UC San Diego

JACOBS SCHOOL OF ENGINEERING

Structural Engineering

STRUCTURAL ENGINEERING

RESEARCH HIGHLIGHTS 2018

WELCOME

It is my great pleasure to present the 2018 issue of Research Highlights, which describes some of the fascinating research activities of our faculty and students. As you may see, the focus of the Structural Engineering Department continues to evolve, integrating multiple disciplines in civil, mechanical, and aerospace engineering, with a common theme on structural materials, mechanics, and design. Our research covers a range of scales and applications, including nano-materials, geomaterials, biological structures, aerospace structures, naval structures, underground structures, buildings, and bridges, aiming to improve the quality of life, the safety of air and surface transportation structures, and the sustainability and resilience of the built environment to natural and man-made hazards. We have five research thrust areas: civil structures, aerospace and composite structures, geotechnical engineering, structural health monitoring, and mechanics and materials, encompassing design, experimental mechanics, theoretical mechanics, and computational methods.

The department has unique state-of-the-art laboratories to support research in different areas, including laboratories for composite materials, safety of aerospace structures, impact/shock testing, non-destructive evaluation/structural health monitoring, and geomechanics, as well as the world-renowned Powell Structural Engineering Laboratories, which house large-scale testing facilities, including the large outdoor shaking table at the Englekirk Structural Engineering Research Center. The outdoor shaking table is the largest earthquake simulator in the US and is part of the NSF NHERI experimental facilities, which are used by researchers nation-wide.

I hope you enjoy reading this issue of Research Highlights. Please do not hesitate to contact any of us or visit our website (structures.ucsd.edu) if you would like to learn more about our department.

Sincerely,

P. Benson Shing
Professor and Chair

2018 RESEARCH HIGHLIGHTS
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FACILITIES

8,900
Student enrollment at the Jacobs School of Engineering

#17
Ranking among Civil Engineering Programs by *2018 US News & World Report*.

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."

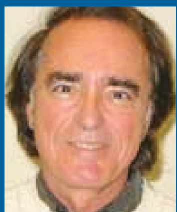
THE ENGLEKIRK CENTER In 2005, the Englekirk Structural Engineering Center opened as an expansion of the Powell Labs, equipped with the world's first outdoor shake table. It is adjacent to the country's largest Soil Foundation-Structure Interaction Testing Facility. The Blast Simulator, housed in the 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.

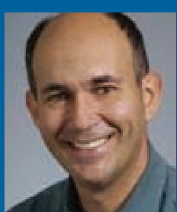
WORLD-CLASS FACULTY



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.

YURI BAZILEVS
Professor
Design of robust and efficient computational methods for large scale, high performance computing.

JIUN-SHYAN (JS) CHEN
Professor
Computational solid mechanics, multiscale materials modeling, modeling of extreme events.



JOEL CONTE
Professor
Structural Analysis and Dynamics, Structural Reliability and Risk Analysis, Earthquake Engineering.

AHMED-WAEIL ELGAMAL
Professor and Associate Dean
Information Technology, Earthquake Engineering, Computational Geomechanics.

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.

CHARLES FARRAR
Adjunct Professor
Analytical and experimental solid mechanics problems with emphasis on structural dynamics.

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

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

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

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

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.

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.

FRANCESCO LANZA DI SCALEA
Professor
Health Monitoring, Non-destructive Evaluation and Experimental Mechanics of Structural Components using novel sensing technology.

KENNETH LOH
Associate 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.

ENRIQUE LUCO
Distinguished Professor
Earthquake engineering, strong motion seismology, soil structure interaction.

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.

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

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.

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.

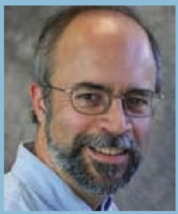
CHIA-MING UANG
Professor
Earthquake engineering, seismic design of steel buildings and bridges.

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

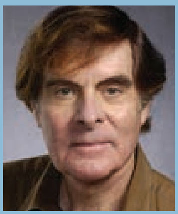
LELLI VAN DEN EINDE
Teaching Professor (LPSOE)

JOSE RESTREPO
Professor
Seismic design of buildings for improved response during earthquakes.

QIANG ZHU
Associate Professor
Ocean engineering, biomechanics.



DAVID BENSON
Professor Emeritus
Computational mechanics & computer methods for solving problems in mechanical engineering.



GILBERT HEGEMIER
Distinguished Professor Emeritus
Earthquake engineering to retrofit bridges, roadways and buildings for improved public safety and structural performance.

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

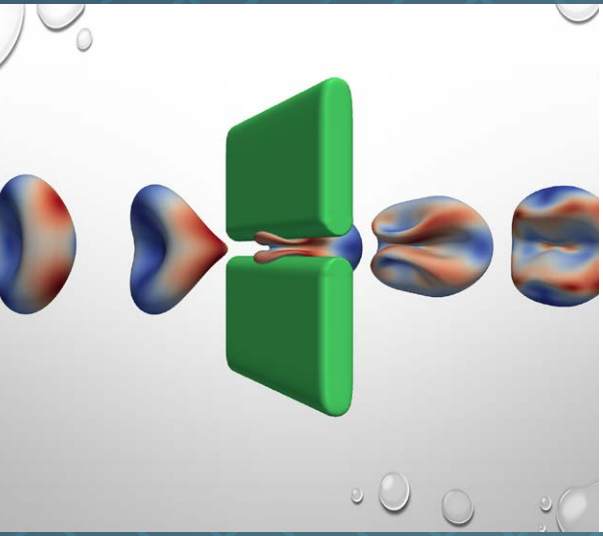
PROFESSOR CHIA-MING UANG

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

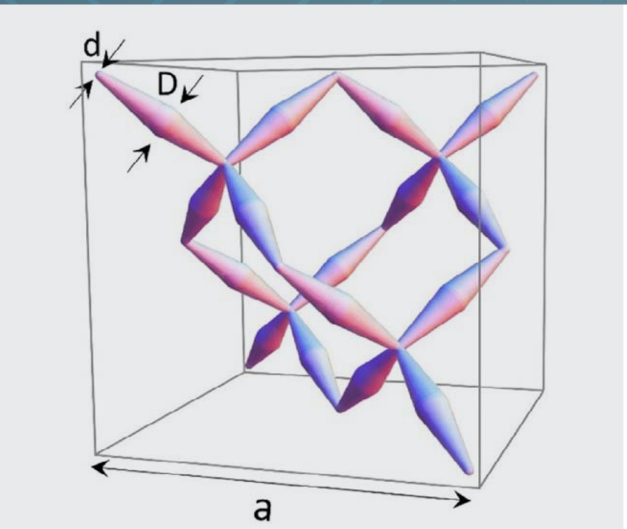
The UC San Diego blast simulator characterizes the response of civilian and military components and systems to terrorist explosive attack and high impact scenarios. It identifies threat mitigation and hardening optimization strategies using both retrofit and new construction methods and materials. The 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

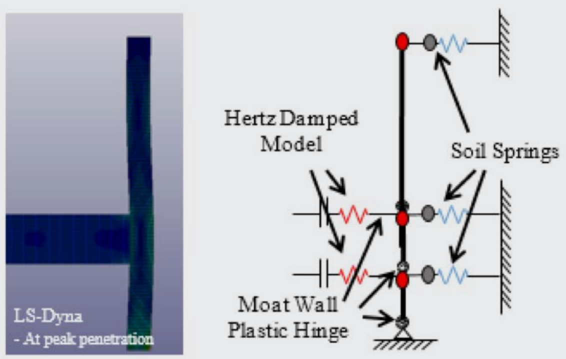
Since the size of red blood cells is comparable to those of micro-vessels and capillaries, in microcirculation blood cannot be treated as continuum fluid. In physiological conditions, red blood cells undergo tremendous deformation due to the combined effect of fluid forcing and constraints from various 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.

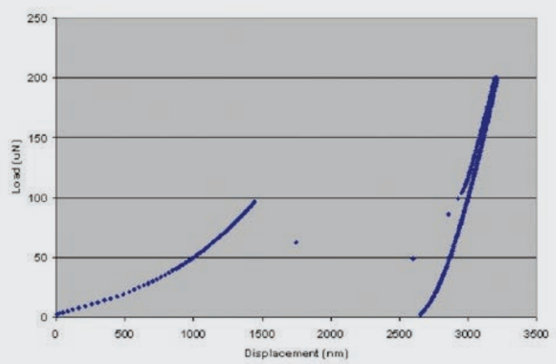


Finite element simulations of NPP base mat impact to moat wall and proposed macro model of moat wall for system level simulations

Seismic Isolation of Nuclear Power Plants

PROFESSOR GILBERTO MOSQUEDA

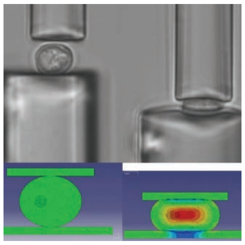
Seismic isolation is one of the most effective strategy to protect critical facilities including Nuclear Power Plants (NPPs) from the damaging effects of horizontal earthquake ground shaking. However, the behavior of the seismic isolation system under extreme earthquakes is not well understood and of 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.

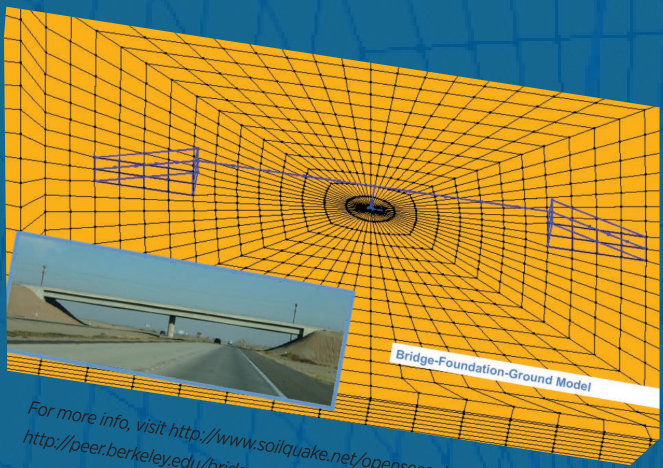


Modeling the Nano-Mechanics Of Single-Cell Structures

PROFESSOR ROBERT J. ASARO

The cell wall of S. cerevisae 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.



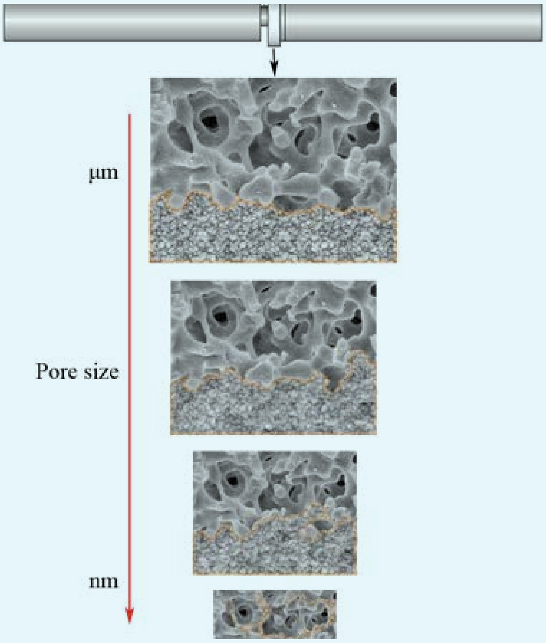


For more info, visit http://www.soilquake.net/openseespl and http://peer.berkeley.edu/bridgepbee

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

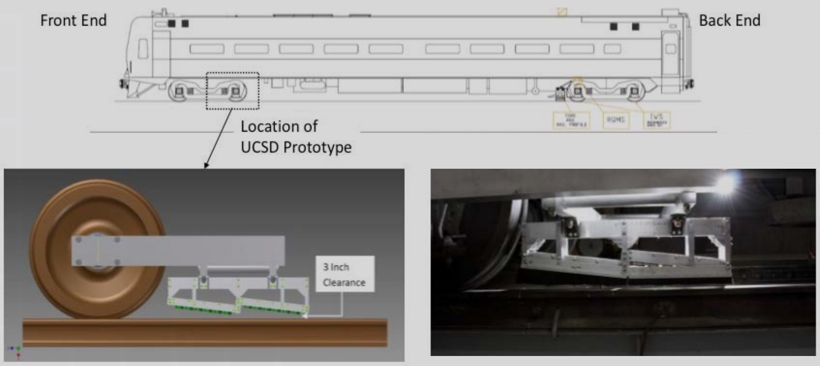
Stress wave mitigation in porous materials, such as silica monoliths and PTFE foams, are investigated. As shown in Figure 1, a hat-shaped setup on the SHPB testing system is used to induce force on the porous silica monoliths with different average pore sizes, from a few nanometers to a few hundreds 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

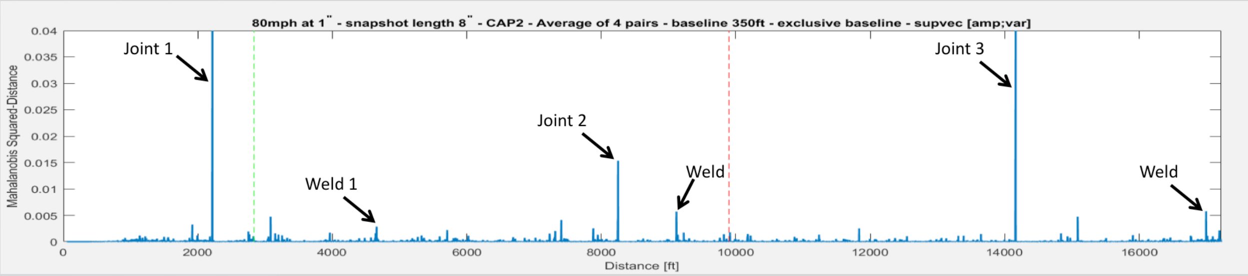
PROFESSOR FRANCESCO LANZA DI SCALEA

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

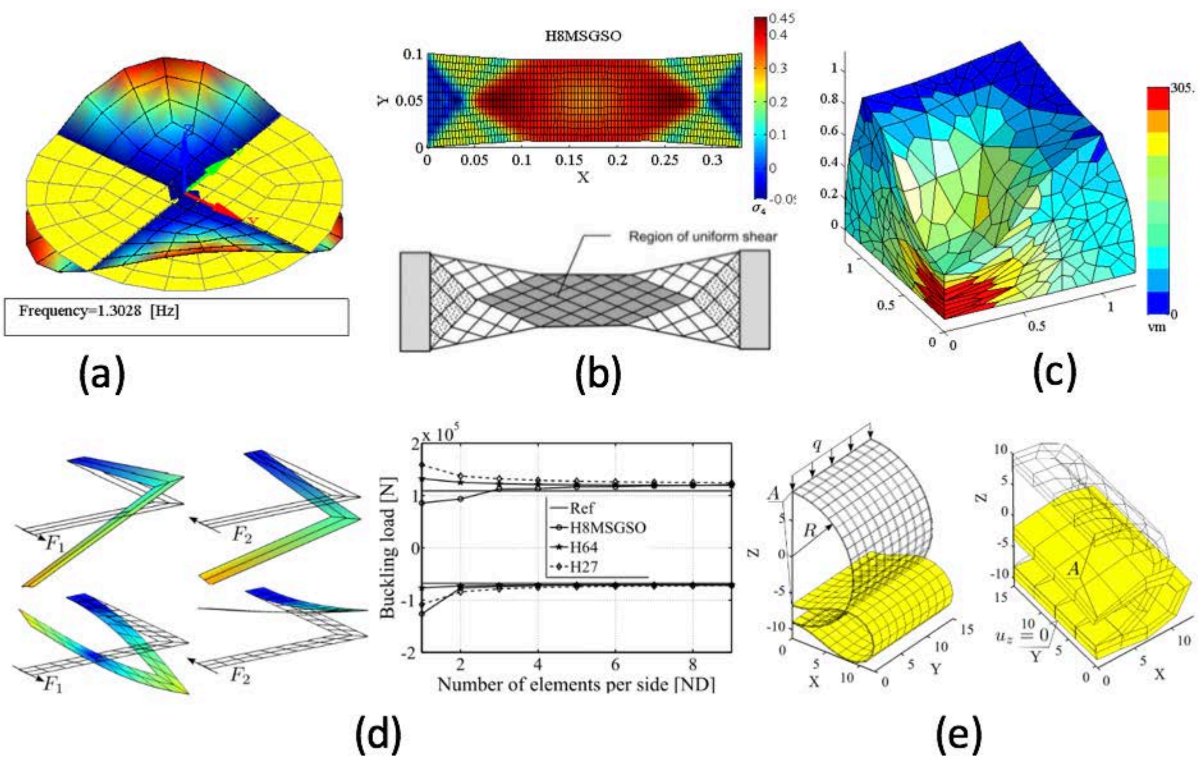
Mean-strain Methodology

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.

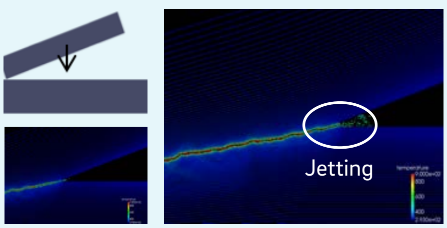


Krysl, P. (2015). "Mean-strain eight-node hexahedron with optimized energy-sampling stabilization for large-strain deformation." International Journal for Numerical Methods in Engineering 103(9): 650-670. Krysl, P. (2015). "Mean-strain eight-node hexahedron with stabilization by energy sampling." International 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.

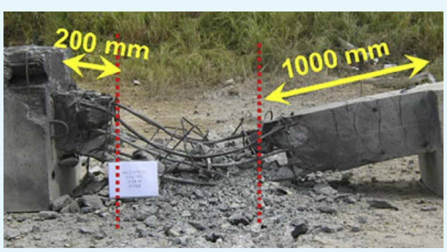
Meshfree Method for Extreme Events Modeling

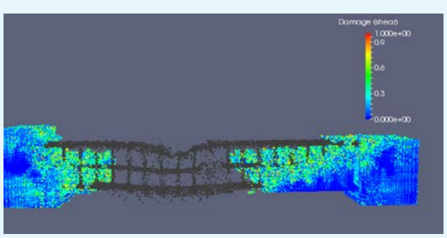
PROFESSOR J. S. CHEN

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.

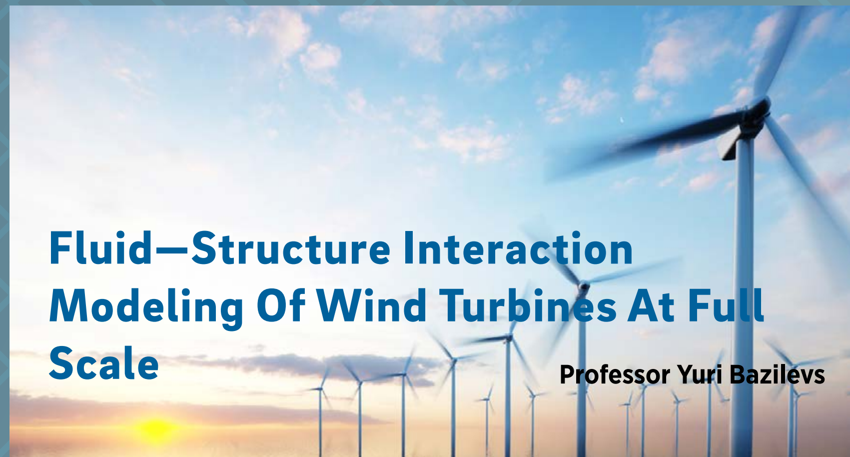


Explosive welding situation





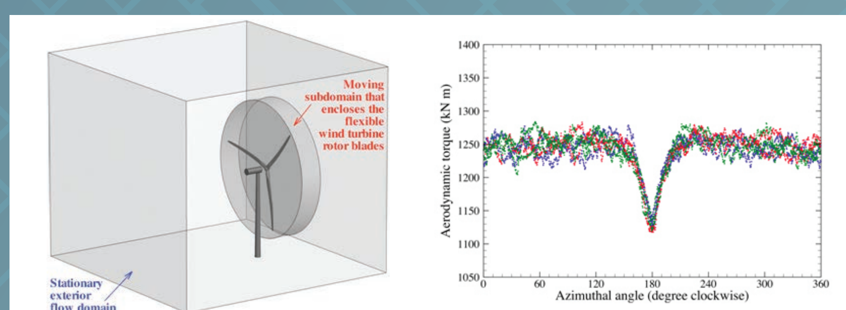
Reinforced concrete beam subjected to blast load



Fluid—Structure Interaction Modeling Of Wind Turbines At Full Scale

Professor Yuri Bazilevs

A fully coupled fluid–structure interaction (FSI) simulation methodology for wind turbines was developed in order to address a variety of engineering questions related to their aerodynamic and structural performance. Our FSI modeling takes place in 3D and at full scale, using novel finite-element-based methods for aerodynamics, and state-of-the-art isogeometric methods for blade structures. This one-of-a-kind FSI modeling methodology for wind turbines was extensively validated against experiments. The modeling ideas and simulation results are illustrated in the figures below.



RESEARCH

Sensing Subsurface Structural Damage using Noncontact Tomography

KENNETH J. LOH, SUMIT GUPTA, GAOCHEN FAN, AND SASHANK SHIVAKUMAR, ACTIVE, RESPONSIVE, MULTIFUNCTIONAL, AND ORDERED-MATERIALS RESEARCH (ARMOR) LAB

Aerospace, civil, marine, and even biological structures and components are susceptible to damage that often initiate beneath the surface, which make them difficult to detect by conventional visual inspection. If damage is left undetected over time, they can propagate and cause component or even system failure. The ARMOR Lab at UC San Diego is actively developing new strategies that enable one to detect, localize, and assess subsurface damage, without having to install tethered sensors or even physically contact the structure. The method relies on a unique measurement scheme and algorithm called electrical capacitance tomography (ECT). The ECT hardware uses a set of electrodes arranged to form a circular ring. An electric field is propagated through the sensing area defined by the array of electrodes (Fig. 1).

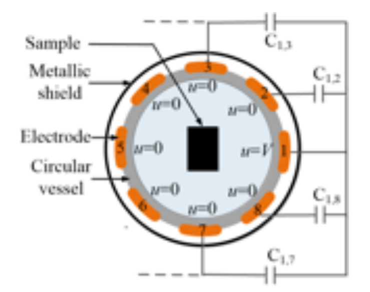


Fig. 1: ECT experimental setup

Depending on how the field interacts with the structural component in the sensing area (i.e., how they penetrate through various aspects of the component), this would affect the measured capacitance response at the other electrodes. The set of capacitance measurements are then used for solving the inverse problem of reconstructing the electrical permittivity distribution of the sensing area. Since damage can cause changes in a material's electrical permittivity, the magnitudes and localizations of permittivity changes determined by ECT allows one to directly detect, localize, and assess damage.

Three example application areas are presented in this article. First, epoxies and polymer-based materials are seeing greater adoption in various industries, such as for fiber-reinforced polymer composites in the aerospace sector or for building additively manufactured (i.e., 3D- and 4D-printed) parts. Improper builds or errors during manufacturing can create voids and defects in components. To demonstrate noncontact detection of voids in polymer-based materials, a cured epoxy specimen was subjected to ECT testing after drilling different sized holes.

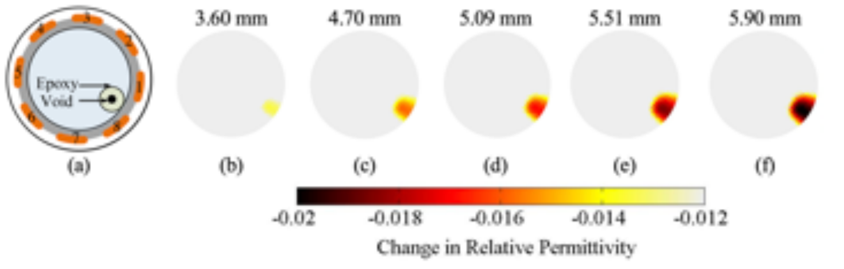


Fig. 2: Detection of the location and sizes of a void in a cured epoxy specimen

Fig. 2 shows the sample and the reconstructed relative permittivity maps of the sensing area corresponding to the different sized defects introduced. These permittivity maps were taken with respect to the undamaged epoxy, so the changes in permittivity identified in Fig. 2 were strictly due to damage. The results show that the location and sizes of damage introduced were clearly identified. Second, reinforced concrete is one of the most widely used civil infrastructure construction material, but rebar corrosion remains a persistent problem. In this study, concrete cylinders were casted with an embedded steel rod. Specimens were subjected to accelerated corrosion tests (Fig. 3), and ECT was performed at different time intervals. Fig. 4 shows ECT permittivity maps of a concrete cylinder with an embedded rebar: (a) prior to corrosion testing; (b) after 24 h of corrosion; and (c) after 36 h of corrosion. It was found that the center rebar region experiences significant electrical permittivity changes as more corrosion byproducts formed. Last, ECT could be extended for use as an imaging and diagnostic tool for the biomedical and healthcare domains. In particular, amputees with osseointegrated prosthesis can suffer from painful and sometimes life-changing infection that occurs beneath the skin and at the human-prosthesis interface. Other studies showed that infection changes the pH of the surrounding tissue. Therefore, to enhance ECT permittivity imaging performance, a pH-sensitive nanocomposite was pre-coated onto a prosthesis phantom (i.e., metal rod). The film was designed so its electrical permittivity changed dramatically due to pH.

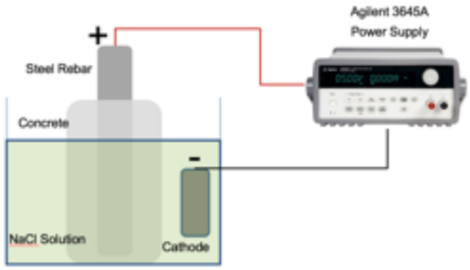


Fig. 3: Accelerated corrosion test setup

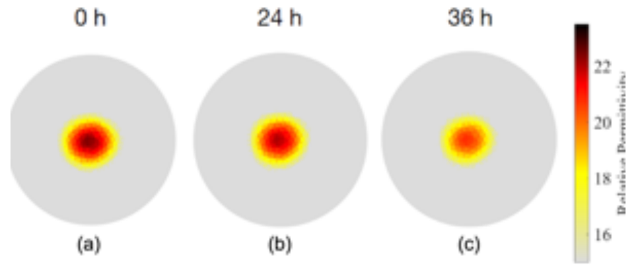


Fig. 4: ECT permittivity maps of concrete with rebar subjected to accelerated corrosion testing

Through this project sponsored by the Office of Naval Research, film-coated prosthesis phantoms underwent ECT testing as they were exposed to different pH buffers to emulate infection (Fig. 5). The results (Fig. 6) again showed that ECT, when coupled with embedded thin film sensors, could be used as a noninvasive diagnostic technique. In the future, we plan to further optimize its sensing performance and explore other applications of this noncontact, noninvasive, material imaging and damage detection methodology.

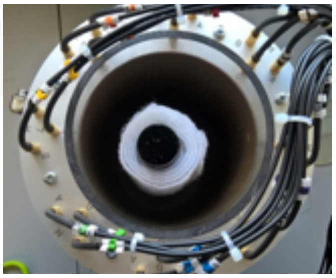


Fig. 5: ECT test of film-coated prosthesis phantom

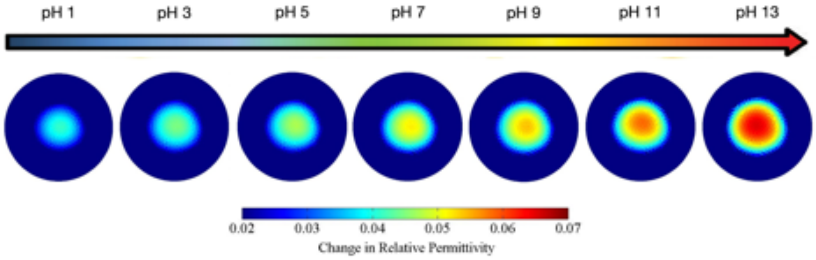
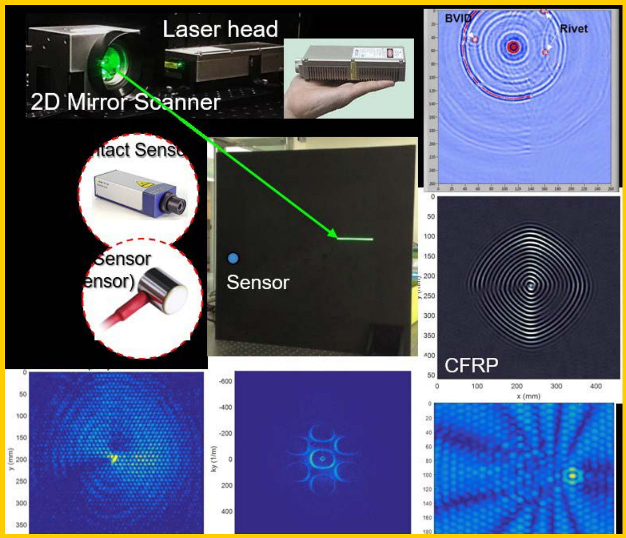


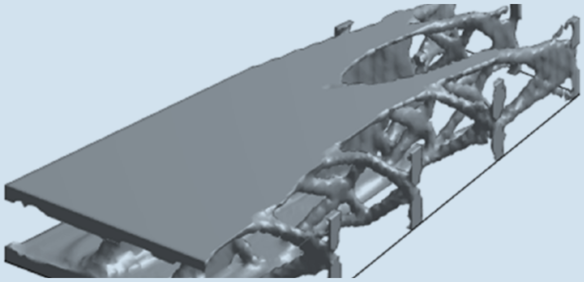
Fig. 6: pH sensing validation using ECT and nanocomposite thin film

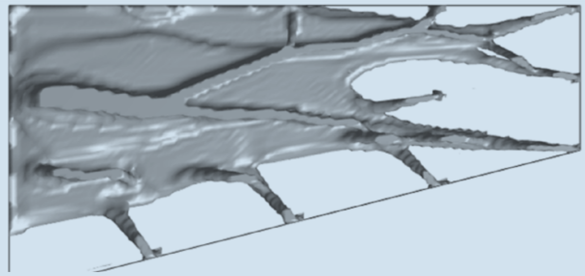
OPTIMAL DAMAGE DETECTION AND PROGNOSIS VIA ULTRASONIC SCATTERING

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.







M2DO: Multiscale and Multiphysics Design Optimization Considering Manufacturability

PROFESSOR H. ALICIA KIM AND DR. HAYOUNG CHUNG

With the development of Additive Manufacturing (AM) technology, an architected material (a material with designed internal architecture, e.g. honeycomb structure) is attracting increasing attention because of the potential of a material manipulation. Through AM technology, an unconventional multiscale and multiphysical behaviors can be realized, such as generating exotic internal material structures and their combinations.

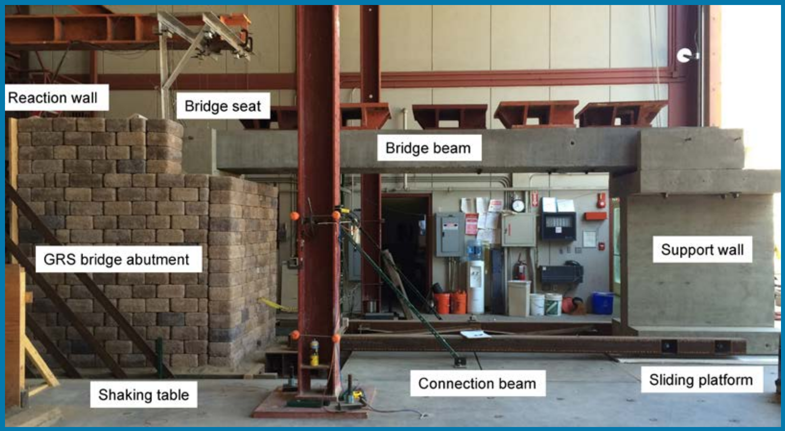
Topology optimization (TO) presents a systematic approach to design optimal material and structures mathematically. A broad scheme of a multiscale topology optimization has recently been introduced, which determines the optimal material properties and simultaneously optimizes spatially varying architected material. Homogenization-based TO is a popular approach to the multiscale optimization, but has a salient limitation as it does not consider how the unit cells are interconnected within the material. Since the unit cells are often disconnected within the structure, the architecture of the material becomes implausible in reality. To overcome such issue, Professor H Alicia Kim and her researchers are pushing the state-of-art techniques of TO, to develop a multiscale optimization framework where the macroscopic structure and multiple well-connected architected materials are simultaneously optimized.

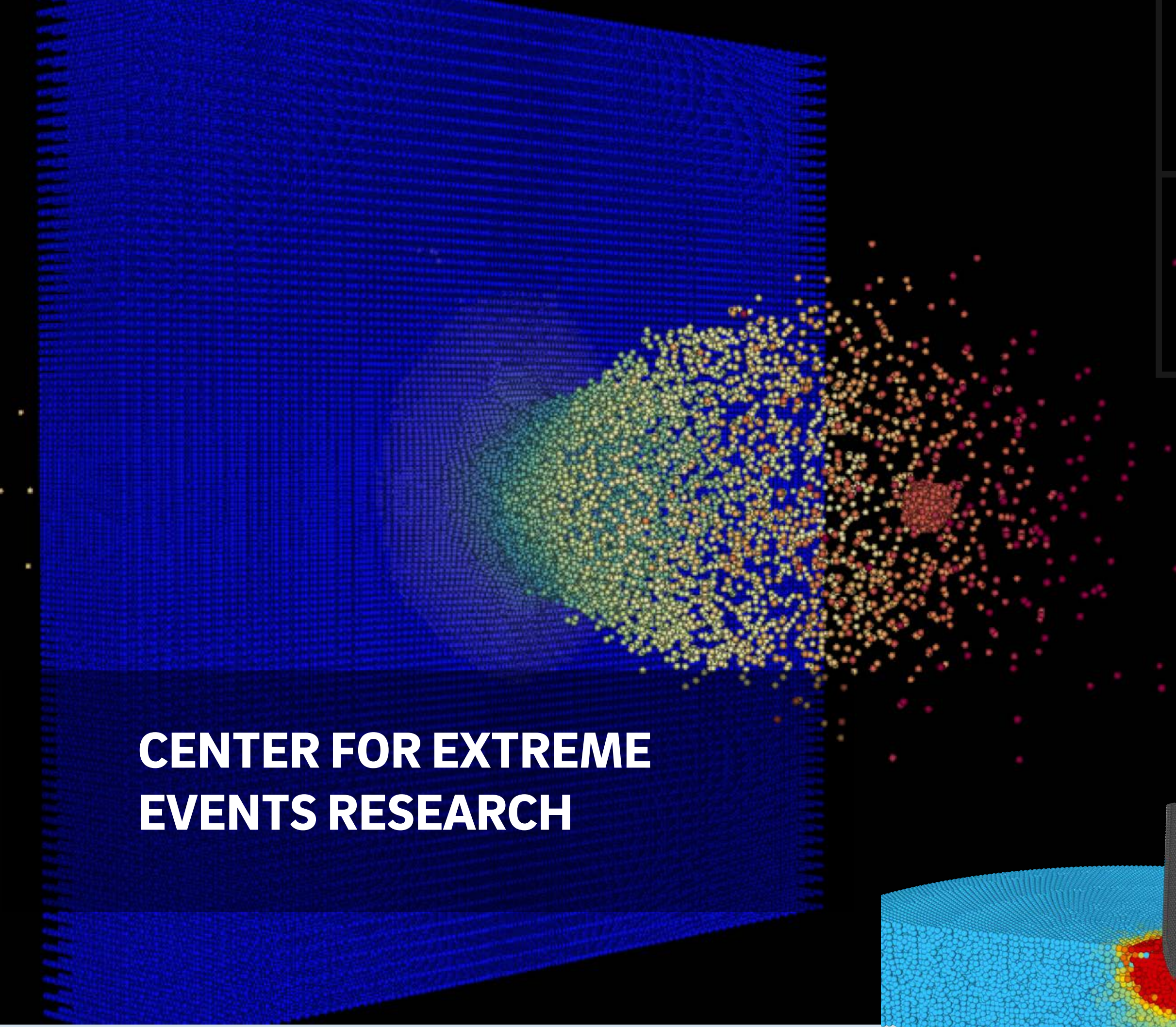
Afterward, this approach is adopted to study coupled multiphysics design problems where the structure interacts with its surroundings, e.g., aeroelasticity-structure coupling, mechanical-thermal systems and acoustic/optical metamaterials, through which the quantitative benefit and potential introduced by multi-scale architecture can be understood clearly.

Seismic Response of Geosynthetic Reinforced Soil Bridge Abutments

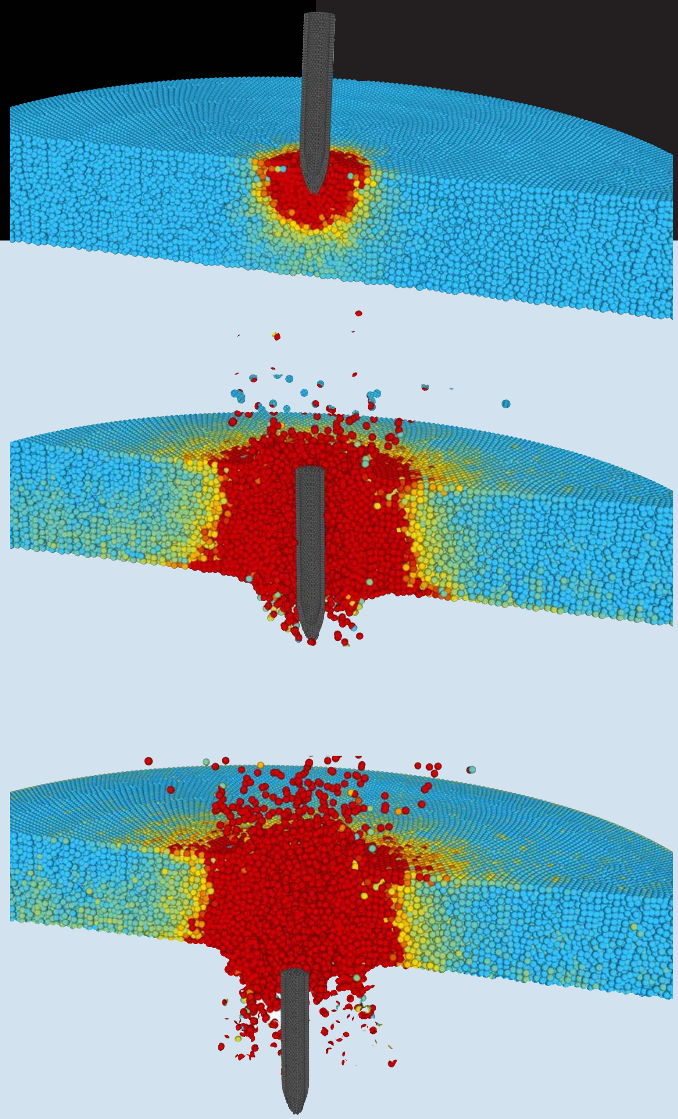
ASSOCIATE PROFESSOR JOHN MCCARTNEY

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.





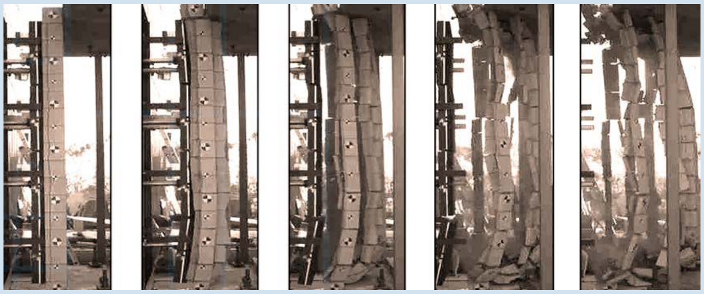
CENTER FOR EXTREME EVENTS RESEARCH



Damage assessment of bullet penetration through concrete wall

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

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.

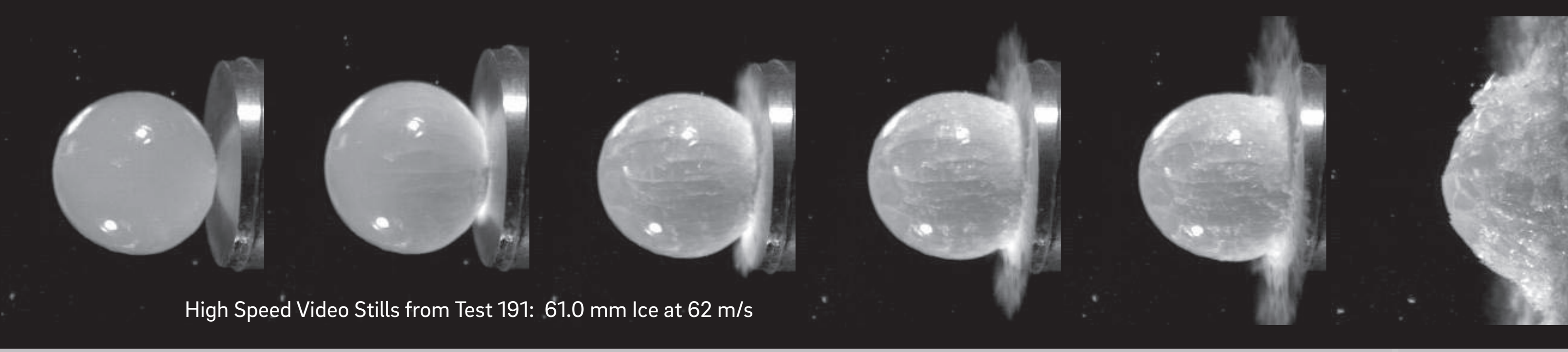
"This is big VR for big data and big science," says Kuester, who also directs the Qualcomm Institute's Center of Interdisciplinary Science for Art, Architecture and Archaeology (CISA3) and the Cultural Heritage Engineering Initiative (CHEI).

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.]

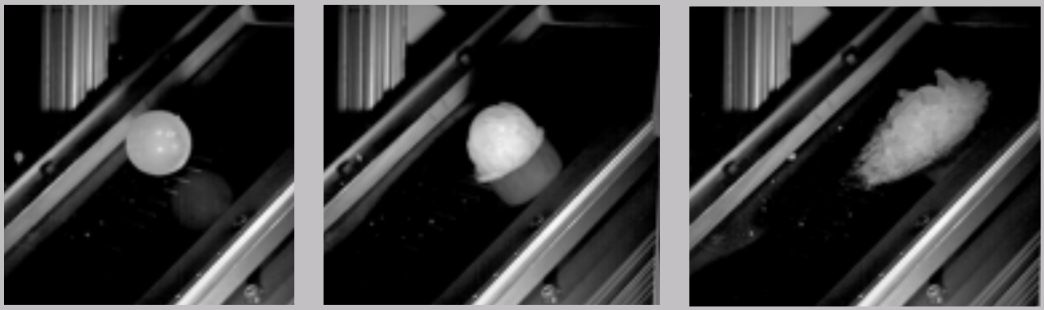


High Speed Video Stills from Test 191: 61.0 mm Ice at 62 m/s

Hail Ice Impact onto Composite Aircraft Structures

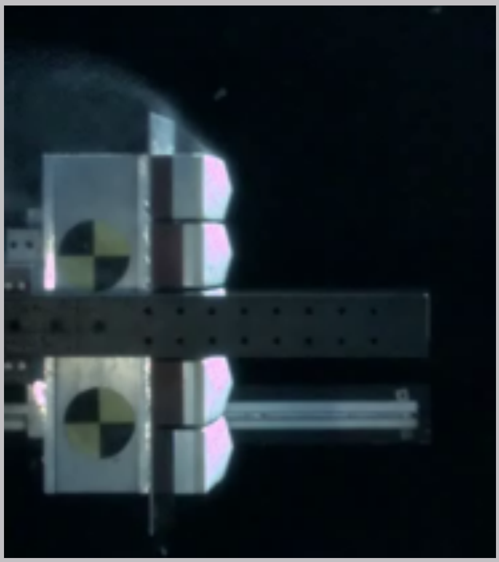
PROFESSOR HYONNY KIM

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.

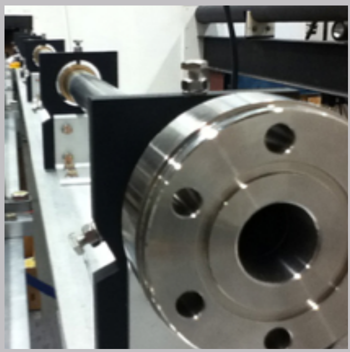


2.0 in. diameter ice impacting composite panel at 108 m/s (242 mph)

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

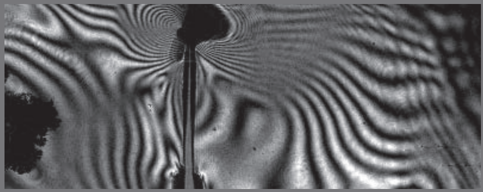


25.4 mm High Speed Impact System

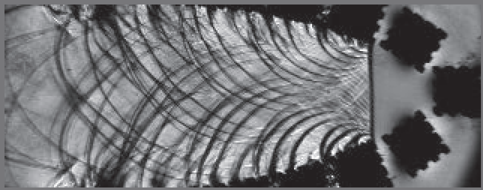
Shock Wave Interaction and Impact

ASSOCIATE PROFESSOR ELIASSON

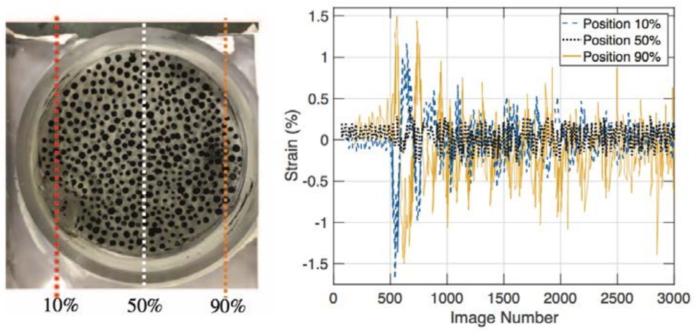
Highly dynamic and extreme conditions occur in both fluids and solids. It can be particularly challenging to predict - using analytical or numerical tools - the dynamic response of materials and structures at very high strain rates. To help understand these dynamic phenomena, the Shock Wave and Impact 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 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.



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.

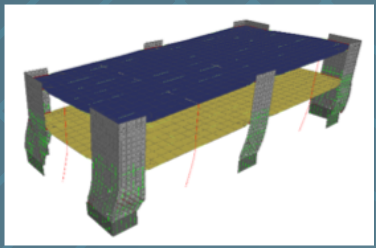


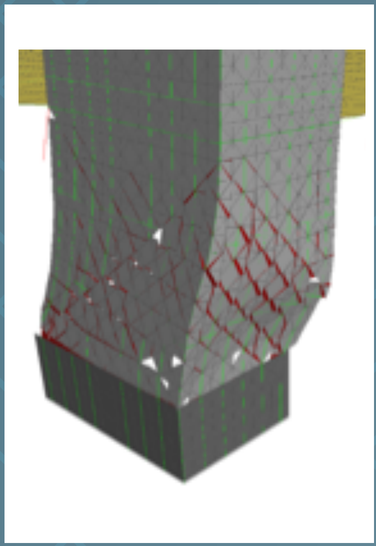
The image to the left shows a model used to study traumatic brain injury. The speckle pattern is used to measure displacements during and after a dynamic impact, and the resulting strains are shown to the right.

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.



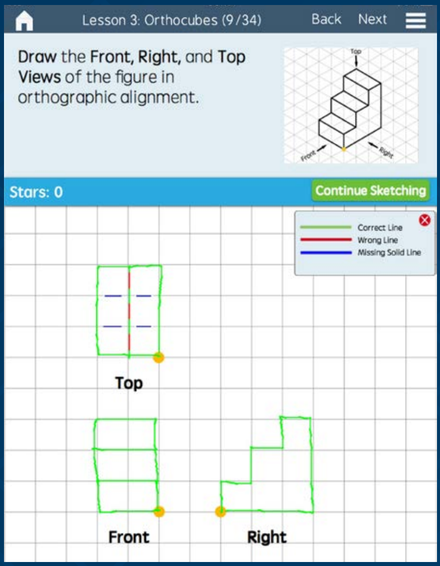


ENGINEERS IN TRAINING

Spatial Visualization Training Using Touchscreen Technology

PROFESSOR LELLI VAN DEN EINDE

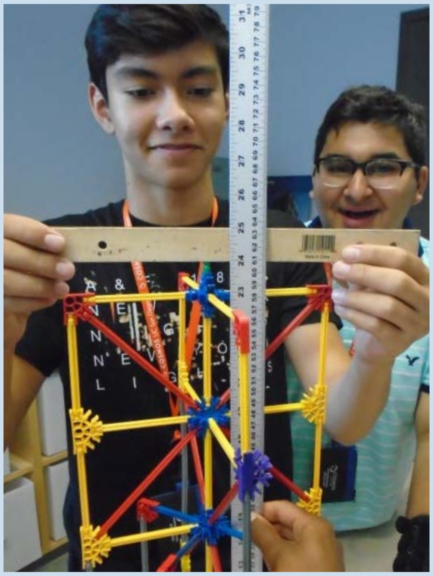
A Spatial Visualization Trainer (SVT) App was developed for an iPad to enable students to freehand sketch isometrics and orthographic projections. The App consists of an algorithm that automatically grades each sketch. When errors are made, students can redraw their sketch or take a peek at the solution, 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 show 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.



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