Inaugural Ceremony of the International Joint Research Center for Engineering Reliability and Stochastic Mechanics (CERSM) &

International Workshop on Engineering Reliability and Stochastic Mechanics (IWERSM 2016)

(May 31, 2016, Shanghai, China)

Organized by : *International Joint Research Center for Engineering Reliability and Stochastic Mechanics*

Tongji University
Rice University
University of Southern California
University of Western Ontario
Leibniz University Hannover
Kanagawa University
Aalborg University
Trinity College Dublin

International Workshop on Engineering Reliability and Stochastic Mechanics (IWERSM 2016)

WORKSHOP PROGRAM

Organized by

International Joint Research Center

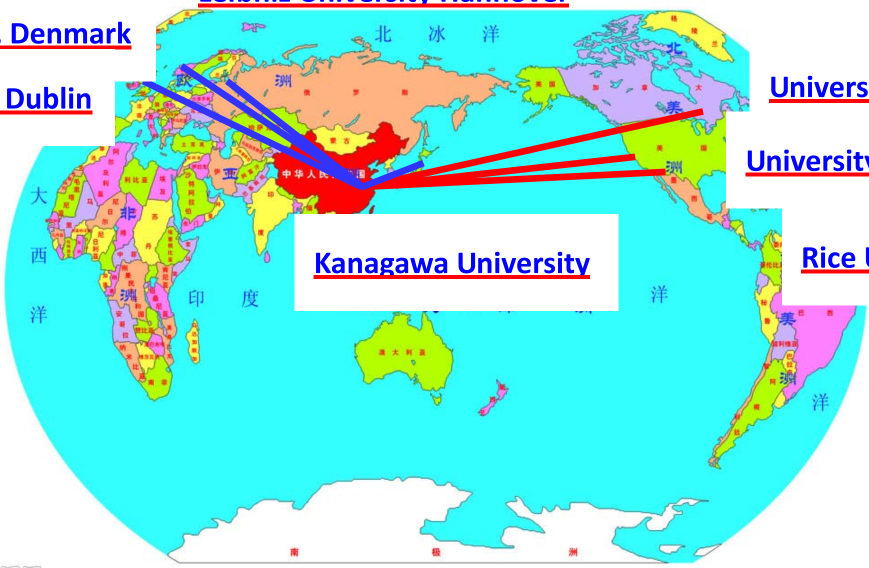
for Engineering Reliability and Stochastic Mechanics

May 31, 2016, Shanghai, China

International Joint Research Center for Engineering Reliability and Stochastic Mechanics (CERSM)

Director	Co-Director	Chairman of the Advisory Committee
Prof. Jie Li	Prof. Pol D. Spanos	Prof. A H-S. Ang
		

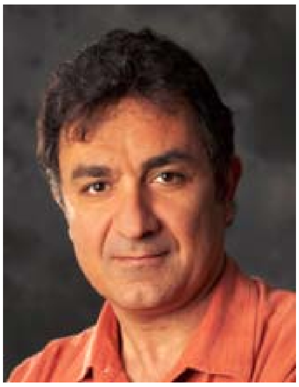
International Partners



International Guest Professors

Prof. P. Spanos
Rice U.

Prof. S.R.K.Nielsen
Aalborg U.



Prof. R.Ghanem
USC

Prof. H.P.Hong
U. W. Ontario

Prof. M.Beer
U. Hannover

Prof. B.Basu
Trinity College Dublin

Prof. Y.G.Zhao
Kanagawa U.

Research fields

- Reliability of structures;
- Reliability of engineering systems;
- Uncertainty quantification methods;
- Modeling of randomness;
- Big-data based emerging techniques in uncertainty quantification;
- Stochastic dynamics;
- Stochastic solid mechanics;
- Multi-scale physical mechanics;
- Applications to civil engineering, offshore engineering, and related areas.

Program Overview, May 31, 2016

Venue: Auditorium A101, Civil Engineering Building

08:30-09:00	**Opening Session**	**Chair: Jianbing Chen**
09:00-10:30	**Keynote Lectures**	**Chair: Bruce R. Ellingwood**
09:00-09:45	**Alfredo H-S. Ang,** 美国工程院院士，国际结构安全性与可靠性协会（**IASSAR**）原主席，美国土木工程师协会 **Freudenthal** 奖章获得者 **Modelling Uncertainty and Minimizing its Effects in Design of Critical Systems**	
09:45-10:30	**Pol D. Spanos** 美国工程院院士，欧洲科学院外籍院士，**IASSAR 10** 人执行委员会委员，**Freudenthal** 奖章获得者 **Potent Emerging Techniques for Stochastic Mechanics Approaches in Civil Engineering Applications**	
10:30-10:45	**Coffee Break**	
10:30-12:00	**Keynote Lectures**	**Chair: Pol D. Spanos**
10:30-11:15	**Bruce R. Ellingwood** 美国工程院院士，**IASSAR 10** 人执行委员会主席，**Freudenthal** 奖章获得者 **The Science Behind Understanding Attributes that Make A Community Disaster-Resilient**	
11:15-12:00	**Dan M. Frangopol & M. Akiyama** **Dan M. Frangopol,** 欧洲科学院外籍院士，**IASSAR 10** 人执行委员会原主席 **Reliability of Aging Structures under Multiple Hazards: Emphasis on Highway Bridges under Earthquake and Tsunami**	
12:00-14:00	**Lunch**	

14:00-15:30	**Keynote Lectures**	**Chair: Jie Li**
14:00-14:45	**Michael Havbro Faber** 国际结构安全性联合委员会（**JCSS**）原主席，国际土木工程风险与可靠性协会（**CERRA**）主席 **Supporting Decisions for Resilient Infrastructures**	
14:45-15:30	**Hanping Hong** 墨西哥工程院外籍院士，中国国家高端外国专家 **A Nonstationary Wind Model & Its Applications**	
15:30-15:45	**Coffee Break**	
15:45-17:15	**Keynote Lectures**	**Chair: Michael Havbro Faber**
15:45-16:30	**Roger Ghanem** 美国土木工程师协会工程力学学会**(ASCE-EMI)**原主席， 中国国家高端外国专家 **Reliability in the age of high fidelity sensors, multiscale models and high-performance computing**	
16:30-17:15	**Jie Li** 教育部首批长江学者，**IASSAR 10** 人执行委员会委员，**CERRA 12** 人主席团成员，**Freudenthal** 奖章获得者 **New Advances of Probability Density Evolution Method**	
17:15-17:45	**Closing Ceremony**	**Chair: Jianbing Chen**
18:30-20:30	**Banquet**	

Bio-Sketches for Keynote Lecturers

Alfredo H-S. Ang

Dr. Ang is currently Research Professor and Professor Emeritus at the University of California in Irvine, California, USA. He is also Professor Emeritus at the University of Illinois at Urbana-Champaign since 1988 where he received his Ph.D. in 1959 and was on the faculty of Civil Engineering from 1959 through 1988.

His main area of research is on the application of probability and reliability in civil and structural engineering, with emphasis on safety of engineering systems, including seismic risk and earthquake engineering, quantitative risk assessment (QRA), life-cycle cost and performance, sustainability of green buildings and infrastructure. He has published about 450 papers and articles, and also a two-volume textbook on probability concepts in engineering, which have been translated into several languages; the 2nd edition of Vol I was published in February 2007. During his academic career, he has directed 55 Ph.D. students and countless post-doctoral researchers from many parts of the world. He has given invited keynote papers and lectures in numerous major national and international conferences, including the 2009 Freudenthal Keynote Lecture at the ICOSSAR'09 in Osaka, Japan and the 2010 Kwang-Hwa keynote at the ISRERM2010 in Shanghai, China.

During his career, he has been serving as consultant and technical adviser to government and industry on technological risk and reliability issues, both in the U.S. and abroad, including the U.S. Department of Defense on nuclear defense, the U.S. Navy on surface effect ships and the mobile offshore base, the U.S. Air Force on missile defense, and the U.S. Coast Guard on marine and offshore structures. He has been involved in a number of other major studies and projects on the seismic safety analysis and design of nuclear power plants in the U.S., Japan, Taiwan, and Korea, and earthquake resistant design of buildings, bridges and other critical infrastructure.

He is active in several engineering societies particularly in the American Society of Civil Engineers where he served as International Director on the Board of Directors in 1998-2001, and as Chair of numerous technical committees including the Structural and Engineering Mechanics Divisions executive committees. He was the ASCE representative to the Asian Civil Engineering Coordinating Council (ACECC) in 2005-2011, and a member of the International Activities Committee. He is also a Fellow of the ASME (American Society of Mechanical Engineers), Associate Fellow of the AIAA (American Institute of Aeronautics and Astronautics), a founding member of IASSAR (International Association of Structural Safety and Reliability), Honorary President of IALCCE (International Association of Life-Cycle Civil Engineering), and a member of several other professional and scientific societies.

He is a member of the prestigious US National Academy of Engineering (elected in 1976) and has received a large number of prestigious awards from the ASCE and other societies, including Honorary Membership in the ASCE and the N.M Newmark Medal, A. Freudenthal Medal, E. Howard Award, Huber Research Prize, State-of-Art Award; the Senior Research Award from ASEE (American Society of Engineering Education); and Research Award from IASSAR; Research Award from the University of California, Irvine; Distinguished Engineering Alumni Award from the University of Illinois; and the 2005 International Prize from the Japan Society of Civil Engineers.

Pol D. Spanos

Professor Pol D. Spanos received his undergraduate degree in Mechanical Engineering and Engineering Science from the Technical University in Athens, Greece and his graduate education at CalTech, where he was awarded the MS degree in Civil Engineering and the Ph.D. degree in Applied Mechanics, with minor-I in Applied Mathematics and Minor-II in Business Economics. His interests are in the area of dynamics and vibrations, with emphasis on probabilistic, non-linear, and signal-processing aspects; and with applications to structural engineering, aerospace engineering, offshore engineering, vehicle engineering, bio-mechanics, and composite materials. He has supervised the MS theses of 75 students and the Ph.D. theses of more than 50 students. His research findings have been disseminated in more than 300 papers in archival journals, technical conferences, and industrial reports. He is Editor-in-Chief of the International Journal of Non-Linear Mechanics, and of the Journal of Probabilistic Engineering Mechanics. He is a Fellow of ASCE, ASME, the American Academy of Mechanics, and the Alexander von Humboldt Association. He has served both as a Chair of the Engineering Mechanics Divison of ASCE and as Chair of the Applied Mechanics Division of ASME He has received numerous awards from ASCE,ASME,The Alexander Von Houmboldt Foundation (senior researcher award),the Chinese National ChangJiang Chair Committee, and the International Association for Structural Safety and Reliability He is a member of the Academy of Athens (National Academy of Greece); the National Academy of Engineering (USA); the Indian National Academy of Engineering; and of Academia Europaea(The Academy of Europe)

Bruce R. Ellingwood

Dr. Ellingwood received his graduate education at the University of Illinois at Urbana-Champaign, and his career of more than forty years has spanned federal agencies and academe. His research and professional interests involve the application of methods of probability and statistics to structural engineering and risk-informed decision-making. He is internationally recognized as an authority on the analysis of structural loads and load combinations, performance of structures under occupancy, environmental and abnormal load conditions, reliability and risk analysis of engineered facilities, and as a leader in the technical development and implementation of probability based codified design standards. He is the author of over 400 technical publications, is Editor of Structural Safety and serves on several other editorial boards. He has held numerous leadership positions in professional societies, including ASCE, AISC, and IASSAR, and is recipient of numerous awards from ASCE and other professional organizations. He is a member of the U.S. National Academy of Engineering.

Dan M. Frangopol

Dr. Dan Frangopol is the first holder of the Fazlur R. Khan Endowed Chair of Structural Engineering and Architecture at Lehigh University. Before joining Lehigh University in 2006, he was Professor of Civil Engineering at the University of Colorado at Boulder, where he is now Professor Emeritus. In 1976, he received his doctorate in Applied Sciences from the University of Liège, Belgium. He is recognized as a leader in the field of life-cycle engineering of civil and marine structures. His main research interests are in the application of probabilistic concepts and methods to civil and marine engineering including structural reliability, probability-based design and optimization of buildings, bridges and naval ships, structural health monitoring, life-cycle performance maintenance, management and cost of structures and infrastructures under uncertainty, risk-based assessment and decision-making, infrastructure sustainability and resilience to disasters, and stochastic mechanics. Dr. Frangopol is the Founding President of the International Associations for Bridge Maintenance and Safety (IABMAS) and Life-Cycle Civil Engineering (IALCCE). He has authored/co-authored 2 books, 40 book chapters, 320 articles in archival journals, including 9 prize winning papers, and many papers in conference proceedings. He is the Founding Editor of Structure and Infrastructure Engineering and of the Book Series Structures and Infrastructures. He is the recipient of several medals, awards, and prizes, from ASCE, IABSE, IASSAR, and other professional organizations, such as the OPAL Award, the Newmark Medal, the T.Y. Lin Medal, the F. R. Khan Medal, and the Croes Medal (twice), to name a few. He holds 4 honorary doctorates and 12 honorary professorships from major universities. He is a foreign member of the Academia Europaea (Academy of Europe, London), an Honorary Member of the Romanian Academy of Technical Sciences, and a Distinguished Member of ASCE. For additional information please visit http://www.lehigh.edu/~dmf206/

Mitsuyoshi Akiyama

Professor, Department of Civil and Environmental Engineering, Waseda University, Tokyo Japan. Dr. Akiyama was Assistant and Associate Professor of Civil Engineering at Tohoku University from 1998 to 2011 before joining Waseda University in 2011. In 2001, he received a doctorate in Civil Engineering from Tohoku University. Dr. Akiyama was a Visiting Research Associate at Lehigh University from October 2008 to September 2009 in the research group of Professor Frangopol under the auspices of the Kajima Foundation. Since his stay at Lehigh University, Dr. Akiyama has collaborated with Professor Frangopol, and they have published several research papers on earthquake engineering, life-cycle structural performance, safety and reliability in structural engineering, and application of probabilistic concepts and methods to the design of civil structures. Dr. Akiyama is the recipient of several awards including the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, JSCE Yoshida Award in 1998, 2007, and 2010, JSCE Encouragement Award for Outstanding Thesis in 2007, and the JCI Award for Engineering Development in 2001. For additional information please visit
http://www.f.waseda.jp/akiyama617/professor/index_e.html

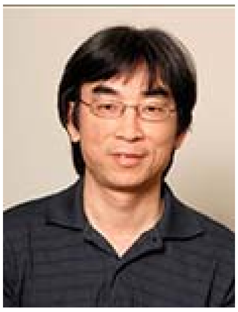
Michael Havbro Faber

Michael Havbro Faber is head of department and professor of risk and safety at the department of civil engineering. On November 1, 2015 he will devote his full time to research and teaching in the field of reliability, risk and safety in engineering in the newly established DTU centre; the Global Decision Support Initiative (GDSI), which he was an initiator of in 2014.

His research interests are directed on decision theory, life safety investments, risk assessment, global catastrophic risks, uncertainty modeling, Bayesian probability theory and applied statistics. Application areas include risk and reliability informed decision making for design, assessment and maintenance optimization of bridges, tunnels, buildings, offshore installations, ship structures, roadway traffic systems and space structures as well as for management of natural hazards including earthquakes, hurricanes, floods, rock-fall and avalanches. His industrial experience mostly originates from COWI, Denmark, Det Norske Veritas, Norway and on-going consultancy work through the specialist consulting company Matrisk GmbH of which he is a founding partner since 2001.

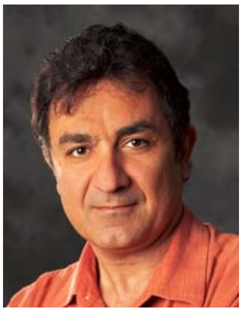
He has been actively involved and taken leadership in several international committees, including: The Joint Committee on Structural Safety (JCSS); acting vice-president, the International Forum on Engineering Decision Making (IFED); founding and acting president, the ISO 2394 Principles of Reliability of Structures; convener, the international Civil Engineering Reliability and Risk Association (CERRA); president, The World Economic Forum, member of Global Agenda Council on Catastrophic Risks, the OECD High Level Risk Forum and the Danish Academy of Technical Sciences.

Hanping Hong



Dr. H.P. Hong is a Professor in the Department of Civil and Environmental Engineering at the University of Western Ontario. He is a foreign member of The Mexican Academy of Engineering, and a fellow of Canadian Society of Civil Engineering. He has expertise in the areas of application of probabilistic analysis, reliability and risk assessment, and natural hazard assessment and evaluations. He has contributed to the reliability-based and economic efficient structural design code development and calibration. He received several awards for his published research works.

Roger Ghanem



Roger Ghanem is Professor in the Departments of Aerospace & Mechanical Engineering and Civil & Environmental Engineering at the University of Southern California where he also holds the Gordon S. Marshall Professorship in Engineering Technology. Dr. Ghanem’s research is focused on risk, reliability, and uncertainty quantification in computational science and engineering and has developed the functional analytic approach to uncertainty modeling as a relevant tool in computational science and engineering. He has worked for the past thirty years to clarify scientific, mathematical and algorithmic foundations of these methods across several applications and disciplines. Dr. Ghanem has co-authored over 300 technical articles related to polynomial chaos methods and more generally, to uncertainty quantification and management. He has supervised the research of over 20 postdoctoral associates, 27 PhD students, and numerous Masters and Undergraduate students.

Dr. Ghanem is an elected member of the US National Committee on Theoretical and Applied Mechanics, an elected member of the Executive Council of the US Association of Computational Mechanics, and a past President of the ASCE Engineering Mechanics Institute. He is the founding Chair of the USACM Committee on Uncertainty Quantification and founding Board member of the SIAM Activity Group (SIAG) on UQ. He taught several short courses on UQ and has organized several workshops on Uncertainty Quantification and Validation.

Dr. Ghanem is the recipient of numerous awards acknowledging his research and teaching contributions.

Jie Li

Prof. Jie Li is currently a Chair Professor in the Structural Engineering at Tongji University in the School of Civil Engineering. He specializes in the area of earthquake engineering and stochastic mechanics. Prof. Li received a Ph.D. in Civil Engineering from Tongji University, China in 1988, and received an honorary doctorate in engineering from Aalborg University, Denmark in 2013. Prof. Jie Li receives the 2014 Alfred M. Freudenthal Medal from ASCE. He has been one of the first group of Cheung Kong Scholar Professors entitled by the Ministry of Education of China since 1999. Prof. Li is the author of six monographs, and is the co-author of over 350 technical publications, including over 300 peer reviewed journal papers, in the fields of earthquake engineering and stochastic structural analysis. He currently serves as one of executive board members of International Association for Structural Safety and Reliability (IASSAR), and one of board directors of International Civil Engineering Risk and Reliability Association (CERRA). Prof. Li serves as the chairman of the Committee of Structural Computational Theory and Engineering Applications of the Architectural Society of China, and the chairman of the Random Vibration Committee of Chinese Society of Vibration Engineering. He is the editor-in-chief of the *Journal of Tongji University (Natural Science Series)* and is in the editorial boarding committee of over 10 international and Chinese academic journals, including the *International Journal of Nonlinear Mechanics* and *Earthquake Engineering and Engineering Vibrations*.

Michael Beer

Michael Beer is Professor and Head of the Institute for Risk and Reliability, Leibniz Universität Hannover, Germany, since 2015. He is also part time Professor at the University of Liverpool and at Tongji University. He obtained a doctoral degree from the Technische Universität Dresden and pursued research at Rice University, supported with a Feodor-Lynen Fellowship from the Alexander von Humboldt-Foundation. From 2007 to 2011 Dr. Beer worked as an Assistant Professor at National University of Singapore. In 2011 he joined the University of Liverpool as Chair in Uncertainty in Engineering and Founding Director of the Institute for Risk and Uncertainty. In 2014 he established the EPSRC and ESRC Centre for Doctoral Training in Quantification and Management of Risk & Uncertainty in Complex Systems & Environments. Dr. Beer's research is focused on non-traditional uncertainty models in engineering with emphasis on reliability analysis. He is Editor in Chief (jointly) of the Encyclopedia of Earthquake Engineering, Associate Editor of the ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Associate Editor of the International Journal of Reliability and Safety, and Member of twelve Editorial Boards including Probabilistic Engineering Mechanics, Computers & Structures, Structural Safety, Mechanical Systems and Signal processing, and the International Journal of Computational Methods. He has won several awards including the CADLM PRIZE 2007 – Intelligent Optimal Design. His publications include a book, several monographs and a large number of journal and conference papers. He is a Fellow of the Alexander von Humboldt-Foundation and Member of ASCE (EMI), ASME, IACM, ESRA, EASD, C(PS)2 of the Bernoulli Society and GACM. Dr. Beer has continuously led various research projects with focus on both theoretical developments and applications. He is partner and leader for large-scale research programs with a multi-million grant volume.

ABSTRACTS

Modelling Uncertainty and Minimizing its Effects in Design of Critical Systems

Alfredo H-S. Ang

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Abstract:

Uncertainties in engineering may be classified into two broad types– the aleatory and the epistemic types. The effects of both types of uncertainty are important and must be incorporated in formulating criteria for the design of structures. From a reliability-based standpoint, the central issue in a design criteria is the specification of the required target reliability; e.g., in terms of a required safety index.

The issue is especially important in the design of complex critical systems. In other words, these are systems for which the required criteria for design are not or cannot be covered by existing standards. The recent development of the PDEM (probability density evolution method) provides a relevant avenue for developing the desired reliability-based target safety index.

The PDEM is known for its effectiveness for assessing the reliability of a complex system due to the effects of the aleatory uncertainty. The result in terms of the PDF of the ultimate performance function of a system is particularly significant as it facilitates the inclusion of the epistemic uncertainty leading to the PDF of the overall system reliability (or safety index). This latter PDF then permits the selection of the target reliability with high confidence levels for design, and thus serves to minimize the effects of the epistemic uncertainty.

Based on the confidence levels that are consistent with good professional practice in the successful design of existing critical systems, such as offshore production platforms and cable-stayed bridges, it appears that target reliabilities for design with confidence levels within 90%-95% are reasonable and acceptable. Therefore, this range of confidence levels, i.e. 90%-95%, is suitable for specifying the required safety index for the design of critical engineering systems.

Key Words: engineering reliability; uncertainty modeling, critical system design

Potent Emerging Techniques for Stochastic Mechanics Approaches in Civil Engineering Applications

Pol D. Spanos

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spanos@rice.edu

Abstract:

The lecture will focus on emerging techniques for addressing stochastic mechanics approaches in civil engineering applications. Particular emphasis will be first put on techniques for capturing localization aspects of evolving frequency content of excitations and responses. Secondly, attention will also be focus to techniques affording capturing of non-local influence in material behaviour. This will be done with particular reference to civil engineering structures. For the first objective the technique of wavelets based representation of time dependent signals will be used; specific references will be made to the use of wavelet based representations in nonlinear structure responses. For the second objective, the concept of fractional calculus will be introduced as a potent tool for nonlocal analysis both for linear and nonlinear behaviour. In addition to the discussion on wavelets and fractional calculus, comments will be made about other developing themes and techniques as they apply to modern problems of civil engineering.

Key Words: stochastic processes, localization, wavelets, nonlinearity, nonlocal mechanics, fractional calculus

The Science behind Understanding Attributes that Make a Community Disaster-Resilient

Bruce R. Ellingwood, Ph.D., P.E., N.A.E.[1]

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Abstract:
Community resilience depends on the performance of the built environment and on supporting social, economic and public institutions which, individually and collectively, are essential for immediate response and long-term recovery within the community following a disaster. The science to measure resilience quantitatively for risk-informed decision-making currently does not exist [1]. A community's social needs and objectives (including post-disaster recovery) are not reflected in the codes, standards and other regulatory documents that engineers typically apply in designing individual facilities [2]. A new approach is needed which reflects the complex inter-dependencies among the physical, social and economic systems on which any healthy community depends. No one discipline has the ability to model community resilience comprehensively; modeling the resilience of communities and urban areas to natural hazards depends on many disciplines, including engineering, social sciences, and information sciences. The vast majority of research on community resilience in the past decade has focused on the impact of severe earthquakes on the physical infrastructure in communities [3, 4], with little attention paid to other natural hazards, including those that might be impacted by climate change [5]. Resilience assessment has become a national imperative, with Presidential Policy Directive 21 [6] providing the impetus for numerous Federal programs in the United States.

The Center for Risk-Based Community Resilience Planning, headquartered at Colorado State University in Fort Collins, Colorado and involving ten universities and nearly 100 investigators, was established by The National Institute of Standards and Technology (NIST) in 2015. The Center's overarching goal is to establish the measurement science for understanding the factors that make a community resilient, to assess the likely impact of natural hazards on communities, and to develop risk-informed decision strategies that optimize planning for and recovery from disasters. To accomplish this goal, the Center is engaged in three major research thrusts. Thrust 1 is developing a multidisciplinary computational environment with fully integrated supporting databases, known as NIST-CORE, which will enable the inter-relationships between physical and social infrastructure systems that determine community resilience to be fully understood and will facilitate resilience planning and risk communication among stakeholders. Thrust 2 is producing a standardized data ontology, robust data architectures, and effective data management tools to support the computational environment developed in Thrust 1. Thrust 3 will validate the resilience data architecture through a series of testbeds that stress the process of data collection, its integration into the computational modeling environment, and the risk-informed decision algorithms.

This presentation provides an overview of the Center's current research activities, explaining the process by which resilience science will be developed over the next five years to support risk-informed decision-making in the public and private sectors. Distinct research tasks include multiple hazards and their cascading effects on infrastructure, identification and articulation of performance metrics and requirements at the community level, the role of supporting and interfacing economic networks and social systems in community resilience planning and assessment, aging

infrastructure, uncertainty analysis and propagation, and standardization of databases. Several community testbed problems are currently being developed, and one of these will be presented in detail. That testbed is designed specifically to allow research teams to initiate, test and modify essential resilience assessment models and algorithms early in the program and prior to when NIST-CORE becomes fully operational; to stress these assessment models in a controlled manner; to examine varying degrees of dependency between physical, social and economic infrastructure systems; to allow issues of scalability in community infrastructure modeling to be addressed; to inform the subsequent development of more refined community resilience assessment methods; and to facilitate interdisciplinary collaborations and approaches to community resilience assessment at an early stage in the development of the NIST-CORE platform. The testbed involves a moderate-size community in the Central United States that is susceptible to earthquake and tornado hazards. It is an average community in most respects, with median household income that is close to the national average in the United States, although there are pockets of low-to-moderate income residents who may be especially vulnerable to a natural disaster. Its economy is diversified, with comercial/retail, profesional services, education/healthcare, industry and government sectors. There are several large employers, including a large box store, a relatively large industrial facility and a regional hospital. The physical infrastructure includes a variety of residential, comercial and industrial buildings, bridges and transportation facilities, and utility networks, each of which represents a distinct spatial infrastructure topology. The presentation will illustrate how these different physical, social and economic infrastructure systems are integrated together to provide quantitative measures of the resilience of this typical community. Such information is invaluable both in community advance planning for a disaster as well as in planning for post-disaster recovery. It will be shown how this testbed informs the subsequent development of more refined interdisciplinary community resilience assessment methods used for planning and decision purposes at appropriate scales and resolutions. The presentation will conclude with an identification of significant research and implementation challenges facing the Center and a summary of projected Center research activities designed to address them.

Key Words: Buildings, Civil infrastructure, Decision algorithms, Hazards, Life-Cycle engineering, Risk, Transportation Networks.

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Reliability of Aging Structures under Multiple Hazards: Emphasis on Highway Bridges under Earthquake and Tsunami

Dan M. Frangopol[1] and Mitsuyoshi Akiyama[2]

[1] *Department of Civil and Environmental Engineering, Lehigh University, Bethlehem, PA 18015-4729, USA*
[2] *Department of Civil and Environmental Engineering, Waseda University, Tokyo 169-8555, Japan*
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Abstract:
The transportation networks including bridges are one of the most critical civil infrastructure systems when a natural disaster occurs (Decò & Frangopol 2011, 2013, Frangopol & Bocchini 2011, 2012). Since the bridge transportation network plays a crucial role in the evacuation of affected people and the transportation of emergency goods and materials, its functionality has to be recovered as soon as possible (Unjoh 2012). A prompt restoration of the critical infrastructure facilities after an extreme event is always a goal of paramount importance (Bocchini & Frangopol 2012a, b).

No structural system can be engineered and constructed to be absolutely risk free because of the aleatory and epistemic uncertainties associated with the system performance (Ang & Tang 2007, Ellingwood 2006). In addition, constructing bridges with very high performance requirements to prevent any damage or failure from a severe earthquake and/or giant tsunami would be unfeasible. Bridge risk assessment is useful in circumstances in which the occurrence of extreme events is rare but their consequences would be severe. Tools that can be used in risk-informed decision making for performance assessment and optimal life-cycle management of bridges under low-probability high-consequence events are developing rapidly.

This invited lecture presents a probabilistic life-cycle methodology for bridges under multiple hazards with an emphasis on earthquake, tsunami, and continuous deterioration. First, a framework for computing the reliability of bridges in an earthquake-prone region and a marine environment is presented. Second, a procedure for estimating bridge reliability under tsunami is presented. Little attention has been devoted to the assessment of the reliability of bridges under tsunami hazard. To evaluate potential tsunami risk or to quantify the promptness of the restoration of the transportation network, a probabilistic estimation of tsunami impact on bridges is necessary. However, this approach is still in the early stages of development (Akiyama et al. 2013). In this lecture, the procedure for establishing a tsunami fragility curve based on simulation and estimating the reliability of a bridge under tsunami hazard is presented. Based on the tsunami fragility and bridge importance, bridges that require additional attention to achieve tsunami resistance must be identified. Comparing life-cycle reliabilities among bridges belonging to a network under seismic and tsunami hazards and hazards associated with continuous deterioration makes the determination of the priority for upgrade and/or repair actions possible.

In the seismic design of bridge structures, brittle failures, such as shear failures, have to be avoided in the components, and a plastic hinge should be formed at the bottom of the bridge pier. These are important requirements in capacity design to guarantee the satisfactory performance of bridges subjected to severe earthquakes (Priestley et al. 1996, Akiyama et al. 2012). These requirements can maximize post-event operability and minimize the need for repair work to damaged bridges after a severe earthquake. To ensure functionality of the transportation network after an event, an optimal hierarchy of resistance of the various bridge components must be identified depending on the hazard

environment. In this lecture, reliability-based capacity design of bridges under seismic and tsunami hazards and hazards associated with continuous deterioration is also discussed.

Key Words: reliability, hazard, fragility, bridges, deterioration, earthquake, tsunami

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Supporting Decisions for Resilient Infrastructures

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Abstract:

Introduction and motivation

During the last 3-4 decades resilience of societal infrastructures has attained a significant interest and importance as a research topic Pimm [1] but also more recently as a focal point on the global political agenda as one of the concerns in the context of climate change and sustainable societal developments. Societal infrastructures such as energy production and distribution systems, housing, workplace and production building systems, transport systems, communications systems, food production and distribution systems, waste disposal and treatment systems play a very significant role for the success of society in the short, medium and not least in the long run. On the one side societal infrastructures provide indispensable functionalities to society and fundamentally provide the basis for economic growth, health and welfare. On the other side societal infrastructures constitute one of the major consumers of raw materials, space, energy and water and thereby severely impose stresses to the environment and at the same time represent significant economic investments and substantial expenditures in terms of maintenance and renewals. Helbing [2] points to serious gaps in the general body of knowledge concerning the performance of complex interlinked systems and highlights that even smaller and localized disturbances of interlinked systems have the potential to trigger scenarios of cascading failures with widespread and disastrous consequences and calls for increased research efforts and focus to close these gaps.

Resilience interpreted as a systems ability to plan for, recover from and adapt to adverse events over time (NAS [3]) provides a strong concept and relevant objectives for the design, operation and management of infrastructure systems however, does not give much guidance on how to achieve these. Linkov [4] points to the many challenges associated with assessing and ensuring the resilience of systems, suggests that present practices of risk based approaches for ensuring resilience are not adequate and calls for the development of a new paradigm.

With the present contribution I forward the proposition to utilize decision analysis as basis for supporting decisions on how to design, operate and manage societal infrastructures. The following contains an extract of the associated lecture where this was elaborated in more detail and also includes concrete suggestions on how to proceed.

Supporting decisions for resilient infrastructures

Bayesian decision analysis (Raiffa and Schlaifer, [5]) provides a theoretical and methodical basis for the ranking of decision alternatives in full consistency with available knowledge, the influencing uncertainties and the preferences of the decision maker. To benefit from this it is necessary to formulate probabilistic models for the performances of the systems as well as the preferences of the decision maker with respect to the possible outcomes of the decisions. Crucial issues obviously concern the probabilistic modeling of the considered systems and also the identification of strategies and options for their design, operation and management. To be able to take benefit from decision analysis these two issues must be appropriately addressed and that necessitates not only expertise with respect to infrastructure systems but also expertise with respect to the other systems with which these are interlinked. This demand in turn calls for collaborative research efforts between the scientists which normally are focusing on individual systems. In support of the modeling of interlinked systems and in support of formulating strategies for their design, operation and management it is instructive to collect insights and perspectives from the different sciences working with systems. With reference to Holling [6], Derissen et al. [7], Cutter et al. [8] and Anderies [9] the following observations from the field of sociology,

ecology and socio-ecology may be identified:

- System failures often occur in scenarios starting with disturbances causing localized damages which then in a second phase evolve into cascading events of failures till the system looses its functionality partly or fully.
- Random variability may significantly affect the performance of systems.
- There typically exist several domains of attraction for the parameters governing the performances of systems. Resilience can be related to the intensity of the disturbance which is sufficient to perturb a system from one such domain to another.
- Resilience is not necessarily good in the sense that the performance of some systems might improve after a disturbance.
- Ecological systems often take benefit from different types of strategists (species) in succession after major disturbances, i.e. r-strategist and K-strategists. r- strategists being simper, with higher rate of reproduction and less efficient and K-strategists be more complex, lower rate of reproduction, specialized and efficient.
- Systems with a high number of alternative r- and K- strategists (redundancy and diversity) tend to perform more resilient.
- The performance of a socio-ecological system critically depends on the accumulated capacity of the sociological system prior to the disturbance.
- A social-ecological system does not necessarily fail due to the failure of ecological system.
- Systems in which the stakeholders are informed and fairly regulated fairly tend to perform more resilient.

Many of these observations are consistent with insights from the engineering sciences normally engaged in the design, operation and management of infrastructure systems and thereby support and augment these for their utilization as part of the model basis across different types of systems. It is suggested that the framework for risk informed decision making for systems suggested by the Joint Committee on Structural safety (JCSS, [10]) is utilized as basis for the modeling of interlinked systems with the necessary modifications to account for the representation of the accumulation of capacity of the interlinked systems over time.

<u>The role of civil engineering and structural mechanics</u>

Appreciating that the profession of civil engineering and structural mechanics play leading roles in the planning and realization of the built environment, a major constituent of most societal infrastructures it appears pertinent that this profession take also a leading role in ensuring that the built environment is resilient. The long and strong traditions in stochastic mechanics regarding probabilistic modelling and analysis of systems as well as in applied decision analysis should comprise an adequate platform for this.

Key Words: Resilience, interlinked systems, infrastructure, decision analysis, uncertainty

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A Nonstationary Wind Model & Its Applications

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Abstract:
Wind speeds are often represented as superposition of the mean and fluctuating components. For stationary winds, the fluctuating wind speed is characterized by its power spectral density (PSD) function such as the von Karman spectrum, Davenport spectrum or Kaimal spectrum [1]. For example, the Kaimal spectrum of the fluctuating wind $u(t)$, $S_u(n)$, for wind with the mean wind speed at z m above the ground $U(z)$, is given by,

$$S_u(n) = \frac{(\sigma(z))^2}{6}\frac{200(z/U(z))}{(1+50(nz/U(z)))^{5/3}} \tag{1}$$

where $\sigma(z)$ denote the standard deviation of $u(t)$, and n Hz represents the frequency. The simulation of the fluctuating winds can be carried out using several approaches, including the spectral representation method (SRM) [2]. However, winds caused by thunderstorms/downbursts exhibit time-varying mean wind speed [3-5]. Several studies [4-6] considered that the nonstationary fluctuating wind component can be represented by a uniformly modulated stochastic process. It implicitly assumes that the frequency content of the fluctuating winds does not change with the time-varying mean wind speed. This is inconsistent with that the frequency content of $u(t)$ depends on the mean wind speed. To maintain the dependency of the frequency content on the mean wind speed for nonstationary winds, first, we note that by letting $\tau = (U(z)/z)t$ and $\tilde{u}(\tau) = u(t)/\sigma(z)$, it can be shown that the PSD functions of $\tilde{u}(\tau)$, $S_{\tilde{u}}(\zeta) = (U(z)/z)\times S_u(n)/\sigma^2(z)$, where $\zeta == nz/U(z)$ denotes the reduced frequency. This leads to,

$$S_{\tilde{u}}(\zeta) = \frac{1}{6}\frac{200}{(1+50\zeta)^{5/3}} \tag{2}$$

Now, for the wind with time-varying mean wind $U(z,t)$ and a nonstationary fluctuating component $u(t)$ with a time-varying standard deviation $\sigma(z,t)$, it is considered that the nonstationary process $u(t)$ can be represented by,

$$u(t) = \sigma(z,t)\times\tilde{u}(\tau(t)) \tag{3}$$

where $\tilde{u}(t)$ is a stationary process (in which $\tau = \tau(t)$) with a PSD function $S_{\tilde{u}}(\zeta)$ shown in Eq. (2), and the time transformation $\tau(t)$ is a smooth and strictly increasing function of t. Following [7], it can be shown that the power spectral density function of $S_u(n,t)$ is given by,

$$S_u(n,t) = (\sigma(z,t))^2 \times \frac{1}{\tau'(t)} S_{\tilde{u}}\left(\frac{n}{\tau'(t)}\right) \tag{4}$$

where the prime on $\tau(t)$ represent the first derivative with respect to t. It relates the power spectral density functions of $u(t)$ and $\tilde{u}(t)$; the nonstationary process $u(t)$ is represented by applying the time and frequency modulations to a stationary process. We proposed that $\tau(t)$ by the following transformation [8],

$$\tau(t) = \left(\int_0^t U(z,\hat{t})d\hat{t}\right)/z \tag{5}$$

$\tau(t)$ represents a dimensionless distance travelled (or dimensionless time used to travel) by the mean wind speed. The use of this transformation is adequate since if the wind has a mean wind speed of $U(z)$ and a variance of $\sigma(z)$, the obtained power spectral density from Eqs. (4) and (5) is consistent with that dictated by the Kaimal spectrum for stationary winds. The simulation of the nonstationary winds can be conveniently carried out using the SRM, resulting in,

$$u(t) = \sigma(z,t) \times \sum_{j=1}^{N} \sqrt{2S_{\tilde{u}}(\zeta_j)\Delta\zeta} \times \cos\left(2\pi\zeta_j \tau(t) + \theta_j\right) \tag{6}$$

where θ_j are independent and uniformly distributed random variables between 0 to 2π.

The simulated winds can be used to evaluate the ductility demand of nonlinear inelastic systems. In particular, if the mean wind is defined by the one-half cycle of a sine wave, $U(z,t) = U(z)\sin(\pi t / t_d)$ for t within 0 and t_d [6], the calculated ductility demand for a nonlinear inelastic single-degree-of-freedom is illustrated in Figure 1. For details on the calculation procedure and the implication of considering the ductile behaviour for structures designed based on linear elastic behaviour, the reader is referred to [8].

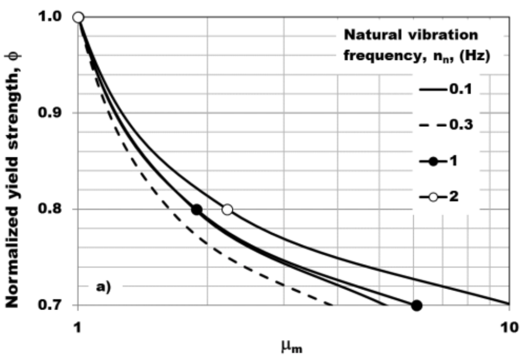

Figure 1. Mean of ductility demand for elastoplastic system, damping ratio of 2%, $U(z)/z$=3, turbulence intensity of 0.1 and t_d =60 s.

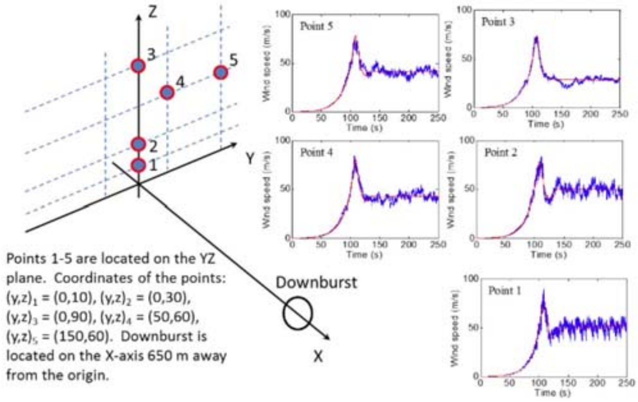

Figure 2. Illustration of simulated nonstationary wind speed time histories for the passage of a modelled downburst.

The above is developed for nonstationary wind at a point. It can be extended to the nonstationary wind field. In such a case, guided by the Davenport's coherency function, we proposed a model resulting in that the lagged coherency, $\left|\gamma_{u,jk}(n, \mathbf{p}_j, \mathbf{p}_k)\right|$, with C_z and C_y denoting model coefficients, is given by,

$$\left|\gamma_{u,jk}(n, \mathbf{p}_j, \mathbf{p}_k)\right| = \exp\left(-\frac{n\left[C_z^2 \times (z_j - z_k)^2 + C_y^2 \times (y_j - y_k)^2 \right]^{1/2}}{\left(U(z_j)/z_j + U(z_k)/z_k \right) / (1/z_j + 1/z_k)} \right) \tag{7}$$

It also results in the phase difference that is not equal to zero if the mean wind speeds at two points $\mathbf{p}_j$ and $\mathbf{p}_k$ differ, indicating that the anisotropy induced by the mean wind speed gradient (i.e., phase delay) [9] is reflected in the proposed model. Eq. (7) differs from Davenport's coherency function on how the mean wind speeds are weighted. Based on the proposed model, and considering the passage of a modelled mean wind field of a downburst [3], the simulated winds at several points are illustrated in Figure 2.

Key Words: coherency, ductility demand, nonstationary wind; time and frequency modulation

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Reliability in the Age of High Fidelity Sensors, Multiscale Models, and High-Performance Computing

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Abstract:
The probability of events is not an inherent property of the events, but of the information available to describe them. The implication of this simple observation, in the context of reliability assessment, is that the probability of failure characterizes not the engineered system, but the engineer's perception of the failure. Failure is, most often, the expression of an instability with physical or social phenomena accelerating across spatial or otherwise interconnected interfaces (such as in the case of social systems). As this instability is approached, relevant observables are increasingly on finer and faster scales, implying that the succession of corresponding mathematical models cease to be valid.

Clearly, while these instabilities can be described from the vantage point of a coarse scale observer, the associated uncertainties will reflect the mismatch between what is being observed and the dominant physics at play. With such an increase in uncertainty, the assessed system reliability is bound to decrease.

Recent technological developments have transformed the manner in which we observe the world around us as well as the sophistication with which we can reason about it. Specifically, and with the advent of extreme resolution sensors, our ability to observe simultaneously behavior at the finest and coarse scales (in both engineered and social systems) allows us to characterize functional and statistical dependencies between corresponding observables, thus permitting us to glean information about either one by observing the other. Likewise, with the advent of extreme scale computing, mathematical and computational models capable of interpreting and assimilating this new-found information are within reach. Instabilities can now be traced to more fundamental observable causes, resulting in a more comprehensive characterization of failure and more reliable systems.

While probability theory is self-consistent and complete, probabilistic tools used by engineers entail numbers of shortcuts that are not adapted to deal with these new features of complexity: **1)** observations across scales with hidden dynamics, and **2)** massively large computational models that must be informed by that data.

I will describe recent procedures for addressing these challenges.

New Advances of the Probability Density Evolution Method

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Abstract:

In engineering reliability evaluation of large civil structures and infrastructure systems, the randomness involved in both the structural/system parameters and the external dynamic actions such as earthquakes, strong wind and huge waves, etc., shall be taken into account in a reasonable manner. Meanwhile, under the above-mentioned disastrous dynamic actions the engineering structures will unavoidably exhibit strong nonlinearity, or even collapse completely. Theory and high-efficient numerical methods for the performance evaluation and reliability assessment of such large structures/system involving strong coupling of randomness and nonlinearity are still in urgent need. The probability density evolution method (PDEM) is one of the progresses to this end. By invoking the principle of preservation of probability, in particular from the random event description, and the embedded physical mechanism, the generalized density evolution equation was established. In contrast to the traditional equations, e.g., the Liouville equation, FPK equation and the Dostupov-Pugachev equation, this is a state-variable decoupled equation governing the evolution of probability density. In the past 15 years, the fundamental theory and numerical algorithm for the PDEM were extensively studied and developed, and were applied in stochastic dynamic response and global reliability evaluation of practical large engineering structures.

The present lecture will be focused on the most recent advances in PDEM, including:

(1) The closed-form solutions of several typical nonlinear systems by the PDEM were obtained.
(2) The enrichment algorithm. The information from the embedded physical system was enriched by taking the response at more points in addition to the originally selected representative points. Therefore, the accuracy could be improved considerably. To this end, the adaption of Kriging method was explored.
(3) Ensemble evolution algorithm. The generalized density evolution equation integrated on partitioned subdomains of the probability assigned space will yield a new form of equation with ensemble velocity, which could further be captured by adopting a PDF of local Gaussian form in the second order accuracy. By doing so, the spurious spikes could be avoided in a rational way, and thus the robustness of numerical results could be greatly enhanced.

Problems to be further studied include: (1) Physical modelling and engineering models for stochastic dynamic actions; (2) Stochastic multi-scale physics and mechanics; and (3) In-depth investigations on probability-dissipated systems, etc.

Key Words: Probability density evolution method; ensemble evolution; enrichment algorithm; probability-dissipated systems; dynamic stability.

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Models for Vague and Imprecise Information

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Abstract:

In our developed societies, engineering structures and systems are characterized by a rapid growth in scale and complexity. The amount of information needed to model these structures and systems with their complexity is, thus, growing as well. In contrast to this increasing need for information the available information remains almost at the same level. Hence, with increasing scale and complexity the gap between required and available information is growing quickly, so that uncertainties and risks are involved in our models and analyses to a greater extent than ever before. Reliability and performance analysis become increasingly complicated due to the growing uncertainties through complexity. The realistic quantification of uncertainties and their numerically efficient processing in complex analyses are, thus, the two key challenges in this context.

Uncertainty induced by limited and vague information represents epistemic uncertainty. Advancements in generalized uncertainty modeling are made to enable the quantification of epistemic uncertainties in form of an optimum compromise solution in the balance between three goals: (i) the complete representation of available information in the theoretical uncertainty model, (ii) the modeling without assumptions, which cannot be justified and potentially introduce artificial information, and (iii) the most appropriate modeling in view of the purpose of the analysis in order to provide the best possible basis for informed decisions. Clearly, the first consideration should be devoted to probabilistic modeling, naturally through subjective probabilities, which express a belief of the expert and can be integrated into a fully probabilistic framework in a coherent manner via a Bayesian approach. While this pathway is widely accepted and recognized as being very powerful, the potential of set-theoretical approaches and imprecise probabilities has only been utilized to some limited extent. Those approaches, however, attract increasing attention in cases when available information is not rich enough to specify subjective probability distributions [2]. Imprecise probabilities provide a significantly increased model flexibility through a combination of set-theoretical models with probabilistic models and keep the nature of the available information consistent throughout the entire analysis.

The conceptual basis for imprecise probabilities is to distinguish between probabilistic subjectivity and imprecision as different forms of epistemic uncertainty, which provides a pragmatic criterion for classifying non-deterministic phenomena according to the nature of information. From this perspective, aleatory uncertainty (stochastic variation) and the subjective probabilistic form of epistemic uncertainty can be summarized as probabilistic uncertainty, whereas imprecision refers to the non-probabilistic form of epistemic uncertainty. This classification helps to avoid confusion if uncertainty appears as both probabilistic and non-probabilistic phenomena simultaneously in an analysis. An illustrative example for this situation is a random sample of imprecise perceptions (e.g., intervals due to limited measurement accuracy) of a physical quantity. While the scatter of the realizations of the physical quantity possesses a probabilistic character (frequentist or subjective), each particular realization from the population exhibits, additionally, imprecision with a non-probabilistic character. If an analysis involves this type of hybrid information, it is imperative to consider imprecision and probabilistic uncertainty simultaneously but not to mix the characteristics, so that imprecision is not described in terms of a probabilistic model and vice versa.

A mathematical framework for an analysis of this type has been established with imprecise probabilities. A key feature of imprecise probabilities is the identification of bounds on probabilities for events of interest; the uncertainty of an event is characterized with two values; a lower probability and an upper probability. The distance between the lower

and upper probability bounds reflects the indeterminacy in model specifications expressed as imprecision of the models. This imprecision results from not introducing artificial model assumptions. It is described by implementing set-valued descriptors in the specification of a probabilistic model. The model description is thereby limited to an appropriate domain, and no further specific characteristics are ascribed. This introduces significantly less information in comparison with a specific subjective distribution function as used in a Bayesian approach. Imprecision in the model description expressed in a set-theoretical form is not translated into probabilities; it is not described in terms of probabilities, instead, it is reflected in the result as a set of probabilities which covers all plausible cases of model assumptions. This feature is particularly important when the calculated probabilities provide the basis for critical decisions. With imprecise probabilities the analysis may be performed with various relevant models to obtain a set of relevant results and associated decisions. This helps to avoid wrong decisions due to artificial restrictions in modeling.

The most straightforward approach to set up an imprecise probabilistic model is to identify respective set-valued distribution parameters. But the capabilities of the modeling are not limited to this approach. Imprecise probabilities are also capable of dealing with imprecise conditions, with imprecise dependencies between random variables, and with imprecise structural parameters and model descriptions [4, 5]. Further, multivariate models and statistical estimations and tests with imprecise sample elements can be constructed, results from robust statistics in the form of solution domains of statistical estimators can be considered directly.

Imprecise probabilities have emerged into several application fields in engineering with structured approaches, see [1, 2]. The largest application field appears as reliability assessment, followed by sensitivity analysis, model validation and verification, design under uncertainty and decision making. Although the advancements in engineering achieved with imprecise probabilities are obvious, some reservation has remained in their adoption so far. Two reasons can be recognized for this reservation. First, imprecise probabilities are frequently misperceived as competitors against established probabilistic methods. But actually, imprecise probabilities are not competitors in this sense; they represent supplementary elements which can complement probability in many cases. Imprecise probabilities enrich the variety of models and can be combined with traditional probabilistic analysis in various manners yielding an improved flexibility and adaptability with respect to the particular situation and providing extended features for engineering analyses. Second, models of imprecise probabilities are perceived as unnecessarily complicated. This argument is, however, only typical for a first view and is not supported by the relatively simple conceptual set up and mechanisms of imprecise probabilities. Another sensitive issue is the diversity of concepts covered under the framework of imprecise probabilities. Although there are very close relationships between the concepts which can be brought together in a unified understanding, they are frequently perceived as basically different. Specifically, it can be shown (see [2]) that probability boxes and fuzzy probabilities possess features to cover all other concepts of imprecise probabilities, and fuzzy probabilities can be considered as nested probability boxes and vice versa.

The situation of growing complexity of our structures and systems clearly demands such models for a coherent and comprehensive quantification of imprecise and vague information and its inclusion in all kinds of engineering analyses. Though these models are generally available, significant further development is needed in order to fully utilize their benefits. Further improvement is needed on a unified understanding of concepts and approaches of imprecise probabilities and on the numerical efficiency of analysis techniques, for example in conjunction with efficient sampling technologies as in [3]. Significant benefits can be obtained by utilizing imprecise probabilities together with the powerful probabilistic approaches. The results from both approaches provide insight from different angles to the same problem and, thus, reveal important additional information.

Key Words: imprecise probabilities, epistemic uncertainty

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2016

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International Workshop on Engineering Reliability and Stochastic Mechanics