

CEE AT ILLINOIS



International Conference on Multi-hazard Approaches to Civil Infrastructure Engineering (ICMAE)

Millennium Knickerbocker Hotel Chicago, Chicago IL

June 26-27, 2014



ILLINOIS

Introduction

There has been a considerable amount of research on the assessment of the seismic vulnerability of structures, the development of new methods to control the earthquake forces transmitted to the structure (through base isolation or energy dissipation devices), the incorporation of the newly acquired knowledge into design provisions, the assessment of the condition of existing bridges, and the planning of retrofit and repair strategies using both conventional and new materials. There is a need now to put all these developments into proper perspective, to examine critically the many methodologies and techniques available, to recommend the most appropriate ones for each case, and to identify remaining research needs.

Furthermore, while the seismic hazard has received over the past years a significant attention, other hazards (like those water and wind related) have caused a significant damage and have had a significant societal impact. Therefore there is a clear need to make progress in the mitigation of multiple hazards and, when appropriate, to expand the methodologies developed for seismic hazard to other hazards. In addition while work has been done considering individual hazards, there has been very limited work toward a uniform reliability of infrastructure considering multiple hazards.

The overarching goal of the International Conference on Multi-hazard Approaches to Civil Infrastructure Engineering (ICMAE) is to promote the mitigation of the impact of natural and human-made hazards on society. The conference will have a strong interdisciplinary character focusing on issues related to reliability analysis, risk determination, risk evaluation and risk management for natural and human-made hazards, and disaster response and recovery.

Specific themes that will be discussed during the conference include: methodologies for vulnerability assessment of structures, including both the general, overall methodologies, and the detailed procedures to estimate the system demands and the structural and component capacities; new techniques to reduce the system demands through control systems; instrumentation, monitoring and condition assessment of structures and foundations, to determine the need to strengthen them, a key step in assessing the vulnerability of existing structures; new techniques for repairing structures that have suffered damage during past events or structures that have been found in need of strengthening, using conventional and new materials (fiber reinforced composites for instance); development of new design provisions that consider multiple hazards; and interdisciplinary participation of social scientists and scholars in law and the humanities with cultural, political, economic, ethical and legal expertise relevant to the management of natural and human-made hazards.

The conference features a number of presentation from scholars and practitioners from diverse national and professional background.

Sponsors

MAE Center
Department of Civil and Environmental Engineering (CEE)
CEE Structural Engineering and Structural Mechanics
CEE Societal Risk Management (SRM) Program
Women and Gender in Global Perspectives (WGPP)

Organizing Committee

Paolo Gardoni (Chair)

Director, MAE Center: Creating a Multi-hazard Approach to Engineering, and Co-director, Societal Risk Management Program, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign
Associate Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign

James M. LaFave

Professor and CEE Excellence Faculty Scholar, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign

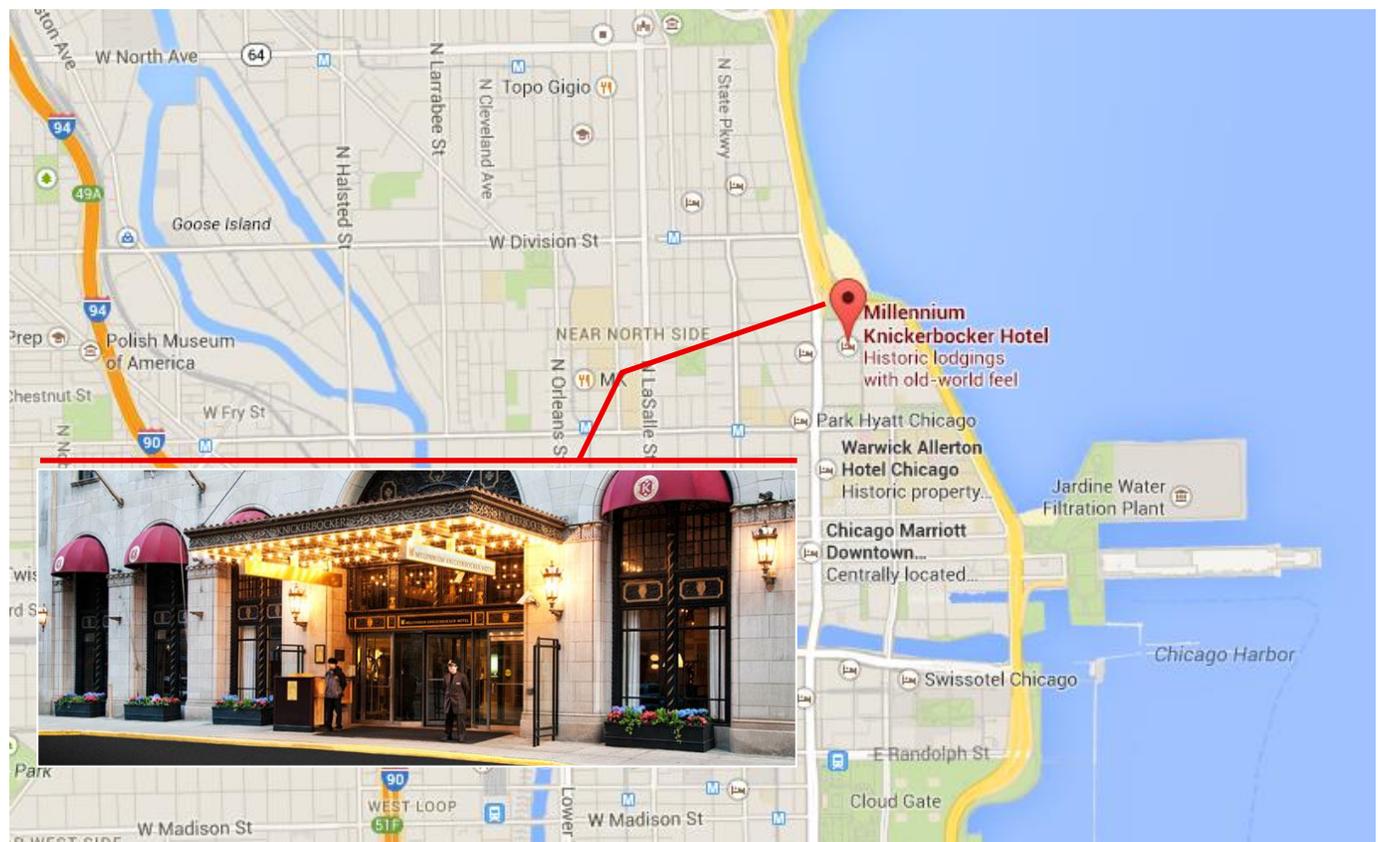
Youssef Hashash

Professor and John Burkitt Webb Endowed Faculty Scholar, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign

Conference Location and Facilities

The conference will be held at the *Millennium Knickerbocker Hotel Chicago*. The *Millennium Knickerbocker Hotel* can be found at 163 East Walton Place, North Michigan Avenue, IL 60611, USA.

All of the conference sessions will be held in the Crystal Ballroom. Lunches will be in the Continental Room.



[Click here for directions to the Millennium Knickerbocker Hotel Chicago.](#)

Presentation Time

Each session includes a keynote and three invited presentations that bring in different perspectives on a common theme. A keynote lecture will be limited to 30 minutes, and each invited presentation will be limited to 20 minutes. A panel discussion will close each session where all four presenters and an industrial panelist will answer questions and generate a broader discussion.

Edited Volume

The papers presented at the conference will be considered for publication in an edited volume published by a prestigious press. Additional details for the authors, including the deadline to submit the full contribution along with a template and page limit, will be provided shortly following the conference.

Website and Registration

The conference has a dedicated website where additional information and last-minute changes are posted. The link to the conference website is <http://mae.cee.illinois.edu/ICMAE>.

Members of the public are welcome to attend the conference upon preregistration also available at the conference website (<https://my.cee.illinois.edu/icmae>). The conference registration fee is \$350 per person and includes attendance at all program sessions, conference materials, refreshments, and lunches on both days of the conference. The conference provides up to twelve (12) Professional Development Hours (PDHs).

Conference Program

Day 1 June 26, 2014

8:30 - 9:00 AM	Opening Remarks
10 min.	<p>Paolo Gardoni <i>Director, MAE Center: Creating a Multi-hazard Approach to Engineering, and Co-director, Societal Risk Management Program, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign</i> <i>Associate Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign</i></p>
10 min.	<p>Benito Mariñas <i>Interim Head, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign</i> <i>Ivan Racheff Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign</i></p>
10 min.	<p>Amr Elnashai <i>Harold and Inge Marcus Dean of Engineering, The Pennsylvania State University</i></p>
9:00 - 9:15 AM	Group Photo
9:15 - 9:30 AM	Break
9:30 - 11:30 AM	Session 1 Probabilistic Methods for Risk Analysis
	<p>Chair/Moderator: Paolo Gardoni <i>Director, MAE Center: Creating a Multi-hazard Approach to Engineering, and Co-director, Societal Risk Management Program, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign</i> <i>Associate Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign</i></p>
30 min.	<p>Keynote Speakers: Armen Der Kiureghian <i>Taisei Professor of Civil Engineering, Department of Civil & Environmental Engineering, University of California, Berkeley</i> “Bayesian network modeling of infrastructure systems”</p>
20 min.	<p>Speakers: Alexandros Taflanidis <i>Associate Professor, Department of Civil & Environmental Engineering & Earth Sciences, University of Notre Dame</i> “Natural hazard probabilistic risk assessment through surrogate modeling”</p>
20 min.	<p>Speakers: Jamie Padgett <i>Assistant Professor, Department of Civil and Environmental Engineering, Rice University</i> “Supporting life-cycle management of bridges through multi-hazard reliability and risk assessment”</p>
20 min.	<p>Speakers: Paolo Bocchini <i>Assistant Professor, Department of Civil and Environmental Engineering, Lehigh University</i> “Correlated maps for regional multi-hazard analysis: ideas for a novel approach”</p>
30 min.	<p>Panel Discussion Industry Panelist: Petros Keshishian <i>Director, Risk Management Solutions (RMS)</i></p>

11:30 AM – 12:30 PM Lunch in the Continental Room	
12:30 - 2:30 PM Session 2 Earthquake Engineering	
	Chair/Moderator: James LaFave <i>Professor and CEE Excellence Faculty Scholar, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign</i>
30 min.	Keynote Speakers: Gian Michele Calvi <i>Professor, IUSS Pavia, Italy</i> “Energy efficiency and disaster resilience: a common approach”
20 min.	Speakers: Khalid Mosalam <i>Professor, Department of Civil and Environmental Engineering, University of California, Berkeley</i> “Progressive collapse simulation of vulnerable reinforced concrete buildings”
20 min.	Speakers: Paolo Pinto <i>Professor, Department of Structural and Geotechnical Engineering, University of Rome "La Sapienza", Italy</i> “Existing buildings: the new Italian provisions for probabilistic seismic assessment”
20 min.	Speakers: Andre Barbosa <i>Assistant Professor, School of Civil and Construction Engineering, Oregon State University</i> “Robustness assessment of steel moment resisting frame structures under mainshock-aftershock cascading events”
30 min.	Panel Discussion Industry Panelist: Rose Grant <i>Program Director, State Farm Insurance Companies</i>
2:30 - 3:00 PM Break	
3:00 - 5:00 PM Session 3 Geo-Hazards	
	Chair/Moderator: Youssef Hashash <i>Professor and John Burkitt Webb Endowed Faculty Scholar, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign</i>
30 min.	Keynote Speakers: Ahmed Elgamal <i>Professor, Department of Structural Engineering, University of California, San Diego</i> “Hazard mitigation: the role of geotechnical engineering”
20 min.	Speakers: Robert Gilbert <i>Professor, Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin</i> “Accounting for unknown unknowns in managing multi-hazard risks”
20 min.	Speakers: Kenichi Soga <i>Professor, Department of Engineering, University of Cambridge, UK</i> “Innovation in instrumentation, monitoring and condition assessment of infrastructure”
20 min.	Speakers: Zenon Medina-Cetina <i>Assistant Professor, Zachry Department of Civil Engineering, Texas A&M University, College Station</i> “Bayesian risk assessment of a tsunamigenic rockslide at Åknes Norway”

30 min. Panel Discussion
Industry Panelist: **Emad Mousavi**
Engineer II, Aker Solutions Inc.

Day 2 June 27, 2014

8:00 -10:00 AM Session 4 Societal Impact of Extreme Events

Chair/Moderator: Eun Jeong Cha
*Assistant Professor, Department of Civil and Environmental Engineering,
University of Illinois at Urbana-Champaign*

30 min. Keynote Speakers: **Louise Comfort**
*Professor, Graduate School of Public and International Affairs, University of
Pittsburgh*
“Digital technologies, complex systems, and extreme events: measuring change in
policy networks”

20 min. Speakers: **Arden Rowell**
*Associate Professor and Richard W. and Marie L. Corman Scholar, College of
Law, University of Illinois at Urbana-Champaign*
“Theories of risk management and multiple hazards”

20 min. Speakers: **Lori Peek**
Associate Professor, Department of Sociology, Colorado State University
“Disaster risk reduction strategies in earthquake-prone cities”

20 min. Speakers: **Therese McAllister**
*Research Structural Engineer, National Institute of Standards and Technology
(NIST)*
“Disaster resilience of communities: the role of the built environment”

30 min. Panel Discussion
Panelist: **Colleen Murphy**
*Associate Professor, Department of Philosophy, University of Illinois at Urbana-
Champaign*

10:00 - 10:30 AM Break

10:30 AM - 12:30 PM Session 5 Wind Hazards

Chair/Moderator: Bill Spencer
*Nathan M. & Anne M. Newmark Endowed Chair in Civil Engineering, Department
of Civil and Environmental Engineering, University of Illinois at Urbana-
Champaign*

30 min. Keynote Speakers: **David Rosowsky**
Provost and Senior Vice President, The University of Vermont
“Event-based models for hurricane hazard characterization: what can we do and
where can we go?”

20 min. Speakers: **David Prevatt**
*Associate Professor, Department of Civil and Coastal Engineering, University of
Florida*
“An engineering-based catastrophe model to predict tornado damage”

20 min. Speakers: **Michele Barbato**
*Associate Professor, Department of Civil and Environmental Engineering,
Louisiana State University*
“Performance-based hurricane engineering: a multi-hazard approach”

20 min. Speakers: **Arindam Gan Chowdhury**
Associate Professor, Department of Civil & Environmental. Engineering, Florida International University
“Wall of wind research and testing to enhance resilience of civil infrastructure to hurricane multi-hazards”

30 min. Panel Discussion
Industry Panelist: **Eric Haefli**
Research Administrator, State Farm Insurance Companies

12:30 - 1:30 PM Lunch in the Continental Room

1:30 - 3:30 PM Session 6 Fire, Blast, Shock and Impact

Chair/Moderator: Larry Fahnestock
Associate Professor and CEE Excellence Faculty Fellow, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign

30 min. Keynote Speakers: **Shalva Marjanishvili**
Sr. Managing Engineer, Hinman Consulting Engineers, Inc.
“Mitigating disasters in the 21st century”

20 min. Speakers: **Maria Garlock**
Associate Professor, Department of Civil & Environmental Engineering, Princeton University
“Fire following earthquake: historical events and evaluation framework”

20 min. Speakers: **Kapil Khandelwal**
Assistant Professor, Department of Civil & Environmental Engineering & Earth Sciences, University of Notre Dame
“Modeling of high temperature creep in ASTM A992 structural steels”

20 min. Speakers: **Venkatesh Kodur**
Professor, Department. of Civil and Environmental Engineering, Michigan State University
“Innovative strategies for enhancing fire performance of FRP-strengthened concrete structures”

30 min. Panel Discussion
Industry Panelist: **Gary English**
Assistant Fire Marshal, City of Seattle Fire Department

3:30 - 4:00 PM Break

4:00 - 4:15 PM Closing Remarks

15 min. **Youssef Hashash and James LaFave**

Conference Organizers



Paolo Gardoni

Paolo Gardoni is an Associate Professor and Co-director of the Societal Risk Management Program in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign. He is also the director of the MAE Center, which was established in 1997 by the National Science Foundation as one of three national earthquake engineering research centers. His research interests include reliability, risk and life cycle analysis; decision making under uncertainty; earthquake engineering; performance assessment of deteriorating systems; ethical, social, and legal dimensions of risk; policies for natural hazard mitigation and disaster recovery; and engineering ethics.



James M. LaFave

James M. LaFave is a Professor and CEE Excellence Faculty Scholar in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign. He joined the faculty in 1999 after over four years of consulting engineering experience at Wiss, Janney, Elstner Associates, Inc. in Princeton, NJ, and Sargent & Lundy Engineers in Chicago. His research interests include the experimental behavior and analytical modeling of structural connections and joints. This includes a number of applications considering multiple hazards like earthquake and wind.



Youssef Hashash

Youssef Hashash is a Professor and John Burkitt Webb Endowed Faculty Scholar in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign. He joined the faculty in 1998 after working at the Geotechnical and Underground Engineering group at Parsons Brickerhoff in San Francisco, California since 1994. His research interests include deep excavations, earthquake engineering, numerical modeling, and soil-structure interaction. He is also involved in the use of visualization and virtual reality techniques in geotechnical engineering applications.

Conference Abstract

Session 1: Probabilistic Methods for Risk Analysis

Bayesian network modeling of infrastructure systems

Armen Der Kiureghian

University of California, Berkeley

The Bayesian network (BN) is a powerful tool for probabilistic modeling, information processing and decision making for infrastructure systems subject to hazards. It offers a transparent framework for modeling, which facilitates model review and verification by disciplinary experts who are not necessarily familiar with probabilistic methods. However, existing algorithms for inference in BNs are not scalable with the size of an infrastructure system. In particular, the memory demand increases exponentially with the number of system components.

This presentation will introduce two alternative approaches for BN modeling of infrastructure systems that address this problem. One approach uses a discrete optimization formulation to construct a BN topology that is chain-like and, therefore, more efficient than the standard formulation. The second approach uses a data compression algorithm to reduce the size of the required computer memory and heuristics to reduce the computation time. Several examples will demonstrate the ideas behind the two methods and their efficiencies relative to the standard algorithm.

Natural hazard probabilistic risk assessment through surrogate modeling

Alexandros A. Taflanidis

University of Notre Dame

Assessment of risk under natural hazards (such as earthquakes, hurricanes, fire) is always associated with a significant computational burden as it requires evaluations of the performance of the structural system under consideration for different system configurations based on the adopted probability models. Recent advances in computer and computational science, such as the popularity of parallel/distributed computing and the introduction of GPU architecture, have contributed in reducing this burden and have undoubtedly increased the popularity of simulation-based frameworks for quantifying/estimating this risk. Still, in many instances, such as for real-time risk estimation, for applications with complex high-fidelity numerical models or when an explicit optimization is considered based on the results of the risk assessment, this burden is considered as prohibitive.

Surrogate models (also frequently referenced as metamodels) offer an attractive solution for addressing this challenge. This is accomplished by establishing a computationally inexpensive input/output relationship based on an initial database of observations obtained through the initial (numerically expensive) simulation model. The upfront cost for obtaining this database is of course high, but once the surrogate model is established all future evaluations require very small computational burden. This presentation considers the implementation of kriging metamodeling in such a context, i.e., to support natural hazard risk estimation. For illustration two different applications are considered, corresponding to two different hazards: seismic risk assessment for a structure retrofitted with viscous dampers and real-time hurricane risk estimation for the Hawaiian Islands. Various implementation issues are discussed, such as: a) superiority of kriging metamodeling approach over other available surrogate models, b) approaches for obtaining high efficiency when the output under consideration is high dimensional (over 10,000) through integration of principal component analysis, c) the explicit incorporation of the prediction error associated with the kriging metamodel into the risk formulation and the impact it has on the calculated risk, and d) advantages when this approach is implemented within an optimal decision making framework.

Supporting life-cycle management of bridges through multi-hazard reliability and risk assessment

Jamie E. Padgett and Sabarethinam Kameshwar

Rice University

Bridge infrastructure is susceptible to damage from a large host of threats including natural hazards, aging and deterioration, and demands that increase with population growth and urbanization. Life-cycle management of bridge infrastructure requires an understanding of the relative contribution of these threats to the risk of damage or impending consequences, such as life-cycle costs. Traditionally, limited attention has been given to understanding the hazard risk profile to bridge infrastructure, defined as the relative risks posed by multiple hazards and the synergies or tradeoffs in protecting for different hazards. Furthermore effective strategies are needed to jointly consider cumulative damage (e.g. from aging) and punctuated damage (e.g. from natural hazards) when assessing the influence of design or upgrade decisions that may mitigate risks from multiple potentially competing hazards. This paper utilizes metamodels as an efficient strategy for developing parameterized time-dependent bridge fragilities for multiple hazards, thereby facilitating multi-hazard risk assessment and life-cycle management. Threats considered in the case studies include earthquakes, hurricanes, aging and deterioration, and live loads. The applications illustrate the relative contribution of earthquake and hurricane hazards to the risk of losses given variation in bridge parameters, the influence of considering aging when assessing the hazard risk profile, and the impact of concurrent threats (e.g. truck and earthquake) on the life-cycle risk.

Correlated maps for regional multi-hazard analysis: ideas for a novel approach

Vasileios Chistou and Paolo Bocchini

Lehigh University

Hazard maps are very popular tools for the probabilistic single- and multi-hazard analysis. For a given Intensity Measure (IM) of choice, representative of the intensity of the investigated natural extreme event, these tools provide the probability to exceed any given value of IM (e.g., peak ground acceleration) at any location. Unfortunately, these tools are appropriate for the analysis of *individual structures*, but not for *distributed infrastructure systems*, because they do not provide information on the correlation among the values of the IM at different locations. Instead, when dealing with interdependent systems and highly coupled problems, it is necessary to know the probability of having simultaneously certain values of the IM at all the locations of interests (e.g., at the location of all bridges of a transportation network).

The scientific community has addressed these issues with two different approaches. The first approach consists in the attempt to assess the correlation among the values of the IM at the various locations. This can be achieved implicitly or explicitly with several analytical or computational techniques, but always using substantial simplifications and assumptions that are convenient, but not necessarily adherent to reality. This family of techniques is very appealing for its closed-form solutions, but the concerns about the sensitivity to the assumptions have made a second approach more popular. This second line of research is based on so-called “hazard-consistent regional intensity maps”. A suite of IM maps associated with real or realistic events is collected and then a subset of scenarios is selected and weighted imposing that the probability of exceedance of the reduced (and weighted) suite of scenarios matches the one obtained by a comprehensive probabilistic hazard analysis (e.g., from USGS hazard maps) for some discrete values and at some grid points. In other words, these techniques require that the cumulative distribution function of the random variable IM is matched at some discrete points. As for the higher order probabilistic characteristics (e.g., correlation), it is implicitly assumed that the use of real or realistic scenarios guarantees an appropriate modeling of the correlation, but this is not necessarily true for the ensemble, and is not verified.

The proposed approach is to embrace the nature of regional IM maps as 2-dimensional random fields. In this way, a novel methodology for the optimal representation of random functions with a limited number of samples can be used. The technique imposes convergence (in the mean square sense) of the ensemble of representative samples to the desired field. As a result, also the correlation is correctly represented, and assessed as a by-product of the

methodology. This technique can be used for any type of hazard and IM: it only needs a generator of maps for a given scenario (e.g., attenuation functions for earthquakes). Some preliminary results on the use of this technique for the simulation of seismic ground motions will be presented.

Session 2: Earthquake Engineering

Energy efficiency and disaster resilience: a common approach

Gian Michele Calvi

IUSS Pavia, Italy

A proposal for integrated assessment of energy efficiency and earthquake resilience outlines the scope of a multi-disciplinary procedure in which environmental and seismic impact metrics are translated into common financial decision making variables.

In the context of seismic *risk* assessment, one of the most important outputs for communication with insurance companies, governmental agencies and other decision making entities is the *Expected Annual Loss* (EAL_S), which translates the mean value of economic *loss* (i.e. cost of repair or rebuilding operations) that a building (or group of buildings) will sustain annually over its life-span due to seismic action. The value of EAL_S is furthermore affected in order to reflect the level of *loss* related with operational and indirect costs, also referred as *downtime* (e.g. costs due to business interruption and people temporary re-allocation).

$$EAL_S = \frac{\text{mean} \cdot \text{annual} \text{ seismic} \text{ loss}}{\text{building} \text{ value}}$$

An analogue reasoning is employed when incorporating the energy efficiency analysis in the equation, by defining an energy *Expected Annual Loss* (EAL_E) that can directly be compared with its seismic counterpart (EAL_S). Thus, if one chooses to consider the building value as the common denominator, the EAL_E can be determined as the ratio between the mean annual *cost* (referred herein as *loss*) of consumed energy and total building value, within a compatible base of comparison:

$$EAL_E = \frac{\text{mean} \text{ annual} \text{ energy} \text{ loss}}{\text{building} \text{ value}}$$

Similarly to what is common practice when evaluating the energy and environmental performance of buildings, discrete classes of both earthquake resilience and energy efficiency are proposed, providing a consistent proxy for building classification - *Green and Resilient Indicators (GRI)* - as a function of EAL_E (*Green Indicator*) and EAL_S (*Resilient Indicator*):

The main advantage of the proposed procedure, in which common classes are established for both *Green* and *Resilient* counterparts, is the possibility to directly compare: a) the expected performance of a building in terms of seismic resilience and energy efficiency; and b) the benefit-cost ratios of investment necessary to upgrade a given *GRI* class, for each approach.

Progressive collapse simulation of vulnerable reinforced concrete buildings

Khalid M. Mosalam and Selim Günay

University of California, Berkeley

There are many vulnerable reinforced concrete (RC) buildings located in earthquake-prone areas worldwide. These buildings are characterized by the lack of seismic details and corresponding non-ductile behavior and significant potential of partial or global collapse. One of the current challenges in earthquake engineering is the identification of such buildings and the determination of effective and economical retrofit methods for their response enhancement. Despite the significant advances in earthquake engineering in the past 50 years, identification of these buildings is not straightforward due to various sources of non-ductile behavior and large number of sources of uncertainty. Furthermore, accurate determination and ranking of the collapse-prone buildings

is important from an economical perspective because resources to retrofit all non-ductile buildings can be prohibitively high. This presentation discusses available techniques to accurately evaluate collapse-vulnerable non-ductile RC buildings with emphasis on the gravity load failure modeling in the context of progressive collapse simulation.

After an introduction of the problem, the presentation covers the basis, advantages, and applications of the element removal approach for progressive collapse simulation using an illustrative example. Element removal of unreinforced masonry (URM) infill walls, which usually increase the vulnerability of non-ductile RC framed buildings under strong ground motions, are covered as an application. Because sudden failure of URM infill walls and complex frame/infill wall interaction may lead to gravity load failure, critical modeling issues of infilled RC frames, e.g. infill wall in-plane/out-of-plane interaction and shear failure of RC columns due to large forces transferred from the infill walls, are covered for accurate collapse determination. To identify the most influential sources of uncertainty on the seismic response and progressive collapse modeling of non-ductile RC building frames with and without infill walls, a deterministic sensitivity analysis method is briefly presented. Finally, fragility curves of as-built and retrofitted non-ductile RC building frames with URM infill walls are presented.

Existing buildings: the new Italian provisions for probabilistic seismic assessment

Paolo Emilio Pinto and Paolo Franchin

University of Rome "La Sapienza", Italy

The new Instructions issued by the National Research Council (CNR-DT 212/2013) on seismic assessment of existing buildings are presented. In their quality of being a normative document (not simply a guideline) they represent an innovative contribution both for Europe and internationally. Detailed procedures are presented for the probabilistic assessment of seismic safety of existing reinforced concrete and masonry buildings, incorporating research advances occurred in the last twenty years. The document starts with a material –independent chapter, in which alternative admissible probabilistic approaches are described, followed by two chapters dealing with aspects specific to reinforced concrete and masonry buildings. Three Appendices follow, the first one containing the theoretical background of some of the choices adopted in the main text, the other two presenting complete applications to real buildings. The document provides information on issues related to the uncertainties on seismic action, on material properties and on structural modeling. It prescribes a preliminary analysis of the building based on initial information, to help guiding the inspections and in-situ testing on the elements/ areas of the building found to be critical. Three assessment procedures of decreasing complexity are described, all of them based on non-linear analysis of structural response. It is intended that, apart of its direct use for cases of special relevance, the document will also be of use in view of a conceptually more rigorous derivation of the present traditional approach to the assessment of structural safety.

Robustness assessment of steel moment resisting frame structures under mainshock-aftershock cascading events

Andre R. Barbosa , Filipe L.A. Ribeiro , and Luis C. Neves

Oregon State University

Reconnaissance reports from recent significant earthquake events in Duzce, Turkey (1999), Chile (2010), New Zealand (2011), among others, have highlighted the fact that aftershock events can increase the damage in structures initially damaged by a mainshock earthquake events, thus significantly increasing their probability of failure of buildings. In this presentation, a reliability-based framework is presented for quantifying structural robustness considering the occurrence of a major earthquake (mainshock) and subsequent cascading hazard events, such as aftershocks that are triggered by the mainshock. Structural robustness refers to the capacity of a structure to sustain post-mainshock damage without reaching failure. The application of the proposed framework is exemplified through three numerical case studies. The case studies correspond to three SAC steel moment frame buildings of three, nine, and 20 stories, which were designed to pre-Northridge codes and standards. Two-dimensional nonlinear finite-element models of the buildings are developed using the Open System for Earthquake Engineering Simulation framework (OpenSees). P- Δ effects are accounted for using a leaning column. Energy-

based strength deterioration is considered in the modeling of beam hinges. The finite element models are subjected to multiple artificial mainshock-aftershock seismic sequences. Seismic performance of the structures is evaluated under mainshock-only and mainshock-aftershock incremental dynamic analyses. For the three buildings analyzed herein, it is shown that the structural reliability under a single seismic event can be significantly different from that under a sequence of seismic events. A novel reliability based robustness indicator shows that the structural robustness is influenced by the extent to which a structure can distribute damage.

Session 3: Geo-Hazards

Hazard mitigation: the role of geotechnical engineering

Ahmed Elgamal

University of California, San Diego

A brief review of civil infrastructure hazards from the view point of geotechnical systems will be presented. Technical approaches towards mitigation strategies will be discussed. Within such a framework, instrumentation and data-driven decision-support strategies will continue playing an increasingly critical role.

Accounting for unknown unknowns in managing multi-hazard risks

Robert B. Gilbert

The University of Texas at Austin

A significant challenge in managing multi-hazard risks is accounting for the possibility of events that are beyond our range of experience. Classical statistical approaches are of limited value because there are no data to analyze. Judgment or subjective assessments are also of limited value because they are derived from within our range of experience. Yet the risks associated with unknown unknowns can be substantial with outcomes and consequences well beyond our imagination.

This talk describes a framework, Decision Entropy Theory, to account for the possibility of unknown unknowns in managing risk. The mathematical basis for this framework is presented and illustrated with real-world applications in civil infrastructure engineering. This framework underscores the importance of developing adaptable approaches to manage multi-hazard risks in the face of unknown unknowns.

Innovation in instrumentation, monitoring and condition assessment of infrastructure

Kenichi Soga

University of Cambridge, UK

Key infrastructure needs to be resilient and able to cope with unplanned events. The ability to survive and sustain performance in the face of these events and developments is linked to the resilience of the infrastructure, which is often defined as a system's ability to deal with unplanned events through its ability to either absorb or adapt to the new situation. Tackling resilience is often hindered by a lack of precise information or knowledge about the exact nature of the past/current/future behaviour of a system (referred to as uncertainty) and by the ability to assess the likelihood of an event as well as its impact (risk). Further issues include whether the focus should be on prediction, prevention or response, and how resilience requirements can influence construction and maintenance.

The Cambridge Centre for Smart Infrastructure and Construction (CSIC) was established in 2011. Its mission is "to transform the future of infrastructure through smarter information" by (i) develop sensing technologies, methodologies & data analysis frameworks, (ii) building industry confidence in CSIC solutions through demonstration, (iii) providing evidence-based business cases for innovative sensor systems and (iv) developing & demonstrating frameworks for a whole-life approach. It is developing sensor technologies such as distributed fibre optic strain measurement, computer vision, crowd sensing and crowd sourcing, wireless sensor networks, MEMS

sensors & energy harvesting as well as investigating ways to improve the efficiency of interpreting data from construction scale to city-scale. CSIC addresses these requirements through its contribution to improvements in the design, construction and operation of infrastructure assets, and its programmes of demonstration, dissemination and training. The talk will introduce recent developments and projects at the centre and discuss potential applications of CSIC technologies for infrastructure resilience.

Bayesian risk assessment of a tsunamigenic rockslide at Åknes Norway

Zenon Medina-Cetina

Texas A&M University, College Station

This paper introduces a Bayesian method for estimating the risk due to a potential tsunamigenic rockslide. This method relies on Bayesian Networks to introduce the notion of probabilistic causal effects, while illustrating the interaction of multiple natural threats when implemented in the Storfjord area in Norway, where the Åknes rockslide (considered one of the major Norwegian natural threats) is expected to trigger a tsunami that would seriously affect several communities in its surroundings. Results generated from the proposed method are based on available evidence stemmed from data, numerical modeling and experts' beliefs. A key component on this approach is the evidence assimilation of experts, who provided technical information, but also their beliefs in terms of probability measures. This strategy introduced a unique approach for incorporating fine engineering judgment into risk measures in a transparent and systematic manner. Results show that risk estimates obtained from a Bayesian method yield significant qualitative differences when compared to a standard risk assessment approach in terms of inference capabilities. On the other hand, their orders of magnitude on the overall expected risks are relatively similar, reflecting for a first time the Åknes rockslide given state of nature.

Session 4: Societal Impact of Extreme Events

Digital technologies, complex systems, and extreme events: measuring change in policy networks

Louise K. Comfort

University of Pittsburgh

The rapid adoption of digital technologies in technical, organizational, economic, financial, and cultural systems creates the possibility of studying the evolving structure, processes, and changing patterns of interaction among complex, multi-organizational systems in near real-time. Significant advances in information/communication technologies have altered performance in organizational, economic, and policy systems. These changes include timely access to, and rapid transmission of, information regarding risk, as well as concepts and methods of analyzing complex, adaptive systems. This sociotechnical transformation in information processing has increased the potential for effective management of extreme events and reduction of risk to communities as they confront complex socioeconomic, technical, physical conditions changing over time and space. Using innovative methods of data collection, analysis, and computational simulation, researchers explore both the potential for greater functionality and collaborative performance in complex, adaptive systems, as well as anticipate points of possible failure and ensuing disruption. Digital technologies provide greater opportunity for monitoring and measuring performance of distinct component sub-systems, as well as interactions among them as risk escalates to larger scales of operation. Methods of inquiry for complex problems have sought, not always successfully, to capture the dynamic, evolving character of the systems designed to manage risk. This paper will explore different methods of analyzing risk, and different strategies of risk reduction in comparison to standard modes of organizational action.

Theories of risk management and multiple hazards

Arden Rowell

University of Illinois at Urbana-Champaign

Regulatory policy offers a rich resource for determinations of how to manage multiple hazards. This presentation will provide an overview of key regulatory theories of risk management—including cost-benefit analysis, risk-risk analysis, the precautionary principle, and the capabilities approach—and will discuss how these different theories can pull decision-makers in different directions when managing multiple risks. It will then provide an overview of existing regulatory policy, and describe how U.S. agencies currently manage multi-risk tradeoffs.

Disaster risk reduction strategies in earthquake-prone cities

Lori Peek, Stacia Sydoriak, and Justin Moresco

Colorado State University

This paper offers an overview of disaster risk reduction activities already underway in 11 earthquake-prone cities around the globe, including: Antakya and Istanbul, Turkey; Bandung and Padang, Indonesia; Chinha and Lima, Peru; Christchurch, New Zealand; Delhi and Guwahati, India; San Francisco, USA; and Thimphu, Bhutan. The goal is to provide baseline information about the tools and resources that practitioners and organizations in these 11 cities already have access to, in order to provide a more comprehensive understanding of DRR strategies and a better sense of the contexts in which future potential products may be created, evaluated, and ultimately adopted. Drawing on both survey and in-depth interview data with earthquake safety practitioners from government, business, health care, education, and grassroots groups, the paper describes earthquake and disaster risk reduction programs and initiatives now in place in these communities; explains what spurred the creation of those programs and initiatives; details the technical tools and resources that practitioners in these cities currently use to assess and mitigate their risk; and analyzes the communication channels that disaster and risk professionals now have access to and find most useful in their work. The paper concludes with a discussion of overarching motivations for adopting new disaster and seismic risk reduction practices and offers practical advice to help guide the development of risk reduction tools for use in earthquake-prone cities around the world.

Disaster resilience of communities: the role of the built environment

Therese P. McAllister

National Institute of Standards and Technology (NIST)

Buildings, facilities, and infrastructure lifelines play a key role in the life of a community by supporting housing, business, government, industry, and other vital services. The concept of disaster resilience addresses the way that communities prepare for and recover from disruptive events. The NIST program focuses on the role that buildings and infrastructure lifelines play in developing community disaster resilience. Needs of citizens and institutions in a community, including public safety, define the performance requirements for buildings and infrastructure systems. However, current practice does not adequately address interdependencies between buildings and infrastructure systems or the role they play in recovery following a hazard event.

Recent examples of how the built environment performs during hazard events, such as Hurricane Katrina or Superstorm Sandy, are used to illustrate the uneven performance and interdependence of infrastructure systems, as well as cascading events, that dramatically affect recovery of the community.

To address these deficiencies, NIST has established a research program to improve guidance, standards, and tools that support communities and disaster resilience planning. The research plan starts with the development of a framework and guidance documents, with the input of stakeholders across multiple disciplines, to identify best practices and gaps and research needs. The longer term research scope includes development of consistent performance goals and metrics for buildings and infrastructure systems, improved standards, codes, guidelines, and tools to enhance community resilience, and development of modeling tools at a community systems level.

Session 5: Wind Hazards

Event-based models for hurricane hazard characterization: what can we do and where can we go?

David V. Rosowsky

The University of Vermont

This talk will provide an overview of current event-based modeling techniques to characterize hurricane hazards. Models for both short and long-term hurricane hazard analyses will be described, the latter including assessment of the impact of climate change. Joint variable hazard characterization (wind speed and storm size) and joint hazard characterization (wind and rain) will be addressed, along with potential applications of evolving hazard models in performance-based engineering.

An engineering-based catastrophe model to predict tornado damage

Xinlai Peng, David B. Roueche, **David O. Prevatt**, and Kurtis R. Gurley

University of Florida

The tornado risk assessments currently used by both private and public agencies utilize empirically derived loss models that rely on historical claims data for predicting effects of future tornadoes. Engineering-based catastrophe models for tornadoes have not been available because a) a widely accepted wind load model for tornadoes does not exist and b) few studies focus on the structural behavior of buildings during tornadoes. The accuracy of these empirical models depends largely upon the extent of the recorded data and the appropriateness of applying these empirical models from one region to another. Without extensive datasets for all tornado-prone regions, there is need for an alternative, and more reliable method to predict the vulnerability of structures in tornadoes.

This paper proposes an approach to develop an engineering-based tornado catastrophe damage model. The tornado strength (i.e. wind pressure at any location within its path) is derived by incorporating a physical vortex model for the tornado wind field, an atmospheric pressure drop model, a probabilistic model for generating wind-borne debris, and a time-variant internal pressure model for a low-rise building. The structural capacity of building components is used to estimate structural damage caused by the tornado. The model enables users to determine the structural damage to a building at successive stages as the tornado translates past the building. The model enables explicit tracking of the consequences of cumulative damage to a single building or to a portfolio of buildings caused by wind and windborne debris impact.

Monte Carlo simulation techniques were used to develop the fragility curves for each building component and for eight wind directions of interest. IN this model, the distribution of wind loads was developed for straight line winds, with the addition of effects due to static pressure drop in atmospheric pressure. An example of the application of this catastrophe damage model is demonstrated using a fully-enclosed one-story light-framed wood structure exposed to several tornado events (2011 Tuscaloosa, AL and Joplin, MO tornadoes).

A discussion is included on the application of this catastrophe model to a generic town. The advantage of an engineering-based damage assessment model is the ability to provide a rational approximation of damage to residential dwellings in a “what if” tornado scenario and predict their performances under an imminent hazard. It enables users to incorporate the laboratory testing dataset and engineering judgment to develop fragility curves when historical tornado damage data are not available for a specific type of house or site. A preliminary validation of the model is conducted used post-tornado damage survey data collected by the authors following the 2011 Joplin, MO tornado.

Performance-based hurricane engineering: a multi-hazard approach

V.U. Unnikrishnan and **Michele Barbato**

Louisiana State University

Hurricanes are among the most costly natural hazards affecting communities worldwide, in terms of both property damage and loss of life. The landfall of a hurricane involves different hazard sources (wind, windborne debris, flood, and rain) that interact to generate the hazard scenario for a given structure. Thus, hurricanes can be viewed and must be analyzed as multi-hazard scenarios. The multi-hazard nature of the phenomena related to hurricanes and their effects on the built environment can manifest in the following three different modalities: (a) independent hazards, when different hazards affect the structure independently; (b) interacting hazards, when the actions produced on a structure by different hazards are interdependent; and (c) hazard chains, when the effects of some hazards modify sequentially the effects of other hazards (Barbato et al., 2013).

In this paper, a probabilistic Performance-Based Hurricane Engineering (PBHE) framework (Barbato et al., 2013), based on the total probability theorem, is used for risk assessment of residential buildings subjected to hurricane hazard. The PBHE framework disaggregates the risk assessment analysis into independent elementary components, namely hazard analysis, structural characterization, interaction analysis, structural analysis, damage analysis, and loss analysis. The framework accounts for the multi-hazard nature of hurricane events by including the separate effects of, as well as the interaction among, hurricane wind, flood, windborne debris, and rainfall hazard.

The presented methodology is illustrated through an application example consisting of the risk assessment of a residential building subjected to wind, windborne debris, flood and rainfall hazards. The risk assessment includes the calculation of the annual hazard, fragility curves for different limit states, and annual probability of exceedance of repair cost of the building due to each hazard and their combined effects in the target residential area.

Wall of wind research and testing to enhance resilience of civil infrastructure to hurricane multi-hazards

Arindam Gan Chowdhury

Florida International University

The Wall of Wind (WOW) at Florida International University (FIU) is the largest and most powerful university research facility of its kind and is capable of simulating Category 5 hurricanes – the highest rating on the Saffir-Simpson Hurricane Wind Scale. The WOW facility has made a significant impact on the mitigation of hurricane damage to civil infrastructure through extensive research conducted by the wind engineering team at FIU's International Hurricane Research Center and Department of Civil and Environmental Engineering. This presentation will focus on WOW interdisciplinary research and testing to enhance the built environment's resilience to hurricane multi-hazards, including wind, rain, and debris. Hurricane engineering research at FIU has confirmed the effectiveness of large- and full-scale *holistic* testing approaches in advancing the understanding of hurricane impacts on buildings and other infrastructure elements, such as traffic and electrical infrastructure elements. Holistic testing procedures entail testing of systems consisting of integrated assemblies of components, as opposed to individual component testing. The latter type of testing can be misleading because it misses the interaction effect of different parts (components) of a structure, which can often be decisive in the understanding and estimation of failure processes and progressive collapse. WOW research has resulted in the development and validation of innovative damage mitigation products and techniques, including Roof Suction Mitigation Devices, Rooftop Equipment Wind Screens, and a Non-Intrusive Roof-to-Wall Connection System. Also, full-scale experimentation results were applied to improve Florida Building Code's wind load provisions on building roof mounted equipment for the State of Florida, including its High Velocity Hurricane Zones. The insurance industry views WOW testing as a development as revolutionary for wind engineering as crash testing -- which led to airbags and other safety features -- was for the automobile industry. The civil engineering community likens WOW to shake table testing, which has significantly contributed to the development of performance-based earthquake engineering. The new test-based data from the WOW facility will help create a sound scientific basis

for developing risk- and performance-based design criteria embodied in code provisions, and contribute to the attainment of a national objective: *achieving more sustainable, hurricane resilient, and energy efficient communities.*

Session 6: Fire, Blast, Shock and Impact

Mitigating disasters in the 21st century

Shalva Marjanishvili

Hinman Consulting Engineers, Inc.

Common engineering practice in multi-hazard design is to consider each natural hazard independently. The underlying assumption is that it is highly unlikely that one disaster will be closely followed by another. This approach dominated large part of the 20th century. As a result, today we have a good understanding of material constitutive modeling and efficient algorithms enabling large computer programs to run analysis on powerful computers. The engineering community has made large strides in designing structures to withstand known hazards, leading to improved reliability and safety of infrastructure. Improved reliability and safety in turn has supported population growth and increased prosperity. As witness to our success, it is common in developed nations to consider it unacceptable for a disaster to cause large scale devastation. However, the nature of the disasters has proved otherwise.

It is unlikely that one extreme event will have catastrophic consequences on communities, because we know how to prepare for a single event. Instead, as experience shows, disasters are more typically comprised by one event followed by one or more other events, exposing the vulnerability of our design assumptions. The examples of multiple disasters are Indonesia (i.e., earthquake followed by tsunami followed by volcano), Haiti (i.e., earthquake followed by cholera outbreak) and Japan (i.e., earthquake followed by tsunami followed by nuclear meltdown). Current methodologies for disaster preparedness and mitigation heavily rely on known methods of statistics and reliability theories to predict the outcome to a given series of events. This approach has a number of difficulties, such as: computers are not fast enough and answers are rarely definitive enough to make an informed and timely decision.

This presentation is focused on discussing the research needs to create efficient, simple and reliable computational methodologies to mitigate the effects of multiple sequential disasters on infrastructure systems.

Fire following earthquake: historical events and evaluation framework

Maria E. Moreyra Garlock, Negar Elhami Khorasani, and Paolo Gardoni

Princeton University

As part of the design procedure for resilient cities, an evaluation of the response of structures to multi-hazard events should be performed, and an assessment of their performance under primary (e.g. earthquake or blast) and secondary (e.g. fire) hazards should be completed. In particular, this presentation examines the multi-hazard context of fire following earthquake. There is disagreement amongst our profession if this is a real threat. So the presentation begins with a literature review by examining historical events of fire following earthquake, its consequences, and the vulnerability of California to this multi-hazard.

A building's structural consequences to fire following earthquake involves many uncertainties, such as the intensity and characteristics of both hazards, and the material properties of elements in the building. Therefore, a probabilistic evaluation framework is recommended for quantification of building performance under multi-hazard scenarios. The presentation introduces a methodology to quantify the probability of failure in steel buildings under post-earthquake fires. The methodology is general enough that can be extended to other structures and hazard scenarios. Previous research, performed on structural performance of post-earthquake fires, has studied the problem in different programming environments for seismic and thermal analyses and within a deterministic approach. This paper discusses the successes and challenges of performing nonlinear seismic and thermal analyses

in one programming environment and within a system-level probabilistic framework.

The proposed methodology to perform reliability analysis under post-earthquake fires is divided into three main parts: developing probabilistic models for the parameters with uncertainty, measuring reliability of structural element, and measuring reliability of the structural system. Example results are given for a 9-story steel building where it is seen that fire following earthquake increases the drift on columns located on the perimeter of the structure. Also, the location of fire in the frame (e.g. lower vs. upper floors) affects the local element response. Overall, this research shows that there is a need to develop a robust approach with integrated computational tools to design and evaluate structural systems under multi-hazard scenarios within a probabilistic framework.

Modeling of high temperature creep in ASTM A992 structural steels

Kapil Khandelwal

University of Notre Dame

Creep in structural steels at high temperatures has been widely observed in experiments; however its inclusion in numerical simulations has been limited due to the lack of creep data for ASTM A992 structural steels and the lack of the corresponding constitutive model for creep. In this study a new creep model for ASTM A992 steels is proposed and this model is calibrated to recently published experimental creep data for ASTM A992 steels. First, the physical mechanisms underlying the creep phenomenon in metals are revisited and the available creep models for the structural steels are presented in a consistent modeling framework. A hyperbolic sine model is then used to fit the experimental creep data for ASTM A992 steel and the corresponding best fit parameters are provided. Finally, high temperature creep buckling of ASTM A992 steel columns is examined using nonlinear fiber element models, and it is shown that creep can play an important role, especially at high temperatures and/or loads.

Innovative strategies for enhancing fire performance of FRP-strengthened concrete structures

Venkatesh Kodur

Michigan State University

In recent years there is a growing interest in the use of fiber reinforced polymers (FRP) for strengthening of concrete structures that are losing their functionality due to aging and corrosion related problems. This is mainly due to high strength, light weight, durability, cost effectiveness and ease of application of FRP which makes it attractive for fixing deteriorating infrastructure. Typically, the capacity of reinforced concrete (RC) columns can be enhanced by wrapping the columns with FRP sheets. Similarly strengthening of beams or slab can be carried out, for enhancing flexural and shear capacity, by applying FRP laminates to the surface of a concrete member and this is designated as externally bonded reinforcing (EB) technique. Alternatively, FRP strips or rods can be inserted into a pre-cut groove(s) on the concrete cover of an RC beam or slab, and then filling the groove(s) with an epoxy adhesive or cementitious grout, and this type of strengthening is referred to as near-surface mounted (NSM) technique.

Fire represents a significant hazard in buildings and thus FRP-strengthened concrete structural members have to meet adequate fire resistance requirements. However, comparatively little is known on the performance of FRP materials and FRP-strengthened concrete members under fire conditions, and this remains a primary factor limiting the widespread application of FRP in building applications.

In the past decade, a number of experimental and analytical studies have been carried out to develop an understanding on the behavior of FRP-strengthened RC beams at ambient conditions. Based on these studies, guidelines have been developed for structural design of FRP-strengthened concrete members. However, there have been only limited experimental and numerical studies on the fire resistance of FRP-strengthened concrete members. Thus, there is very little guidance available in codes and standards for the fire design of FRP-strengthened concrete members.

To overcome some of the current knowledge gaps, a series of experimental and numerical studies have been

carried out to evaluate fire response of FRP-strengthened concrete columns and beams. Data generated from fire tests was utilized to develop a macroscopic finite element for tracing the fire response of FRP-strengthened RC columns and beams under various configurations. The validated model was applied to conduct a set of parametric studies to quantify the influence of critical factors on fire response of FRP strengthened members. Results generated from fire resistance experiments and numerical studies are utilized to develop a rational design methodology for evaluating fire resistance of FRP-strengthened concrete members.

In the presentation, the performance problems associated with FRP-strengthened concrete structures will be illustrated. Data from both material testing and full-scale fire tests will be utilized to discuss fire performance of FRP strengthened concrete members. The various factors influencing fire response of FRP strengthened concrete members will be discussed and the development of a rational design methodology for evaluating fire resistance of FRP-strengthened concrete members will be outlined. Examples of innovative strategies that can be developed for enhancing fire performance of FRP-strengthened concrete structures will be presented. Overall, it is demonstrated that, while currently available FRP strengthening systems are sensitive to the effects of elevated temperatures, appropriately designed and protected FRP strengthened concrete structures are able to achieve satisfactory fire performance.

Notes

Throughout the world each year, natural disasters kill approximately 80,000 people, render millions homeless, and result in economic losses of \$50 billion-\$60 billion (WB and UN joint report).

Mitigation pays back at a ratio of over 1:5; for every dollar spent, more than \$5 are saved, not including measures of human suffering (World Bank, 2008).

There is a need for interdisciplinary research that advances risk determination, risk evaluation and risk management for natural and human-made hazards, and disaster response and recovery.

The mission of the MAE Center is to develop through research and disseminates through education and outreach new integrated approaches to minimize the consequences of future natural and human-made hazards. Specifically, the MAE Center has been creating a Multi-hazard Approach to Engineering by conducting interdisciplinary research to estimate damage and vulnerability across regional and national networks, and characterize different hazards. Through these activities, the center has been supporting stakeholder and societal interests in risk assessment and mitigation.

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