports collisions, and natural disasters such as landslides. Challenges we address are: protecting the nation's built infrastructure, performing extreme event mitigation and recovery, and protecting bio-system injuries from extreme loading.



Masonry wall subjected to blast load



Damage assessment of bullet penetration through concrete wall



## DroneLab Participates in Earthquake Test on UC San Diego Shake Table

Engineers record damage to building during seismic and fire events simulated on the UC San Diego outdoor shake table.

**PROFESSOR FALKO KUESTER**  
**PROFESSOR TARA HUTCHINSON**  
**PROFESSOR JOEL CONTE**



If the prospect of a mega-earthquake has you quaking — fear not, because UC San Diego engineers are making sure our world will withstand the rumble. And in addition to using the world's largest outdoor shake table, researchers at the Jacobs School of Engineering also turned to drones to capture the damage from a simulated, large-scale earthquake on a six-story, lightweight steel-frame building on the UC San Diego shake table. The goal: to determine how the structure would fare during a tremor and fires that may follow.

The structure, the tallest cold-formed steel-frame structure to undergo tests on a shake table, was built to represent a multifamily residential condominium or apartment. It was placed through a series of simulated

temblors of increasing intensity that mimicked actual earthquakes.

As a better way to determine stress on the materials, the building's performance was captured by an extensive array of more than 250 analog sensors, as well as digital cameras and aerial drones. Structural engineering professor (and CSE faculty affiliate) Falko Kuester, who leads UC San Diego's DroneLab, used unmanned aerial vehicles (UAVs) to capture both the seismic and fire testing and create a high-resolution 3D model and video of observed damage. Engineers can use virtual reality (VR) to zoom in to see the tiniest details, such as cracks and changes in shape and color.

"This is big VR for big data and big science," says Kuester, who also directs the Qualcomm Institute's Center of Interdisciplinary Science for Art, Architecture and Archaeology (CISA3) and the Cultural Heritage Engineering Initiative (CHEI).

As for the building? "It could have been easily repaired," said structural engineering professor Tara Hutchinson. "The occupants would have gotten out safely." Hutchinson

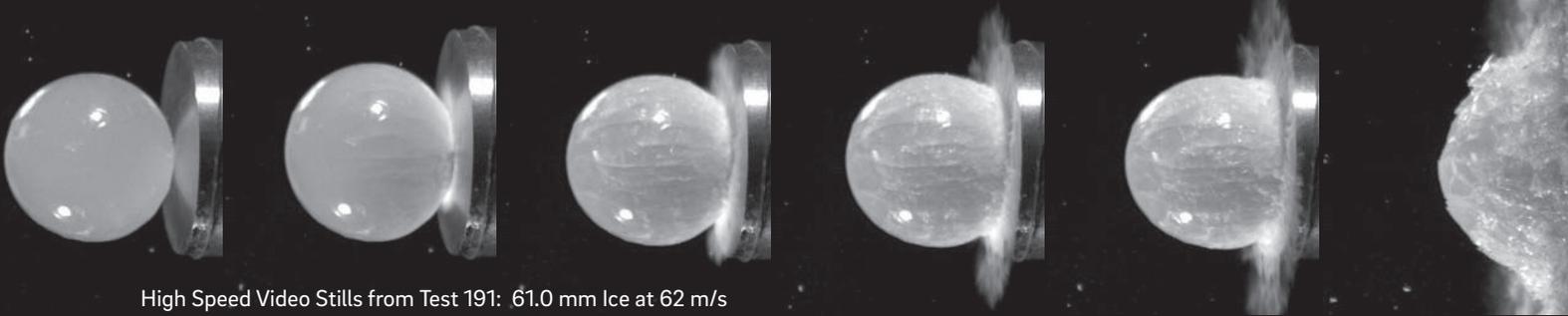
believes the structure fared well because it is lighter than a concrete building and has less mass to generate damaging forces.

Fire was less kind to the structure, however. Plastic fixtures and hardware melted, as did several video cameras installed to capture the fire's progression. Simulated quakes occurring after the fire tests further weakened the structure's floors, bringing it close to collapse.

All the better to learn these effects in a test environment, however. The combination of these technologies—a one-of-a-kind outdoor shake table and powerful data visualization methods—allows structural engineers at the Jacobs School to produce an incredibly detailed digital model of the structures they test. This in turn allows them to make recommendations to improve design methods and building codes around the nation and around the world for when the Big One, or maybe the Mega One, hits.



[This article was adapted from a feature by Ioana Patringenaru in the Winter 2017 issue of TRITON, the UC San Diego Alumni Magazine, Vol. 14, No. 1.]

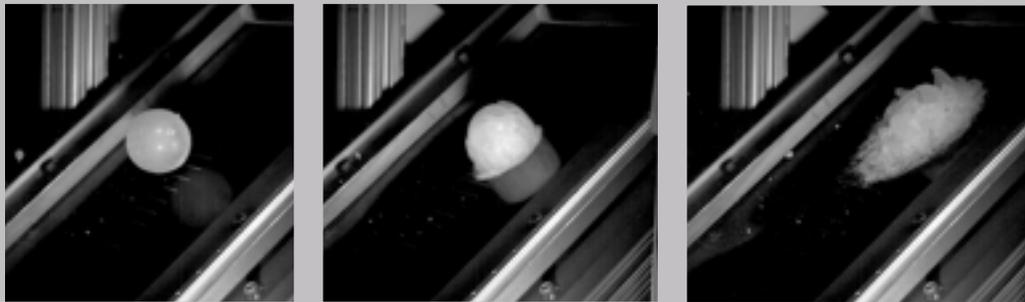


High Speed Video Stills from Test 191: 61.0 mm Ice at 62 m/s

## Hail Ice Impact onto Composite Aircraft Structures

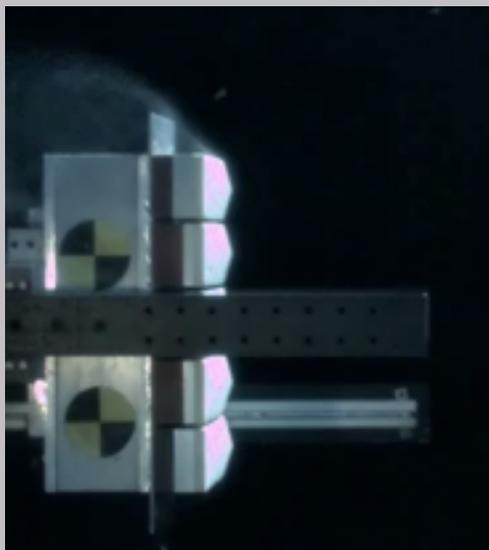
PROFESSOR HYONNY KIM

Impact damage to laminated composite aircraft structures, when subjected to in-flight impact by hailstones, can be extensive internally while exhibiting low external visual detectability. Basic research studies have established methods for determining minimum aircraft skin thickness to be resistant from hailstone impacts. Fundamental study of ice behavior and properties enabled establishment of finite element based modeling simulation which accurately represents the ice during impact.

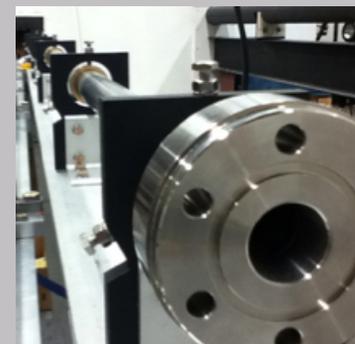


2.0 in. diameter ice impacting composite panel at 108 m/s (242 mph)

Conventional methods for evaluating blast loads on structures require the use of explosives and remote test facilities. Although detonating charges provides the most realistic test conditions for understanding blast effects, non-explosive techniques such as shock tubes and gas guns are popular alternatives to recreate (simulate) blast events in a safe, controlled lab environment. Some advantages include repeatable, consistent application of loads, no fire and debris cloud obscuring high speed camera observation, and limited shockwaves which can damage sensors and equipment. Generally, these non-explosive methods test smaller specimens and/or produce limited impulse levels. This research activity has developed a non-explosive methodology for applying representative blast loads onto large-sized (e.g., 610 x 610 mm or greater) flexible composite panels using fast (25 m/s) servo-hydraulic actuators tuned to match the specific impulse of an equivalent explosive charge. Control of the applied impulse loading and time-dependent characteristics of the pulse are controlled using "pulse-shaping" techniques and spatial-tuning of the impact mass distribution.



Vehicle Armor Blast Response

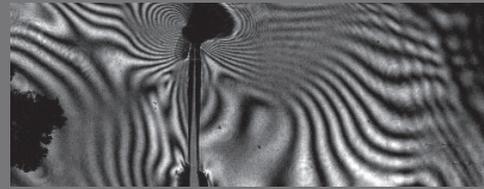


25.4 mm High Speed Impact System

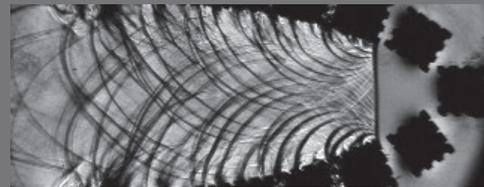
# Shock Wave Interaction and Impact

ASSOCIATE PROFESSOR ELIASSON

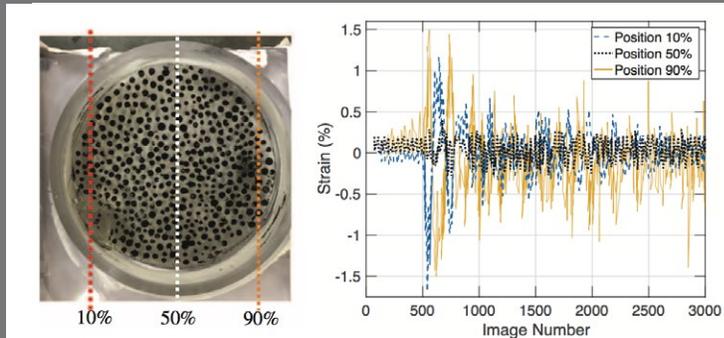
Highly dynamic and extreme conditions occur in both fluids and solids. It can be particularly challenging to predict - using analytical or numerical tools - the dynamic response of materials and structures at very high strain rates. To help understand these dynamic phenomena, the Shock Wave and Impact Laboratory performs experimental work on both fluids and solids, often with some type of coupling between the two media. In particular, we focus on non-invasive visualization techniques that can help us to 'see things' that are invisible to the naked eye. Thus, the newest equipment we have recently acquired is an ultra high-speed camera that can capture photographs with frame rates up to ten million frames per second. This setup allows us to study a range of diverse phenomena such as shock wave



The image shows photoelastic fringe patterns generated during dynamic fracture of a polycarbonate specimen.



The image shows a schlieren image of a shock wave interacting with 15 square obstacles containing small grooves.



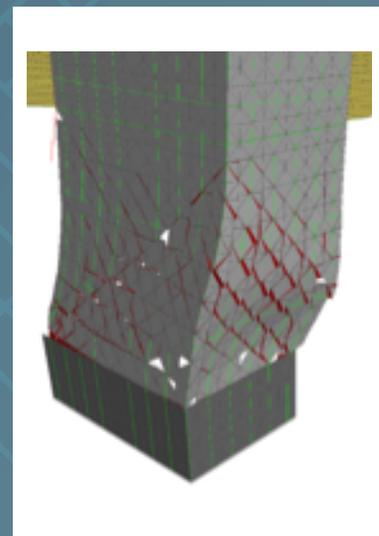
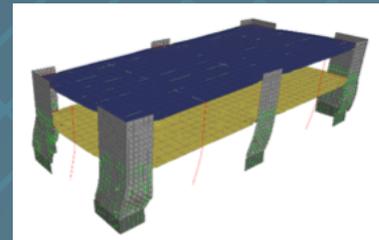
The image to the left shows a model used to study traumatic brain injury. The speckle pattern is used to measure displacements during and after a dynamic impact, and the resulting strains are shown to the right.

interaction between multiple synchronized shock waves (sponsored by AFRL), mechanical and biological response during traumatic brain injury, and dynamic fracture initiation and propagation of polymeric materials (sponsored by ONR). With the knowledge gained through this work, we aim to in the future help to create structures, devices, and vehicles that are stronger, lighter, faster and with improved properties.

# Seismic Collapse Potential of Reinforced Masonry Buildings

PROFESSOR BENSON SHING

Buildings designed according to current codes in the US are expected to have a low probability of collapse in an extreme seismic event. In specific, ASCE 7 targets a collapse probability of not greater than 10% in a 2,500-year event. To develop effective design specifications to achieve this goal, reliable analytical tools are essential for assessing the collapse potential of a building design. Simulation or prediction of collapse is especially challenging for shear wall structures. Depending on the reinforcing details, the aspect ratios of wall components, and the interaction of various structural elements in the system, the behavior of a reinforced masonry or concrete wall structure can vary from very brittle to ductile with vastly different failure mechanisms. In an on-going research, SE graduate student, Andreas Koutras, and Prof. P. Benson Shing have developed refined 3-D finite element models to capture the inelastic seismic response of reinforced masonry buildings through collapse in detail. The models account for geometric as well as material nonlinearities, including the cracking and crushing of masonry, the possible buckling and fracture of reinforcing bars, the bond slip and the dowel action of reinforcing bars, as well as the possible inelastic action of horizontal diaphragms and their connections with walls. This entails the development and implementation of new material models in LS-DYNA. In a parallel effort, graduate student, Jianyu Cheng, is developing simplified models that are computationally more efficient for the assessment of collapse potential of reinforced masonry buildings using Incremental Dynamic Analyses. The simplified models are calibrated with results of detailed finite element analyses. With funding from the NSF NHERI program, several single-story reinforced masonry wall systems will be tested to collapse on the outdoor shaking table at the Englekirk Structural Engineering Research Center to verify the computational models.

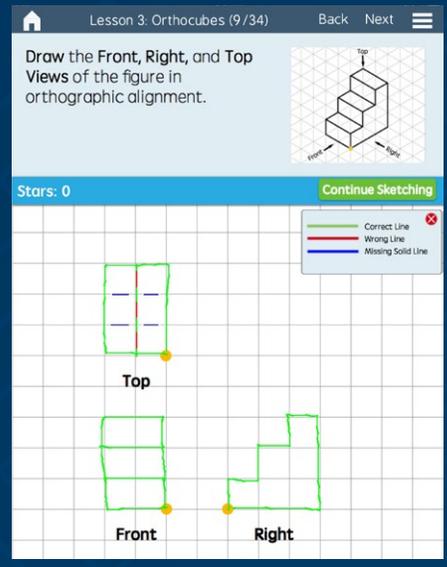




# ENGINEERS IN TRAINING

## Spatial Visualization Training Using Touchscreen Technology PROFESSOR LELLI VAN DEN EINDE

A Spatial Visualization Trainer (SVT) App was developed for an iPad to enable students to freehand sketch isometrics and orthographic projections. The App consists of an algorithm that automatically grades each sketch. When errors are made, students can redraw their sketch or take a peek at the solution, which highlights the lines in their sketch that are correct or incorrect. The objective of the App is to teach spatial visualization and freehand sketching skills, which have been shown to increase retention in STEM majors, especially among under-represented and women students. A unique aspect of this App compared to other eLearning tools is that the sketching assignments are not multiple-choice, and thus require students to synthesize their complete solution. As a result, data that tracks how engaged students are at different stages of an assignment can be collected. The App has been integrated into a 1-unit Spatial Visualization class to assess learning gains and provide feedback on it in terms of usability, functionality, and quality of sketching assignments. The goal of the study is to demonstrate the potential and provide guidance on how to further improve eLearning tools to teach spatial visualization as well as other topics. A K-6 version of the App is also under development.

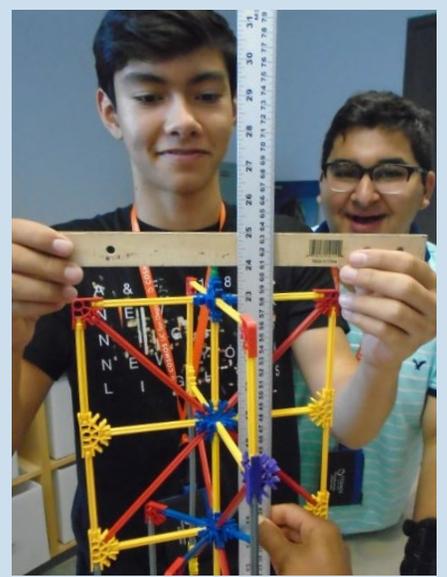


## Earthquake Engineering Curriculum For K-12

PROFESSOR LELLI VAN DEN EINDE

Current Next Generation Science Standards (NGSS) calls for introducing engineering design principles as early as Pre-K. Age appropriate, hands-on project based learning activities are being developed for K-12 that are aligned with standards, are well documented, and can be easily taught to a range of teachers for broad dissemination. The modules lead students through hands-on and research activities to learn basic earthquake engineering design principles and make use of an electronic instructional shaking table that allows students to test structures under representative earthquake loading. A project geared for 4th-6th grades requires students to build K'Nex™ buildings, while the high school curriculum requires students to design and build seismically

sound timber, masonry and reinforced concrete structures, structures to avoid soft story mechanisms, base isolated structures, structures with tuned-mass dampers, and soil or foundation systems to avoid liquefaction. Students design and construct small-scale models and test them on a shake table, develop predictions of structural response, and compare expected structural behavior with measured response observed through the experiments. These curricula allows students to learn about the engineering design process, to observe failure mechanisms and interpret data from testing, to learn how to define a design problem in terms of success criteria and constraints, to draw specific evidence-based conclusions about design and testing and iterate on the design.



UC San Diego

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