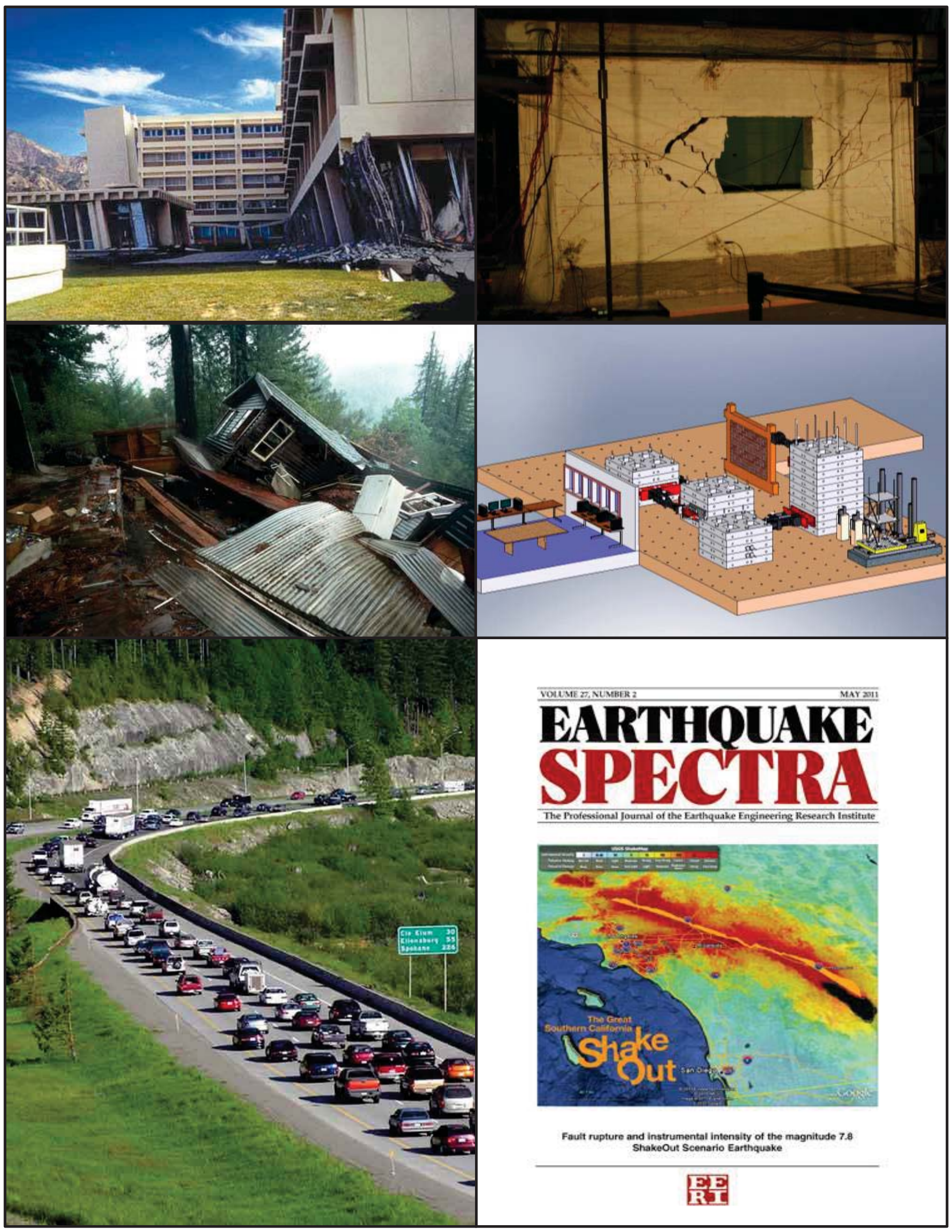
Structural Engineering and Structural Mechanics Research

Civil, Environmental, & Architectural Engineering

UNIVERSITY OF COLORADO **BOULDER**




Corotis


Hearn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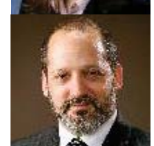
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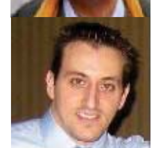
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June 20, 2015

TO: Structural engineering and structural mechanics researchers and students

SUBJECT: Experimental and analytical capabilities of the CU's earthquake engineering faculty

Dear colleague,

This brochure introduces the University of Colorado's structural engineering and structural mechanics (SESM) faculty in the Department of Civil, Environmental and Architectural Engineering.

Prof. **Ross B. Corotis**, PE, NAE, Denver Business Challenge Professor of Engineering, has research and application expertise in probabilistic concepts and risk perceptions in the decision process, and in particular to societal tradeoffs for hazards in the built infrastructure. Prof. **George Hearn's** expertise is in the analysis and design of transegrity and tension structures with applications to rockfalll barriers. His current research is in strategic decision-making and maintenance of the national bridge inventory. Prof. **Abbie Liel** is an expert on performance-based assessments of seismic collapse risk, especially of reinforced concrete frame structures, and has examined the implications of these assessments to improve building code provisions and the safety of the built environment. Prof. **Mija H. Hubler** addresses structural evaluation and redesign. Her focus is on construction materials testing, developments in the design code, and infrastructure and construction material ageing. Prof. **Keith A. Porter**, PE, is a world leader in seismic vulnerability and loss estimation, and helped to pioneer the technology of second-generation performance-based earthquake engineering (PBEE-2), by which one estimates future seismic performance of facilities in terms of dollars, deaths, and downtime. Prof. **Victor Saouma** specializes in nonlinear (static and dynamic) finite element analysis of massive reinforced concrete structures (dams and nuclear power plants), modeling of concrete deterioration (ASR in particular), real time hybrid simulation of reinforced concrete structures, and fracture mechanics. Prof. **Petros Sideris'** research focuses on the development of seismic-resistant low-damage bridge systems for accelerated construction in seismic regions. His research studies combine experimental performance evaluation of large-scale structural systems with nonlinear structural modeling and analysis. Prof. **Jeong-Hoon Song's** research interests include: predicting material deterioration process in various length scales, virtually characterizing and designing new advanced materials through computational multiscale approach, and predicting behaviors of multiphysics-induced material interaction systems. Prof. **Yunping Xi's** expertise covers the broad area of structural materials with focus on concrete and cementitious materials exposed to extreme temperatures and harsh environments. His research includes the development and use of solid wastes and phase-change materials in energy-efficient cement-based materials.

You will find attached to this letter a biographical sketch of each of us and a series of short research abstracts, to give a sense of our research interests and capabilities. Please feel free to contact us to discuss your interests in earthquake engineering research.

Sincerely,
The Structural Engineering and Structural Mechanics faculty at CU Boulder

ROSS B. COROTIS

Biographical Sketch

Ross B. Corotis, PE, NAE, Distinguished Member of ASCE, Denver Business Challenge Professor of Engineering at the University of Colorado Boulder, has research interests in the application of probabilistic concepts and decision perceptions for civil engineering problems, and in particular to societal tradeoffs for hazards in the built infrastructure. With degrees from MIT, he was on the faculty at Northwestern University, established the Department of Civil Engineering at The Johns Hopkins University, and was Dean of the College of Engineering and Applied Science in Boulder. He has numerous research, teaching and service awards, chaired several committees on structural safety for ASCE (Safety of Buildings, Technical Administrative Committee on Structural Safety and Reliability, and ASCE 7 Live Loads Subcommittee), the International Association for Structural Safety and Reliability (Scientific Committee, Executive Committee and Advisory Board), and ACI (Structural Safety), served on the steering committee of the National Academies Disasters Roundtable, chaired The National Academies Assessment Panel for the NIST Building and Fire Research Laboratory, and was Editor of the international journal *Structural Safety* for a decade. He currently chairs The National Academies' Committee on NIST Technical Programs, is the past Editor of the ASCE *Journal of Engineering Mechanics*, a member of the Editorial Board of the *International Journal of Risk Assessment and* Management, and a member of the Advisory Council of the International Forum on Engineering Decision Making. He was Chair of the Civil Engineering Section of the National Academy of Engineering, and a Jefferson Science Fellow at the U.S. Department of State, where he served full-time in 2007-2008. He is the author of more than 200 publications and has made over 100 technical presentations. Additional information can be found at http://ceae.colorado.edu/~corotis, or by phone at (303) 735-0539 or email at Corotis@colorado.edu.

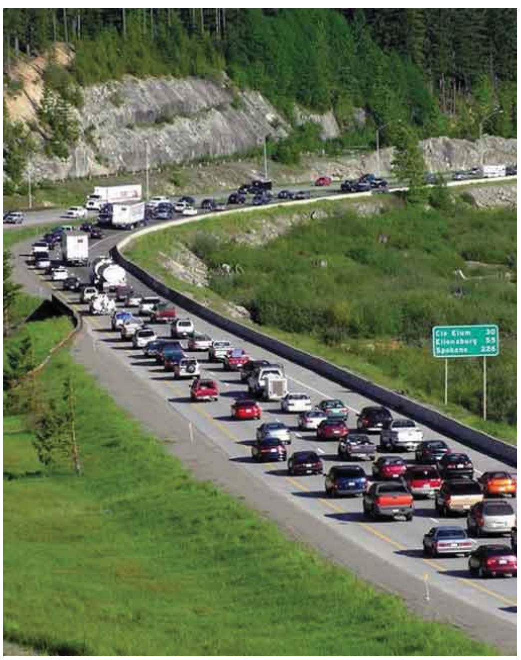
Development of Risk-Based Decision Methodology for Facility Design

Sponsored by the Colorado Department of Transportation

By Ross B. Corotis and Abbie Liel

Risk analysis is a critical tool for objective-based decision-making for modern asset management. Due to ever-increasing demands on our infrastructure, a reliability-based life-cycle cost approach is essential for the management of fixed assets, such as highways, bridges and associated structures to meet today's and tomorrow's needs in the most cost-efficient manner. Benefit and cost analyses for both the agency and the traveling public can only be fully utilized when they are based on a consistent, theoretical foundation incorporating a comprehensive risk- and consequence-based evaluation.

Utilization of modern risk analysis life-cycle concepts starts with the engineering issues and factors, incorporating economics as well as issues of public awareness and acceptance of risk. This project establishes the methodology to apply the principles of risk-based decision making in these areas. The goals of this research study are more effective utilization of construction and maintenance funds to develop consequent-consistent risk approach to facility design for CDOT. The primary objectives are:



- Develop a Colorado-specific methodology for risk analysis of various types of facilities designed and built by CDOT, accounting for natural and intentional hazards and incorporating life-cycle assessment considerations. The facilities of interest have been chosen in coordination with CDOT engineers, who provide the requisite design details, analyses and data to the investigators.

- Conduct a full risk-based analysis of seismic design standards for bridges and of maintenance and operations of signalization mast arms, and develop draft design guidelines for a risk-based assessment based on this analysis.

- Provide operational guidelines for further development of consequent-consistent risk-based approaches for performance design of other types of CDOT facilities.

Ross B. Corotis is Denver Business Challenge Professor of Engineering at CU-Boulder specializing in probabilistic hazard modeling and societal risk in the built environment. See http://ceae.colorado.edu/~corotis or call (303) 735-0539 for more information.

Structural Reliability and Sustainable Resilience

By Ross B. Corotis

The goal of this research is the enhanced concept of community resilience by the incorporation of recent theoretical and computational capabilities from structural system reliability. The fundamental theory builds upon the integrity of a structure in terms of its role in the physical, social and economic well-being of the community it serves. This leads to an approach to structural design based on the inherent tradeoffs for societal investment in structures in terms of their sustainability for intended functions, and the consequent resilience of the community. Inherent in this concept is the sensitivity of the performance of structures to such issues as low probability, high consequence events, and even black swans. To accomplish this overarching goal, structural system reliability algorithms are utilized to investigate the sensitivity of structures to multiple failure modes and compound load combinations, leading to an evaluation of their impact on overall integrity and functionality. This forms the basis for the relationship between resilience and life cycle evaluation, the building block of sustainability. Alternative measures of uncertainty are incorporated into models of structure and community resilience as time-varying processes, enabling the development of efficient approaches to holistic infrastructure.

This research directly enhances the relationship between structural reliability and long-term sustainability, increasing the effectiveness of investments in the built environment, especially in a life cycle context. Potential consequences due to occupancy, environmental degradation, and both natural and intentional hazards ultimately impact community development decisions regarding growth patterns, land use restrictions, building codes and mitigation plans. The results of this research will lead to more robust, resilient and efficient built environments. New educational paradigms will also result, with interdisciplinary approaches to civil systems and hazards from both engineering and sociological perspectives.

Ross B. Corotis is Denver Business Challenge Professor of Engineering at CU-Boulder specializing in probabilistic hazard modeling and societal risk in the built environment. See http://ceae.colorado.edu/~corotis or call (303) 735-0539 for more information.

GEORGE HEARN

Biographical Sketch

George Hearn is an Associate Research Professor in the Department of Civil, Environmental & Architectural Engineering at the University of Colorado Boulder. His research interests include bridge inspection, preservation, and maintenance He can be reached at George.Hearn@colorado.edu or 303-492-6381. For additional information, see http://civil.colorado.edu/~hearn/

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ABBIE B. LIEL

Biographical Sketch

Dr. Liel is an Assistant Professor in the Department of Civil, Environmental and Architectural Engineering at the University of Colorado Boulder. Her research focuses on using performance-based earthquake engineering methods to assess the risk of structural collapse, the potential threat to public safety and possible economic losses. These measures of structural performance, obtained from detailed nonlinear analysis models, can be used to improve building code provisions, develop policies for mitigating risky structures, and help building owners make better decisions about mitigating their seismic risk. Recent projects include assessment of the collapse risk of potentially vulnerable non-ductile reinforced concrete frame structures, including those with masonry infill walls, the development of techniques for assessing the reliability of roof structures under snow loads, and improved methods for quantifying regional losses. Dr. Liel holds a B.S.E. degree in civil engineering from Princeton University, where she also earned a certificate from the Woodrow Wilson School of Public and International Affairs. She earned a M.Sc. in Civil Engineering at University College London and a second M.Sc. at University College London's Development Planning Unit in Building and Urban Design and Development, exploring the socioeconomic side of mitigating natural hazards. Her Ph.D. is in civil engineering from Stanford University. Additional information can be found at http://bechtelrh.colorado.edu/~liel, or (303) 492-1050.

Influence of Masonry Infill Walls on the Seismic Collapse of Concrete Frame Buildings

By Abbie Liel and Siamak Sattar, Ph.D. Candidate

Reinforced concrete (RC) frames with masonry infill walls are prevalent in high seismic areas worldwide, posing a significant risk to occupants in terms of life safety and economic losses. This study has two parts. First, the authors develop a multi-scale modeling technique to simulate the response of masonry infilled RC frames that can be implemented in the performance-based earthquake engineering framework. In this technique, the macro (frame/strut) model of the masonry infilled frame is developed from response extracted from the micro (finite element) model for the infill and frame configuration of interest. The proposed modeling approach benefits from the accuracy of the micro model as well as the computationally efficiency of the macro model. The performance of the proposed multi-scale modeling approach is examined through comparison with a set of experimental studies.

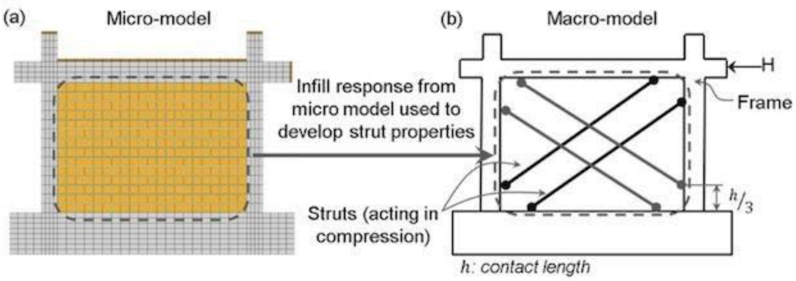
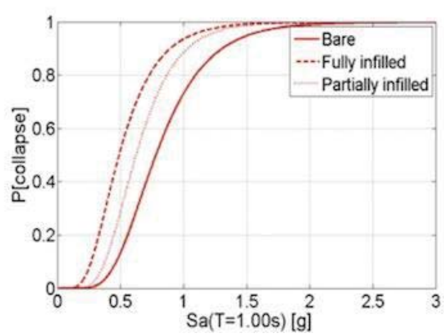


Illustration of proposed multi-scale modeling approach.

In the second part of study, the authors use the proposed multi-scale modeling methodology to assess the seismic performance of existing buildings through the dynamic analysis of a case study building representative of 1920s era construction in Los Angeles. The study finds that frames with masonry infill tend to have higher collapse risk than those without masonry infill, although the response depends on the relative behavior of the wall and frame.



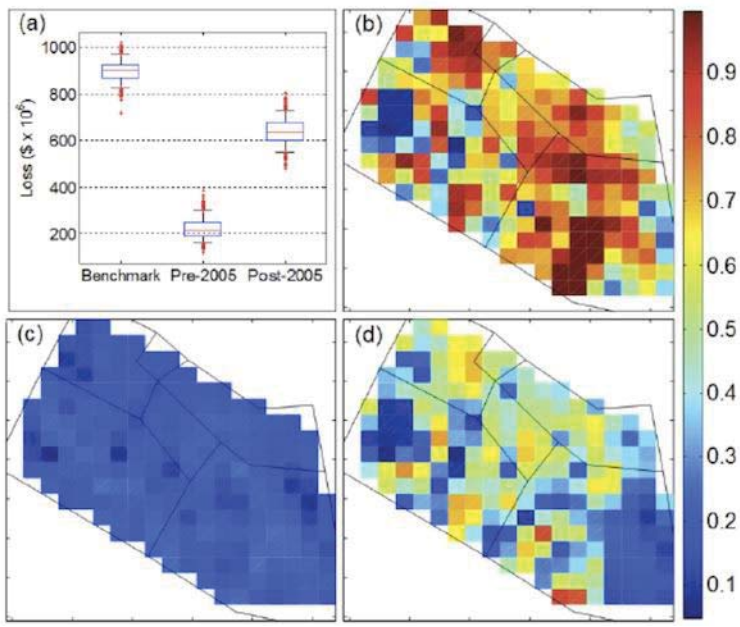
Collapse fragility functions for a 4-story 1920s era reinforced concrete frame building with different infill configurations.

Abbie Liel is Assistant Professor at CU-Boulder specializing in performance-based earthquake engineering and non-ductile reinforced concrete. See http://bechtelrh.colorado.edu/~liel or call (303) 492-1050 for more information.

Advances in Probabilistic Methods for Regional Seismic Loss Assessment

By Abbie Liel and D Jared DeBock, Ph.D. Candidate

There have been a number of the recent advances in probabilistic assessment of seismic-induced losses for individual buildings. However, the possible losses for a portfolio of buildings are of interest for insurance and reinsurance companies, developers, and policy makers. Probabilistic estimates of earthquake-induced losses to portfolios of buildings require quantifying correlations between losses of the different buildings comprising the building stock. One of our primary contributions to Monte Carlo based regional seismic loss assessment methods is to quantify spatial correlations of structural responses to earthquakes. He has also incorporated these findings into a regional seismic loss assessment framework that computes earthquake-induced losses in each building the portfolio based on predictions of correlated building responses.



Recently, work has investigated possible simplifications to the proposed regional seismic loss assessment framework that will allow analysts to compute regional losses without directly estimating building responses, yet still obtain an accurate probabilistic regional loss distribution. We are currently implementing these methods in Matlab, with the intention of creating a tool to develop community fragility functions.

Comparison of three regional seismic loss assessment methods showing (a) Boxplots of regional losses for 1000 realizations and maps of average predicted loss as a fraction of replacement cost for (b) Benchmark, (c) Pre-2005, and (d) Post-2005 methods for the ShakeOut scenario. For more details about the loss assessment methods considered see the paper presented at ICOSSAR in 2013.

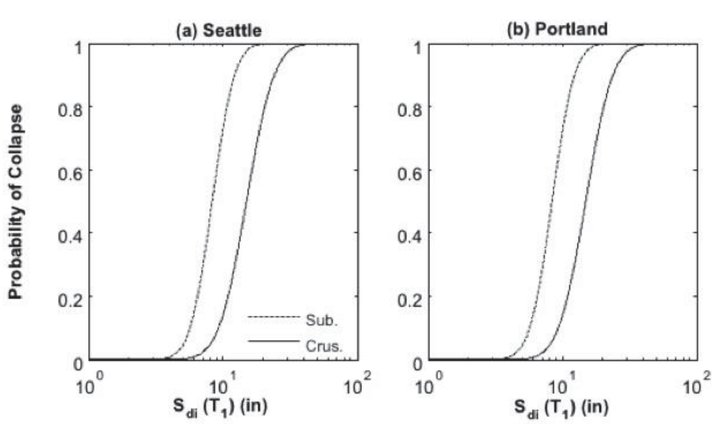
Abbie Liel is Assistant Professor at CU-Boulder specializing in the collapse response of structure under uncertain loads, behavior of non-ductile reinforced concrete and performance-based earthquake engineering. See http://bechtelrh.colorado.edu/~liel or call (303) 492-1050 for more information.

Investigation of Structural Collapse Risk in Cascadia Subduction Zone

By Abbie Liel and Meera Raghunandan, Ph.D. Candidate

Geological evidence suggests that at least seven large subduction earthquakes of magnitude (MW) greater than 9 have occurred in the last 3500 years at the Cascadia subduction zone. These subduction earthquakes are similar in nature to some of the most devastating earthquakes the world has experienced, such as the Tohuku, Japan (Mw 9.0, 2011) and Maule, Chile (Mw 8.8, 2010) events. The seismic hazard due to Cascadia subduction zone was not realized until the late 1980s and was included in the Universal Building Code (UBC) in 1994 for building design. Consequently, buildings in the Pacific Northwest designed before 1994 may not have sufficient strength to withstand the ground motions generated from the expected subduction earthquakes. To complicate the matters further, the ground motions from subduction earthquakes are longer in duration and have high energy associated with longer periods as compared to the more frequently recorded and studied shallow crustal earthquakes.

This projects aims to quantify and compare the seismic collapse risk of the buildings in the Pacific Northwest region of United States, accounting for both crustal and subduction type events. Incremental dynamic analysis is carried out on 2D analytical models of low-rise, mid-rise and high-rise reinforced concrete moment frames designed according to building codes ranging from the 2012 IBC to the 1967 UBC, for Seattle, Washington and Portland, Oregon. The 1967 buildings represents the non-ductile reinforced concrete moment frames that were part of the lateral load resisting system prior to 1973 and are susceptible to brittle shear and axial failure due to less reinforcement detailing present in the structural elements and joints. In addition to assessing the vulnerability of building infrastructure in the Pacific Northwest, this study also evaluates whether current design ground motions are achieving the target 1% in 50 year collapse probability throughout the U.S.



Building collapse fragility curves for 4-story buildings designed according to current codes (2012 IBC), obtained by subjecting buildings to either crustal or subduction ground motions. This figure shows the higher vulnerability of structures on being subjected to ground motions from subduction earthquake events.

Abbie Liel is Assistant Professor at CU-Boulder focusing on applications of performance-based engineering to structural safety. See http://bechtelrh.colorado.edu/~liel or call (303) 492-1050 for more information

MIJA H. HUBLER

Biographical Sketch

Dr. Hubler joined the Civil, Environmental and Architectural Engineering Department at the University of Colorado Boulder as an Assistant Professor in the Structural Engineering and Structural Mechanics Group in January 2015. She received her MS from Cornell University in 2009 and PhD in Structural Engineering from the Northwesten University in 2013. Prior to that, she received her BS in Civil Engineering from the University of Illinois at Urbana-Champaign in 2006. Dr. Hubler's research addresses structural evaluation and redesign. Her focus is on construction materials testing, developments in the design code, and infrastructure and construction material ageing. Her research interests include: cementitious materials; micro-structure quantification and design; permeability; fracture mechanics; micro- and meso- scale experimental testing and simulation techniques; failure prediction of construction materials; and construction material health risks and toxicity.

KEITH A. PORTER

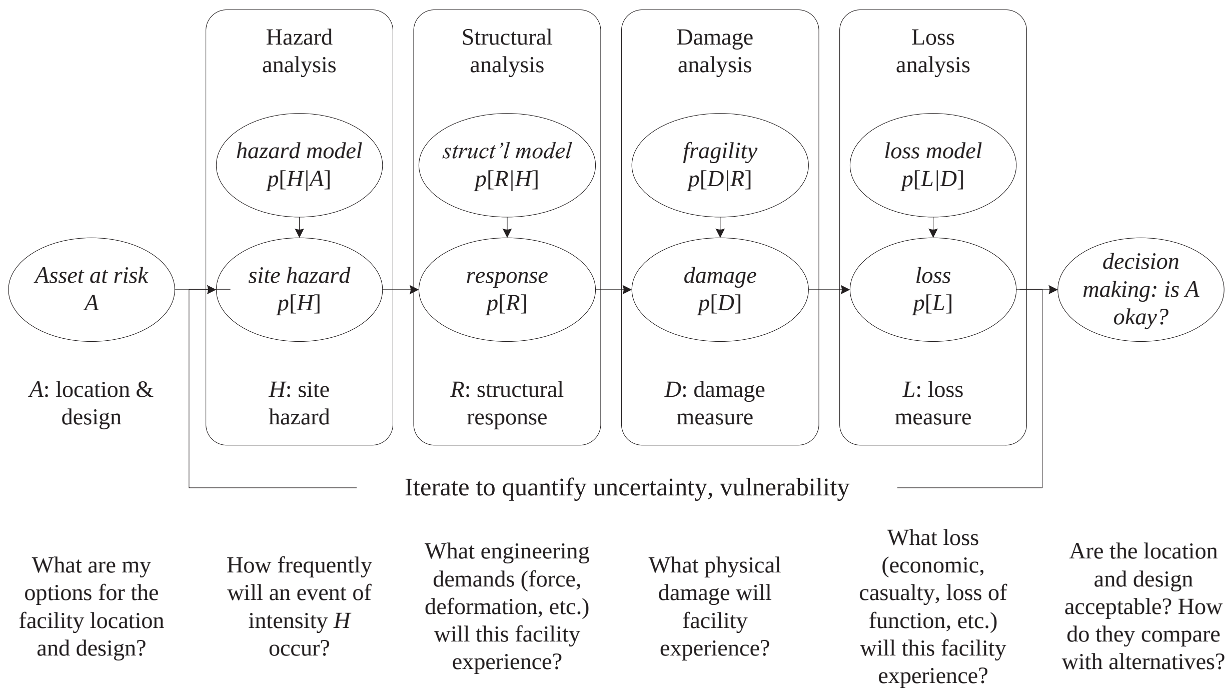
Biographical Sketch

Dr. Porter is a Research Professor in Structural Engineering and Structural Mechanics at the University of Colorado Boulder. He is a licensed Professional Engineer and received degrees in civil and structural engineering from UC Davis, UC Berkeley, and Stanford University. He developed 2nd-generation performance-based earthquake engineering methods to estimate dollars, deaths, and downtime in buildings. He performs pure and applied research in natural-disaster risk. He helped lead the ***Mitigation Saves*** study that estimated that FEMA's natural hazard mitigation saves $4 per $1 spent. He helped to lead the USGS's ***ShakeOut*** earthquake scenario, ***ARkStorm*** winter storm scenario, ***SAFRR Tsunami Scenario***, and ***HayWired*** earthquake scenario. He helped lead the calculations of the costs and benefits of mitigation for the San Francisco ***Community Action Plan for Seismic Safety*** (***CAPSS***) that informed San Francisco's 2013 mandatory soft-story ordinance. He is the author of 140 articles, book chapters, and reports. He has worked with insurers, banks, utilities, and governments to measure and manage natural-hazard risk. For more information, see http://spot.colorado.edu/~porterka.

Second Generation Performance-Based Earthquake Engineering (PBEE-2)

By Keith Porter

A 2nd generation methodology for performance based earthquake engineering (PBEE-2) has been developed by the author and colleagues working with the CUREE-Kajima Joint Research Program, the Pacific Earthquake Engineering Research (PEER) Center, and the Applied Technology Council (ATC). PBEE-2 comprises a set of procedures for a practicing engineer to estimate the future seismic performance of buildings bridges and other facilities in terms of repair cost, life safety, and loss of functionality, i.e., dollars, deaths, and downtime. PBEE-2 operates on a model of a single, particular building whose site, structure, and nonstructural features are completely known. The model is subjected to four analyses in sequence: (1) hazard analysis, in which potential ground motion time histories are selected to represent the facility's seismic environment; (2) structural analysis, in which one calculates the member forces and deformations that result from those ground motion time histories; (3) damage analysis, in which physical damage to the structural and nonstructural components of the building is calculated; and (4) loss analysis, in which the dollars, deaths, and downtime of the facility resulting from the damage are calculated.



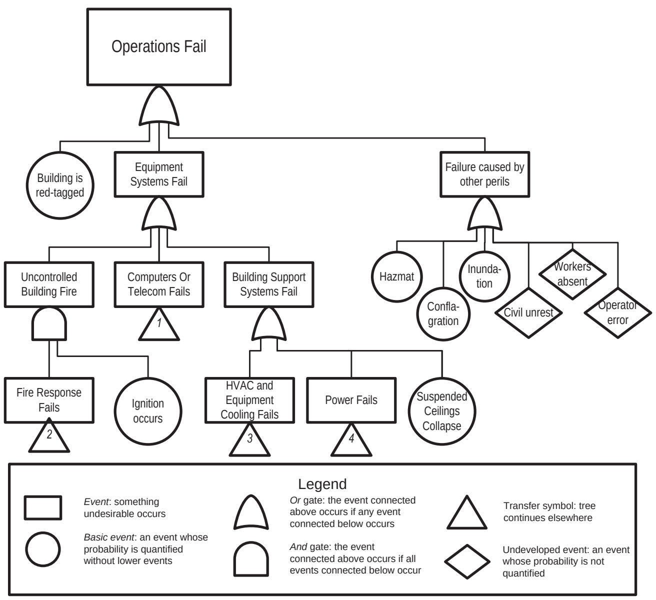
Second generation performance-based earthquake engineering

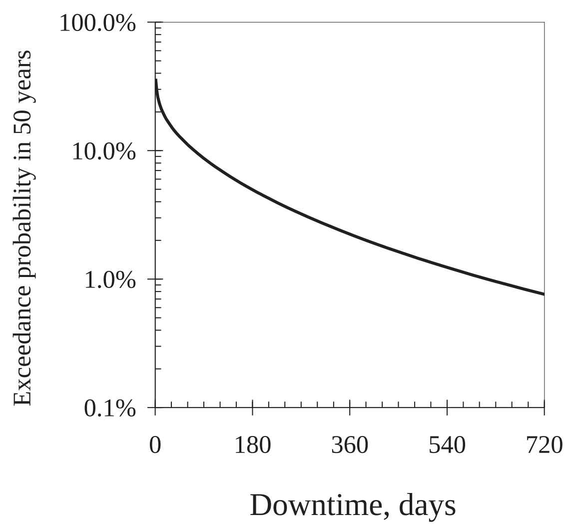
Keith Porter is an Associate Research Professor specializing in seismic vulnerability and PBEE-2. See http://spot.colorado.edu/~porterka or call +1 (626) 233-9758 for more information.

A Performance-Based Earthquake Engineering Method to Estimate Downtime using Fault Trees

By Keith Porter

A method is offered to estimate downtime (the time to restore a facility to operability, *not* total repair time) for second-generation performance-based earthquake engineering (PBEE-2). It applies in cases where downtime is primarily controlled by nonstructural systems (although red-tagging, lifeline failure, and other offsite hazards are addressed); restoration begins immediately after the earthquake; and components are repaired in parallel. It uses fault trees to relate component damage to a building's post-earthquake operability. Restoration time for upper events that occur only if all lower events occur (i.e., events above "and" gates) is the minimum of the lower-event restoration times. For "or" gates, the upper-event restoration time is the largest lower-event time. With a system fault tree, structural response, and probability distributions of component capacity and component repair times, one can calculate probabilistic downtime either via Monte Carlo Simulation or in a closed-form manner that does not require simulation.



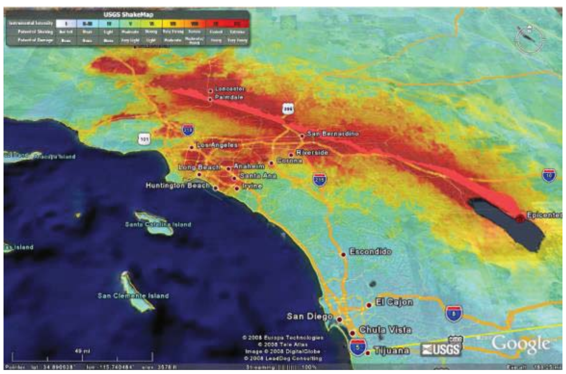


Keith Porter is Associate Research Professor at CU-Boulder specializing in societal loss estimation, seismic vulnerability, and performance-based earthquake engineering. See http://spot.colorado.edu/~porterka for more information.

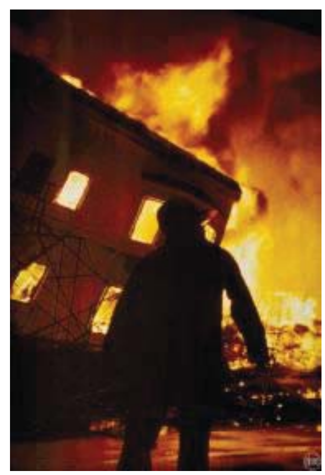
The Southern California ShakeOut Scenario

Research sponsored by the United States Geological Survey
By Keith Porter

A large earthquake planning scenario was recently released by the USGS and California Geological Survey. It was created by more than 300 earth scientists, engineers, and social scientists, and hypothesizes the occurrence and effects of a M_W7.8 earthquake on the southern San Andreas Fault. Keith Porter led the overall assessment of physical damages to buildings and lifelines. In the scenario, fault offsets reach 13m. State-of-the-art mathematical models were used to generate maps of shaking intensity, with peak motions greatly exceeding those of the 1994 Northridge earthquake and strong shaking occurring over are area of 10,000 km^2. An analysis using the FEMA-funded risk software HAZUS$^{\text{®MH}}$ was performed, along with 18 special studies to characterize the effects of the earthquake on the built environment, including a substantial study by Charles Scawthorn of fire following earthquake.



The scenario is posited to result in 1,800 deaths and 53,000 injuries requiring emergency-room care. Approximately 1,600 fires are ignited, 1,200 of which are too large to be controlled by a single engine company, and despite the lack of Santa Ana winds, the fires destroy 200 million square feet of the building stock, equivalent to 130,000 single-family dwellings. Fire contributes $87 billion of the total $213 billion in economic loss, with most of the rest coming from shake-related building and content damage ($46 billion) and business interruption unrelated to fire ($74 billion). Emergency response activities are considered in detail. The losses would be much greater if not for steadily improving building codes and other efforts to mitigate seismic risk in existing buildings and lifelines. This is the most comprehensive analysis ever of what a major Southern California earthquake would mean. It is the scientific framework for the largest earthquake preparedness drill in California history, which occurred on November 13, 2008. ShakeOut has since become a byword for a societal disaster exercise, which in 2012 involved 17 million people worldwide.



Keith Porter is an Associate Research Professor at the University of Colorado Boulder. He specializes in seismic vulnerability and performance-based earthquake engineering. Further information can be found at http://spot.colorado.edu/~porterka.

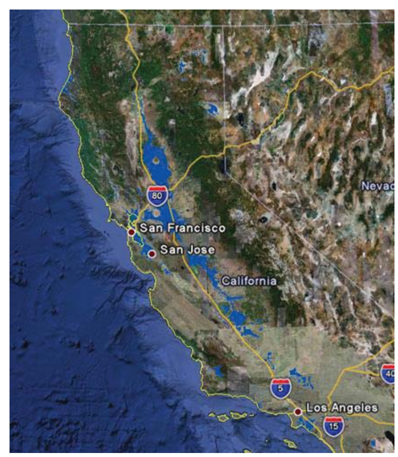
The ARkStorm Scenario

Research sponsored by the United States Geological Survey
By Keith Porter

The USGS Multi Hazards Demonstration Project (MHDP) creates new hazards science and applies it to help communities make informed decisions about enhancing their resiliency to natural disasters. The first public product of the MHDP was the ShakeOut Earthquake Scenario, published in May 2008, and which has since become a byword for community earthquake preparedness exercises worldwide. The MHDP's second major public project is a winter storm scenario, a hypothetical event generated by an atmospheric river (AR) striking the US West Coast similar to intense California winter storms of 1861-1862 and 6 other California storms of the past 1,800 years. This scenario, developed by 125 scientists, engineers, public-policy experts, insurance experts, and employees of the affected lifelines, produced new science, highlighted pressing research needs, and concluded that the following outcomes could realistically occur with roughly the same probability as the ShakeOut. Keith Porter was ARkStorm's engineering coordinator and lead author of the open file report that documented it.

K St, Sacramento, 1861-1862

The hypothetical storm produces precipitation that in many places exceeds levels only experienced on average once every 500 years or more. Extensive flooding results, in many cases overwhelming the state's flood-protection system. The Central Valley experiences flooding 300 miles long and up to 50 miles wide. Serious flooding occurs in Orange, Los Angeles, and San Diego counties, the San Francisco Bay area, and elsewhere. Windspeeds in reach 125 mph. Thousands of landslides occur, damaging roads, highways, and homes. Power, water, sewer, and other lifelines experience damage taking weeks or more to restore. Flooding requires the evacuation of 1.5 million residents. Property damage exceeds $300 billion. Demand surge, agricultural, and business interruption losses bring the loss to $725 billion, 3 times that of a California earthquake of similar recurrence frequency, only $20 to $30 billion of which is recoverable through insurance. An ARkStorm represents a nearly existential threat to California's economy.



A 300-year storm could inundate 1000 square miles of California and cost $750 billion in losses

The ARkStorm has been used as the basis for California's Northern California Flood Response Plan, a community preparedness plan in Ventura County, the US Navy Southwest's 2011 Citadel Rumble emergency response exercise, and other weather-related disaster planning scenarios.

Keith Porter is an Associate Research Professor at the University of Colorado Boulder. He specializes in seismic vulnerability and performance-based earthquake engineering. Further information can be found at http://spot.colorado.edu/~porterka.

USGS SAFRR Tsunami Scenario

Research sponsored by the United States Geological Survey
By Keith Porter

The US Geological Survey's Science Application for Risk Reduction (SAFRR) program produced the ShakeOut and ARkStorm scenarios, and in September 2013 produced the SAFRR Tsunami Scenario, in collaboration with the National Oceanic and Atmospheric Administration, California Geological Survey, and others. The scenario depicts in granular detail a single realistic outcome of a hypothetical but likely large tsunami affecting the west coast of the United States. The scenario addresses earth-science effects, damage and restoration of the built environment, and social and economic impacts. It employs the state of the art in many of the relevant disciplines. Like the ShakeOut and ARkStorm scenarios, the purpose of the SAFRR Tsunami Scenario is to apply science to understand and help decision-makers to understand and reduce the impacts of natural disasters, in this case a rare but realistic tsunami. Keith Porter coordinated the estimation of physical damages.

The scenario begins with the occurrence of a magnitude 9.1 megathrust earthquake in the eastern Aleutian Islands. Wave heights reach 15 ft and velocities in some locations exceed 16 kt. The tsunami is particularly damaging to harbors and marinas, damaging or sinking $1/3^{rd}$ of coastal boats and more than half the floating docks. Currents and flooding damage Pacific ports, more than 1 million square feet of buildings in 1800 census blocks, and results in between \$4 and \$5 billion in property damage, plus \$1 to \$5 billion in business interruption losses. Resilience strategies and preparedness planning could greatly reduce the damage and economic consequences of the tsunami.

Keith Porter is an Associate Research Professor at the University of Colorado Boulder. He specializes in seismic vulnerability and performance-based earthquake engineering. Further information can be found at http://spot.colorado.edu/~porterka.

Trimming the UCERF2 Logic Tree

Research sponsored by the Southern California Earthquake Center
By Keith Porter

The problem of model complexity. What do we do with a model of seismic hazard that captures our uncertainty about earthquake occurrence, but is so complex that many people who most need to apply it, can't? A research team led by Keith Porter that included researchers from the USGS and USC recently completed a study identifying the important sources of uncertainty in the leading model of California seismicity. It uses statewide annualized earthquake loss to buildings as a measure of which hazard-model elements have the strongest or most geographically widespread impact on model uncertainty. The study shows that a model that includes only a small subset of model elements produces the same distribution of annualized loss as the larger model does, with a fraction of the computational demand.

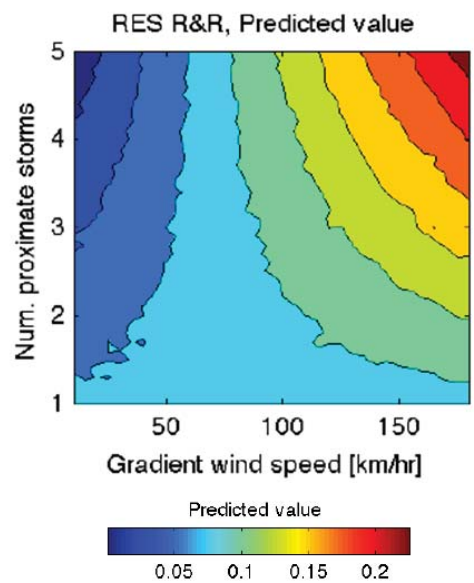
UCERF2. From 2008-2013, the Uniform California Earthquake Rupture Forecast, version 2 was the USGS's leading mathematical model of where all of California's seismic sources are & how frequently each produces earthquakes of various magnitudes. One of its most interesting features is that it is so uncertain. Scientists quantify that uncertainty by depicting the model with a logic tree, in this case a tree with 480 branches, each branch essentially representing one deterministic model of California seismic sources and their activity. One can look at UCERF2 as 480 different models, each one having a measure of confidence expressed by the UCERF2 scientists. 480 models can impose a heavy computational burden for modeling earthquake loss, especially when combined with other uncertainties, like the choice of which ground-motion-prediction equation to use (4 good choices in California), what soil model to use (2 good choices), and what set of vulnerability functions (maybe 3 good choices). 480x4x2x3 = 11,520 different ways to calculate the seismic risk to a single asset. If you are an insurer with tens or hundreds of thousands of earthquake policies and you've got to track all those uncertainties to properly manage your risk, then such a complex model can become a real computational burden. Even 480 branches are too many for some users. At least one insurer uses a single branch of UCERF2 that produces something like the average hazard. That can be fine for calculating expected annualized loss, but may be problematic for rare losses. Ignoring important uncertainties generally means a steeper loss-exceedance curve and lower 250-year loss, the value for which insurers often reinsure themselves. Which means they are underestimating their risk, underinsuring themselves, and facing a higher risk of ruin than they think they are. Maybe a 1-branch tree is too simple. Is there some middle ground between 1 and 480 that is both tractable and sufficiently uncertain?

Achieving a 98% reduction in model complexity without illusory accuracy. Most of the 480 UCERF2 model branches differ only slightly in terms of statewide expected annual loss, and one can use just 10 models to capture virtually all the uncertainty. A 98% reduction in model complexity can save a lot of computer time and allow a big insurer to do its actuarial duty to track uncertainty without spending days or weeks on supercomputers. *Trimming the UCERF2 Logic Tree* appears in the September-October 2012 issue of Seismological Research Letters.

Demand Surge

Sponsored by the Willis Research Network
By Anna Olsen and Keith Porter

After large-scale natural disasters, the costs of repair and reconstruction are higher for a given group of damaged assets than if the same assets had been subjected to the same local excitation in a smaller-scale event. This phenomenon is often referred to as demand surge, and it has been observed after hurricanes, earthquakes, and other natural disasters. Following Hurricane Katrina, AIR, a catastrophe modeling company, recommended increasing loss estimates by 30% to account for demand surge. Hurricane Andrew (1992) was believed to have caused up to a 60% increase in costs relative to non-catastrophe conditions, and the 1994 Northridge Earthquake was believed to have caused a 20% increase. Demand surge is currently poorly documented and is addressed to varying degrees of sophistication in catastrophe models. In research for the Willis Research Network, we derived an improved quantitative understanding of demand surge with the goal of enabling insurers and others to better plan for or reduce its effects.



Researchers at the University of Colorado at Boulder studied the underlying mechanisms of demand surge and produced an empirical model of demand surge that relies on construction costs in the two quarters prior to hurricane season, number of proximate storms during the season, and peak windspeeds at a city center, as a proxy for societal losses. Six models were created, the most significant being two that estimate the increased cost for labor and materials for baskets of repair serves for residential or commercial buildings.

Anna Olsen was the Willis Research Network Fellow at the University of Colorado Boulder from 2008-2011. Keith Porter is an Associate Research Professor at CU-Boulder specializing in seismic vulnerability, loss estimation, and performance-based earthquake engineering. See http://spot.colorado.edu/~porterka for more information.

Vulnerability of Soft-story Woodframe Construction

Sponsored by the San Francisco Department of Building Inspection
By Keith Porter

San Francisco has approximately 2,800 woodframe, soft-story buildings 3 or more stories tall, with 5 or more housing units. Soft-story construction refers to a building whose lowest story is significantly weaker, more flexible, or both, than those above. These buildings performed badly in the 1989 Loma Prieta earthquake. They house 58,000 people—8% of the population—in 29,000 housing units. To inform mitigation policy, the Applied Technology Council coordinated two studies (ATC-52 and ATC-52-2) for the City of San Francisco's Community Action Plan for Seismic Safety (CAPSS) project, quantifying the risk. Soft-story buildings were a focus of one part of ATC-52-2. The CAPSS studies estimated the impacts on these buildings from each of 4 large, hypothetical, but realistic scenario earthquakes on the San Andreas and Hayward faults.

Collapsed apartment building in the San Francisco Marina District after the 1989 Loma Prieta earthquake

Custom vulnerability models were created using laboratory evidence, earthquake experience, and other information to represent the relationship between shaking intensity, damage, and repair cost, for each building, along with 3 seismic retrofit alternatives for each building. Earth scientists estimated seismic shaking intensities in terms of damped elastic spectral acceleration response across San Francisco. Fragility and vulnerability functions for the index buildings were assigned to the 2,800 buildings in DBI's database. Site-specific shaking intensities were applied to the vulnerability models estimate damage and loss.

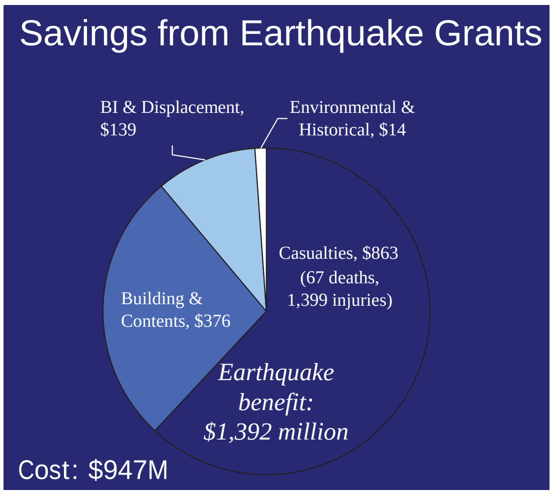
Average shaking citywide is 2 to 4 times stronger than in the Marina District in the 1989 Loma Prieta Earthquake, where 15% of all corner soft-story apartment buildings were completely damaged or collapsed. In one scenario, 5 in 10 of these buildings are damaged to the point of being unsafe to occupy, and an addition 3 in 10 collapses. Retrofitting the ground floor with cantilever columns and new wood sheathing reduces collapses to fewer than 1 in 100, at a cost of $10,000 to $20,000 per housing unit. The methodology is validated against experience in the 1989 event.

Keith Porter is an Associate Research Professor at the University of Colorado Boulder. He specializes in seismic vulnerability and performance-based earthquake engineering. Further information can be found at http://spot.colorado.edu/~porterka.

Cost-Effectiveness of Multihazard Risk Mitigation

Applied research sponsored by the Multihazards Mitigation Council
By Keith Porter

In 1999, the US Congress instructed the Federal Emergency Management Agency (FEMA) to sponsor an independent study quantifying the future savings from natural-hazard mitigation efforts. The study was carried out by the Applied Technology Council (ATC) under the direction of the National Institute of Building Sciences' (NIBS) Multihazard Mitigation Council (MMC). It examined mitigation activities related to earthquake, wind, and flood funded through three major FEMA grant programs. It found that FEMA's mitigation activities from 1993 to 2003:



$1.4 billion saved through seismic risk mitigation

Were cost-effective, reducing future losses from earthquakes, floods, and windstorms. The average benefit-cost ratio (BCR) for all grants was 4.0, meaning a present value of $4 avoided future loss for every $1 spent.

Resulted in significant net benefits to society as a whole (individuals, states, and communities) in terms of future reduced losses, saving $14 billion in total from $3.5 billion expenditures; and

Provided significant potential savings to the federal treasury in increased future tax revenues and reduced hazard-related costs.

This study involved two components. The first was the benefit-cost analysis of FEMA mitigation grants. It estimated the future savings from FEMA expenditures on mitigation activities. It was quantitative and considered a statistical sample of FEMA-funded mitigation activities selected from the National Emergency Management Information System (NEMIS) database. The unit of analysis was the individual FEMA-funded grant.

The second study component, community studies, assessed the future savings from mitigation activities through empirical research on mitigation activities carried out in community contexts. The community studies were quantitative and qualitative and examined mitigation activities in a sample of communities. They provided insight into mitigation effectiveness by exploring how mitigation activities percolate throughout the community via synergistic activities — mitigation efforts that would not have occurred had it not been for the original FEMA grant. The unit of analysis was the individual community.

Keith Porter is an Associate Research Professor at the University of Colorado Boulder. He specializes in seismic vulnerability and performance-based earthquake engineering. Further information can be found at http://spot.colorado.edu/~porterka.

VICTOR SOUMA

Biographical Sketch

Dr. Saouma is a Professor in the Department of Civil, Environmental and Architectural Engineering, University of Colorado Boulder, former Director of the CU-NEES center for Fast Hybrid Testing, and President of the International Association of Fracture Mechanics for Concrete and Concrete Structures IA-FraMCoS. He has taught and conducted research in Italy, France, Switzerland and Italy. He was funded for 9 years by the Tokyo Electric Power Company (TEPCO) to develop models for the nonlinear transient response of arch dams subjected to strong earthquakes. More recently, he was a consultant for the investigation of the delamination of the Crystal River nuclear containment vessel, and is presently collaborating with the Oak Ridge National Laboratory to better understand, model, and make long term predictions of the deterioration of nuclear power plants affected by ASR.
His research interests are multiple:

Earthquake engineering
- Nonlinear transient analysis of concrete dams.
- Dynamic 3DOF pushover tests of an R/C column.
- Nonlinear real hybrid simulation of a 402 DOF R/C frame.
- Intersection of earthquakes and cultures.

Fracture mechanics
- Fracture of concrete, rocks, ceramics, and polymers.
- Fractal analysis

Concrete and reinforced concrete deterioration
- Alkali-aggregate reactions.
- Chloride diffusion

Nonlinear finite element simulation of reinforced concrete structures, in particular
- Dams (gravity, arch) subjected to strong seismic excitation, or alkali-aggregate reactions.
- Nuclear reactor containers, in particular: aging, cracking, structural assessment.

Representative Publications:

- Saouma, V. E. (2013) **Numerical Modeling of Alkali Aggregate Reaction**, CRC Press, 2013
- Saouma, V.E. and Martin, R. and Harir, M. (2013) **A Mathematical Model for the Kinetics of the Alkali Silica Reaction**, under Review, *ACI Materials Journal*.
- Saouma, V.E. (2013) **Applications of Fracture Mechanics to Cementitious Materials; A Personal Perspective**, in print *ACI Special Publication on Applications of Fracture Mechanics of Concrete*, G.L. Cusatis Editor.
- Saouma, V., Kang, D., Haussman, G. (2012), **A Computational Finite-Element Program for Hybrid Simulation**, *Earthquake Engineering and Structural Dynamic Journal*, Vol. 41, pp. 375-389.

- Saouma, V., Haussmann, Kang, D.H, Ghannoum, W. (2013), **Real Time Hybrid Simulation of a Non Ductile Reinforced Concrete Frame**http://civil.colorado.edu/~saouma/RTHS, in print *ASCE Journal of Structural Engineering*.
- Ghannoum, W., Saouma, V., Haussmann, G., Polkinghorne, K. and Eck, M. (2012) **Experimental Investigations of Loading Rate Effects in Reinforced Concrete Columns**, *ASCE Journal of Structural Engineering*, Vol. 138, pp. 1032-1041,

PETROS SIDERIS

Biographical Sketch

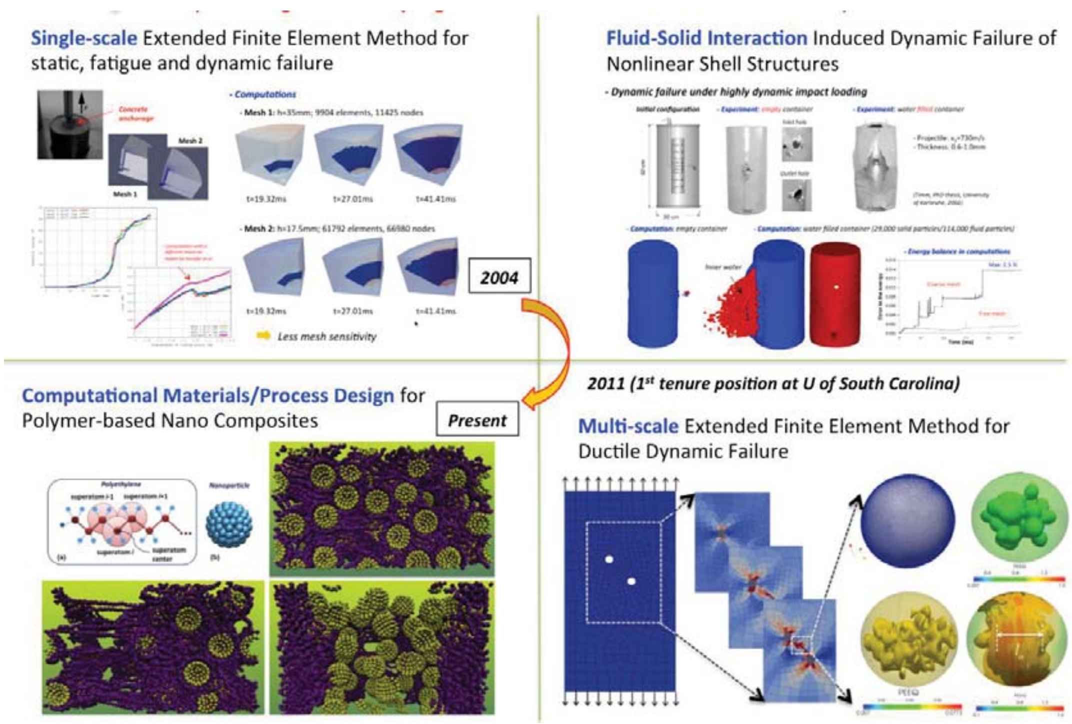
Dr. Sideris is an Assistant Professor in the Department of Civil, Environmental and Architectural Engineering of the University of Colorado Boulder. His research primarily focuses on the development of seismic-resistant low-damage bridge systems of accelerated construction in seismic regions. Dr. Sideris' research studies combine experimental performance evaluation of large-scale systems with nonlinear structural modeling and analysis. His research experience includes shake table testing of a large-scale post-tensioned segmental bridge system, quasi-static cyclic testing of large-scale segmental bridge columns, nonlinear finite element analysis of post-tensioned concrete segmental bridges, tensile cyclic testing and numerical modeling of unbonded monostrands with their anchorage hardware, shake table testing and numerical modeling of steel storage racks, development of friction and rigid body dynamics models and software, and numerical/analytical investigation of the response of structural elements incorporating softening materials. Dr. Sideris is an Associate Member of the American Society of Civil Engineers (ASCE) and serves in the ASCE/SEI Seismic Effects Committee. He also serves as a reviewer for the ASCE's Journal of Structural Engineering and the ASCE's Journal of Engineering Mechanics.

Dr. Sideris received his Master's (2008) and Ph.D. (2012) in Civil Engineering from the University at Buffalo - SUNY. He also holds a diploma in Civil Engineering (2005) from the National Technical University of Athens, Greece. Prior to joining the University of Colorado at Boulder, he was appointed as Post-doctoral Research Fellow and Adjunct Lecturer at the University at Buffalo - SUNY (September 2012 - May 2013). During his academic studies, Dr. Sideris received several awards including the 2010 Paul J. Koessler Memorial Scholarship Award by the Peace Bridge Authority and the ASCE Buffalo Section, and the 2010 Liu Huixian Earthquake Engineering Scholarship Award by the US-China Earthquake Engineering Foundation (U.S.A.) and the Huixian Earthquake Engineering Foundation (China). Additional information can be found at https://sites.google.com/site/petros0sideris0/, or by email at petros.sideris@colorado.edu.

JEONG-HOON SONG

Biographical Sketch

Dr Song is an Assistant Professor in the Department of Civil, Environmental and Architectural Engineering at the University of Colorado Boulder. He specializes in the development of theoretical and computational models to investigate various multiscale/multiphysics problems including computational characterization/ prediction of material behaviors in atomistic, quasi-continuum and continuum length scales, computational material and manufacturing process design for tailoring capabilities on demand, computational prediction of multiphysics-induced multiscale system failure/interaction behaviors. Dr. Song also focuses on developing new advanced computational analysis schemes such as the extended finite element method (XFEM), extended element-free Galerkin method (XEFGM), extended particle difference method (EPDM), adaptive part reduced order model (APROM) and system interaction analysis algorithms to predict wide range of multiscale/multiphysics-induced engineering mechanics/science problems.



Some of Dr. Song's current research topics include:

- Developing physics-based computational analysis methods to investigate material behaviors in micro (atomistic)/meso (quasi-continuum)/macro (continuum) length scales
- Developing multiscale failure analysis methods for ductile failure under extreme dynamic loading conditions
- Developing multiphysics-based failure analysis scheme for coupled thermo- mechanical-electro-magnetic fields.

For more information, please visit Dr. Song's research group site https://cm2lab.wordpress.com/ or write an email to jh.song@colorado.edu

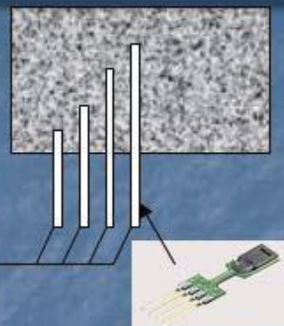
YUNPING XI

Biographical Sketch

Dr. Yunping Xi is a Professor in the Department of Civil, Environmental and Architectural Engineering at the University of Colorado Boulder. He specializes in the research areas of experimental and theoretical analyses of long-term performance of concrete materials and reinforced concrete structures; structural health monitoring; and development of sustainable construction materials. Since 1993, Dr. Xi has participated more than 100 sponsored projects as PI or co-PI sponsored by NSF, DOE, FHWA, FAA, NASA, the Air Force, EPA, Sandia National Lab, Oak Ridge National Lab, Colorado DOT, CDPHE, New Jersey DOT, NYSERDA, and several private companies. The total funding is more than $8.6 million dollars. Dr. Xi is the Administrator of Colorado Local Technical Assistance Program (CLTAP) sponsored by Federal Highway Administration, Colorado Department of Transportation, and University of Colorado at Boulder. Dr. Xi is the chairman of the committee on Experimental Analysis & Instrumentation, ASCE/EMI, and a member of editorial boards for *Magazine of Concrete Research* and *Computer & Concrete* . He has more than 140 publications in technical journals, conference proceedings, and project reports. Dr. Xi holds a PhD degree in structural engineering from Northwestern University. See http://spot.colorado.edu/~xiy for more information, or call (303) 492-8991.

Sustainable Development of Construction Materials and Long Term Structural Health Monitoring and Modeling
– Research Topics of Prof. Yunping Xi's Research Group (http://spot.colorado.edu/~xiy/)

Multiple sensors including hermal and moisture sensors



Structural Health Monitoring

- Remote monitoring by wireless technologies
- Long term monitoring by harvesting energy from the environment and structures
- Application of multiple sensors: thermal and moisture sensors together with strain and displacement sensors
- Combining sensor network with structural simulation models for more reliable and real time monitoring

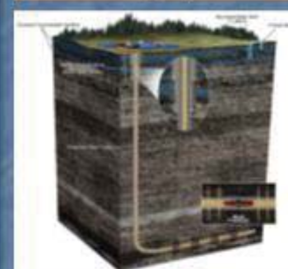
Sustainable development of construction materials

- Waste tires
- Mixed color recycled glass
- Bioconcrete from microorganisms
- Roller compact concrete (RCC)
- Alkali-activated cements
- Recycled aggregate concrete

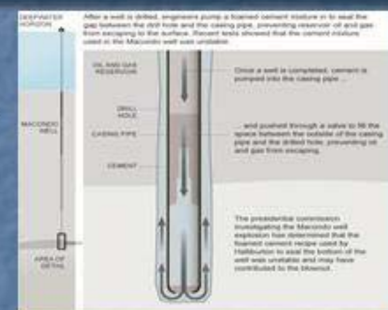
Prediction of long-term performance of concrete Structures

❖ *De-icers (with chloride and other ions) are used on the road for ice and snow control*
❖ *Penetration of chloride ions into concrete causes the corrosion of embedded steel in reinforced concrete structures*
❖ *Prediction of the penetration of chloride and other ions into concrete is important*

Mechanical properties of oil well cement



Oil well cement is used to seal wells. The stability and strength of the cement are studied by experiments and models, which are very important for safe operation of the oil and natural gas industry.



Long-term performance of nuclear containment structures and nuclear waste storage facility

Many nuclear power plants were built about 30 to 40 years ago.
- Fracture in containment structures
- High temperature damage
- Gamma ray and neutron radiation
- Freeze/thaw damage
- Drying shrinkage

New materials for energy efficient buildings and energy storage structures

Building envelope: Exterior walls, windows and roofs

PCM microcapsules

Insulation mortars with rubber particles and phase change materials for exterior walls

- **Recycled tires**: There are about 300 million scrap tires, approximately one tire per person per year, generated in the United States.
- **Phase change material** (PCM): PCM is a substance, which has a high heat of fusion, melting and solidifying at a certain temperature. It is capable of storing and releasing large amounts of energy.