

NIST Grant Contractor Report
NIST GCR 26-073

Forward-Looking Codes and Standards: Engineering Design Guidelines and Criteria

Workshop Report
Sept. 25–26, 2025, Reston, VA

Jayantha Obeysekera, Ph.D., P.E., F.EWRI, M.ASCE
Jennifer Goupil, P.E., F.SEI, F.ASCE
Meg Ackerson, P.E.
Joe Ackroyd, P.E., M.ASCE
Joseph Barsugli, Ph.D.
Kevin Borth, P.E., S.E., M.ASCE
Michel Ghosn, Ph.D., F.SEI, M.ASCE
Matt Gilbertson, P.E., S.E., M.ASCE
Elisabeth Gilmore, Ph.D.
Jack Hogan, P.E.
Sihan Li, Ph.D., P.Eng., M.ASCE
Mari Tye, Ph.D., C.Eng, M.ASCE

This publication is available free of charge from:
<https://doi.org/10.6028/NIST.GCR.26-073>

NIST Grant Contractor Report
NIST GCR 26-073

**Forward-Looking Codes and Standards:
Engineering Design Guidelines and
Criteria**

Workshop Report
Sept. 25–26, 2025, Reston, VA

Jayantha Obeysekera, Ph.D., P.E., F.EWRI, M.ASCE, *Florida International University*
Jennifer Goupil, P.E., F.SEI, F.ASCE, *Structural Engineering Institute of ASCE*
Meg Ackerson, P.E., *Arup*; Joe Ackroyd, P.E., M.ASCE, *New York City Department of Buildings*
Joseph Barsugli, Ph.D., *University of Colorado Boulder*; Kevin Borth, P.E., S.E., M.ASCE, *HGA*
Michel Ghosn, Ph.D., F.SEI, M.ASCE, *The City College of New York*
Matt Gilbertson, P.E., S.E., M.ASCE, *Simpson Gumpertz Heger*
Elisabeth Gilmore, Ph.D., *Carleton University*
Jack Hogan, P.E., *Arup*; Sihan Li, Ph.D., P.Eng., M.ASCE, *RWDI*
Mari Tye, Ph.D., C.Eng, M.ASCE, *Johns Hopkins University*

This publication is available free of charge from:
<https://doi.org/10.6028/NIST.GCR.26-073>

July 2026



U.S. Department of Commerce
Howard Lutnick, Secretary

National Institute of Standards and Technology
Arvind Raman, NIST Director and Under Secretary of Commerce for Standards and Technology

Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of the National Institute of Standards and Technology (NIST) or the National Ocean and Atmospheric Administration (NOAA), or the U.S. Department of Commerce. Additionally, neither NIST, NOAA, nor any of its employees make any warranty, expressed or implied, nor do they assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, product, or process included in this publication.

This report was prepared under Contract No. 1333ND24PNB730652 between NIST and the Structural Engineering Institute of the American Society of Civil Engineers. The statements and conclusions contained in this report are those of the authors and do not imply recommendations or endorsements by NIST, NOAA, or the U.S. Department of Commerce.

NIST Technical Series Policies

[Copyright, Use, and Licensing Statements](#)

[NIST Technical Series Publication Identifier Syntax](#)

How to Cite this NIST Technical Series Publication

Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, M. Tye (2026) Forward-Looking Codes and Standards: Engineering Design Guidelines and Criteria: Workshop Report, Sept. 25–26, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-073. <https://doi.org/10.6028/NIST.GCR.26-073>

Abstract

Forward Looking Codes and Standards: Engineering Design Guidelines and Criteria workshop report includes recommended research needs on the following themes: nonstationary reliability, service life, design loads, resistance, and structural capacity degradation.

Keywords

Codes and standards; Building codes; Future hazards; Load effect: Design guidelines; Design criteria; Structural capacity; Adaptation; Resilience.

Contents

Preface	iv
1. Section 1: Workshop Overview	1
1.1. Introduction	1
1.2. Workshop Scope and Purpose	1
1.3. Workshop Development Process	2
1.4. Workshop Framework.....	5
1.5. Workshop Report Organization	5
2. Section 2: Current State of the Art	7
2.1. Workshop Presentations.....	7
2.2. Goals for Future State	8
3. Section 3: Discussion for Advancing Engineering Design and Guidelines Criteria.....	10
3.1. Breakout 1. Structural Capacity (In Person).....	10
3.2. Breakout 2. Structural Capacity (Virtual)	15
3.3. Breakout 3. Future Guidelines (In Person).....	18
3.4. Breakout 4. Future Guidelines (Virtual)	28
4. Section 4: Recommendation of Research Needs	32
4.1. Breakout 1. Structural Capacity (In Person).....	32
4.2. Breakout 2. Structural Capacity (Virtual)	33
4.3. Breakout 3. Future Guidelines (In Person).....	34
4.4. Breakout 4. Future Guidelines (Virtual)	34
5. Section 5: Analysis of Research Needs.....	36
5.1. Prioritized Research Needs Indexed to Themes	36
5.2. Discussion of Results.....	45
5.2.1. Future Hazard Data and Information	45
5.2.2. Future Load Effects and Infrastructure Conditions	46
5.2.3. Design Guidelines, Criteria, and Tools.....	46
5.2.4. Resilience and Adaptation.....	47
5.2.5. Planning and Design Frameworks	47
5.2.6. Codes and Standards	47
5.3. Summary	48
6. Section 6: Acronyms and Abbreviations	49
7. Section 7: References	50

Appendix A. Discussion of Priority Research Needs	52
Appendix B. Workshop Materials	55
B.1. Workshop Agenda.....	55
B.2. Workshop Presentations.....	58
B.2.1. Day 1: Overview Presentation.....	58
B.2.1.1. Structural Capacity and Degradation: Structural degradation modeling and life-cycle assessment considering future climate effects; Fabio Biondini	68
B.2.1.2. Structural Capacity and Degradation: How uncertainties of structural degradation and condition assessment impact project design; James R. Harris	81
B.2.1.3. Structural Capacity and Degradation: Structural degradation and condition assessment of waterfront structures in marine environments; Ming Liu	89
B.2.1.4. Future Guidelines: Decision Science - Future design scenarios considering deep uncertainty; Rob Lempert.....	100
B.2.1.5. Future Guidelines: Project Case Study: California High Speed Rail; Jack Hogan	106
B.2.1.6. Future Guidelines: Regulatory Case Study: NYC Waterfront Code; Stirling Moore	111
B.2.2. Day 2: Overview Presentation.....	128
B.2.2.1. Breakout Session Reports	130
Appendix C. Workshop Participants.....	140

Preface

In October 2024, the Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE) commenced a project under National Institute of Standards and Technology (NIST) Contract No.1333ND24PNB730652 to develop workshops on *Forward-Looking Codes and Standards*. This report documents the results of the third workshop on *Forward-Looking Codes and Standards: Engineering Design Guidelines and Criteria* based on contributions to the workshops by scientists, natural hazard experts, structural engineers and other design professionals, and standard and code development experts.

The following are the themes of the four workshops:

1. **Future hazards for design:** Confidence/uncertainty in hazard projections, local downscaling of global models, and conversion of hazard projections to engineering design criteria;
2. **Future load effects on the built environment:** Changes in hazard demand relative to historical basis, changes in structural capacity due to changes in material properties, and geotechnical conditions;
3. **Engineering design guidelines and criteria:** Nonstationary reliability, service life, design loads, resistance, and structural capacity degradation; and
4. **Adaptation and resilience:** Adaptive design for buildings and infrastructure systems, considering future hazards, material durability, structural capacity degradation, and strategic planning methods for future conditions.

The impetus for the project was the observed increases in land and ocean temperature extremes; sea-level change; frequency and length of heat waves; and changes in the frequency and intensity of heavy precipitation, flash floods, severe storms, and cyclones. Because of potential changes in environmental hazards and structural capacity over time, the need to advance design practices to incorporate future hazard predictions and their uncertainties into codes and standards for buildings and infrastructure is urgent. NIST continues to conduct research and provide leadership in the advancement and knowledge of these hazards and to provide the science and engineering that supports the development of standards and guidelines that will lead to more resilient communities and economic continuity across the nation.

The workshop development process started with a review of ongoing research, guideline development efforts, and relevant case studies. An extensive workshop preparation process followed this review that convened four one-and-a-half-day workshops to obtain input from experts in these areas and resulted in report preparation and review by the Workshop Steering Committee (Obeysekera et al. 2026a, b, c, d).

The workshops identified a broad range of research and development activities required to advance codes, standards, and engineering design practice that capture the effects of future conditions and have the goal of reducing impacts from severe environmental hazards. This report includes the discussion of current needs in design practice and specific recommendations on research needs to advance next generation building standards and codes and to achieve specific goals of adaptation and resilience.

SEI is indebted to the leadership of Jayantha “Obey” Obeysekera, Ph.D., P.E. F.EWRI, M.ASCE who served as the Workshop Director and the Workshop Steering Committee members Meg Ackerson, P.E.; Joe Ackroyd, P.E., M.ASCE; Joseph Barsugli, Ph.D.; Kevin Borth, P.E., S.E., M.ASCE; Michel Ghosn, Ph.D., F.SEI, M.ASCE; Matt Gilbertson, P.E., S.E., M.ASCE; Elisabeth Gilmore, Ph.D.; Jack Hogan, P.E.; Sihan Li, Ph.D., P.Eng., M.ASCE; Mari Tye, Ph.D., C.Eng., M.ASCE for their contributions to putting the workshop together and developing this report.

SEI gratefully acknowledges NIST for its leadership and vision for this project. Appreciation is also extended to the many individuals who participated in the workshop. Appendix C lists the names and affiliations of all who participated in the workshop and, therefore, contributed to this report. Thank you to the ASCE staff— especially Katie Stueckle, who served as Workshop Coordinator; Jessica Jun, who served as a Workshop Conference Manager; James Pullis, who served as the Conference Center Manager; and Addie Gordon, who served as a Workshop Coordinator and drafted and edited the final report.

Jennifer Goupil, P.E., F.SEI, F.ASCE
Managing Director Structural Engineering Institute and American Society of Engineers Chief
Resilience Officer

1. Section 1: Workshop Overview

1.1. Introduction

The National Institute of Standards and Technology (NIST) has a long history of conducting research and development to identify methods and practices; to advance codes and standards; and to support the resilience of buildings, physical infrastructure, and communities.

NIST's commitment to the effects of hazards on codes and standards for the built environment, and on engineering more broadly, is reflected in its being the lead agency for the National Earthquake Hazard Reduction Program, the National Windstorm Impact Reduction Program, and its Disaster and Failure Studies Program and Community Resilience Program. Similarly, ASCE/SEI is actively committed to integrating future hazard data and future conditions into technical standards, especially within the national model design standard for structural loads in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE/SEI 7-22, ASCE 2022). The next edition, ASCE 7-28, is currently developing a new section for future hazard design loads. To continue with these efforts, one of NIST's strategies is to further develop codes and standards to better prepare for future hazards and conditions.

The third workshop for *Future-Looking Codes and Standards: Engineering Design Guidelines and Criteria*, held on September 25–26, 2025, and this resulting report, focused on the research and development efforts needed to implement future hazards and associated design criteria in codes and standards, including the potential degradation of structure capacity, to inform strategic planning for future requirements in the built environment and to understand potential changes to design requirements.

1.2. Workshop Scope and Purpose

The purpose of the workshops was to provide a science-based assessment of data and development needs to advance design practice and building standards for future natural hazards and conditions across U.S. communities.

The workshop scope covered the broad subject area of future hazards for codes and standards development, specifically the needed input from scientists, practitioners, and researchers on how to do the following:

- Prioritize research and development needs to advance design practice for future hazards and conditions (beyond the ongoing efforts of ASCE/SEI 7-28);
- Use the best available science to characterize future hazards and conditions for design practice;
- Identify a path toward improving building standards and design practice; and

- Consider resilience, adaptation, and social and economic impacts to businesses and communities.

1.3. Workshop Development Process

The development of these workshops began with the selection of the Workshop Steering Committee (WSC) for all four workshops, which includes climate scientists, structural engineers, and social scientists. They are qualified academics and practicing experts who have worked in the fields of future hazard projections, engineering design, social impacts, resilience, and adaptation. The WSC included the following experts:

- Meg Ackerson, P.E., Arup;
- Joe Ackroyd, P.E., M.ASCE, Assistant Commissioner; Technical Affairs & Code Development; New York City Department of Buildings, NYC;
- Joseph Barsugli, Ph.D., Research Scientist III, CIRES, University of Colorado Boulder, NOAA Physical Sciences Laboratory Affiliate;
- Kevin Borth, P.E., S.E., M.ASCE, Sr. Structural Project Engineer | Associate Vice President, HGA;
- Michel Ghosn, Ph.D., F.SEI, M.ASCE, Professor, the City College of New York/CUNY;
- Matt Gilbertson, P.E., S.E., M.ASCE, Sr. Technical Manager, Simpson Gumpertz & Heger;
- Elisabeth Gilmore, Ph.D., Professor, Carleton University;
- Jack Hogan, P.E., Associate Climate Risk and Resilience Engineer, Arup;
- Sihan Li, Ph.D., P.Eng., M.ASCE, Senior Specialist, Associate, RWDI; and
- Mari Tye, Ph.D., C.Eng, M.ASCE, NIST PREP Fellow, Whiting School of Engineering, Johns Hopkins University.

The WSC started meeting in February 2025 to develop the content of the workshop. The WSC selected the following topics as critical issues, and the participants were selected based upon their expertise in these areas:

- Confidence and uncertainty in hazard projections,
- Downscaling of global climate models, and
- Conversion of hazard projections to design loads and associated criteria.

The one-and-a-half-day workshop was convened on September 25–26, 2025, to identify the highest-priority needs that form the basis of this report. The WSC, industry-leading experts, academics, and representatives from key government agencies attended the workshop. Members of the public were also able to view speaker presentations on the first morning of the workshop via Zoom webinar. The workshop was held at Crown Plaza Hotel in Herndon, Virginia (Figure 1-1), and was simultaneously streamed for virtual participants (Figure 1-2). Thirty-two in-person and 38 virtual participants attended the workshop.



Figure 1-1. In-person participants at the NIST/SEI *Forward Looking Codes and Standards: Engineering Design Guidelines and Criteria* workshop on September 25, 2025.

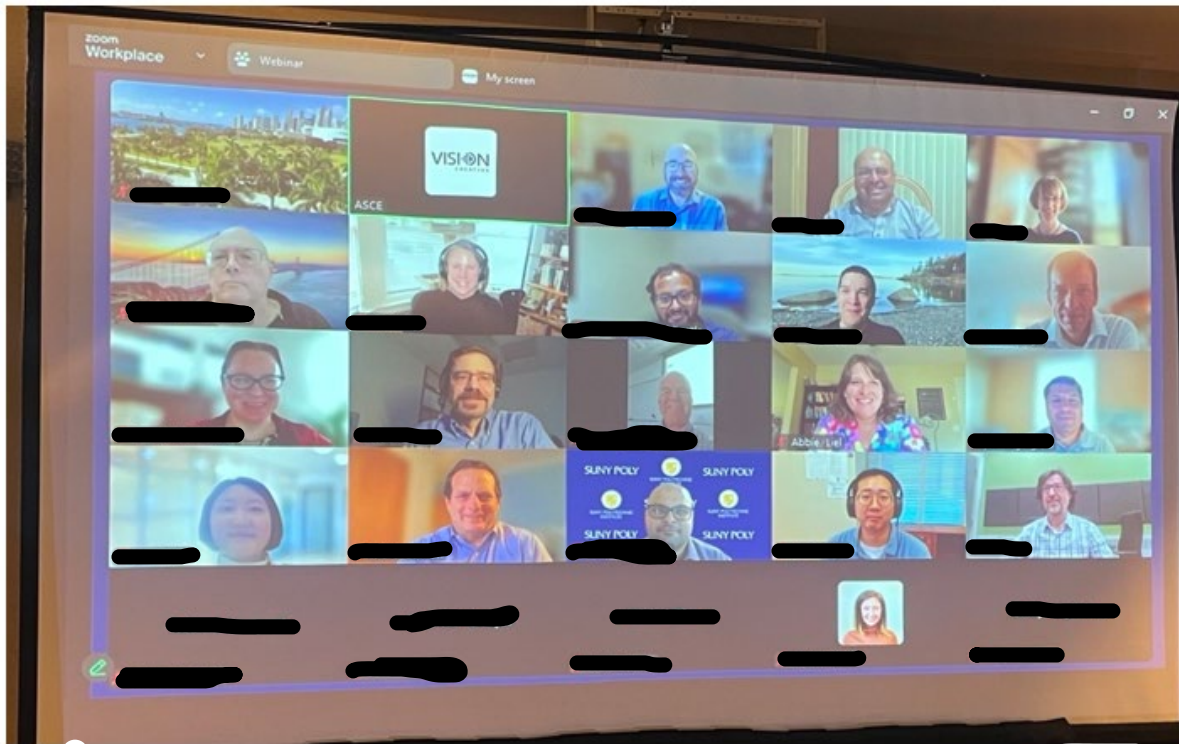


Figure 1-2. Virtual participants at the NIST/SEI *Forward-Looking Codes and Standards: Engineering Design Guidelines and Criteria* workshop on September 25, 2025.

The design of the NIST/SEI *Forward-Looking Codes and Standards* workshop enabled all in-person and online participants to contribute in multiple ways. The workshop began with subject matter expert presentations of ongoing, synergistic efforts and several state-of-the-practice presentations that were also viewed by registered public attendees.

Following the presentations, the public session concluded, and a plenary session engaged the participants in a discussion to define the state of the art and the future ideal state needed to advance engineering design guidelines and criteria.

The participants were then divided into four breakout groups based on two focus areas for next-generation goals: structural capacity and future guidelines. Each topic had one in-person breakout group and one virtual breakout group. The goal of the structural capacity breakout groups was to consider the most impactful future conditions on structural capacity and to identify what would be needed to characterize future structural capacity and degradation effects. The goals of the future guidelines breakout groups were to consider what is needed to address updates about future effects and performance criteria and how to address these updates between code and standard cycles and to consider how to best review and publish criteria for design practice that are beyond codes and standards. In these breakout groups, the

participants were given three prompts to answer their group goals: (1) identify data and tool needs, (2) identify next-generation research needs, and (3) prioritize the top five research needs.

Each breakout group then reported back to all the workshop participants in a general session and described its prioritized research and development needs. Following these presentations and subsequent discussions, all the workshop participants prioritized the research and development needs developed in separate breakout groups.

1.4. Workshop Framework

The framework for Workshop 3 was developed around key questions and intended outcomes from the WSC and was organized into two main topics.

The first was to understand the next-generation goals for structural capacity. To do so, participants were asked to consider (1) the most impactful future conditions or effects on structural capacity and (2) what is needed to characterize future structural capacity and degradation effects.

The second topic explored next-generation goals in terms of future guidelines. Participants considered (1) what is needed to address standard updates about future effects and performance criteria, (2) how updates between code and standard cycles should be addressed, and (3) how criteria beyond codes and standards should be reviewed and published for design practice.

These topics framed the final set of questions posed to participants, which centered on identifying the data and tools desired for future design guidelines and the next-generation research needs.

1.5. Workshop Report Organization

Following Section 1, Workshop Overview, the workshop report is organized as follows:

- Section 2 describes the current state of the art and summarizes presentations from the workshop,
- Section 3 describes the discussions on advancing the workshop goals that were held during breakout discussions,
- Section 4 describes the top recommended research needs that were identified during the breakout sessions,
- Section 5 describes the analysis of research needs that were identified during the breakout sessions,
- Section 6 lists acronyms and abbreviations, and
- Section 7 provides the references cited.

The report also includes three appendices. Appendix A Priority Research Needs includes additional details about the priority research needs identified by each breakout session during the workshop. Appendix B Workshop Materials contains the workshop agenda, copies of the presentations. Appendix C Workshop Participants lists the workshop participants in alphabetical order.

2. Section 2: Current State of the Art

2.1. Workshop Presentations

The first set of presentations focused on structural capacity and degradation, highlighting synergistic efforts in the field and specific case studies. The following summarizes the presentations.

First, Fabio Biondini (Appendix B.2.1.1) provided an overview of structural degradation modeling and life-cycle assessment considering future effects. His talk highlighted how corrosion, driven by environmental factors such as temperature, humidity, and atmospheric carbon dioxide (CO₂), affects the long-term performance of structures. He advocated for integrating life-cycle concepts into design codes and standards to bridge the gap between research and practice. He also highlighted the importance of prototype testing in the lab. Biondini stressed the need for interdisciplinary collaboration among climate scientists, structural engineers, and code developers to address nonstationarity in design.

Next, James R. Harris (Appendix B.2.1.2) explored how uncertainties in structural degradation and condition assessment influence project design decisions, focusing on structures that are particularly vulnerable to environmental exposure. Harris discussed how water penetration leads to wood rot and steel corrosion, especially in modern materials like engineered lumber and blended cements. The presentation emphasized the need for improved leak detection, maintenance practices, and protective systems. Drawing from historical changes in ACI 318 (ACI 2019) standards and real-world examples, Harris advocated life-cycle cost analysis and better technologies for condition assessment. This underscored the importance of adapting design practices to evolving environmental and societal conditions.

Ming Liu (Appendix B.2.1.3) presented a detailed case study on the degradation of waterfront structures exposed to marine environments. He described the types of infrastructure affected, including piers, dry docks, and seawalls, and explained how corrosive elements like chloride and sulfate accelerate deterioration. Liu outlined the zones of marine exposure and their respective corrosion rates. He discussed the impact of future hazards such as sea-level rise, storm surges, and increased CO₂ on structural integrity. The presentation also covered nonstructural components like pipelines and mooring hardware and emphasized the need for continuous monitoring, accelerated testing, and performance-based design tools.

The following set of presentations focused on future guidelines beyond codes and standards.

Rob Lempert (Appendix B.2.1.4) introduced the concept of Decision Making Under Deep Uncertainty (DMDU), offering an alternative to traditional “predict then act” approaches. This concept suggests that when future conditions are highly uncertain, planning should focus on robustness using stress-testing rather than the optimality used in current practice. Lempert

proposed using adaptive pathways and/or scenario planning to stress test strategies across multiple futures. As an example, he illustrated how sea-level-rise projections and adaptive pathways using “subway maps” can guide long-term infrastructure decisions. His presentation demonstrated that DMDU helps organizations make better decisions by exploring a range of futures and identifying resilient strategies, rather than relying on potentially inaccurate predictions in the presence of significant uncertainties.

Jack Hogan (Appendix B.2.1.5) discussed the California High-Speed Rail project as a case study of embedding resilience into infrastructure design. With a 100-year design life, the project integrates state mandates and sustainability policies into its design criteria. Hogan explained the structured risk-based framework used to assess future hazards like heat, drought, and flooding at the component level. He described how adaptation options are evaluated through cost-benefit analysis. The project uses the ALARP (As Low As Reasonably Practicable) principle to balance risk, cost, and effort. Hogan emphasized the importance of agency-driven frameworks and decision triggers in developing scalable and pragmatic design guidelines.

Last, Stirling Moore (Appendix B.2.1.6) presented the development of the New York City (NYC) Waterfront Code, a regulatory initiative aimed at addressing the unique challenges of waterfront structures. He explained the lack of existing national or international codes and the need for a dedicated framework to guide design, construction, and maintenance. The code will complement the NYC Building Code and introduce typology-specific provisions for nonbuilding waterfront structures. Moore outlined the phases of development, including research, drafting, committee work, and city council submission. He emphasized the importance of addressing future uncertainties through flexible design mechanisms and periodic updates and highlighted the need for robust code development processes and leveraging of jurisdictional requirements to ensure resilience and safety.

2.2. Goals for Future State

The workshop plenary discussion focused on two major topics: structural capacity and future guidelines. Participants were asked to consider the capabilities and resources that will be needed in the next decade to address evolving structural design challenges. The discussion anticipated future conditions, such as environmental changes, material degradation, and uncertainty in performance, rather than focusing on immediate implementation strategies.

For structural capacity, several key points emerged. Attendees suggested that improving deterioration modeling and data collection would reduce uncertainty in design and maintenance. Examples included developing asset-class-specific standards for condition assessment and creating better methods for monitoring and testing existing structures. Spatial variability in deterioration was noted as a critical challenge, as current models often assume uniform degradation, which does not reflect real-world conditions. Participants also stressed the importance of scalable approaches that can be applied across large infrastructure networks.

Regarding future guidelines, the conversation centered on updating codes and standards to incorporate adaptive design strategies and future climate conditions. Ideas included creating flexible frameworks or “code elasticity” to allow real-time adjustments, improving reporting standards for data collection, and integrating climate indicators into engineering practices. Participants noted regulatory uncertainty as a barrier to implementing adaptive pathways, proving the need for coordination with permitting agencies. Additionally, participants called for overarching, multidisciplinary guidelines that link climate data, engineering design, risk management, and community resilience goals.

The workshop participants envisioned a future design ecosystem where design guidelines are available for every asset type and interdependent system and provide robust outcomes through flexible applications. This vision includes the following:

- Structural capacity acceptance criteria data, methods, and models that allow projects to be evaluated for nonstationary hazards and degradation effects;
- Adaptive, flexible design guidelines that link environmental hazard data, load effects, structural capacity, design, risk management, and community resilience goals;
- Engineers and design professionals with access to flexible design approaches outlined in guidelines, design standards, and codes to satisfy project needs; and
- Project teams who will be empowered to meet project performance objectives by achieving consensus-based acceptance criteria in a manner that accommodates new information within a flexible process.

3. Section 3: Discussion for Advancing Engineering Design and Guidelines Criteria

This section includes summaries of the discussions that occurred in the breakout groups. The participants in the breakout groups discussed several prompts before agreeing on the research needs, which are summarized in Section 4.

3.1. Breakout 1. Structural Capacity (In Person)

Breakout group 1 addressed major topics on the relationship between structural capacity and the advancement of engineering design, including research needs on capacity and degradation effects and structural degradation modeling and performance prediction. Discussion of next-generation research needs moved the conversation toward selecting top priorities, which are presented in Section 4.

The workshop identified several research needs to better understand and characterize future structural capacity and degradation effects. Knowledge should be leveraged from bridge design to improve inspection methods and tools. Distinguishing between the structural capacity of new and existing structures is also needed, as materials and detailing differ between the two. Additionally, new methods are needed to quantify the capacity of materials in a manner that is independent of the material itself.

The need for improved performance prediction models for corrosion rates and degradation is critical, emphasizing the importance of calibrating and validating these models with field data or full-scale experimental data. Current models may be inaccurate or incomplete, particularly in terms of transport mechanisms and the application of alternative materials. Validating current models using data on the long-term performance of new materials is also needed.

Structural degradation prediction and modeling need to be improved for future hazards and conditions, particularly those that are expected to increase in magnitude. Time-dependent factors that reduce a structure's capacity over its lifespan—material degradation, future hazards, and changes in structural and ground conditions—necessitate new modeling and design considerations and proactive maintenance. While many of these processes are understood and modeled, the predictions are often unreliable due to uncertainties that are poorly defined or vary over time.

Material degradation refers to the long-term weakening of materials due to both mechanical and chemical processes. For structural steel and concrete, degradation mechanisms include corrosion, creep, shrinkage, and fatigue. Corrosion deterioration of steel reinforcement (rebar) in concrete due to exposure to moisture, chlorides, or reactive gases can lead to spalling,

cracking, and a potentially significant loss of structural strength. The volume reduction in concrete due to moisture loss can induce stresses and cracking, particularly in restrained elements. Creep is a time-dependent deformation (straining) of concrete or other materials under a sustained load, which can lead to stress redistribution and a reduction in load-bearing capacity. Fatigue refers to progressive, localized damage in structural materials subjected to fluctuating or cyclic stresses (like wind or waves), which can lead to sudden, premature failure after an initial crack forms and propagates.

An increase in the severity and frequency of natural hazard events and climatic conditions (e.g., temperature, humidity, drought) can induce or accelerate structural degradation mechanisms. Similarly, the sinking or settlement of land due to factors like excessive groundwater pumping can damage foundations and major infrastructure, thereby restricting or reducing their operational capacity. Successful structural performance for structural systems subject to degradation will require designing for future hazards and conditions and associated degradation mechanisms.

Data collection, monitoring, and analysis comprise a category that covers various methods. For model verification and validation, improved methods are needed to collect and standardize monitoring and performance data from existing structures. These methods include continuous monitoring, rapid and cost-effective sampling, and the utilization of large datasets (such as LIDAR/INSAR). These methods need advice on what data to collect, how to record and utilize data, and how to effectively manage the vast amounts of data generated.

The development of robust monitoring methods is crucial, particularly for monitoring substructures and groundwater levels. A need exists to identify critical locations for data collection and to develop optimum data collection methods that collect information at appropriate time intervals. The use of data collected from monitoring also requires further research, including identifying the critical data needed and methods to collect them. Furthermore, the development of corrosion detection systems that can be inexpensively installed in existing structures is needed.

Integrating advanced technologies (e.g., artificial intelligence (AI), machine learning (ML), digital twins) with physics-based understanding was another topic. Generative and data-driven design, powered by AI and ML, can provide design support by automating complex structural analysis and generating optimized designs that maximize performance through optimal material utilization, structural integrity, and resilience against future threats. Structural design, assessment, and monitoring should leverage new data algorithms, ML, and AI, while verifying them with physics-based models.

Digital monitoring uses technology to assess and manage a structure's performance or "health" in real time. Structural health monitoring (SHM) systems utilize Internet of things sensors embedded in materials to continually track conditions such as stress, strain, temperature, and moisture. Assessment of these measures over time can enable early detection of structural issues and proactive maintenance.

Digital twin models are virtual representations of physical structures and can be used for real-time analysis to identify the onset of performance changes, stress testing under extreme conditions, and optimizing long-term performance and maintenance schedules. However, these sensors and methods need further development to optimally collect performance data on time-varying material and structural properties in a cost-effective manner.

Risk-informed design and decision-making under uncertainty was also discussed. Robust tools are needed to account for time-varying uncertainties in performance prediction and to support decision-making. Future hazards and conditions, along with their time-varying effects on structural materials and systems, underscore the importance of incorporating deep uncertainty into decision-making processes. This is likely best addressed with design methods that are risk-informed and driven by performance criteria. It also includes identifying critical damage states, repair actions, and future alternatives to address changing conditions.

Developing comprehensive guidelines and standards for service life and resilience is important. To advance engineering practice for structural design, monitoring, and assessment, guidelines and technical reference standards are needed to address future performance in time-varying conditions. Topics include degradation prediction; performance criteria; life-cycle objectives; future mitigation or modification; resilience and functional recovery; and compounding of hazards and low-intensity, high-frequency events in design.

The workshop emphasized the need for a more comprehensive, performance-based approach, focusing on performance criteria that address structural safety and recovery and resilience. The future capacity of structures can be advanced by innovations in materials, such as self-healing concrete that can autonomously repair small cracks to maintain integrity; carbon-negative concrete that absorbs CO₂ from the atmosphere while offering improved performance characteristics; and fiber-reinforced composites that provide stronger, lighter, and more durable materials for composite designs.

Additionally, more effective ways are needed to communicate the results of this research to insurance companies and other stakeholders. By addressing these research needs, we can improve understanding of structural capacity and degradation effects, ultimately leading to more resilient and sustainable infrastructure.

Next-generation research needs were identified for each topic.

To develop comprehensive guidelines and standards for service life and resilience, the conversation focused on future performance. To advance engineering practice for structural design, monitoring, and assessment, guidelines and technical reference standards are needed that address future performance in time-varying conditions for new and existing structures. Codes need to address frequent events that affect degradation and extreme events.

Research is needed to develop repair guides and measure the effectiveness and limitations of corrosion mitigation approaches and guidelines. This will help ensure that repair efforts are effective and that structures can be maintained and restored to a safe and functional condition. By addressing these next-generation research needs, we can improve understanding of structural behavior and develop more effective strategies for maintaining and preserving infrastructure.

Incorporating deep uncertainty into decision-making processes and moving toward risk-informed, performance-driven design methods are crucial. Decision support tools may include maps that provide information on the risks associated with various hazards and conditions (e.g., changes in temperature, humidity, drought) across the nation. Additionally, improved understanding of how more frequent hazards (e.g., flooding less than design levels) can impact structural capacity and rates of degradation is needed. Such information can help designers develop plausible scenarios for analysis and design in different localities.

New approaches are needed to incorporate uncertainty in reliability analysis, as degradation can change the probability distributions of random variables. Establishing performance targets for different structures is important, particularly for assets expected to last a long time. Furthermore, developing resilience metrics for assets and identifying critical damage that requires safety repair are essential for ensuring the safety and resilience of structures.

For data collection, monitoring, and analysis better criteria, methods, and standards are needed for gathering and managing large datasets from existing structures, including guidelines on data collection for continual monitoring. A need also exists to develop technologies for nondestructive testing, particularly for monitoring below the surface. This will enable a better understanding of the condition of structures and the impact of various stressors.

Improved models, along with robust calibration and validation methods, are critically needed to predict corrosion rates and degradation, especially for alternative materials. Furthermore, past performance data are needed to support assessments and stress tests for uncertain future

conditions. A structural equivalent to paleoclimatological historical characterization methods could guide new sensor and monitoring methods for determining long-term structural damage accumulation.

Balancing new data algorithms, ML, and AI with physics-based models is essential to enhance structural understanding and design.

Life-cycle modeling is another central area. The next generation of structural research needs to focus on enhancing the durability, resilience, and life-cycle management of new and existing structures to address future hazards and conditions.

Validation and monitoring require extensive data gathering from existing structures and full-scale experimental testing to validate life-cycle models. This effort requires the development of nondestructive remote monitoring technology, particularly for below-surface structural assessments, by adapting successful technologies from fields such as geotechnical and bridge engineering.

Critical damage states need to be defined to accurately inform safety and reliability assessments and repair requirements, especially for damage accumulation and the contributing effects of minor damage, such as seismic cracking, on long-term issues like reinforcement corrosion. Therefore, the effects of environmental factors, including temperature, humidity, and CO₂ concentration, should be studied.

Finally, an economic model for cradle-to-cradle life-cycle costs needs to be developed, specifically for critical structures, to support the assessment of benefits and comparison of alternative solutions for long service lives. Policy tools, such as resilience metrics that can inform financial incentives and risk maps (e.g., the Federal Emergency Management Agency (FEMA) National Risk Index), are needed to inform resilience planning and design with information on infrastructure conditions, hazards, population characteristics, and economic indicators. From a design standpoint, societal requirements for structural performance, including functional recovery and life safety, need to be clearly articulated. Future hazards require determining ranges of values and reduction factors for design hazard maps, specifically characterizing and quantifying uncertainty. Last, comprehensive guidelines are needed for various corrosion-mitigation approaches (like epoxy coatings) to assess their effectiveness, limitations, and costs.

Addressing the challenges posed by changing future conditions is paramount. Examples include assessing evolving conditions and future hazards (e.g., increased intensity of precipitation, flood, drought, hurricanes), shifts in soil properties (post-wildfire) that increase the risks of

landslide or liquefaction, and changes in future groundwater levels. Research is also needed to determine how compounding (sequential) hazards interact with time-varying structural conditions.

To enhance design practice for future hazards and conditions, climate data from reliable sources, such as the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration, should be integrated into design hazard maps, with clear descriptions of the updates and changes. Traditional seismic areas also face climate-related risks, including landslides and erosion. However, updates of hazard maps between published versions of standards (e.g., ASCE/SEI 7) need to be clearly labeled as updated to maintain transparency regarding sources and intended uses.

3.2. Breakout 2. Structural Capacity (Virtual)

Breakout participants included university-based engineering faculty, NIST researchers, climate scientists, and practicing engineers in the private sector. One participant had participated in the development of climate data for the National Building Code of Canada, and another had direct experience in researching material degradation. The breakout session first identified topics and questions for discussion, then elaborated on needed research, and finally prioritized these into five research needs. This summary of the breakout discussion is grouped topically according to the questions raised rather than chronologically.

How conservative are current “code minimum” designs? Are reliability targets being met or exceeded? What data are needed to determine this?

The discussion began with a statement from a participant that, in their experience, current standards can be overly conservative. The example given was for hurricanes impinging on industrial facilities designed for Risk Category III that nonetheless sustained minimal damage. A lively discussion followed, which noted that, since Hurricane Andrew (1992), design wind speeds had been measured in only two hurricanes that made landfall in the Contiguous United States: Michael (2018) and Laura (2020). However, the structures in question may not have experienced the peak winds of the hurricane, making it difficult to relate damage (or lack thereof) on the ground to extreme weather events without in situ measurement. Participants generally agreed that more data on the behavior of structures during significant events are needed. In addition, more in situ observation of extreme winds from thunderstorms and hurricanes (tropical cyclones) would better characterize the hazard. Some data on structural damage from storms exist, but much are proprietary.

Going into more detail, the group foresaw a centralized, open-source, open-access database of significant events, including data on hazard level and damage incurred. Information could come from post-hazard damage assessments and inspection reports sent to a central authority, or

information gathered upon demolition. However, owners (private, but also some public) are often reluctant to share the data publicly. If this hurdle can be overcome, such a database could provide a solid baseline for users (e.g., agencies, Authorities Having Jurisdiction, designers, building owners) to understand the remaining capacity of existing buildings and would be used to better calibrate models of future structural performance.

What are the implications of long (> 50 year) service life when both hazard and capacity may be changing?

Designing for changing structural capacity and degradation of materials is seen as particularly salient for structures with a long service life (longer than 50 years). Current assumptions about reliability targets and risk categories could be reevaluated for longer-lived structures and perhaps adjusted to accommodate anticipated changes in structural capacity.

Structural capacity generally declines over time, which could be significant for long-lived structures such as dams. Should dams be designed for a 200-year life rather than 100 years as is typical? Over such a long lifetime the structure could also face significantly different, and potentially much higher, hazard levels due to future conditions. However, climate science does not have the capacity to reliably project that far into the future. Climate models are currently run out to around the year 2100 (with some exceptions), though the next phase of the Coupled Model Intercomparison Project (CMIP7) will go further into the future. Nonetheless, the uncertainty level for century-scale projections in CMIP7 will likely remain large. The National Building Code of Canada does not currently consider these very long lifetimes, at least from a future conditions perspective.

Building systems have different lifetimes. For example, cladding and HVAC may be replaced before structural elements. Cladding is a significant factor in avoiding or reducing material degradation and maintaining structural capacity. The shorter timeline for these systems allows for some level of adaptability to changing conditions or uncertainty in long-term performance of materials.

Currently, common practice for designing buildings assumes that the structural system is enclosed within an air and water barrier and that material degradation does not occur, or is so small as to be inconsequential. Of course, this rule has exceptions. As an example, designers of parking ramps in northern climates where deicing salts are used may take extra precautions in their design for enhanced durability such as increased concrete cover and coated reinforcing bars. While engaging parking ramp owners in conversations about maintenance schedules, coating replacement, and inspection routines is valuable, the ongoing execution of these tasks lies outside the scope of the designer's responsibilities during the lifespan of the parking ramp.

How applicable is accelerated laboratory testing to the long-term durability of structural materials (e.g., concrete, steel, wood) and nonstructural materials (e.g., coatings, sealants)? How relevant is this to the performance of structural systems?

The use of new and innovative materials, such as new formulations of concrete, led to discussion of their long-term performance. How well does accelerated laboratory testing reflect real-world performance in 50 or more years? One participant used the following analogy: An egg at 38 °C for 30 days gets you a chicken. At 100 °C for 10 minutes, you get breakfast. This example highlights the potential nonlinear response of materials and structures. A database of real-world performance, as noted previously, would help address these questions.

The plenary talks discussed performance of primary structural materials such as steel, wood, concrete, and so forth. The breakout group emphasized that research should also address the durability of nonstructural materials including epoxy, sealants, galvanization, coatings, surface treatments, and so on, that are critical to minimizing degradation of the structural materials themselves. The long-term performance of “connections” was also flagged as needing more research and data.

To understand the real-world behavior of structures under future loads and structural capacity, the group saw a need to engage cross-disciplinary teams of engineers, material scientists, and climate scientists to investigate how the microlevel (degradation) affects the macrolevel (structural system capacity). The group dubbed this topic “micro to macro.” For example, system reliability could be determined in lieu of, or in addition to, member reliability, while still incorporating the effects of degradation of the components.

How to consider concurrent or compounding modes of material degradation?

Real-world failures rarely have a single cause. One possible example could be an alkali-silica reaction in concrete occurring along with corrosion of the steel reinforcement. More research is needed on how to account for multiple factors and the effects of multiple modes of degradation. Is a simple “sum of squares” that assumes independence adequate, or are the effects assumed to co-occur? Earlier workshops in this series discussed compound climate hazards, and the question arose as to whether this also applies to material degradation. For example, increasing CO₂ concentrations in the atmosphere may lead to increasing humidity in a region, and both factors may impact the strength of concrete.

The potential for repeated exposure to sub-design-level events could also lead to degradation. Knowing how the frequency of these events is projected to change in the future is important. Such changes might have implications for the treatment of fatigue, where current standards account for degradation over time. A change in the frequency of sub-design-level winds might also affect serviceability, for example, in the design for high-rise buildings where the sway of the building due to winds affects the comfort of occupants.

What are the most significant future conditions factors for material degradation and structural capacity? What climate data are needed to address these effects?

The specifics of how future climate conditions might affect structural capacity were discussed in this context as well. Some examples were mentioned: the effects of atmospheric humidity on coatings on bridges; geotechnical considerations, such as groundwater intrusion or increasing salinity of groundwater; and the effects of soil temperature and frost depth penetration on foundations.

Climate scientists need to know the types of data that are required to evaluate future material degradation. Typically, continuous time-series data are required for this purpose, not simply the extreme hazard levels from a future period or for a single “level.” Climate models (and downscaled climate model projections) can often provide this type of data; however, specialized data processing and evaluation of fitness for purpose by climate scientists is often required. Therefore, including climate scientists early in the research is important.

How to address acceptable reasonable risk in the face of uncertainty?

The topic of determining an acceptable level of risk arose several times. The discussion primarily concerned the level of risk to the owner, but other stakeholders and entities are involved and may have different risk tolerances. Community-level risk was also mentioned: for example, how many failures can a community tolerate and is the community aware of the implications of the current reliability targets? Engineers also have protection of the public as “society-level” performance objectives.

Several potential research needs were discussed to determine reasonable risk or target safety levels, including developing methods to determine the remaining capacity of existing infrastructure while incorporating future conditions and methods for incorporating uncertainty in material degradation and future structural capacity. The application of DMDU methods to future structural capacity was seen as a possible way forward when uncertainty is large.

The participants then developed their list of the top five research priority needs, which are presented in Section 4.

3.3. Breakout 3. Future Guidelines (In Person)

The technical literature emphasizes the need to incorporate resilience of structures and risk to communities from extreme events as a main goal of the structural design process to ensure the safety of the public and the users of the civil infrastructure system. Evaluating resilience requires a comprehensive life-cycle assessment that (1) analyzes the long-term capacity of structures to withstand the impact of future loads, (2) estimates the level of damage they may

sustain under extreme events, and (3) verifies their ability to recover from disasters while (4) minimizing their environmental footprint. The process would involve advanced structural analysis techniques and the application of principles of performance-based design. This report of breakout group 3 of the third ASCE/NIST *Forward-Looking Codes and Standards* workshop discusses the tools and data needs and the research topics that should be investigated to help develop future design guidelines that will produce resilient structures and civil infrastructure systems.

TOPIC 1: What do you wish you had for data and tools?

Workshops 1 and 2 identified the climate hazards with the highest impact on structural safety. However, the focus was on identifying the data needed to ensure the survivability of a structural system at risk from the most extreme events. The climatic hazards identified in previous workshops that directly affect loadings on structural systems consist of temperature; all forms of precipitation including rain, ice, and snow; all types of winds (e.g., hurricane, extratropical, thunderstorm, tornado); and riverine and coastal floods including sea-level rise. Hazards that degrade structural capacity include temperature; humidity; CO₂ and sulfur emissions; freeze-thaw cycles; and water-borne, airborne, and deicing salts and chlorides. All these climate-related hazards are still relevant for developing future design guidelines that incorporate resilient design concepts.

The previous workshops emphasized estimating the intensities of the maximum yearly loading events and those of the absolute maximum event in a reference service period. However, over its long service life, a structural system may be subject to loading events of various types, levels of intensity, and duration. Even though the vast majority of these will not necessarily threaten structural safety or lead to failures on their own, they may cause different levels of damage that will reduce service life, necessitating repairs and rehabilitation, or leading to a progressive reduction in capacity and increasing the risk to less severe events than the maximum anticipated ones. Therefore, the development of future design guidelines will require a full probabilistic analysis of the intensities, frequencies of occurrence, and durations of all pertinent hazards.

Guidelines for ensuring resilience may entail some level of advanced analysis and performance-based design. Depending on the complexity of the project, requirements of the owners, the engineer's training, and code criteria, the analysis may require different levels of data preparation. For example, at a low level, applying generic regional hazard data may be sufficient. For more advanced analyses, the data may need to be more narrowly classified up to a point where site-specific data are needed to meet the expectations of the project owner and relevant authorities.

According to ASCE/SEI 7, the four building categories should meet different target reliability levels depending on the risk to the structure and its users (Table 3-1).

Table 3-1. ASCE/SEI 7 Target Reliability Indices for 50-Year Reference Service Period

Basis	Risk Category			
	I	II	III	IV
Risk in the event of failure	Low risk to human life	Structures other than those in Risk Categories I, III, and IV	Substantial risk to human life or economic impact or disruption of everyday life	Substantial hazard to the community
Failure that is not sudden and does not lead to widespread progression of damage	$\beta = 2.5$	$\beta = 3.0$	$\beta = 3.25$	$\beta = 3.5$
Failure that is either sudden or leads to widespread progression of damage	$\beta = 3.0$	$\beta = 3.5$	$\beta = 3.75$	$\beta = 4.0$
Failure that is sudden and results in widespread progression of damage	$\beta = 3.5$	$\beta = 4.0$	$\beta = 4.25$	$\beta = 4.5$

The reliability analysis that determined the ASCE/SEI 7 nominal design loads was based on the same hazard data for all four categories. For performance-based designs and resilience analyses, some suggest that using more reliability and higher-quality data for the higher risk categories would be more appropriate. This is something that is done to some extent in bridge design and may need to be considered when developing future structural design guidelines.

In all cases, engineers must have confidence in the source of available hazard data and be able to assess their quality and reliability. Criteria need to be established to assist engineers in making a proper assessment of the quality of the data and their applicability to the project's requirements. Therefore, hazard data for resilience analysis must be assembled by relevant authorities in formats suitable for adoption by engineers, and these should be accompanied by indicators that give design professionals confidence in their reliability and applicability to their projects.

Available datasets treat each climate hazard independently, but structural design standards and codes do provide load combination factors to account for the possibility that hazards may occur simultaneously. Yet these load combination factors assume uncorrelated load coincidences and

account neither for possible correlations among hazards nor for compounding effects. Appropriate data for studying load combinations and compounding effects must be made available for engineers involved in developing next-generation codes and standards and for those involved in performance-based designs and advanced resilience analysis.

Can engineers use AI techniques to extrapolate existing data for estimating future conditions? Such extrapolations would give some, perhaps imperfect, projections, but they would still be better than nothing when no projection models are available. What methods can one use to verify that AI projections are reasonable?

Damage assessment is another factor to consider. At the design stage, resilience analysis requires an estimation of the physical damage that would result from an extreme event and the relation between the damage and the extent of loss of function. While well-calibrated advanced structural analysis methods can be used to determine the response of structures to applied loads and how closely they approach or exceed specific limit states, establishing relationships between those analytical limit states and the physical damage to various structural and nonstructural components remains a difficult task. Another challenge is establishing the relationship between the physical damage and the reduced level of functionality of the structure so that, following each event, each facility could be associated with a facility condition index (FCI) that would help in developing a plan for restoration and recovery.

Even more challenging is estimating the combined physical damage from multiple occurrences of the same hazard or the combined effects of simultaneously or sequentially applied different hazards.

Assessing the damage to a structural system, a portfolio of structures, and an entire community with multiple interdependent infrastructure systems and ensuring that the assets meet appropriate resilience criteria remain difficult tasks. Ensuring recovery after a disastrous event requires rapidly assessing structural damage to individual structures; relating the observed physical damage to structural safety; assessing the functionality of the structure as a result of structural and nonstructural damage; and determining how nonstructural damage, such as felled trees, downed cables, and so forth, affects the recovery process. Advanced tools based on satellite and drone imaging should be calibrated and trained to help gather and interpret all types of damage.

System recovery is an important feature of resilient systems and communities in their ability to quickly recover from the aftermaths of disasters. Recovery must take two forms: physical recovery of structural components that are repaired to their original load-carrying capacities or to meet the latest structural design standards and functional recovery that would allow the users to reengage in the activities related to the original purpose of a structure, an infrastructure system, or a portfolio of systems that define a community. This implies the repair

of all sorts of nonstructural damage. Estimating the time and costs necessary for partial and full recovery following hazards of different intensities is an important component of assessing resilience. Thus, developing future guidelines requires the availability of tools that resemble multidimensional fragility curves that relate physical damage, loss of functionality, cost of recovery, and time to recovery to hazard intensity. These multidimensional fragility curves or recovery factors should provide the required information for analysis of resilience as a function of the type and the intensity of potential hazards.

To ensure quick recovery, the structural design process should anticipate and accommodate future adjustments to the initial design as new data on the performance of the structure, its aging process, and hazards become available over time. In that regard, the idea of adaptive design is becoming more widely accepted. How to establish adaptive design criteria and actions and their sensitivity to variations in regional hazards and construction practices remain important points of discussion.

The first issue related to resilience criteria and policies is identifying the up-to-date, scientifically credible, fit-for-purpose sources of future-looking building codes. Some suggest that groups like the ASCE/SEI 7 committee should play a primary role in that regard. These authorities should establish the main objectives of a future code and develop criteria to protect life and ensure the safety and welfare of the public. Thus, in addition to ensuring future structural performance, establishing a vision of how to address the issue of resilience at the community level is especially critical.

Once formed, the main purpose of the authority that will develop future resilience-targeted guidelines is to provide a framework for building resilience and propose guidelines that engineers can follow to develop strategies for ensuring resilience. Examples of such guidelines are being established by International Organization for Standardization (ISO) standards such as ISO 22316:2017 (*Security and resilience—Organizational resilience—Principles and attributes*) and ISO 22336:2024 (*Security and resilience—Organizational resilience—Guidelines for resilience policy and strategy*). The ASCE 7 committee has already initiated a first small step in that direction by developing a chapter on future conditions, which will provide “change factors” to account for future hazards.

The future authority in charge of developing the resilience framework should coordinate its effort with relevant government agencies and insurance providers in an effort that could perhaps emulate and benefit from the experience with FEMA’s Flood Insurance Rate Maps, which show flood hazard areas, and with that of the National Flood Insurance Program (NFIP). NFIP provides flood insurance to communities that adopt and enforce floodplain management regulations. The up-to-date, scientifically credible, fit-for-purpose source should extend that effort to other than flood hazards. However, note that ensuring community-level resilience should not be constrained by the presence or absence of an insurance program.

The FCI and multidimensional fragility curves provide important metrics of building damage and usability. The future source should develop minimum acceptable standards for such metrics to help decision-makers work out their initial design and eventual recovery strategies.

Another issue driving decisions on resilience-informed designs is the long-term insurability of buildings, which makes them viable to finance. Significant problems will arise if insurance costs exceed the benefit-cost ratio because no insurance means no financing. The source must coordinate its effort with the insurance industry to avoid possible conflicts.

Establishing a framework and criteria for resilience assessment requires large datasets. The sources must establish criteria for identifying acceptable sources of data and for determining their reliability, including the sources and levels of uncertainty, for quality control and quality assurance purposes. While many public agencies collect hazard data and make them accessible through their web portals, much of the data on damage assessment, cost of structural design, and structural repairs are proprietary, owned by either engineering firms or the insurance industry. The relevant questions include (1) can regulators establish a framework between private and public sectors to share critical data that are essential for establishing frameworks for resilience assessment; (2) what strategies for storing and making these data readily accessible in a standardized format will the sources need to develop; (3) how can insurance loss data be used for understanding the impact of extreme events and updating codes and standards; and (4) what mechanisms can be used to compel private entities, such as engineering firms and insurance firms, to make their data available for use for the public good by public agencies, code writers, and planners?

Because of the large variety in infrastructure types, ownership structures, and risk impacts across various fields, the future framework must be pragmatic and permit some individual initiatives so as to avoid stifling innovative ideas. Different owners may be given a certain level of flexibility. For example, at a much different level and for a small range of applications, local NYC laws provide some examples of leniency and alternative compliance paths depending on the size of the structure and its level of occupancy.

Different communities relate to hazards and associated impacts in different ways. Therefore, establishing risk criteria and communicating these criteria in a way that the public understands are important tasks for future sources. Each community must be able to establish its risk tolerance over an appropriately defined time frame and be able to balance short-term reliability with reliability at the end of design life.

TOPIC 2: What are the next-generation research needs?

The most important future research goals concern developing a framework to establish resilience-based future design guidelines. The framework should describe what type of data is needed; how to ensure the reliability of the data; and how to apply the data to reduce the risk

of failure in future conditions; minimize the expected damage; and facilitate a quick, affordable, and sustainable recovery. The framework should accommodate different levels of analysis, some of which may be standardized while others may involve site-specific data and performance-based design criteria. Researchers may benefit from recent and ongoing development of ISO standards along those lines.

Because of the large uncertainties in estimating future loads and structural component deterioration, the expectation is that the resilience-based design framework would allow for the implementation of adaptive pathways. These will provide flexible decision-making processes that determine sequences of actions over time to help structure and infrastructure systems adapt to uncertain future conditions. The framework should be sufficiently flexible to allow for adjustments based on information gathered over time on the performance of the structure and improved projections of changing loads.

Because developers have traditionally tended toward minimizing their initial investment costs, especially in sectors where privately owned structures undergo relatively quick turnovers in ownership, several conditions must be met to allow the adaptive pathways approach to “work.” Among these are (1) identifying the asset managers and the transition in management over time, (2) instituting asset management codes, (3) determining the requirements of owners, (4) modeling the impact of compounded hazards, (5) defining functional recovery and its implications for building users, (6) developing criteria to evaluate the consequences of failure of a single project on the community and its impact on the public’s wellbeing, and (7) developing guidelines for a constructive peer review process.

Structural design codes and standards are based on risk-informed principles that utilize “notional” reliability and risk criteria calibrated based on an assessment of the performance of structures and infrastructure systems defined in terms of analytically determined limit states. Establishing risk communication processes is necessary to help engineers, owners, users, and the general public understand and relate to future risks and establish risk tolerance criteria that will facilitate social understanding of the value of changes in design standards.

The successful implementation of all these research goals hinges on the availability of data that will help code developers and engineers develop the proposed framework, perform the necessary adaptive designs, and collect site-specific information and project future conditions. We need to develop methods for data quality control and quality assurance to help engineers use appropriate datasets to make informed extrapolations and projections of future conditions. This may require the adoption and calibration of new sensing technologies such as remote satellite and drone imaging, robotics in combination with advanced statistical analysis under deep uncertainty, and AI and ML tools.

TOPIC 3: Identify needs that you believe are required to advance the next generation of research.

A framework for adaptive design is one major need. Implementing adaptive design principles is believed to provide an ideal approach for minimizing the initial cost of construction when deep uncertainties are involved in estimating future conditions. Adaptive design would allow engineers to adjust the original structural design as information is gathered on the behavior and response of the structure to changing hazards over time. However, that assumes that the original design is created in a way that can accommodate efficient, easy-to-implement, cost-effective changes to improve the capacity of the structure. Such adaptive design principles have been implemented for the design of flood walls, where the foundations were designed to accommodate future increases in the wall height if current projections of sea-level rise and coastal flooding are higher than anticipated. Research is needed to examine the applicability of adaptive design principles to different structure types or assets and different hazards. The research should explore how to classify structures based on their suitability for adaptive design. Questions that need to be answered include the following: Is adaptive design possible for all buildings and structure types and sizes? Does adaptive design apply to all climatic hazards? Should new risk categories be created based on the adaptability of the structural design? What format would adaptation ratings take? What bases should be used to set adequate risk-informed criteria and targets for each category? What conditions would trigger the implementation of the preplanned adaptation strategy?

Reliability criteria for nonstationary conditions is another major need. Current risk-informed, reliability-based design standards were developed on the assumption of stationary conditions. The reliability targets and the reference service period were set based on the analysis of previous generations of structures that performed adequately over the years when the statistical parameters of the hazards were found to be practically time independent, that is, the hazards were considered to be stationary processes. The applicability and compatibility of current reliability calibration methodology for nonstationary conditions are questionable. Research is needed to address the following questions: How to account for the large number of cases in which actual service life may differ from the reference life set in design standards, or when the hazards beyond the reference period could be significantly more severe than the hazards within the reference period? Should the design be based on cumulative probability of exceedance over the reference period, or should one assume a worst-case scenario and adopt a more conservative approach? How can one project hazard intensities over long service periods that go beyond the limitations of existing climate models and data? The current standard essentially ignores aleatory uncertainties in projecting future conditions, which was demonstrated to be acceptable for reliability-calibrated codes under stationary conditions. However, the large uncertainties associated with any shared socio-economic pathways (SSPs) and its emissions scenario and the uncertainties in the estimated changes in hazard intensities and frequencies within each scenario, may require a review of basic code calibration approaches, including a review of the adequacy of current risk categories and whether a more formal risk benefit-cost analysis would be more appropriate in some cases (ClimateData.ca. 2026). For example, bridge safety is important for life safety, while the height of a seawall can

be built based on cost-benefit analysis. Should engineers develop their own interim updates before the code is formally updated? If so, how do we review and publish interim data?

Adaptation of existing structures is another area for further research. Unlike structures that are intentionally designed to include features that permit adaptation to changes, most structures were built under the assumption of stationary conditions and were not necessarily designed or constructed to accommodate major changes to improve their load-carrying capacities should it become necessary as more information on their deterioration levels and the applied hazards is made available. Given the observed changes in damaging hazards, existing structures must be monitored and evaluated regularly to plan necessary repairs and rehabilitation. In bridge engineering, existing structures are assessed based on lower reliability targets than for new designs. This is done following the concept of a cost-benefit analysis where rehabilitating existing structures to higher standards involves higher direct and indirect costs. The same is evidently true for all types of structures even if the cost-benefit concept for bridges was done informally based on experience rather than in response to an actual detailed analysis. Therefore, new research is necessary to determine adequate assessment criteria for existing structures and whether these criteria should depend on different sectors and types of structures. Other questions pertain to the determination of existing load-carrying capacities of the components and the levels of deterioration and how to account for the uncertainties in current methods for assessing the strength of the materials and how fast they are degrading. These should identify when intervention would be necessary. The framework for existing structures should also determine the reliability level that an existing structure should be restored to and the future service period it should be expected to survive. This is especially important when the original design may have been based on previous generations of codes that may be inconsistent with the standards at the time of intervention.

Performance-based design was another research need that the breakout group discussed. The assessment of existing structures, the design of critical structures—even designs that are developed in periods that fall between code and standard cycles—or projects that require site-specific studies might be improved using performance-based design principles. While standards such as ASCE/SEI 7 already incorporate basic principles of performance-based design, the consideration of future conditions in performance-based design requires new guidelines and/or standards that will provide specific procedures for data collection and validation. The guidelines must include a procedure to describe (1) how to review existing design criteria, or if necessary, to develop new ones to account for new information; (2) how to handle uncertainty in the criteria; (3) how and when to use available hazard data and other information as opposed to requiring the engineers to collect new data and information; (4) how to select the target for increased temperature or which SSP model to use; (5) which of the hazards require more research; and (6) what are the procedures for a peer review process?

Deep uncertainties must be accounted for. The emphasis of previous code calibration efforts was on aleatory uncertainties in hazard estimation. This was based on the fact that the code

was calibrated to match the reliability levels of structures that had performed satisfactorily over previous years. The calibration process proved to be “robust” under stationary conditions, in the sense that the load and resistance factors were not very sensitive to changes in the statistical parameters if the reliability levels observed for the historically well-performing structures were used to calibrate the load and resistance factor design code. However, the performance of structures that were subjected to hazards with time-independent statistical parameters may no longer provide valid indicators of the performance of structures that will be exposed to changing conditions. Thus, developing risk-informed, resilience-based design guidelines that consider future conditions requires a review of the effects of the large uncertainties involved in the “robustness” of current code calibration procedures. Research on assessing the effects of uncertainty in projected climate scenarios on the performance of structures and their expected reliability is needed. The large uncertainties not only relate to the differences among SSP scenarios but also to estimated temperature variations within each scenario. Additional uncertainties are associated with modeling the intensities of the various climate hazards for a given temperature change timeline and the impact of climate parameters on the deterioration of structural components. The research should also account for the correlations among different hazards and the combined impact of the hazards on both structural loading and structural resistance and in determining the physical damage to structures exposed to extreme events. The research should investigate whether the DMDU framework that is being advocated for hydraulic structures can be effectively and efficiently extended to other structure types. DMDU essentially investigates the possibility of developing designs that would be sufficiently robust to account for various scenarios and various hazards and that may accommodate changes should additional information become available.

Assets require monitoring over time. In addition to long-term projection of expected hazard intensities, designing structures for life-cycle resilience requires information on the long-term deterioration of the load-carrying capacities of structures and the damage structures sustain after various types and levels of extreme events. To monitor the behavior and deterioration of bridges over time, transportation agencies have been developing and installing SHM systems (such as strain sensors, accelerometers, tilting and deflection measuring devices, impact echo and corrosion-monitoring instruments) and various imaging tools (drones, LIDAR, satellite) to inspect bridges and detect damage. Drone and satellite images are also used to detect major structural and other nonstructural damage (such as collapsed buildings, felled trees, downed electric and communication towers and cables, landslides, etc.) following extreme events. Such information is necessary to assess the extent of damage and estimate the cost and time needed for recovery. Research is needed to study the possibility of using similar monitoring techniques to assess the deterioration of and the damage to various types of structures over time and after extreme events. Can asset management systems that have been implemented for highway pavements and bridges be extended to cover other types of assets? Can information gathered and lessons learned from monitoring one asset type be transferable to study other types?

Risk assessment and risk communication are other factors to consider. Historically, risk-informed codes and standards were developed based on “notional” measures of risk that were based on the opinion of experts in structural design and probabilistic risk assessment methodologies. The approach worked well because the codes were calibrated to match the reliability of structures that have historically safely resisted extreme hazard conditions. Research is needed to (1) investigate whether the same “notional” measures of risk and associated building categories can still be used to develop codes under nonstationary conditions; (2) relate these “notional” measures to more accurate measures of risk for various structure types and loading conditions; and (3) effectively communicate structural risk to owners and developers, relevant authorities, engineers, users, and the general public. The goal is to define and measure risk tolerance and connect it to the “notional” measures of risk that are used to define structural risk categories and associated design equations and give the public an appreciation of what to expect under various hazardous events.

3.4. Breakout 4. Future Guidelines (Virtual)

The fourth breakout group also discussed topics relating to future guidelines, including research needed for future standard updates and changing performance criteria, updates between code cycles, and criteria beyond codes and standards. Section 4 presents the top research priorities from this breakout group.

TOPIC 1: What is needed to address standard updates about future effects and performance criteria?

Data gaps and climate information need to be considered. Workshop participants voiced concerns that the current update schedule is too slow to incorporate new hazards and loading data on, for example, flooding, extreme precipitation, or winds. Outdated flood hazard maps, particularly those that reflect the risks from inland, groundwater, or compound floods, were specifically noted as a hindrance to effective decision-making. Participants considered the ability to scale existing methodologies to reflect future conditions to be an approachable task with immediate benefits for practitioners.

Participants also noted the technical difficulties of translating large-scale output from Earth system models into actionable engineering design loads and criteria. Engineers require clear, definitive thresholds and benchmarks to integrate projected climate data. An opportunity exists to enhance the knowledge of building performance to inform research, for instance, by incorporating sensors, monitors, and digital twins that can be related to weather observations. Participants noted that some categories of building already incorporate structural sensors. Access to these data could provide a deeper understanding of material degradation and deterioration that would supplement the information gained from lab testing of accelerated degradation. This may also support the use of novel materials that are often discounted by strict adherence to outdated codes. Design codes can stifle innovation in materials given the

lack of performance data. However, implementing monitoring faces practical barriers, including the high cost of installation, lack of standardized protocols, and issues surrounding data ownership and liability within the private sector.

Uncertainty surrounding Earth system simulations and the relationship to observed conditions is compounded by the knowledge gap surrounding structural degradation under future conditions. As climate stressors increase (e.g., higher humidity, greater temperature swings, more freeze-thaw cycles), the long-term reliability and service life of traditional and innovative sustainable materials—like cross-laminated timber, or low CO₂ concrete—become unknown variables. Without updated, standardized testing protocols and robust degradation data, codes risk becoming barriers to sustainable innovation. Participants stressed that enhanced cross-disciplinary collaboration is essential to align the goals and data output of climate scientists with the specific, resolution-dependent needs of the engineering community. For instance, engineers identified a need to accommodate other uncertainties within their design processes (e.g., changing demands, occupation, land-use planning) in addition to those associated with future climate conditions. Engineers requested clear instructions from climate scientists on (1) how to handle uncertainty in their design approaches, (2) how to identify different sources of uncertainty presented by different modeling approaches, (3) how to select the most appropriate models, and (4) how to translate the information into engineering loads.

TOPIC 2: How should updates between code and standard cycles be addressed?

Building code updates must be timely and flexible. Workshop participants identified a disconnect between the pace of updated building code cycles and that of peer-reviewed research outputs. While the six-year cycle of ASCE/SEI 7 seems too long to incorporate scientific advances and new research, it is not clear that enough progress is made to align updates with the shorter, three-year cycle of the International Building Code. Participants cautioned that frequent updates that may conflict with a previous iteration could lead to confusion among practitioners or hesitation to adopt updates. However, interim updates and simple tools are needed to support engineering practice and promulgate the current state of knowledge in between cycles. Such documents need to be peer-reviewed, nonmandatory supplements that could be published and publicized by credible organizations such as ASCE. This rapid communication channel was considered essential for bridging the gap between scientific discovery and formal code adoption.

Tools must expand to support performance-based design (PBD). Workshop participants discussed how PBD could support a more flexible approach to flood hazard design. Comparison was made to the success of PBD in seismic design, where probabilistic methods allow for tailored, site-specific risk mitigation. Extending this approach to flooding, while challenging, might be particularly effective for dealing with complex compound flood hazards (e.g., simultaneous heavy rain and high tide) and inland flooding. Methods developed by the U.S.

Nuclear Regulatory Commission might be applicable to extending PBD to hazards beyond seismic.

The absence of a reliable, standard tool for generating site-specific flood maps that project both current and anticipated future inundation depths across the United States is a concern. Research to develop hydrological models that can represent different flood sources, together with the underpinning model standards, is critically needed. Such models, leveraging future climate models, would allow for proactive flexible design, particularly with respect to Risk Category III and IV structures. Furthermore, greater collaboration with the insurance and reinsurance industries could be fruitful to inform improved mapping and to create a synergistic reduction in insurance premiums driven by improved resilience.

TOPIC 3: How should criteria beyond codes and standards be reviewed and published for design practice?

Advancing the new generation of structural design codes requires rethinking the traditional approach to funding research and the timing of research into practice. Reliance on traditional sources, such as federal research programs and small nonprofit organizations, is insufficient given the scale of research and budget restrictions. Participants proposed a paradigm shift involving cost-sharing models that engage the primary financial beneficiaries of resilient construction and accurate hazard data, including public agencies, utility companies, and the insurance and reinsurance industries. These sectors rely heavily on public data for risk assessment and thus have a vested interest in funding the underlying research for better standards.

The translation of research into modern codes and standards relies on volunteer input, inevitably slowing the pace of code development and potentially limiting the availability of willing participants in the process. Furthermore, the timeline for research needs to be separated from that of updating codes and standards. A flaw in the recent ASCE/SEI 7 update process was that underpinning research occurred in tandem with the development of the standard text. In the future, ensuring that research directions have been determined independently by the needs of the standards committees and are completed independently of the codes and standards process would be preferable.

Finally, the participants stressed that resilience cannot be achieved through code changes alone. The effort must look beyond prescriptive codes to ensure broad implementation, which involves

- Local land-use ordinances: Integrating future-focused hazard data into local zoning and planning;
- Regulatory requirements: Monitoring and reporting on the in situ performance of large and critical infrastructure; and

- User engagement: Dedicated, sustained efforts to support the uptake and use of revised codes and standards, for instance among code committees, engineers, building officials, community planners, and local government leaders who are responsible for adopting and enforcing new standards.

In summary, breakout group 4 identified the following points:

- Timely updates: Code cycles are too slow for evolving climate risks. Interim, peer-reviewed mechanisms are needed.
- Data modernization: Outdated hazard datasets hinder practice. Engineers need up-to-date, scientifically credible, fit-for-purpose, future-ready data products that are aligned across agencies.
- Uncertainty management: Clear thresholds and benchmarks are required to responsibly incorporate new science into codes.
- Degradation and innovation: Research into long-term material performance and standardized monitoring protocols is critical to manage risk and enable innovation.
- Performance-based futures: Flood design is a leading candidate for performance-based frameworks that account for current and future hazards.
- Funding and beneficiaries: Advancing next-generation standards will require new funding approaches, including exploring return on investment and cost allocation across beneficiaries (owners, agencies, insurers, communities).
- Beyond codes: Broader adoption will also depend on local ordinances, education, and stakeholder engagement to ensure implementation reaches practitioners and communities.

4. Section 4: Recommendation of Research Needs

In their discussions, each breakout group identified the top five priority items and/or research needs to best develop the next-generation goals for engineering design for structural capacity (groups 1 and 2) or future guidelines (groups 3 and 4).

4.1. Breakout 1. Structural Capacity (In Person)

Breakout group 1 concentrated on next-generation goals for engineering design as it relates to structural capacity and identified five priority needs:

- Codes and standards that address capacity degradation. Codes need to address frequent events that affect degradation as well as extreme events. This could be implemented through maps (e.g., ASCE hazard tool) of future environmental conditions (e.g., temperature, humidity, CO₂ concentration) and associated reduction factors for degradation in structural design and evaluation.
- Adaptive design methods. For the DMDU approach, the selection basis for scenarios, models, and stress tests for design that maintains an acceptable level of risk needs to be identified. Threshold values and time intervals for decision support and a strong foundation for such thresholds are needed. Societal requirements should be developed for structural design and expected performance and life cycle based on an economic model of cradle-to-cradle life-cycle costs to deliver long service lives for critical structures.
- Optimal, effective monitoring to assess new versus existing structures. Inexpensive tools can be used for monitoring degradation, such as corrosion or delamination. However, a need exists for technology for nondestructive remote monitoring, including below-surface applications that adapt existing technologies used by other disciplines (bridges, geotechnical, etc.). The field needs models to identify optimal monitoring frequency and locations based on degradation type, load paths, failure modes, spatial variability, and uncertainty.
- Data-driven life-cycle models. Well-validated degradation models are needed, as are models that can be updated with structural monitoring data. Similarly, where, when, and why degradation happens in structures must be understood to improve the effectiveness of retrofits, designs, and reliability assessments. Data are needed from existing structures, as is full-scale experimental testing to validate life-cycle models.
- Assessment of changing conditions and future hazards. To accomplish this assessment, we need to develop improved characterization of compounding (sequential) hazards and time-varying structural conditions; study relative impacts of future conditions, including extreme and frequent events, and their impact on structural

capacity/degradation over time; and develop plausible scenarios for regions that designers might consider.

4.2. Breakout 2. Structural Capacity (Virtual)

Breakout group 2 also focused on next-generation goals for engineering design as it relates to structural capacity. The group found two areas that require further development: an open-source database that would include in situ material characteristics and structural system behavior to calibrate performance models under hazard events (e.g., information gathered during post-hazard assessments or upon demolition) and guidelines to incorporate uncertainty in future structural capacity when evaluating designs for acceptable reasonable risk (e.g., using decision-making under uncertainty). The participants then came to a consensus on five priority research needs, as follows:

- Develop an open-source database of in situ material characteristics and structural system behavior to better calibrate performance models under hazard events. This database could include information gathered during post-hazard assessments or upon demolition. Improve in situ measurement capability for hazard levels and building performance during significant events. Work with private and public sector owners to overcome hesitations in sharing existing structural damage assessments.
- Evaluate long-term durability characteristics of structural materials (e.g., concrete, steel, wood) and nonstructural materials (e.g., coatings, sealants) with a focus on anticipated future effects and relating accelerated lab testing to real-world long-term behavior. This was seen as particularly important for new and innovative materials without a long track record in the field.
- Characterize effects due to concurrent or compounding modes of material degradation that reflect real-world behavior. Understand to what extent these modes of degradation can be treated as independent or correlated. Understand how changing climatic conditions affect these modes of degradation.
- Develop a better “micro-to-macro” understanding of how the microscale degradation of materials impacts components and how this affects the macroscale behavior of the structural system. For example, developing system reliability in lieu of, or in addition to, member reliability incorporating degradation to the components.
- Develop guidelines to incorporate uncertainty in future structural capacity when evaluating designs for acceptable reasonable risk. This research could include developing nonstationary reliability analysis that incorporates structural capacity changes, revisiting reliability targets to compare the design assumptions with real-world performance, and applying DMDU methods where large uncertainty is present.

4.3. Breakout 3. Future Guidelines (In Person)

Breakout group 3 discussed future guidelines for codes and standards development. The group members identified three research needs to improve future engineering design guidelines, suggested developing guidelines for monitoring existing structures and for determining appropriate criteria and thresholds, and identified a need to develop guidelines and standards for data validation for interim updates. More specific needs include the following:

- Research on implementation of adaptive design and whether the current risk categories apply for all types of hazards and asset sizes and numbers of users. Future guidelines should include adaptation/adaptive capacity-rating categories to extend the current four risk categories.
- Development of guidelines for monitoring existing structures and for determining appropriate criteria and thresholds for adapting existing assets to future conditions and to evaluate the performance of adaptive designs over time.
- Research on the applicability of current code calibration methods used for stationary conditions to the design of structures in nonstationary conditions.
- Research on assessing the effects of uncertainty in climate scenarios and associated uncertainties in the damaging effects of different hazards.
- Updates between code and standard cycles might be achieved by applying performance-based design principles. Guidelines and/or standards for data validation for interim updates are also needed.

4.4. Breakout 4. Future Guidelines (Virtual)

Breakout group 4 also focused on future guidelines for codes and standards development. More specific needs include

- Timely and flexible code updates. The current three- to six-year cycles for codes and standards are often too long to incorporate rapidly evolving climate science and engineering research. Mechanisms are needed to publish vetted interim requirements or supplements without confusing practitioners or undermining the authority of codes. Also important is providing advice for nontraditional entities that regulate development through local land-use ordinances.
- Future-oriented hazard and load data. Practitioners need up-to-date, scientifically credible, fit-for-purpose datasets (e.g., precipitation, wind, flood) that reflect future conditions rather than outdated baselines like NOAA Atlas 14.(NOAA 2026) Scalable methods (e.g., simple adjustment factors, ensembles) could provide usable interim tools until full datasets are refreshed.
- Uncertainty, reliability, and threshold criteria. Engineers require clearer ways to handle uncertainty in climate projections and structural degradation. Establishing benchmark thresholds, reliability criteria (for research, e.g., number of papers or consensus of percentage increase), and peer-reviewed vetting processes would help ensure that updates are scientifically defensible and practical for design.

- Monitoring, materials, and degradation research. More research is needed on long-term performance of structures under future conditions, covering new materials, degradation mechanisms, and sensor-based monitoring of public and private infrastructure. Standardized protocols for instrumentation and data-sharing could make real-world data more accessible for codes and practice (and ensure that data are used for good, no liability from providing entities further down the line).
- Performance-based and future conditions design frameworks. The demand for performance-based approaches (e.g., for flooding) and methods to overlay current and future hazard conditions at the site level is strong. These frameworks would allow codes and standards to evolve beyond prescriptive rules, enabling adaptation to compounding hazards and long-term climate shifts.
- Research funding, governance, and dissemination pathways. The development of next-generation codes and standards requires clarity on how research is funded, coordinated, and translated into practice. Industry groups, insurers, standards bodies, and government agencies all play roles in shaping research priorities, publishing new standards, and influencing updates—yet stronger mechanisms are needed to ensure consistent dissemination of requirements not only to engineers but also to planners, policymakers, and other decision-makers who shape the built environment.

5. Section 5: Analysis of Research Needs

Following the breakout sessions, the workshop participants reconvened and reviewed the recommended research needs from each breakout session. Along with the review, the participants engaged in robust discussions about the identified research needs, noting some duplication. As the workshops progressed, the WSC noticed the emergence of several themes that were aligned with, but not quite identical to, the focus of the specific workshop. Consequently, the WSC reviewed the prioritized research needs and indexed each according to the themes identified below.

5.1. Prioritized Research Needs Indexed to Themes

A summary discussion of results is useful for understanding the scope and complexity of the workshop topic. In general, the workshops were designed to build upon each other and progress the participants' thinking and understanding of the research needs. While each workshop focused on a specific aspect of overall need, each workshop yielded meaningful discussions in several areas. In review of the results, six themes emerged and the research priorities identified were aligned with the themes to consistently organize all topics across all of the workshops. The following briefly describes these themes.

1. *Future Hazard Data and Information.* Development of **up-to-date, scientifically credible and fit-for-purpose, future-ready hazard data frameworks** that are scientifically robust, transparent, and directly usable in engineering and planning decisions. Identifies future hazard datasets and associated information, including projections and their uncertainties, that are needed for future engineering design criteria.
2. *Future Load Effects and Infrastructure Conditions.* Advancement of **load characterization under future conditions, infrastructure performance modeling, and structural capacity assessments** that explicitly account for future climate, nonstationarity, and evolving built-environment conditions. The aim is to enable reliable, transparent, and forward-looking load and infrastructure condition assessments that support resilience modeling, code development, and risk-informed engineering decisions under future conditions.
3. *Design Guidelines, Criteria, and Tools.* Modernization of **design guidelines, criteria, and engineering tools** to explicitly address nonstationary hazards, future climate conditions, and time-dependent infrastructure performance. Translates evolving climate science and infrastructure performance knowledge into practical, transparent, and flexible design guidelines that support resilient infrastructure under future conditions.
4. *Resilience and Adaptation.* Advancing **resilience- and adaptation-focused engineering frameworks** that move beyond prescriptive design toward performance-based, risk-

informed, and decision science–based approaches suited for future conditions. The aim is to enable transparent, scalable, and socially informed adaptation strategies that support long-term infrastructure performance and community resilience under evolving climate and risk conditions.

5. *Planning and Design Frameworks*. Evolution of engineering practice toward **risk-informed, adaptive, and life-cycle-based decision frameworks** capable of addressing nonstationary hazards and long-term climate uncertainty. Includes research needs to align engineering design, planning, and code development with long-lived infrastructure performance, community resilience outcomes, and evolving societal risk preferences under future conditions.
6. *Codes and Standards*. **Modernization of codes, standards, and design philosophies** to reflect system-level risk, nonstationary hazards, and long-term infrastructure performance under future climate conditions. Enables adaptive, evidence-based codes and standards that support resilient infrastructure, informed decision-making, and timely adoption of best available knowledge.

The final outcome is the list of research needs indexed according to the six themes identified by the WSC (Table 5-1). Note that the list of research needs are those prioritized by the workshop participants, but the list is not in priority order. Additional details from each breakout group, along with preliminary indexing, are provided in Appendix A.

Table 5-1. Priority Research Needs Identified by the Workshop Participants Indexed across Six Themes *

Topic	Future Hazard Data and Information	Future Load Effects and Infrastructure Conditions	Design Guidelines, Criteria, and Tools	Resilience and Adaptation	Planning and Design Frameworks	Codes and Standards
Codes and standards that address capacity degradation. Codes need to address frequent events that affect degradation as well as extreme events. This could be implemented through maps (e.g., ASCE hazard tool) of future environmental conditions (e.g., temperature, humidity, CO2		1	2			3

concentration) and associated reduction factors for degradation in structural design and evaluation.						
Adaptive design methods. For DMDU approach, identify selection basis for scenarios, models, and stress tests for design that maintains an acceptable level of risk. Need thresholds values and time intervals for decision support and a strong foundation for such thresholds. Develop societal requirements for structural design and expected performance and life cycle based on an economic model of cradle-to-cradle life-cycle costs to deliver long service lives for critical structures.			2	2	1	
Optimal, effective monitoring to assess new vs. existing structures. Inexpensive tools for monitoring degradation, such as corrosion or delamination. Technology for nondestructive remote monitoring, including below surface; adapt existing technologies used by other disciplines (bridges, geotechnical, etc.). Need models to identify optimal monitoring frequency and locations based on degradation type, load		2	1			

paths and failure modes, spatial variability, and uncertainty.						
Assessment of changing conditions and future hazards. Develop improved characterization of compounding (sequential) hazards and time-varying structural conditions. Study of relative impacts of future conditions, including extreme and frequent events, and their impact on structural capacity/degradation over time. Develop plausible scenarios for regions that designers might consider.		1	2		3	
Develop guidelines to incorporate uncertainty in future structural capacity when evaluating designs for acceptable reasonable risk. For example, using DMDU.		1		2	3	
Develop an open-source database including in situ material characteristics and structural system behavior to calibrate performance models under hazard events. For example, information gathered during post-hazard assessments or upon demolition.	2	2	1			

Data-driven life-cycle models. Well-validated degradation models are needed. Also needed are models that can be updated with structural monitoring data. Understanding of where, when, and why degradation happens in structures is needed to improve effectiveness of retrofits, designs, and reliability assessments. Need data from existing structures and full-scale experimental testing to validate life-cycle models.		1	2			
Evaluate durability characteristics of structural materials (e.g., concrete, steel, wood) and nonstructural materials (e.g., coatings, sealants) with a focus on anticipated future effects and relating accelerated lab testing to real-world long-term behavior.		1	2			
Better understanding of “micro to macro”: how materials degradation impacts components and how this affects the behavior of the structural system. For example, developing system reliability in lieu of, or in addition to, member reliability incorporating degradation into the components.		1	2		3	
Characterize effects due to concurrent or compounding material		1	2			

degradation modes that reflect real-world behavior.						
Performance-based and future conditions design frameworks. Demand for performance-based approaches (e.g., for flooding) and methods to overlay current and future hazard conditions at the site level is strong. These frameworks would allow codes and standards to evolve beyond prescriptive rules, enabling adaptation to compounding hazards and long-term climate shifts.				1	2	3
Uncertainty, reliability, and threshold criteria. Engineers require clearer ways to handle uncertainty in climate projections and structural degradation. Establishing benchmark thresholds, reliability criteria (for research, e.g., number of papers or consensus of percentage increase), and peer-reviewed vetting processes would help ensure that updates are scientifically defensible and practical for design.			1	2		

Monitoring, materials, and degradation research. More research is needed on long-term performance of structures under future conditions, covering new materials, degradation mechanisms, and sensor-based monitoring of public and private infrastructure. Standardized protocols for instrumentation and data-sharing could make real-world data more accessible for codes and practice (and to ensure that data are used for good, no liability from providing entities further down the line).		1	2			3
Develop guidelines for monitoring existing structures and for determining appropriate criteria and thresholds for adapting existing assets to future conditions and for evaluating the performance of adaptive designs over time.				1	2	
Updates between code and standard cycles might be promoted by applying performance-based design. A need exists to develop guidelines and standards for data validation for interim updates, including guidelines for assessing existing structures for future conditions and procedures explaining how we can review and				1	2	3

update established criteria in codes and standards.						
Research on implementation of adaptive design and whether the current risk categories apply for all types of hazards, asset sizes, and numbers of users. Future guidelines should include adaptation/adaptive capacity-rating categories to extend the current four risk categories.				2	1	
Research on assessing the effects of uncertainty in climate scenarios and associated uncertainties in the damaging effects of different hazards.		1	2			
Research on applying current methodology used for stationary conditions to the design of structures in nonstationary conditions.			1		2	
Timely and flexible code updates. The current 3- to 6-year cycles for codes and standards are often too long to incorporate rapidly evolving climate science and engineering research. Mechanisms are needed to publish vetted interim requirements or supplements without confusing practitioners or					1	2

undermining the authority of codes. Also needed is requirements for nontraditional entities that regulate development through local land-use ordinances.						
Future-oriented hazard and load data. Practitioners need up-to-date, scientifically credible, regularly updated datasets (e.g., precipitation, wind, flood) that reflect future conditions rather than outdated baselines like NOAA Atlas 14. Scalable methods (e.g., simple adjustment factors, ensembles) could provide usable interim tools until full datasets are refreshed.	2	1	2			
Research funding, governance, and dissemination pathways. The development of next-generation codes and standards requires clarity on how research is funded, coordinated, and translated into practice. Industry groups, insurers, standards bodies, and government agencies all play roles in shaping research priorities, publishing new standards, and influencing updates—yet stronger mechanisms are needed to ensure consistent dissemination of requirements not only to engineers but also to					1	2

planners, policymakers, and other decision-makers who shape the built environment.						
--	--	--	--	--	--	--

*Table Key:

- 1 = Primary research need
- 2 = Secondary research need
- 3 = Related research need

5.2. Discussion of Results

The outcomes of Workshop 3 on engineering design guidelines and criteria provide a solid technical foundation for estimating loads due to future hazards and determining structural degradation under future conditions. The goals developed in the workshop will provide essential information for design practice, planning frameworks, and code and standards that will be required for design practice under future conditions.

5.2.1. Future Hazard Data and Information

Research topics prioritized in Workshop 3 emphasize the primary role of hazard characterization including structural capacity degradation in enabling climate-informed design, planning, and ultimately codes and standards. Specific topics focus on improving confidence in future hazard estimates by advancing methods to integrate observational data, process-based models, and climate projections across spatial and temporal scales relevant to infrastructure performance. The topics recognize that traditional stationary assumptions are no longer adequate under future conditions and that hazard data must explicitly account for nonstationarity and compounding effects.

Several topics emphasize the need for standardized and transparent methodologies to develop future hazard datasets. These include research on best practices for downscaling climate model outputs, translating climate signals into engineering-relevant hazard metrics, and documenting

uncertainty in ways that are usable to practitioners. Workshop participants also emphasized the need to develop fit-for-purpose hazard products to support specific applications such as design storms, flood frequency analysis, or compound hazard assessments. Also important are the data stewardship, metadata standards, and centralized repositories that synthesize datasets across agencies and disciplines. Creation of AI-ready hazard datasets that are updated regularly is also important.

5.2.2. Future Load Effects and Infrastructure Conditions

This theme addresses how evolving hazards translate into changing loads in the built environment and how infrastructure capacity degrades over time. Research topics highlight the need to better quantify future load effects associated with climate-driven changes in extreme events, including increased rainfall intensity, flooding, wave action, and compounding hazard scenarios. A major topic of significance is the assessment of infrastructure performance under future conditions, including degradation mechanisms, aging, and interactions among multiple stressors. Research topics call for improved methods to represent how materials, components, and systems respond to repeated or intensified loading, and how maintenance, retrofits, and operational changes influence long-term performance. Monitoring and inspection are highlighted as essential for validating models and detecting early signs of structural degradation.

Other topics include translating probabilistic hazard and load information into a framework that is compatible with existing design practice and performance-based design approaches. Important topics in this theme also extend toward system-scale assessments, including how interconnected infrastructure networks respond to cascading failures and how future load effects propagate across regions and sectors.

5.2.3. Design Guidelines, Criteria, and Tools

Research under this theme focuses on bridging the gap between emerging science and day-to-day engineering practice with due consideration of nonstationarity. The topics emphasize the development of adaptive and performance-based design methods that explicitly incorporate future conditions and uncertainty. These topics recognize that prescriptive approaches based solely on historical data are increasingly insufficient and that engineers need requirements that supports flexible, risk-informed decision-making. They also focus on consistent requirements across disciplines, reducing inconsistencies among standards, manuals, and agency practices;

addressing longer-term needs such as training and capacity building; and developing case studies that demonstrate how new requirements can be applied in real projects.

5.2.4. Resilience and Adaptation

This theme includes research topics aimed at ensuring infrastructure systems can anticipate, withstand, recover from, and adapt to future hazards. These topics emphasize resilience-based design approaches that account for uncertainty, including situations of deep uncertainty, and evolving risk over long planning horizons. These topics stress the importance of defining performance objectives that go beyond life safety to include serviceability, recovery time, and societal impacts.

A key research area is the integration of resilience metrics into engineering and planning decisions. Topics emphasize the need for methods that quantify benefits of adaptation strategies, including nature-based solutions, hybrid designs, and phased or modular interventions. Life-cycle cost analysis and benefit-cost frameworks are emphasized as essential tools for evaluating adaptation investments under uncertain future conditions.

5.2.5. Planning and Design Frameworks

This theme addresses alignment of engineering decisions with broader planning, policy, and societal objectives. The resulting research needs emphasize systems-based approaches that consider interactions among infrastructure, environment, and communities. These topics recognize that future-ready design requires coordination across sectors and scales. Specific research needs include frameworks for incorporating future hazard and load information into long-range planning, capital improvement programs, and land-use decisions. They also emphasize scenario planning, adaptive pathways, and robust decision-making approaches that can accommodate changing conditions and new information over time. Improving communication and stakeholder engagement and ensuring that technical analyses are translated into actionable practice are also highlighted.

5.2.6. Codes and Standards

This theme addresses the mechanisms by which research and practice are formalized and disseminated under future conditions. Specific topics focus on the challenge of incorporating rapidly evolving climate science and engineering knowledge into codes and standards that are traditionally updated on multiyear cycles. They also highlight the need for flexible pathways,

such as interim requirements that allows vetted information to reach practitioners without undermining code authority.

5.3. Summary

Across all themes, the highest-priority research topics consistently emphasize **integration**, linking future hazard data to loads, infrastructure response, design guidelines, planning frameworks, and ultimately to codes and standards. The priorities highlight a clear need to move from fragmented, discipline-specific advances toward coordinated, decision-relevant research that supports reliable performance under future conditions. Collectively, these topics help advance climate-informed engineering practice while maintaining transparency, consistency, and practical usability.

6. Section 6: Acronyms and Abbreviations

AI	Artificial Intelligence
ASCE	American Society of Civil Engineers
CMIP7	Coupled Model Intercomparison Project
CO ₂	Carbon Dioxide
DMDU	Decision Making under Deep Uncertainty
FCI	Facility Condition Index
FEMA	Federal Emergency Management Agency
ISO	International Organization for Standardization
ML	Machine Learning
NFIP	National Flood Insurance Program
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NYC	New York City
PBD	Performance-Based Design
SEI	Structural Engineering Institute
SHM	Structural Health Monitoring
SSP	Shared Socio-economic Pathways
WSC	Workshop Steering Committee

7. Section 7: References

- ACI (American Concrete Institute). ACI 318. ACI Committee 318. *Building Code Requirements for Structural Concrete (ACI 318-19): An ACI Standard; Commentary on Building Code Requirements for Structural Concrete (ACI 318)*. Farmington Hills, MI: American Concrete Institute.
- ASCE. 2022. *Minimum design loads and associated criteria for buildings and other structures*. ASCE/SEI 7-22. Reston, VA: ASCE.
- ClimateData.ca. 2026. "Understanding Shared Socio-economic Pathways (SSPs)." Accessed March 31, 2026. <https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/>
- ISO (International Organization for Standardization). 2017. *Security and resilience—organizational resilience—principles and attributes*. ISO 22316:2017. Geneva: ISO.
- ISO. 2024. *Security and resilience—organizational resilience—guidelines for resilience policy and strategy*. ISO 22336:2024. Geneva: ISO.
- NOAA Atlas 14. U.S. Climate Resilience Toolkit. "NOAA Atlas 14 – Precipitation Frequency Data Server (PFDS)." Accessed March 31, 2026. <https://toolkit.climate.gov/tool/noaa-atlas-14-precipitation-frequency-data-server-pfds>.
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Future Hazards: Workshop Report, June 4–5, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-071. <https://doi.org/10.6028/NIST.GCR.26-071>
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Future Load Effects: Workshop Report, July 29–30, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-072. <https://doi.org/10.6028/NIST.GCR.26-072>
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Engineering Design Guidelines and Criteria: Workshop Report, Sept. 25–26, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-073. <https://doi.org/10.6028/NIST.GCR.26-073>
- Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Adaptation and Resilience: Workshop Report, Oct. 29–30, 2025. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-074. <https://doi.org/10.6028/NIST.GCR.26-074>

Obeysekera, J., J. Goupil, M. Ackerson, J. Ackroyd, J. Barsugli, K. Borth, K. Dixon, M. Ghosn, M. Gilbertson, E. Gilmore, J. Hogan, S. Li, A. McCarty, M. Tye (2026) Forward-Looking Codes and Standards: Final Report, March 31, 2026. National Institute of Standards and Technology, Gaithersburg, MD, NIST GCR 26-075. <https://doi.org/10.6028/NIST.GCR.26-075>

Appendix A. Discussion of Priority Research Needs

Tables A-1 and A-2 summarize the breakout session research needs and their prioritization ranking.

Table A-1. Breakout Sessions 1 and 2 on Structural Capacity: Research Needs, as Voted on and Prioritized by the Workshop Participants

Priority need	% of total ranking
Codes and standards that address capacity degradation. Codes need to address frequent events that affect degradation as well as extreme events. This could be implanted through maps (e.g., ASCE hazard tool) of future environmental conditions (e.g., temperature, humidity, CO2 concentration) and associated reduction factors for degradation in structural design and evaluation.	41.7%
Adaptive design methods. For DMDU approach, identify selection basis for scenarios, models, and stress tests for design that maintains an acceptable level of risk. Need threshold values and time intervals for decision support and a strong foundation for such thresholds. Develop societal requirements for structural design, expected performance, and life cycle based on an economic model of cradle-to-cradle life-cycle costs to deliver long service lives for critical structures.	39.6%
Optimal, effective monitoring to assess new vs. existing structures. Inexpensive tools for monitoring degradation, such as corrosion or delamination. Technology for nondestructive remote monitoring, including below surface; can adapt existing technologies used by other disciplines (bridges, geotechnical, etc.). Need models to identify optimal monitoring frequency and locations based on degradation type, load paths and failure modes, spatial variability, and uncertainty.	35.4%
Assessment of changing conditions and future hazards. Improve characterization of compounding (sequential) hazards and time-varying structural conditions. Study of relative impacts of future conditions, including extreme and frequent events, and their impact on structural capacity/degradation over time. Develop plausible scenarios for regions that designers might consider.	35.4%
Develop guidelines to incorporate uncertainty in future structural capacity when evaluating designs for acceptable reasonable risk. For example, using DMDU.	31.3%
Develop an open-source database including in situ material characteristics and structural system behavior to calibrate performance models under hazard events. For example, information gathered during post-hazard assessments or upon demolition.	29.1%
Data-driven life-cycle models. Need well-validated degradation models. Also needed are models that can be updated with structural monitoring data. Need to understand where, when, and why degradation happens in structures to improve effectiveness of retrofits, improve designs, and carry out reliability assessments. Need data from existing structures and full-scale experimental testing to validate life-cycle models.	25%
Evaluate durability characteristics of structural materials (e.g., concrete, steel, wood) and nonstructural materials (e.g., coatings, sealants) with a focus on anticipated future effects and relating accelerated lab testing to real-world long-term behavior.	25%

Better understanding of “micro to macro”: how material degradation impacts components and how this affects behavior of the structural system. For example, developing system reliability in lieu of, or in addition to, member reliability incorporating degradation of the components.	25%
Characterize effects due to concurrent or compounding material degradation modes that reflect real-world behavior.	6.3%
Other	6.3%

Table A-2. Breakout Sessions 3 and 4 on Future Guidelines: Research Needs, as Voted on and Prioritized by the Workshop Participants

Priority need	% of total ranking
Performance-based and future conditions design frameworks. Demand for performance-based approaches (e.g., for flooding) and methods to overlay current and future hazard conditions at the site level is strong. These frameworks would allow codes and standards to evolve beyond prescriptive rules, enabling adaptation to compounding hazards and long-term climate shifts.	39.6%
Uncertainty, reliability, and threshold criteria. Engineers require clearer ways to handle uncertainty in climate projections and structural degradation. Establishing benchmark thresholds, reliability criteria (for research, e.g., number of papers or consensus of percentage increase), and peer-reviewed vetting processes would help ensure that updates are scientifically defensible and practical for design.	35.4%
Monitoring, materials, and degradation research. More research is needed on long-term performance of structures under future conditions, covering new materials, degradation mechanisms, and sensor-based monitoring of public and private infrastructure. Standardized protocols for instrumentation and data-sharing could make real-world data more accessible for codes and practice (and to ensure that data are used for good, no liability from providing entities further down the line).	35.4%
Develop guidelines for monitoring existing structures and for determining appropriate criteria and thresholds for adapting existing assets to future conditions and to evaluate the performance of adaptive designs over time.	31.3%
Updates between code and standard cycles might be sped up by applying performance-based design. A need exists to develop guidelines and standards for data validation for interim updates, including guidelines for assessing existing structures for future conditions and procedures explaining how we can review and update established criteria in codes and standards.	31.3%
Research on implementation of adaptive design and whether the current risk categories are applicable for all types of hazards, asset sizes, and numbers of users. Future requirements should include adaptation/adaptive capacity rating categories to extend the current four risk categories.	27.1%
Research on assessing the effects of uncertainty in climate scenarios and associated uncertainties in the damaging effects of different hazards.	20.8%
Research on the applicability of current methodology used for stationary conditions to the design of structures in nonstationary conditions.	18.8%

Timely and flexible code updates. The current 3- to 6-year cycles for codes and standards are often too long to incorporate rapidly evolving climate science and engineering research. Mechanisms are needed to publish vetted interim requirements or supplements without confusing practitioners or undermining the authority of codes. This also includes providing requirements for nontraditional entities that regulate development through local land-use ordinances.	18.8%
Future-oriented hazard and load data. Practitioners need up-to-date, scientifically credible, fit-for-purpose datasets (e.g., precipitation, wind, flood) that reflect future conditions rather than outdated baselines like NOAA Atlas 14. Scalable methods (e.g., simple adjustment factors, ensembles) could provide usable interim tools until full datasets are refreshed.	18.8%
Research funding, governance, and dissemination pathways. The development of next-generation codes and standards requires clarity on how research is funded, coordinated, and translated into practice. Industry groups, insurers, standards bodies, and government agencies all play roles in shaping research priorities, publishing new standards, and influencing updates—yet stronger mechanisms are needed to ensure consistent dissemination of requirements not only to engineers but also to planners, policymakers, and other decision-makers who shape the built environment.	16.7%
Other	6.3%

Appendix B. Workshop Materials

B.1. Workshop Agenda



STRUCTURAL
ENGINEERING
INSTITUTE

SEI NIST Forward-Looking Codes and Standards: Engineering Design Guidelines and Criteria Workshop

DATE: September 25–26, 2025

LOCATION: Crowne Plaza Dulles Airport,
2200 Centreville Rd, Herndon, VA 20170

VIRTUAL: Zoom and MS Teams links, sent separately

Workshop Agenda_v2

Workshop Director: Jayantha “Obey” Obeysekera, Ph.D., Research Professor,
Director of Sea Level Solutions Center, Institute of Environment at FIU

WORKSHOP MATERIALS: [Link to Digital Materials Package](#) (password: engineeringdesign)

Day 1: September 25, 9:00am–5:00pm ET

8:00am–9:00am: NETWORKING CONTINENTAL BREAKFAST PROVIDED

GENERAL SESSION: ZOOM LINK

9:00am–9:30am: Welcome

- Welcome, Purpose, and Workshop Agenda and Goals
 - Welcome and Opening Remarks—Jayantha “Obey” Obeysekera, Ph.D., P.E., Research Professor, Director of Sea Level Solutions Center, Institute of Environment at FIU
 - Purpose—Therese McAllister, Ph.D., P.E., F.SEI, Dist.M.ASCE, Deputy Chief, Materials and Structural Systems Division, NIST
 - Workshop Agenda and Goal—Jennifer Goupil, P.E., F.SEI, F.ASCE, Managing Director SEI, Chief Resilience Officer ASCE
- Introductions—All Participants

9:30am–10:45am: Structural Capacity and Degradation

Presentations on current, ongoing synergistic work.

- **Structural Degradation Modeling and Life-Cycle Assessment Considering Future Climate Effects;** Fabio Biondini, Ph.D., P.E., F.SEI, F.ASCE; Department of Civil and Environmental Engineering, Politecnico di Milano [15 min]
- **Case Study: How Uncertainties of Structural Degradation and Condition Assessment Impact Project Design;** James R. Harris, Ph.D., P.E., F.SEI, Dist.M.ASCE, NAE; JR Harris & Company [15 min]
- **Case Study: Structural Degradation and Condition Assessment of Waterfront Structures in Marine Environments;** Ming Liu, Ph.D., P.E., F.ASCE; NAVFAC [15 min]
- **PANEL Discussion on Structural Capacity and Degradation with Q&A** [30 min]
 - Moderator: Jayantha Obeysekera

10:45pm–11:00am: PICTURE + COFFEE BREAK

11:00am–12:15pm: Future Guidelines beyond Codes and Standards

Presentations will examine what is being addressed in decision-making outside of traditional consensus processes.

- **Decision Science: Future Design Scenarios Considering Deep Uncertainty;** Rob Lempert, Ph.D.; RAND Corp. [15 min]
- **Project Case Study: California High Speed Rail;** Jack Hogan, P.E.; Arup [15 min]
- **Regulatory Case Study: NYC Waterfront Code;** Stirling Moore, AIA; AECOM [15 min]
- **PANEL Discussion on Guidelines beyond Code and Standards with Q&A** [30 min]
 - Moderator: Jayantha Obeysekera

12:15pm–12:45pm: WORKING LUNCH PROVIDED

PLENARY SESSION: MS TEAMS LINK

12:45pm–1:30pm: Plenary Discussion

Session to define “what do we need to be thinking about,” followed by instructions for the breakout sessions.

- **Next-Generation Goals:** [40 min]; ALL
Moderators: Jayantha Obeysekera, Therese McAllister
TOPIC 1: Structural Capacity GOAL: What are the most impactful future effects on structural capacity? What is needed to characterize future structural capacity and degradation effects?
TOPIC 2: Future Guidelines GOAL: What is needed to address updates about future effects and performance criteria? How should updates between code and standard cycles be addressed? How should criteria beyond codes and standards be reviewed and published for design practice?
- **Charging Breakouts:** [5 min]; Jennifer Goupil
Instructions on how the breakouts will work.
PROMPTS:
 - What do you wish you had for data, tools?
 - What are the next-generation research needs?

1:30pm–1:45pm: Move to assigned breakout rooms

1:45pm–3:15pm: Concurrent Breakout Sessions

3:15pm–3:30pm: COFFEE BREAK

3:30pm–4:45pm: Concurrent Breakout Sessions (cont.)

4:45pm–5:00pm: Reconvene

- Summary and Adjourn Day 1

Day 2: September 26; 9:00am–12:00pm ET

8:30am–9:00am: NETWORKING CONTINENTAL BREAKFAST PROVIDED

9:00am–9:15am: Welcome

- Purpose and Goals of Day 2

9:15am–10:15am: Report Out

- Breakout Session Report Out: [15 min EACH = 10 min + 5 min Q&A]

15-minute COFFEE BREAK

10:30am–11:45am: Prioritization

- Moderated Discussion of Breakout Reports [30 min]
Moderator: Jayantha Obeysekera
- Prioritization of Research Needs, Survey [15 min]
- Discussion of Survey Results [30 min]

11:45am–12:00pm: Conclusion

- Summary and Adjourn Day 2

12:30–3:00pm: Workshop Steering Committee Meeting

B.2. Workshop Presentations

B.2.1. Day 1: Overview Presentation

FUTURE ENGINEERING DESIGN GUIDANCE

*The workshop presentations and discussion do not necessarily reflect
the views or policies of NIST or the United States Government.*

Sept. 25-26, 2025
SEI/NIST Forward Looking Codes and Standards Workshop #3



Notice & Disclaimer

Presentation materials may not be reproduced without express written permission. These materials may not be shared, duplicated, distributed, resold, or used for any commercial purposes. Use or reproduction of these materials (including replays/recordings associated with these materials) for any paid event or presentation is considered a “commercial purpose” and is strictly prohibited without written authorization from The Structural Engineering Institute of ASCE.

AI Usage Restrictions

These materials, included but not limited to this slide deck, recordings of this presentation, and audio transcripts from this material, may not be uploaded to, used to train, or incorporated into any artificial intelligence system or model without written authorization from The Structural Engineering Institute of ASCE.



FORWARD-LOOKING CODES AND STANDARDS: WELCOME

Jayantha 'Obey' Obeysekera, Ph.D., P.E.

Research Professor & Director, Sea Level Solutions Center,
Institute of Environment at Florida International University
Project Director, SEI/NIST Workshops



WELCOME & OVERVIEW

- Already observing increasing land and ocean temperature, more frequent and prolonged heat waves, increased frequency and intensity of heavy precipitation, severe storms and cyclones, and increased droughts in some areas.
- There is an urgent need to advance design practices to incorporate future hazard projections into codes and standards of buildings and infrastructure.
- The Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE) has contracted with the National Institute of Standards and Technology (NIST) to develop and execute a series of **four workshops** on Forward-Looking Codes and Standards.



OVERARCHING GOAL: RESEARCH ROADMAP INFORMED BY WORKSHOPS

- Address future hazards, conditions, and structural impacts for design:
 - **Future Conditions**
 - Temperatures (atmospheric, sea surface); Humidity; Drought
 - **Future Hazards**
 - Precipitation (rain, snow, ice, hail); Flood (sea level; flooding)
 - Wind (convective storms, hurricanes); Earthquake (landslides, liquefaction)
 - Wildland-urban interface (WUI) fires
 - **Structural Impacts**
 - Material/Structural degradation; Adaptation and Resilience
- Identify and prioritize *next generation* gaps and research needs for implementing future hazards and associated design criteria in codes and standards.
- Inform strategic planning for future requirements in the built environment, and potential changes to design parameters.



WORKSHOP STEERING COMMITTEE

- PROJECT DIRECTOR: **Obey Jayantha**, Ph.D., Research Professor, Director of Sea Level Solutions Center, FIU
- **Meg Ackerson**, P.E., Arup (Co-participant with Jack Hogan)
- **Joe Ackroyd**, Assistant Commissioner; Technical Affairs & Code Development; New York City Department of Buildings, NYC
- **Joseph Barsugli**, Ph.D., Research Scientist III, CIRES, University of Colorado Boulder, NOAA Physical Sciences Laboratory Affiliate
- **Kevin Borth**, P.E., S.E., Sr. Structural Project Engineer | Associate Vice President, HGA
- **Keith Dixon**, Ph.D., Deputy Division Head of the GFDL Marine Ecosystems & Downscaling Division, NOAA Geophysical Fluid Dynamics Laboratory
- **Michel Ghosn**, Ph.D., Professor, The City College of New York / CUNY
- **Matt Gilbertson**, Sr. Technical Manager, Simpson Gumpertz Heger
- **Elisabeth Gilmore**, Professor, Carleton University
- **Jack Hogan**, P.E., Associate Climate Risk and Resilience Engineer, Arup
- **Sihan Li**, Ph.D., P.Eng., Senior Specialist, Associate, RWDI
- **Amanda McCarty**, Director, NOAA Climate Ready Nation
- **Mari Tye**, Ph.D., Project Scientist II, Climate and Global Dynamics Laboratory (CGD), National Center for Atmospheric Research (NCAR)



WORKSHOP STEERING COMMITTEE (CONT.)

NIST

Materials and Structural Systems Division, Engineering Laboratory

- **Terri McAllister**, Ph.D., P.E., MSSD Deputy Chief, Research Structural Engineer for Community Resilience Group
- **Marc Levitan**, Ph.D., Research Structural Engineer, Structures Group
- **Siamak Sattar**, Ph.D., Earthquake Engineering Group Leader, Research Structural Engineer
- **Jennifer Helgeson**, Ph.D., Acting Group Leader and Program Manager, Community Resilience Program
- **Scott Jones**, Ph.D., Research Material Scientist, Infrastructure Materials Group

ASCE/SEI

- **Jennifer Goupil**, P.E., ASCE Chief Resilience Officer and Managing Director, Structural Engineering Institute of ASCE
- **Katie Stueckle**, Structural Engineering Institute of ASCE
- **Jessica Jun**, Structural Engineering Institute of ASCE



WORKSHOPS THEMES

ASCE/NIST will host 4 workshops in 2025 for advancing building and infrastructure codes and standards. Cross-cutting topics will include future hazards, design impacts, and social and economic consequences:

1. **JUNE 4-5: Future hazards for design** - confidence/uncertainty in hazard projections, downscaling of global models, converting hazard projections to design criteria
2. **JULY 29-30: Future load effects on the built environment** - (a) load effects for future hazards, (b) changes in load effects relative to historical basis, (c) changes in structural performance, material properties, soils, ...
3. **Sep 25-26: Engineering design guidance and criteria** - non-stationary reliability, service life, design loads, resistance, deterioration
4. **OCT. 28-29: Adaptation and resilience** - buildings and infrastructure system assessment, material durability, mitigation, retrofit,...



FORWARD-LOOKING CODES AND STANDARDS: PURPOSE AND SCOPE

Terri McAllister, Ph.D., P.E., F.SEI., Dist.M.ASCE,
MSSD Deputy Chief, Research Structural Engineer for
Community Resilience Group; NIST



PURPOSE AND SCOPE

- **Purpose:** to provide a ***science-based assessment of data and development needs*** to advance ***design practice and building standards*** for future natural hazards and conditions across US communities.
- **Scope:** Input from scientists, practitioners, and researchers is needed on how to:
 - Prioritize what is needed to achieve ***the next generation of future hazards and conditions for design*** (beyond ASCE 7-28)
 - Identify a path forward to improve building standards and design practice.
 - Consider resilience, adaptation, and social and economic impacts to businesses and communities.



STANDARD DEVELOPMENT ORGANIZATIONS

- **National Building Code of Canada (NBCC) 2025**

The 2025 version addresses Future Conditions

- **ASCE 7-28: Standard for Minimum Design Loads for Buildings and Other Structures**

The 2028 version will have a new section on Future Conditions

- **Other SDOs**

ASTM, American Concrete Institute, American Institute of Steel Construction, NDS for Wood Construction, etc.

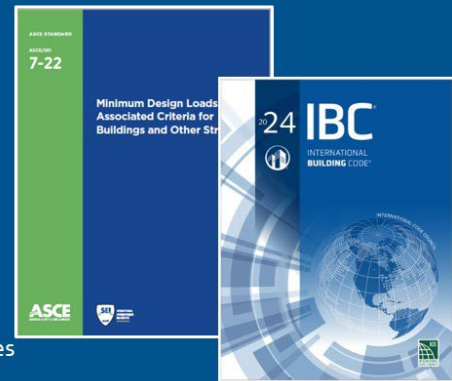
- **NIST/NOAA Grants to support ASCE 7-28**

Hazards and Conditions

- Wind, snow, rain, atmospheric ice hazards and loads

Structural Capacity and Performance

- Nonstationary reliability methods
- Corrosion in reinforced concrete
- Ground failure and impacts on structures
- Adaptive design and assessment of reinforced concrete structures



COMMUNITY AND BUSINESS RESILIENCE

- Develop performance goals that include functional recovery
- Assess current and future exposure and interdependencies
- Identify primary risks and hazards
- Evaluate potential solutions for new and existing infrastructure
- Prioritize investments
 - Infrastructure vulnerabilities
 - Social and community consequences



Shopping Center
Marianna, FL

Tyndall AFB, FL

Hurricane
Michael
2018



SYNERGISTIC EFFORTS

NIST Climate Science and Building Codes Workshop -- Jan 2021

- *Future hazard needs of building regulatory community*

SEI Climate impacts workshops -- March, May, Oct 2022

NIST-ASCE-NOAA Community Resilience Workshops -- Nov 2023 to Jan 2024

- *Leading practices for future hazards in community resilience planning*

ASCE 7-28 Future Conditions Subcommittee

ASCE-NOAA Task Force Summit -- Feb 2023

- *Temperature, Rainfall Workshop*---Sep 2022
- *Extreme Wind, Coastal Hazards Workshop*---Oct 2022

ASCE-NOAA Summer Workshop: Building the Resiliency Business Case -- Jun 2025

ASCE Committee on Adaptation to a Changing Climate

ASCE/SEI Special Report -- 2024

- *Effects of Climate Change on Life-Cycle Performance of Structures and Infrastructure Systems*



WORKSHOP #3 GOALS FOR FUTURE ENGINEERING DESIGN GUIDANCE

Current State of the Art

Guidelines and Standards

- Canadian Approach in NBCC 2025
- ASCE/SEI 7-28 Future Hazards & Load Effects
- ASCE Manuals of Practice
- Material Standards (Concrete, steel, wood, etc.)
- Existing structures assessment

Structural Capacity and Adaptation

- Structural and materials degradation
- Lifecycle and condition assessment
- Structural modifications and adaptation

Next Generation Goals

TOPIC 1: Structural Capacity

What are the most impactful future conditions or effects on structural capacity?

What is needed to characterize future structural capacity and degradation effects?

TOPIC 2: Future Guidance

What is needed to address standard updates about future effects and performance criteria?

How should updates between code and standard cycles be addressed?

How should criteria beyond codes and standards be reviewed and published for design practice?

FORWARD-LOOKING CODES AND STANDARDS: AGENDA AND GOAL

Jennifer Goupil, P.E., F.SEI., ASCE/SEI

ASCE Chief Resilience Officer and Managing Director, Structural
Engineering Institute of ASCE



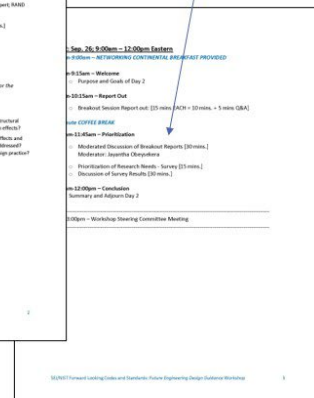
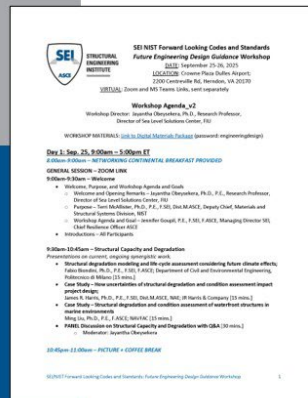
AGENDA

**Fully Hybrid = PLEASE
STATE YOUR NAME WHEN
YOU ARE SPEAKING!**

Digital Package

(password: engineeringdesign)

- AGENDA
- Participant List
- Slide Decks



SELF INTRODUCTION

Name, Organization



PARTICIPANTS SELF INTRODUCTIONS:

- **NAME**
- **ORGANIZATION**

IN-PERSON:

We will go around the room

VIRTUAL:

We will go down the list, so you know when to unmute!

IN-PERSON:

- Abigail Beck
- Fabio Biondini
- Kevin Borth
- Chris Clavin
- Jan Dale
- Irem Efe
- Michel Ghosn
- Elisabeth Gilmore
- Jennifer Goupil
- Jim Harris
- Jennifer Helgeson
- Ayse Hortascu
- Mohammad Houshmand
- Mija Hubler
- Katherine Johnson
- Scott Jones
- Ann Kosmal
- Ken Kunkel
- Kingsley Lau
- Sihan Li
- Ning Lin

- Ming Liu
- Terri McAllister
- Stirling Moore
- Aron Newman
- Sissy Nikalou
- Jayantha Obeysekera
- Adam Reeder
- Milad Roohi
- Siamak Sattar
- Peter Vickery
- Yating Zhang

VIRTUAL

- Ahmed Abdelaal
- Joe Ackroyd
- John Allen
- Michele Barbato
- Joseph Barsugli
- Alex Cannon
- Eun J Cha
- William Coulbourne
- Shideh Dashti
- Keith Dixon
- Lakshmana Doddipatla
- Bruce Ellingwood
- Graziano Fiorillo
- Matt Gilbertson
- Emily Guglielmo
- Ruohua Guo
- Amin Hariri
- Jack Hogan
- John Ingargiola
- Yuchuan Lai

- Robert Lempert
- Marc Levitan
- Abbie Liel
- Roy Lobo
- Kris May
- Amanda McCarty
- Lauren Mudd
- Manuel Perotin
- Daniel Rhee
- Tori Tomiczek
- Mari Tye
- Dan Walker
- Silky Wong
- Xuebin Zhang
- Erik Zuker

STRUCTURAL CAPACITY AND DEGRADATION

9:30 am – 10:45 am



PRESENTATIONS

- **Structural degradation modeling and life-cycle assessment considering future climate effects**
Fabio Biondini, Ph.D., P.E., F.SEI, F.ASCE; Department of Civil and Environmental Engineering, Politecnico di Milano
- **Case Study: How uncertainties of structural degradation and condition assessment impact project design**
James R. Harris, Ph.D., P.E., F.SEI, Dist.M.ASCE, NAE; JR Harris & Company
- **Case Study: Structural degradation and condition assessment of waterfront structures in marine environments**
Ming Liu, Ph.D., P.E., F.ASCE; NAVFAC
- **PANEL Discussion on Structural Capacity and Degradation with Q&A**
Moderator: Jayantha Obeysekera



B.2.1.1. Structural Capacity and Degradation: Structural degradation modeling and life-cycle assessment considering future climate effects; Fabio Biondini

STRUCTURAL DEGRADATION MODELING AND LIFE-CYCLE ASSESSMENT CONSIDERING FUTURE CLIMATE EFFECTS

Fabio Biondini, Ph.D., P.E., F.SEI, F.ASCE; Department of Civil and Environmental Engineering, Politecnico di Milano



STRUCTURAL DEGRADATION MODELING AND LIFE-CYCLE ASSESSMENT CONSIDERING FUTURE CLIMATE EFFECTS

Fabio Biondini, Ph.D., P.E., F.SEI, F.ASCE

Politecnico di Milano, Milan, Italy

fabio.biondini@polimi.it | <https://biondini.faculty.polimi.it>



POLITECNICO
MILANO 1863

SEI/NIST Forward Looking Codes and Standards:
Future Design Guidance Workshop
Sept. 25-26, 2025

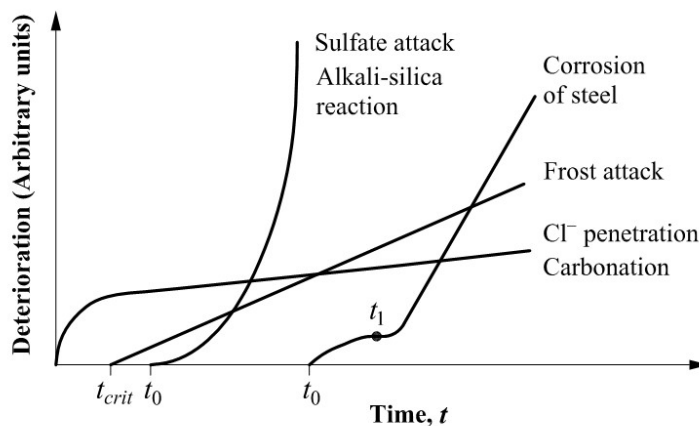


Outline

- ❑ INTRODUCTION
- ❑ STRUCTURAL DEGRADATION: CORROSION IN RC BRIDGES
- ❑ LIFE-CYCLE ASSESSMENT UNDER UNCERTAINTY
- ❑ INCORPORATING FUTURE CLIMATE EFFECTS
- ❑ MODEL VALIDATION BASED ON EXPERIMENTAL TESTS
- ❑ CONCLUDING REMARKS



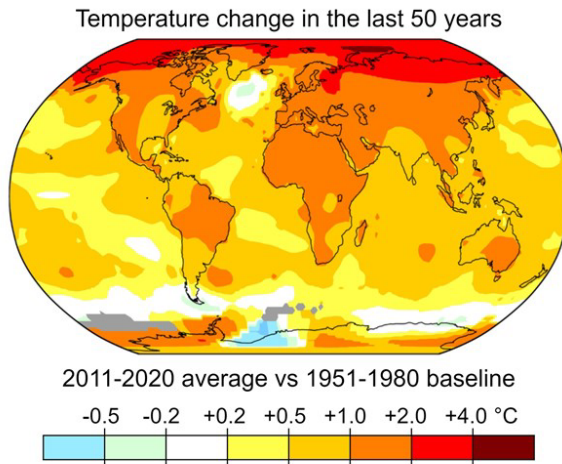
Structural Aging and Deterioration



(Clifton & Knab 1989; Ellingwood 2005)



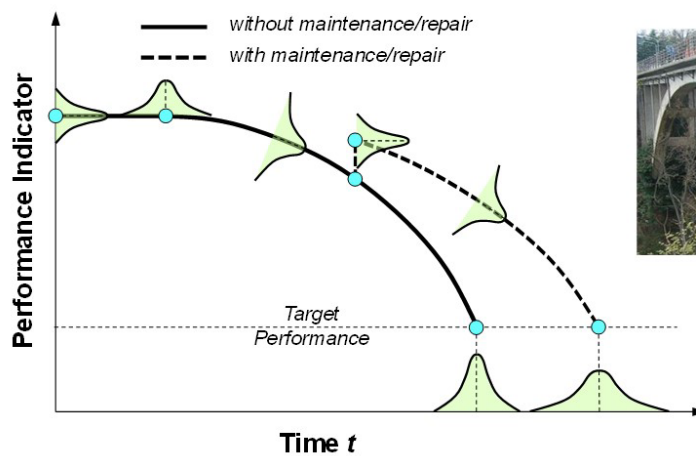
Future Climate Effects



- INCREASE CLIMATIC LOADS AND ALTER ENVIRONMENTAL CONDITIONS
- EXACERBATE OCCURRENCE OF EXTREME EVENTS
- ACCELERATE AGING AND STRUCTURAL DETERIORATION PROCESSES
- POTENTIAL CATASTROPHIC IMPACT ON STRUCTURAL SAFETY



Life-Cycle Performance under Uncertainty



Biondini, F., Frangopol, D.M., 2016. Life-Cycle Performance of Deteriorating Structural Systems under Uncertainty: Review, *Journal of Structural Engineering*, ASCE, 142(9), F4016001, 1-17.



Effects of Corrosion in RC Structures



➤ The experimental evidence shows that the **main effects of corrosion** of steel reinforcement in concrete structures include:

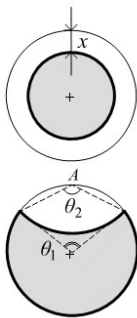
1. **Steel mass loss**, with reduction of the cross-section of the reinforcing steel bars.
2. **Reduction of steel ductility**, which may lead to brittle failure modes, and steel strength (negligible).
3. **Deterioration of concrete**, associated to the formation of oxidation products which may lead to propagation of splitting cracks.



Corrosion Modelling

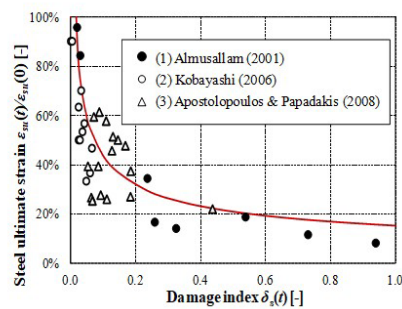
REDUCED
STEEL BAR AREA

$$A_s = A_{s0}(1 - \delta_s)$$



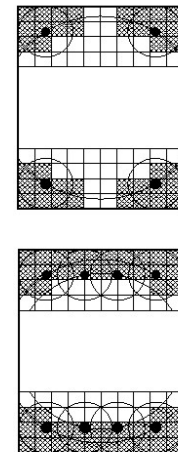
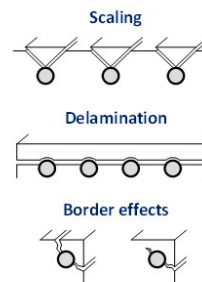
REDUCED
STEEL ULTIMATE STRAIN

$$\varepsilon_{st} = \varepsilon_{st}(\delta_s)$$



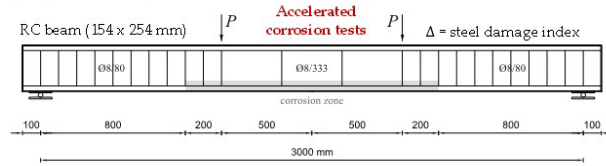
REDUCED
CONCRETE STRENGTH

$$f_c = f_c(\delta_s)$$

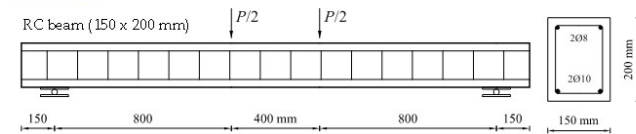


Biondini, F., Vergani, M., 2015. Deteriorating beam finite element for nonlinear analysis of concrete structures under corrosion, *Structure and Infrastructure Engineering*, Taylor & Francis, 11(4), 2015, 519–532.

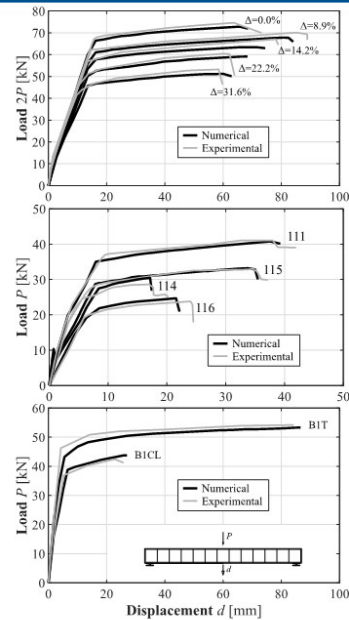
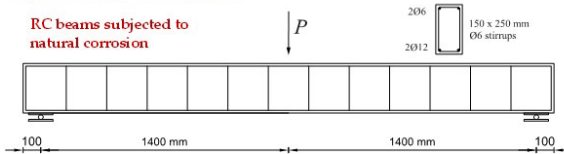
- El Maaddawy et al. (2005). Long-term performance of corrosion-damaged reinforced concrete beams. *ACI Structural Journal*



- Rodriguez et al. (1997). Load carrying capacity of concrete structures with corroded reinforcement. *Construction and building materials*



- Castel et al. (2000). Mechanical behaviour of corroded reinforced concrete beams. Part 1: Experimental study of corroded beams. *Materials and Structures*



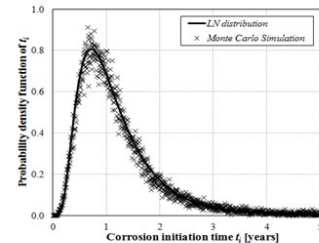
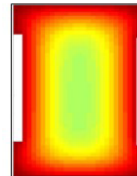
Anghileri, M., Biondini, F., 2025. Validation of life-cycle-oriented computational methods for nonlinear analysis of RC/PC structures based on experimental tests, *Structure and Infrastructure Engineering*, 21(7–8), 1193–1216.

Chloride Ingress and Diffusion Process

- Fick's second law (1D, 2D, 3D)

$$\nabla^2 C = \frac{1}{D} \cdot \frac{\partial C}{\partial t}$$

C = Concentration
 D = Diffusivity
 t = Time

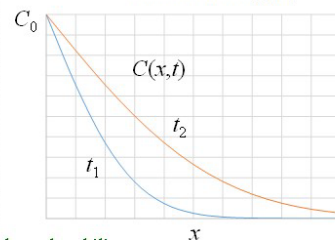
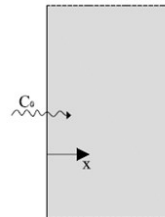


- Simplified approach – Solution of the 1D problem



$$C(x, t) = C_0 \left[1 - \operatorname{erf} \left(\frac{x}{2\sqrt{D_e t}} \right) \right]$$

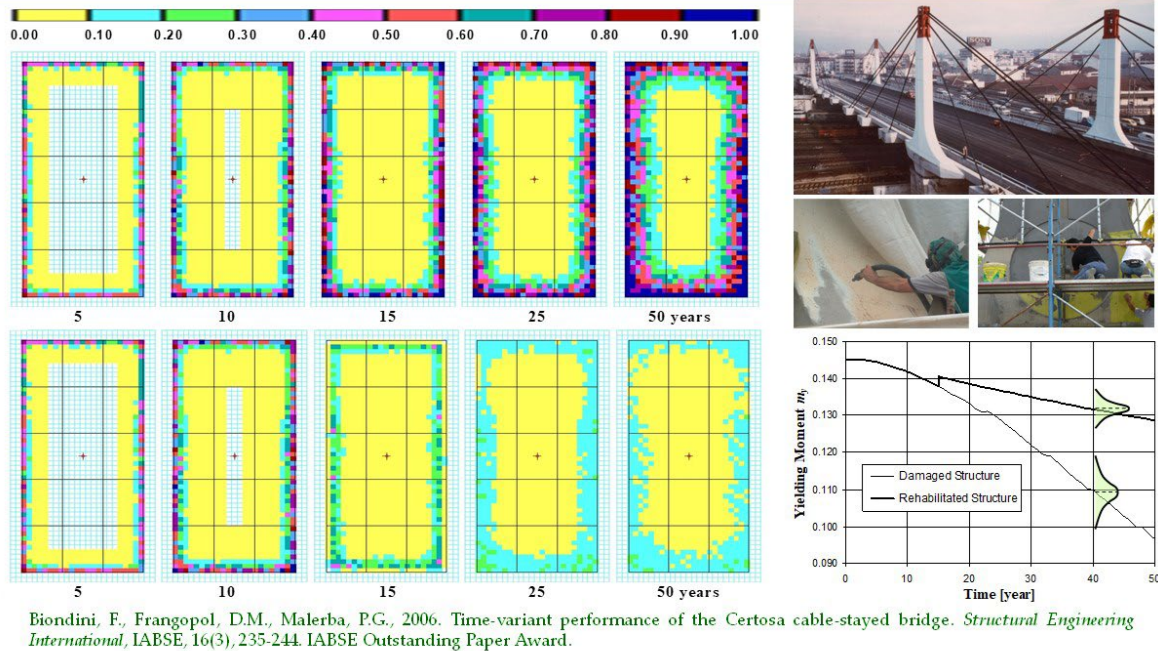
Model Code for Service Life Design
fib Bulletin No. 34, 2006



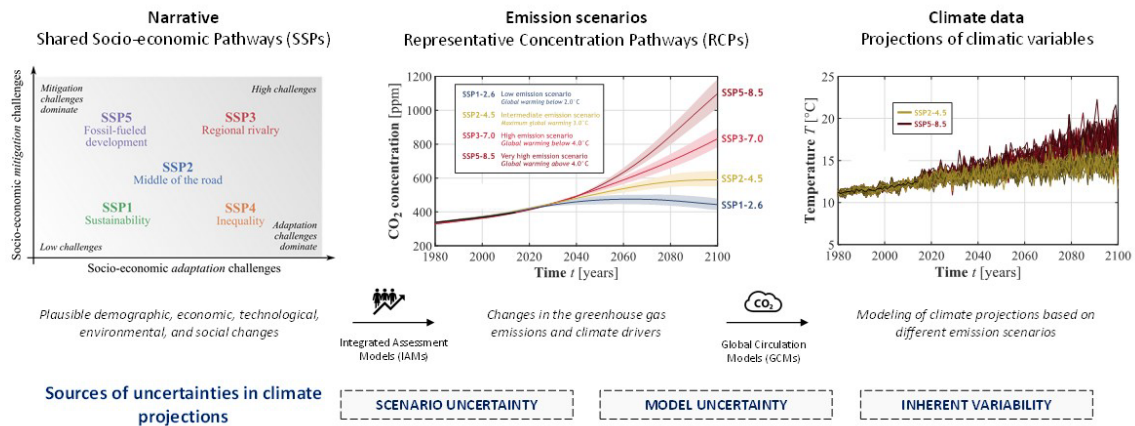
Biondini, F., Bontempi, F., Frangopol, D.M., Malerba, P.G., 2004. Cellular automata approach to durability analysis of concrete structures. *Journal of Structural Engineering*, ASCE, 130(11), 1724–1737.

Titi, A., Biondini, F., 2016. On the accuracy of diffusion models for life-cycle assessment of concrete structures, *Structure and Infrastructure Engineering*, Taylor & Francis, 12(9), 1202–1215.





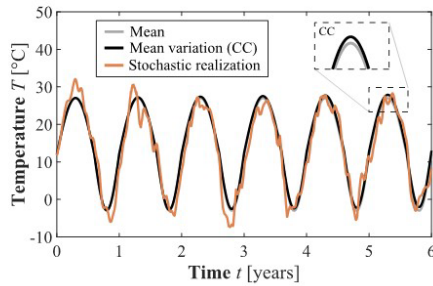
Future Climate Effects and Role of Uncertainties



Anghileri, M., Biondini, F., 2025. Life-cycle structural reliability of RC bridges under carbonation-induced corrosion in a changing climate. *14th International Conference on Structural Safety and Reliability (ICOSSAR 2025)*, June 1-6, 2025, Los Angeles, CA, USA.

Carbonation-induced Corrosion

Carbonation is modeled as a **time-variant diffusion random process** associated with temperature T , relative humidity RH , and CO_2 concentration altering the concrete diffusion coefficient D_{CO_2}



$$x_c(t) = \sqrt{\frac{2 f_T(t) f_{RH}(t) D_{\text{CO}_2}(t)}{a}} C_{\text{CO}_2}(t) \times \sqrt{t}$$

Carbonation depth Influence of T and RH on diffusivity D_{CO_2} Atmospheric carbon dioxide

$$f_T(t) = \exp\left\{\frac{E}{R}\left[\frac{1}{293.15} - \frac{1}{273.15 + T(t)}\right]\right\}$$

$$f_{RH}(t) = \left[\frac{1 - RH(t)^5}{1 - RH_{\text{ref}}^5}\right]^{2.5}$$

$$T(t, \omega) = \mu_T(t) + \Delta T_{\text{SSP}}(t) + H_T(t, \omega)$$

SCENARIO & MODEL

INHERENT

When $x_c(t) \geq \text{concrete cover}$, corrosion starts

$$\Delta(t) = 0.0116 \times i_{\text{corr}}(T, RH, t) \times \Delta t$$

Steel damage index

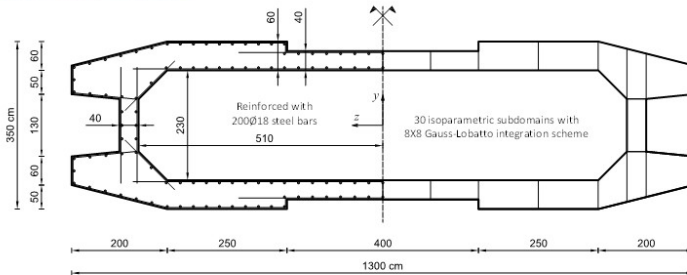


Structural Capacity of Existing Concrete Bridges

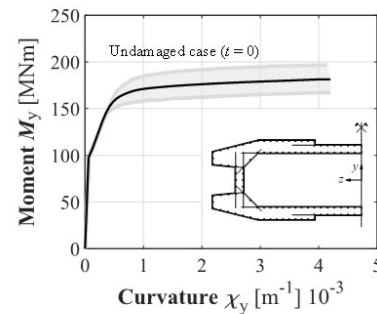


11 High-Speed Railway Viaducts (126 spans)

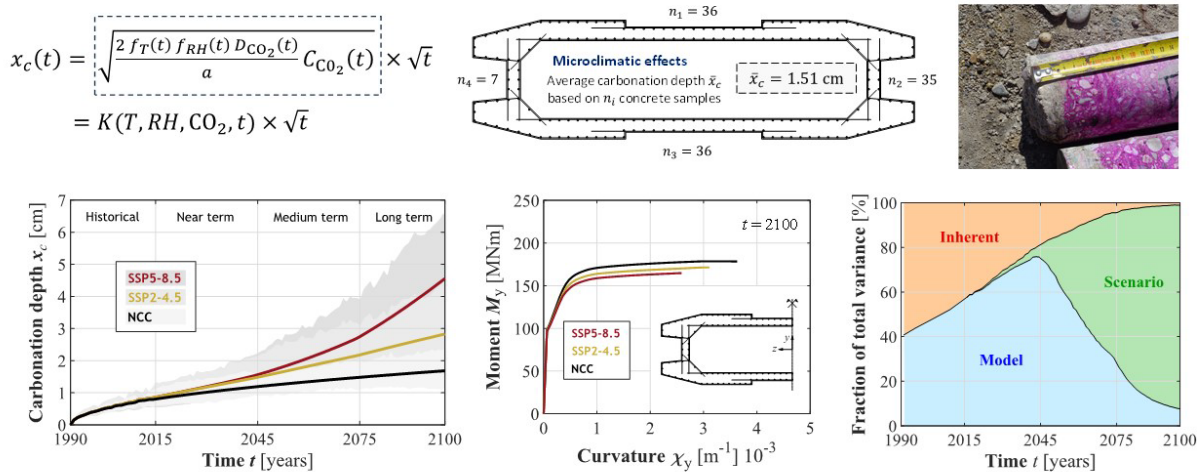
Random variable X	Mean μ_X	CoV
Concrete compressive strength f_c	-31.85 MPa	0.22
Concrete elastic modulus E_c	31.52 GPa	0.05
Concrete tensile strength f_{ct}	1.69 MPa	0.25
Steel yielding strength f_{sy}	453 MPa	0.10
Steel elastic modulus E_s	200 GPa	0.10
Steel ultimate strength f_{su}	712 GPa	0.10
Steel ultimate strain ϵ_{su}	9.58 %	0.27



Lognormal RVs with parameters based on the results of laboratory tests on concrete and steel samples



Impact of Time-variant Aleatory and Epistemic Uncertainty



ASCE JSE Survey



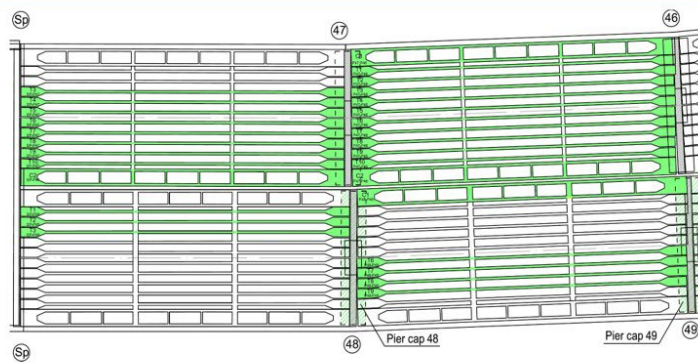
Life-Cycle Performance of Civil Structure and Infrastructure Systems: Survey

F. Biondini and D.M. Frangopol

ASCE Journal of Structural Engineering
Vol. 144, No. 1, 2018

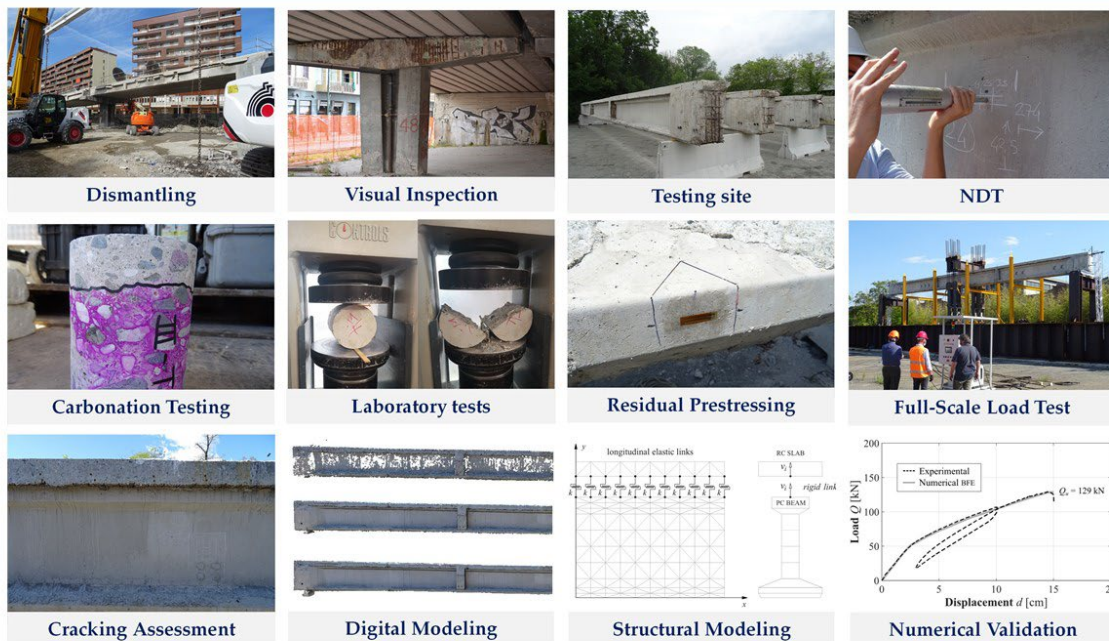
- ❑ Life-cycle-oriented computational models are well established for some of the most detrimental damage processes, such as **corrosion and fatigue**, and are rapidly becoming available for a wider spectrum of deterioration mechanisms.
- ❑ However, **deterioration and vulnerability models are very sensitive** to change of the **key damage parameters**. Robust validation and accurate calibration are difficult tasks because of limited availability of data.
- ❑ Further efforts in this direction, aimed at **gathering new data** from both **existing structures and experimental tests**, are crucial for a successful implementation of life-cycle frameworks.

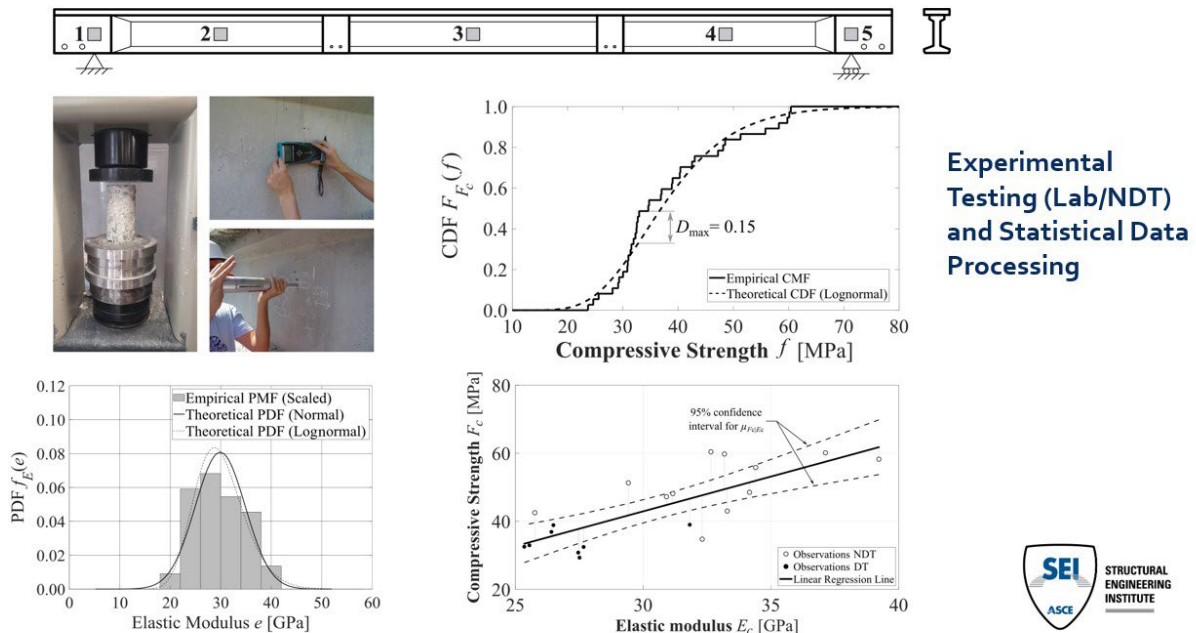
Experimental Testing on Existing Structures



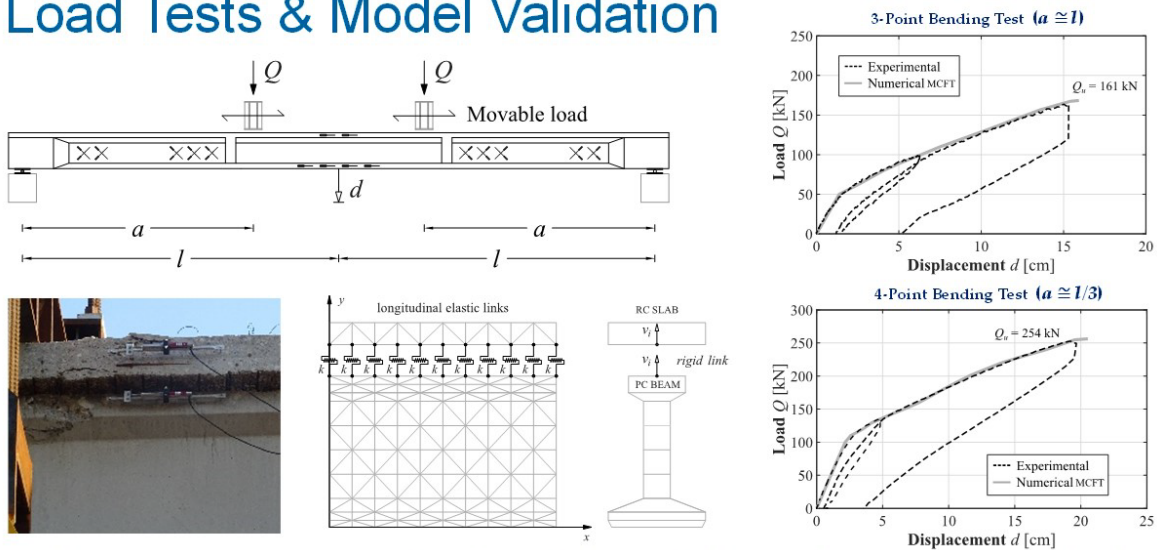


Savino, P., Tondolo, F., Sabia, D., Quattrone, A., Biondini, F., Rosati, G., Anghileri, M., Chiaia, B., 2023. Large-scale experimental static testing on 50-year-old prestressed concrete bridge girders, *Applied Sciences*, 13(834), 1–22, 2023.



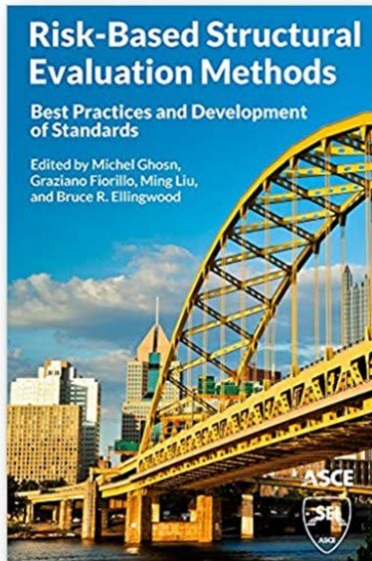


Load Tests & Model Validation

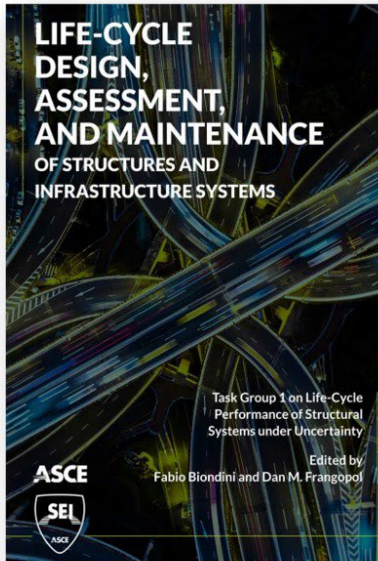


Anghileri, M., Biondini, F., 2025. Bayesian updating of the residual structural performance of existing concrete structures based on experimental tests, *Civil Engineering and Environmental Systems*, 42(2), 140-163.

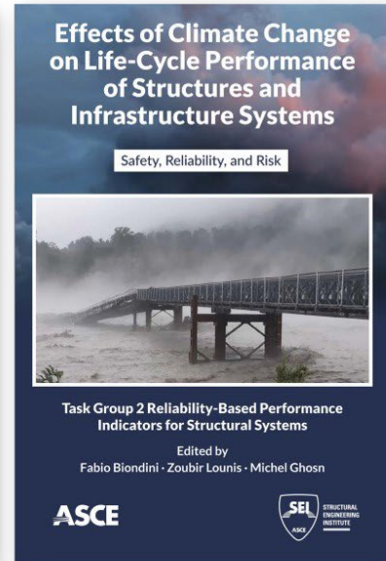
SEI/ASCE Technical Council on *Life-Cycle Performance, Safety, Reliability and Risk of Structural Systems* (2008-2023)



2019



2019



2024

Concluding Remarks

- ❑ Incorporating **life-cycle concepts, methods and tools** in design codes and standards, including **structural degradation modeling** and **explicit consideration of the time factor**, is essential to filling the gap between research and practice.
- ❑ Considering future climate projections, **closer interdisciplinary coordination** between climate scientists, experts in structural reliability methods, and code writers is necessary to develop methods and tools to integrate **non-stationarity** in current code philosophy.
- ❑ Future code developments should address methods and tools to exploit knowledge and data from **existing structures and experimental tests** for calibration and validation of **life-cycle methods**.
- ❑ Great progress has been made in advancing **higher and continuing education programs** to include **life-cycle methods into civil engineering courses** to ensure that the **next generations of engineers** will be prepared to meet the **challenges** and exploit the **opportunities in life-cycle engineering**.
- ❑ **Short courses and thematic seminars** should also be developed for practitioners by engineering institutions, universities, ASCE/SEI, and other professional societies.





B.2.1.2. Structural Capacity and Degradation: How uncertainties of structural degradation and condition assessment impact project design; James R. Harris

STRUCTURAL CAPACITY AND DEGRADATION

SEI/NIST Forward Looking Codes and Standards:
Future Design Guidance Workshop
Sept. 25-26, 2025



Copyright Notice & Disclaimer

Presentation materials are the exclusive property of The Structural Engineering Institute of ASCE and are protected by copyright law. All graphics, images, and visual elements contained herein are either licensed for use by The Structural Engineering Institute of ASCE or are original creations and may not be reproduced without express written permission. These materials may not be shared, duplicated, distributed, resold, or used for any commercial purposes. Use or reproduction of these materials (including replays/recordings associated with these materials) for any paid event or presentation is considered a "commercial purpose" and is strictly prohibited without written authorization from The Structural Engineering Institute of ASCE.

AI Usage Restrictions

These materials, included but not limited to this slide deck, recordings of this presentation, and audio transcripts from this material, may not be uploaded to, used to train, or incorporated into any artificial intelligence system or model without written authorization from The Structural Engineering Institute of ASCE.



CASE STUDIES: HOW UNCERTAINTIES OF STRUCTURAL DEGRADATION AND CONDITION ASSESSMENT IMPACT PROJECT DESIGN



Focus on Building Structures

James Robert Harris, P.E., Ph.D., NAE
J. R. Harris & Company, Denver, CO

Disclaimer: although this image of the partial collapse of Champlain Towers South is shown, nothing in this presentation should be considered a report on the NCST investigation of that event.



SETTING THE STAGE

- Structural elements in most buildings are protected: roofing and wall cladding provide a raincoat; notable exceptions include
 - Parking garages
 - Exposed structural walls – masonry and concrete
 - Exposed structural decks
- Changes in precipitation and temperature are clearly important, but changes in human behavior and societal practices can be even more substantial; examples include
 - Use of deicing salts
 - Maintenance of building envelopes
 - Changes in structural materials: engineered lumber; blended cements...

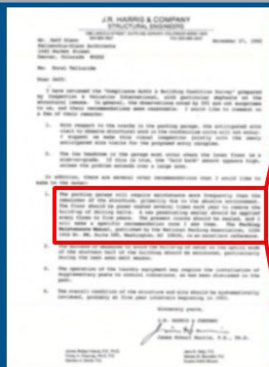


ISSUES FOR BUILDINGS

- For most buildings, the envelope generally protects the structure from environmental exposure. Water penetration is the known bad actor
 - Rot of wood; this can be worse with modern engineered lumber products than with old style solid-sawn members (some bugs like there food ground!)
 - Corrosion of steel – hot rolled and cold formed (much, but not all CFS is galvanized)
 - Corrosion of steel reinforcement in concrete
 - *Need for improved/automated leak detection notification*
- Some types of structures do have severe exposures; a few examples
 - Parking garages in snowy climates – the increasing use of deicing salts – the building design industry could benefit from the work done for transportation structures
 - Swimming pools and similar structures with high humidity, especially in cold climates



OVERLOOKED RECOMMENDATIONS



The parking garage will require maintenance more frequently than the remainder of the structure, primarily due to the abusive environment. The floor should be power washed several times each year to remove the build-up of deicing salts. A new penetrating sealer should be applied every three to five years. The present cracks should be sealed, and I will make a specific recommendation once I see them. The **Parking Maintenance Manual**, published by the National Parking Association, 1126 16th St. NW, Suite 300, Washington, DC 20036, is an excellent reference.



CAST IN PLACE GARAGE, MILD REINF



CAST IN PLACE GARAGE, MILD REINF



CAST IN PLACE GARAGE, PT



PRECAST CONCRETE GARAGE



PRECAST CONCRETE GARAGE



PARKING GARAGES (AND BRIDGES) – SHORT HISTORY IN DENVER

- Control of slick conditions on highways and streets: The first techniques were to use sand to improve traction
- 1970s: State highway department began using deicing salts; City stayed with sand
- 1980s: City began using deicing salts: initial public pushback (concern was corrosion of automobile bodies, with upper Midwest cities as an example)
- 1990s: City increased use of deicing salts



STEEL IN CAR WASH BUILDING; WOOD IN CRAWL SPACES AND INDOOR SWIMMING POOLS



Water on structural elements is almost never a good thing



ISSUES FOR BUILDINGS

- Improved warning systems for failures of envelopes on protected structures
- For parking garages, capitalize on the knowledge base developed for highway bridges
 - Chlorides as a “load”
 - Protective systems
 - Regular inspection and maintenance practices
- Condensation issues due to improved energy conservation measures (less air passage through the envelope, dewpoint issue)



HOW TO APPROACH THE PROBLEM

- Improved guidelines for service life objectives:
 - Not all buildings should really have the same life expectancies; what makes economic sense - apply life cycle cost philosophies and methods and capitalize on cross-disciplinary knowledge
- Improved guidelines for initial design: materials and details that survive
 - Personal concern about lack of knowledge about long term behavior of concrete made with blended cements
- Improved guidelines for maintenance practices
- Improved technologies for problem detection
- Improved technologies for condition assessment



CONCLUSION

We need a lot of improvements!



B.2.1.3. Structural Capacity and Degradation: Structural degradation and condition assessment of waterfront structures in marine environments; Ming Liu

CASE STUDY: STRUCTURAL DEGRADATION AND
CONDITION ASSESSMENT OF WATERFRONT
STRUCTURES IN MARINE ENVIRONMENTS

Ming Liu, Ph.D., P.E., F.ASCE; NAVFAC



CASE STUDY – STRUCTURAL DEGRADATION AND
CONDITION ASSESSMENT OF WATERFRONT
STRUCTURES IN MARINE ENVIRONMENTS

Ming Liu, Ph.D. P.E. F.ASCE
NAVFAC - EXWC



Disclaimer: the work presented herein is not related to the author's employment at NAVFAC-EXWC. The views, information or options expressed in the presentation are solely those of the author and do not necessarily reflect the views of any governmental agencies. NAVFAC-EXWC is not responsible and does not verify for accuracy of any information contained herein.



OUTLINE

- Waterfront Structures and Infrastructure Systems
- Marine Environments and Corrosive Sites
- Current Status on Structural Degradation, Condition Assessment, and Corrosion Mitigation
- Effects of Future Hazards on Structural Degradation and Future Research Needs
- Summary



WATERFRONT STRUCTURES AND INFRASTRUCTURE SYSTEMS

Buildings (e.g.,
office, storage
warehouses)

Parking lots, roads,
railroads, and bridges



WATERFRONT STRUCTURES AND INFRASTRUCTURE SYSTEMS

Buildings (e.g.,
office, storage
warehouses)

Parking lots, roads,
railroads, and bridges



Berth with pipelines
and mooring hardware

Dry dock with
water inlet and
outlet tunnels

Heavy duty
cranes with
power supply
systems



STRUCTURAL TYPES

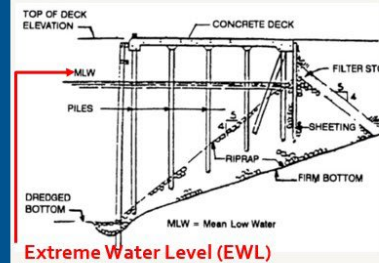
- ① Most of berths, piers, and wharves are the pile-supported structures, including steel pipe piles, steel H-piles, and concrete piles and shafts



- ② Dry docks are similar to concrete dams and retaining walls subjected to soil-structure or water-structure interaction. Seawalls usually are steel sheet piling structures.



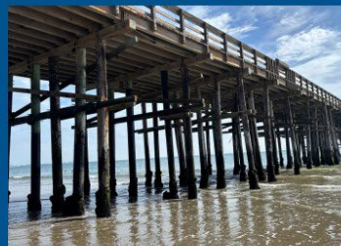
EWL includes (1) Tides, (2) Storm Surge, (3) Sea Level Rise (SLR)



(<https://www.loc.gov/resource/hhh.wao565.photos/>)

MARINE ENVIRONMENTS

- Land (soil and air) within 1,000 feet of ocean or marine water (i.e. a chloride content greater than or equal to 500 ppm) (*Atmospheric Zone*);
- Marine water permanently 3 feet below the Mean Lower Low Water (MLLW) elevation (*Immersed Zone*); and
- Marine water and air extending from 3 feet below the MLLW to 20 feet above the Mean Higher High Water (MHHW) and land (soil and air) within 20 feet from the edge of marine water at the MHHW (*Splash Zone, tidal fluctuation*).



KEY FACTORS FOR STRUCTURAL DEGRADATION

Key factors for steel corrosion

- Soluble salts in the soil or water or air
- Moisture to form solutions of the soluble salts
- Conductivity of the solution
- Hydrogen activity of the solution (pH)
- Oxygen concentration (aeration)

Definition of Corrosive Sites per CalTrans (California Department of Transportation)

- Chloride concentration ≥ 500 ppm for steel corrosion
- Sulfate concentration $\geq 1,500$ ppm for both steel and concrete deterioration
- The pH ≤ 5.5 for concrete deterioration



GENERAL EFFECTS OF COASTAL HAZARDS ON WATERFRONT FACILITIES

Design loads and load effects

- (i) Increase on wind and wave loads.
- (ii) Storm surges may be comparable with tsunami loads (ASCE 7, Chapter 6).
- (iii) SLR will change the loads applied on the piling system due to the mooring loads
- (iv) SLR will increase the load effects due to longer pile length

Accelerated structural deterioration due to future hazards

Increases in atmospheric CO₂ concentration, sea surface temperature (SST), relative humidity, ocean acidification, rainfall, etc. can lead to reduced time to corrosion initiation and accelerated corrosion propagation

Operational / non-structural component impacts

- (i) SLR and coastal flooding may cause erosion that creates voids on roads and foundations.
- (ii) The electric motor systems located at the base of the cranes may be inundated due to SLR so that the cranes may be immovable.
- (iii) Component degradation



STRUCTURAL DEGRADATION OF STEEL PILES

Steel sheet piles

Two surfaces exposed to corrosive environment, similar to **steel H-piles**, but one side exposed to marine water and another side exposed to corrosive soils. Typical thickness = 10 mm (6 to 20 mm)



Steel piles

- (i) Availability of oxygen in soils, particularly in the disturbed soils due to excavation and backfilling near the top of the piles.
- (ii) The most vulnerable portion of the piles subject to corrosion in marine environments starts from the bottom of the pile cap or footing. (i.e. in Splash Zone)
- (iii) CalTrans corrosion rates (2021) (e.g. steel pipe piles)

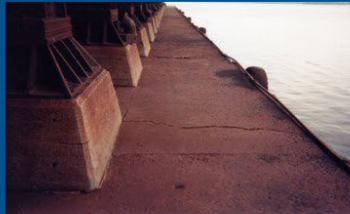
Atmospheric Zone	0.002 in. (0.051 mm) per year
Immersed Zone	0.004 in. (0.102 mm) per year
Splash Zone	0.006 in. (0.152 mm) per year
- (iv) Local corrosion may occur due to combinations of local soil properties, construction debris, and waste inorganic materials.



STRUCTURAL DEGRADATION OF CONCRETE

Cast-In-Drilled-Hole (CIDH) concrete shafts

Only in the Splash zone



Reinforced Concrete Structures

Minimum concrete cover to reinforcement

Corrosion resistant concrete mix design (dense concrete)

Reduced water to cement ratio



NON-STRUCTURAL COMPONENT DEGRADATION

Steel Pipeline



Pipe riser degradation on a pier

Saltwater pipeline degradation on a dry dock



Reinforced Concrete Pipeline



Mooring Hardware



Soil and Rock Anchor (steel tendons)

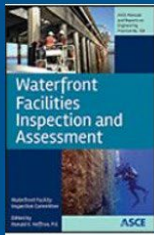
Tie-back and tie-down anchors with corrosion sheathing of PVC, HDPE, epoxy-coated steel reinforcement and cementitious grout are commonly used in retaining walls.



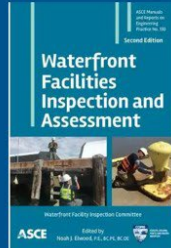
CONDITION ASSESSMENT FOR WATERFRONT STRUCTURES

ASCE MOP 130-2025 Waterfront Facilities Inspection and Assessment

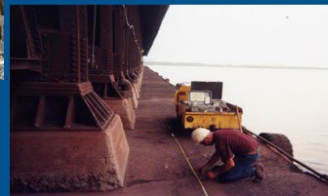
sponsored by the Waterfront Facility Inspection Committee of the Technical Committee on Ports and Harbors of the Coasts, Oceans, Ports, and Rivers Institute (COPRI) of ASCE.



2015 first edition



2025 second edition



CORROSION MITIGATION

Corrosion allowance

Protective coating (e.g., galvanizing, epoxy coating, viscous elastic coating, and waterproofing)

Cathodic Protection (CP)



Performance prediction
(e.g. no reliable equation
for corrosion rate
prediction of steel piles)

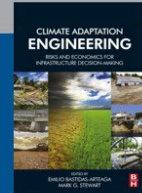
New construction
materials (e.g.
stainless steel alike,
CFRP, and UHPC)

Uncertainty in
Performance
and Life-cycle
Costs



POTENTIAL EFFECTS OF FUTURE HAZARDS ON STRUCTURAL DEGRADATION

Scenario	Root Causes	Carbonation (concrete)	Chloride Corrosion (steel)
Better than Current	SST increase $\leq 2^{\circ}\text{C}$	6% rate increase by 2100	12% rate increase by 2100
Current Trend	Combination of SST and CO ₂ concentration from 430 ppm (2025) to 602 ppm by 2100	20% rate increase by 2100	22% decrease in initiation years for bridge deck steel reinforcement corrosion
Worse than Current	CO ₂ concentration from 379 ppm (2005) to 1,135 ppm by 2100	65% rate increase by 2100	N/A



UNCERTAINTIES ON FUTURE STRUCTURAL DEGRADATION

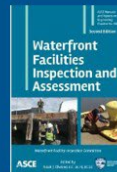
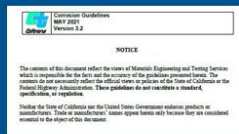
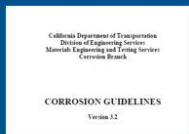
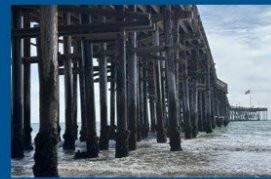
Scenario	Root Causes	Chloride Corrosion (steel)	Carbonation (concrete)
Changes in Relative Humidity (RH)	RH < 50%	Negligible rate	Negligible rate
	RH from 65% to 60%	15% rate decrease	11% increase in diffusion coefficient
	RH from 80% to 75%	15% rate decrease	25% decrease in diffusion coefficient

- **Spatial and temporal variability** of corrosion resistance capacities of construction materials (e.g., steel, concrete, timber among others), particularly for **condition assessment of existing structures**



FUTURE RESEARCH NEEDS ON STRUCTURAL DEGRADATION

- Detection and continuous monitoring techniques
- Modeling degradation mechanisms, considering downscaling of climate data to structural component levels
- Accelerated testing
- Validation for risk-based adaptation strategies
- Design tools. (e.g., site-specific design requirements and performance-based design codes)



SUMMARY

- The "Corrosion Guidelines" published by CalTrans provides the general information for current practice on corrosion protection of waterfront facilities.
- The costs associated with corrosion of waterfront facilities are significant since current waterfront structures usually require major maintenance and repairs every 10 to 15 years with the expected lifetime of 30 years only. The annual cost to corrosion for DoD facilities and infrastructure was \$1.4 billions in FY2005 and \$3.0 billions in FY2011
- Future hazards such as SST, CO₂ concentration, and RH will directly affect corrosion rates and structural degradation of waterfront structures.
- Future hazards such as SLR, storm surge, and tsunamic will affect the splash zone, which will indirectly affect the corrosion costs.
- Uncertainties associated with future hazards and structural degradation warrant the future research needs, focusing on modeling degradation mechanisms with considerations of climate downscaling and developing performance-based design codes and tools.



PANEL DISCUSSION WITH Q & A

Structural Capacity and Degradation

Moderator: Jayantha Obeysekera

- Fabio Biondini, Ph.D., P.E., F.SEI, F.ASCE; Department of Civil and Environmental Engineering, Politecnico di Milano
- James R. Harris, Ph.D., P.E., F.SEI, Dist.M.ASCE, NAE; JR Harris & Company
- Ming Liu, Ph.D., P.E., F.ASCE; NAVFAC



PHOTO & BREAK

10:45 – 11:00 am



FUTURE GUIDANCE BEYOND CODES AND STANDARDS

11:00 am – 12:15 pm

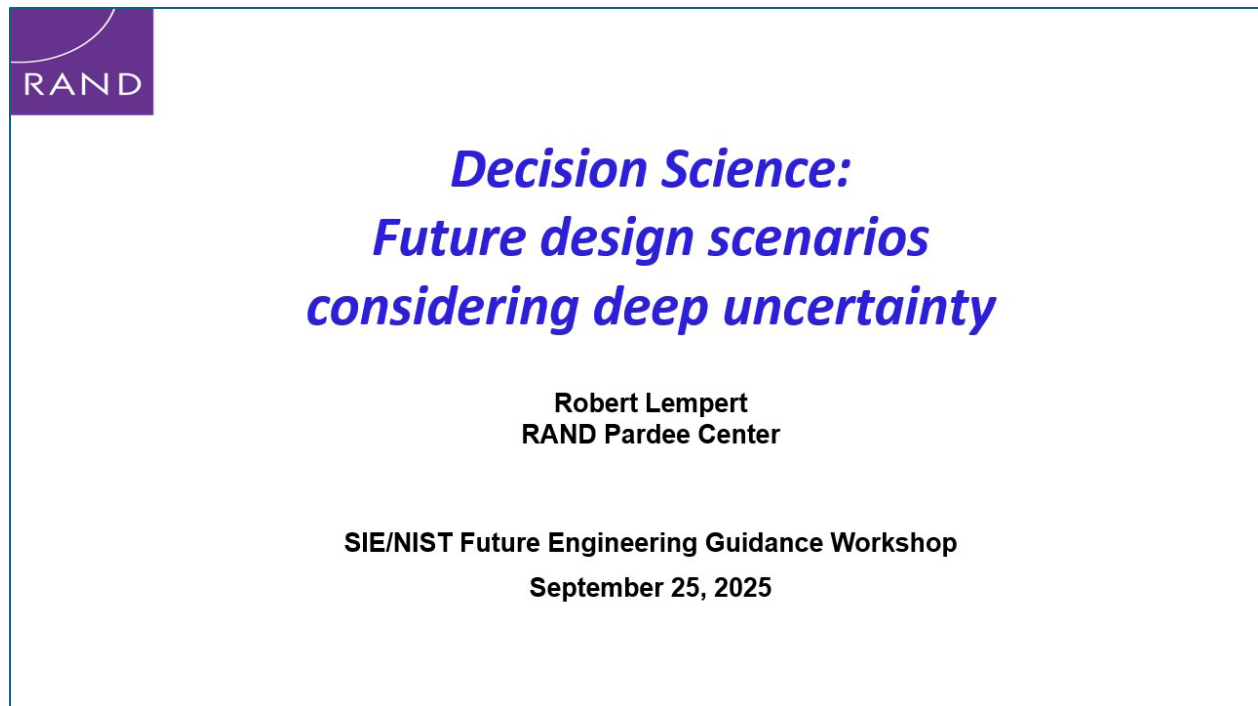


PRESENTATIONS

- **Decision Science: Future design scenarios considering deep uncertainty**
Rob Lempert, Ph.D., RAND Corporation
- **Project Case Study: California High Speed Rail**
Jack Hogan, P.E., Arup
- **Regulatory Case Study: NYC Waterfront Code**
Stirling Moore, AIA, AECOM
- **PANEL Discussion Guidance beyond Code and Standards with Q&A**
Moderator: Jayantha Obeysekera



B.2.1.4. Future Guidelines: Decision Science - Future design scenarios considering deep uncertainty; Rob Lempert



How Can Scientific Information Best Inform Engineering Guidance When Surprise is Certain?

We know some things about the future

- It will surprise us
- We need good information to shape it
- It may seem obvious that scientific information can best inform our decisions by making predictions about the future
- But predictions -- a core principle of the scientific method -- can complicate the use of quantitative information when:
 - Uncertainties are deep
 - People disagree

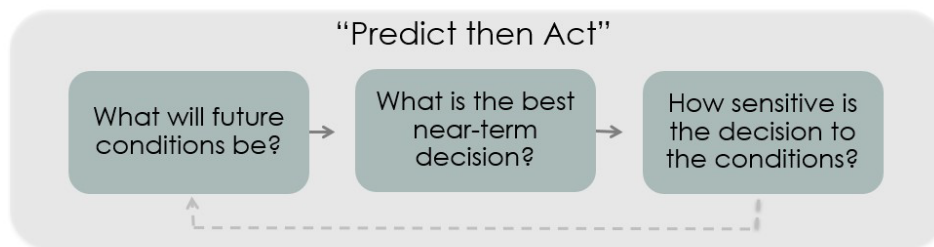


RAND

Fortunately, there is a better way

-103-

Traditional Decision Analysis Begins with a Consensus Understanding of the Future



Predictions:

- Are foundation of scientific method
- Demonstrate mastery

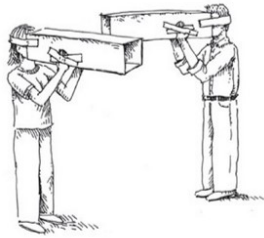
Predictions as joint probability distributions provide:

- Normatively correct ranking of decision options
- Concise summary of information about the future

RAND

-104-

“Predict then Act” Can Break Down When Uncertainties are Deep



Under conditions of deep uncertainty:

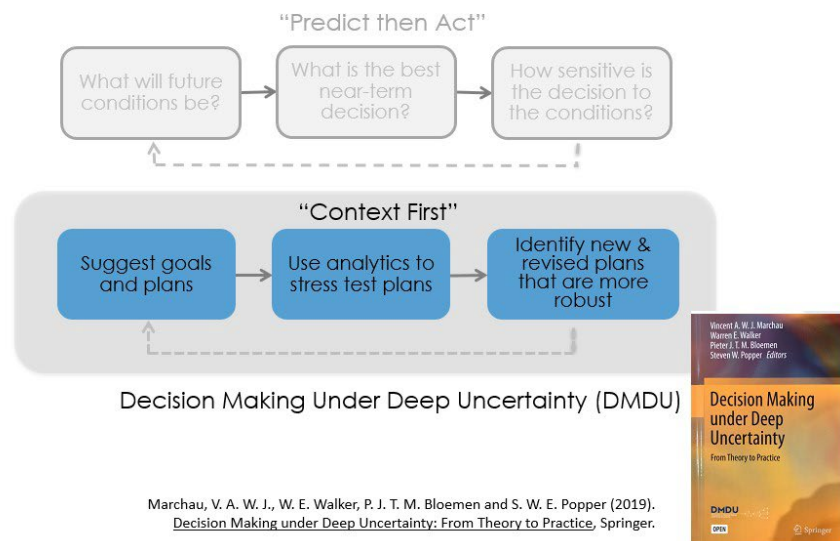
- Uncertainties are often **underestimated**, leading to brittle plans
- Problem **framing** can be **skewed** towards the demands of prediction
- Quest for prediction can distract from the task of **seeking creative solutions**

***Deep uncertainty occurs**
when the parties to a decision do not know or do not
agree on the likelihood of alternative futures
or how actions are related to consequences*

RAND

-105-

With Decisions Under Deep Uncertainty, Best to Begin at the End

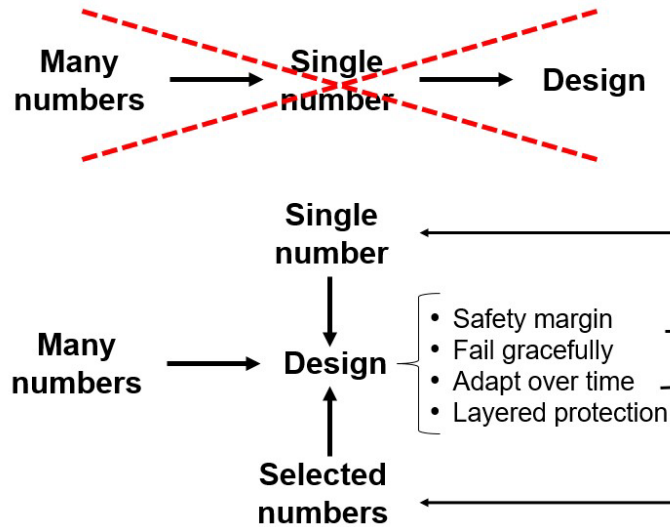


RAND

Marchau, V. A. W. J., W. E. Walker, P. J. T. M. Bloemen and S. W. E. Popper (2019).
Decision Making under Deep Uncertainty: From Theory to Practice, Springer.

-106-

How Should DMDU Inform Engineering Design?

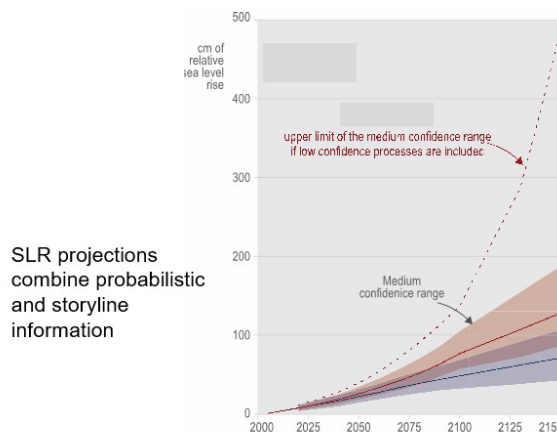


RAND

Thanks to Michelle Miro and Sarah Fendrich

-107-

Scientists Characterize Sea Level Rise Uncertainty to Facilitate Adaptive Planning



Low confidence processes include earlier-than-projected disintegration of marine ice shelves; the abrupt, widespread onset of Antarctic ice sheet instability; and faster than projected ice flow loss from Greenland

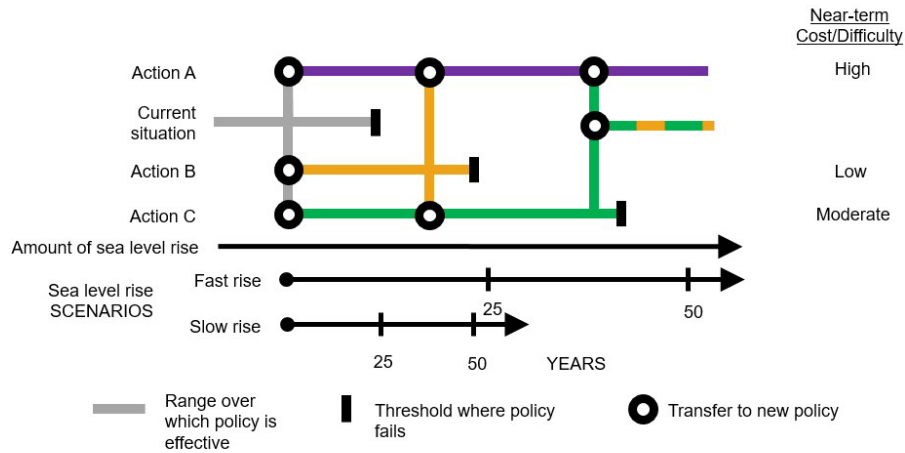
RAND

AR6 WGI (2021), Chap 9: Ocean, Cryosphere and Sea Level Change

-108-

Adaptative Pathways “Subway Maps” Help Organize Thresholds and Actions Over Time

How to prepare for sea level rise?

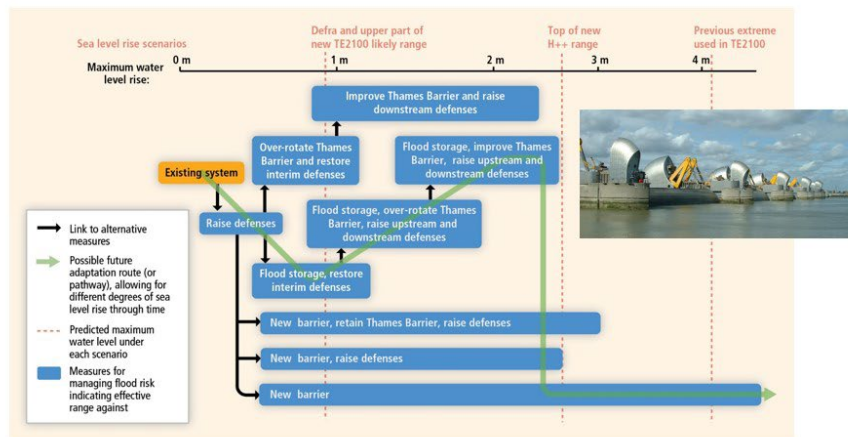


RAND

-109-

Adaptation Pathways Have Informed Significant Investments

Adaptation Pathway Map for Thames River Estuary



RAND

<http://blogs.worldbank.org/sustainablecities/go-flow-adaptive-management-urban-flood-risk>, Accessed May 22, 2023

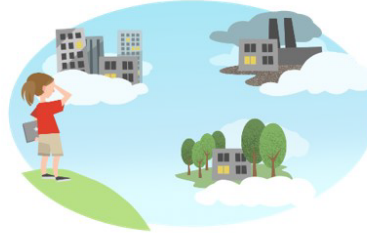
-110-

DMDU Helps People Make Better Decisions, Not Better Predictions

Basic principles

1. Consider multiple futures, not one single future, in your planning. Choose these futures to stress test your organization's plans
2. Seek robust plans that perform well over many futures, not optimal plans designed for a single, best-estimate future
3. Make your plans flexible and adaptive, which often makes them more robust
4. Use analytics to facilitate exploration, problem-solving, and deliberation – not using computers to tell people what to do

Plan over multiple futures



Prediction is perilous

Manage uncertainty by identifying robust plans whose good performance is insensitive to what we don't know

RAND

-111-

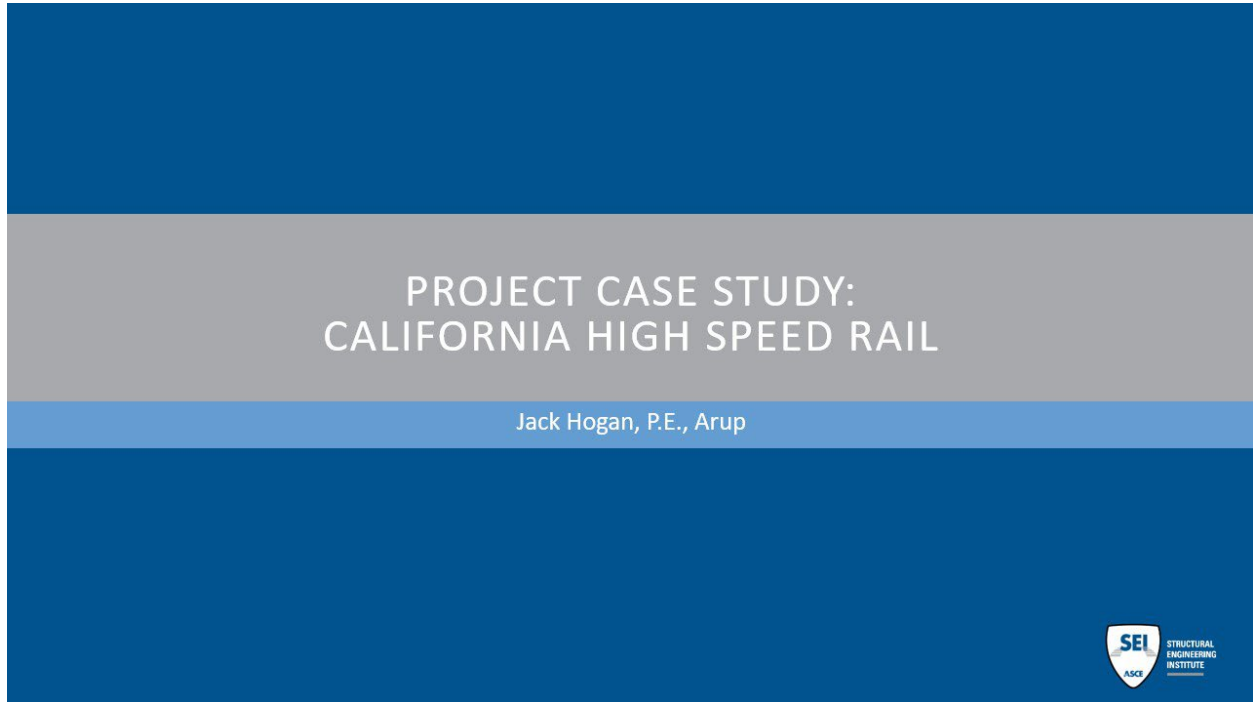
QUESTIONS?

lempert@rand.org
www.rand.org/pardee
www.deepuncertainty.org

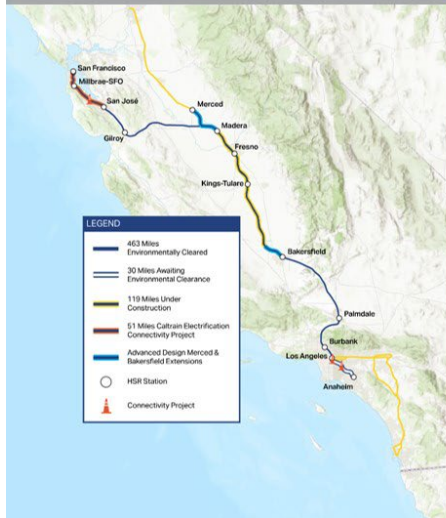
RAND

-112-

B.2.1.5. Future Guidelines: Project Case Study: California High Speed Rail; Jack Hogan



CLIMATE RESILIENCE POLICY & CONTEXT



- Among the largest infrastructure programs in the U.S.
- 100-year design life, designed to withstand climate stressors
- First U.S. megaproject to embed state-mandated climate resilience directly into its design manual
- A testbed for “forward looking” design guidance

State Mandates

- Executive Orders
- Assembly & Senate Bills

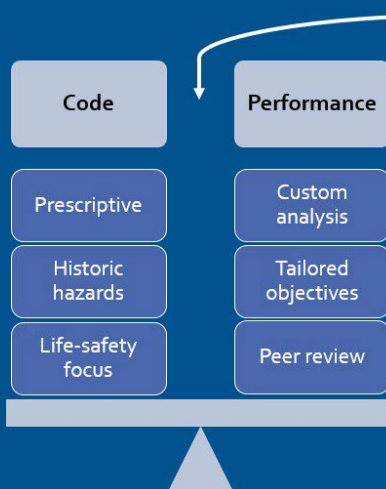
Authority Policy

- CHSRA Sustainability Policy, 20212

Design Criteria Manual



DESIGN APPROACH DICHOTOMY



HSR resilience approach finds middle ground

- Structured, risk-based framework
- Project specific requirements
- Cost-effectiveness emphasis



HSR RISK ASSESSMENT FRAMEWORK

The framework consists of several key components:

- Table 1.1: Hazard-Severity Categories**: A matrix mapping hazard types (e.g., seismic, wind, flood) to severity levels (1-4).
- Table 1.2: Hazard-Severity Categories**: A matrix mapping hazard types (e.g., seismic, wind, flood) to severity levels (1-4).
- Table 1.3: Risk Assessment Matrix**: A matrix mapping hazard types (e.g., seismic, wind, flood) to severity levels (1-4).
- Table 1.4: Risk Assessment Matrix**: A matrix mapping hazard types (e.g., seismic, wind, flood) to severity levels (1-4).

- Designers must address future hazards: heat, drought, flooding, sea level rise, wildfire
- Stress test future hazards and stressors at the **component level** (culverts, bridges, embankments)
- Identify **unacceptable and intolerable risks**
- Develop **adaptation measures** for pertinent risks
- Evaluate **cost-effectiveness of adaptation options**
- **Decision point** for the Authority

ABSTRACT TO REALISTIC

Flood risk flagged at multiple hydraulic structures (culverts)

Traditional code-based sizing insufficient for future hazards

Apply climate stress test to evaluate options

Tied to specific consequences by order of magnitude (e.g., >\$10M, >\$1M, >\$100k)

	Severity			
Frequency	1 Catastrophic	2 Critical	3 Marginal	4 Negligible
(A) Frequent	1A	2A	3A	4A
(B) Probable	1B	2B	3B	4B
(C) Occasional	1C	2C	3C	4C
(D) Remote	1D	2D	3D	4D
(E) Highly unlikely	1E	2E	3E	4E
(F) Eliminated				

Tied to specific return periods (e.g., >100yr, >10yr, >1yr)

HSR Box Culvert Bridges / HSR Culverts

Risk rating

Unacceptable

Undesirable

Tolerable

Acceptable

Eliminated

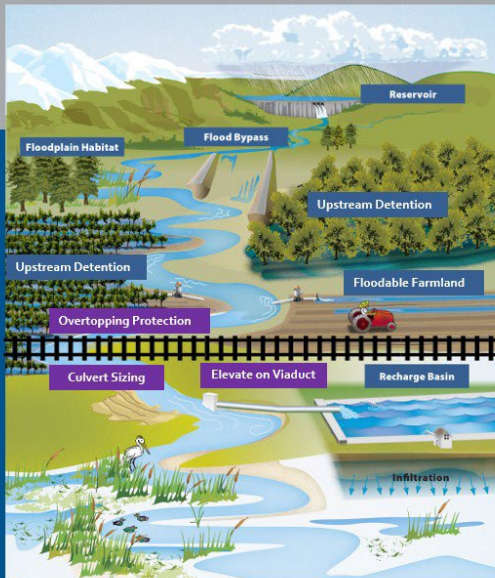


Image credit: California DWR

ADAPTATION OPTIONS

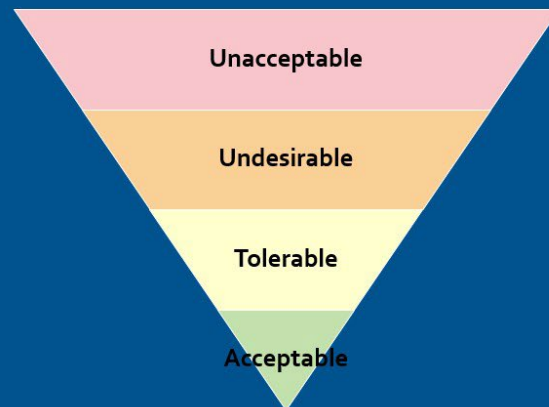
- Upstream flow attenuation / storage
- Nature-based solutions
- Hardening for overtopping
- Elevate on viaduct
- Upsizing culverts

Cost-benefit analysis used to identify optimal choice



ALARP

- *ALARP = As Low As Reasonably Practicable*
- Reduce risks to lowest level feasible, balancing **risk**, **cost**, and **effort**
- Adaptations may be omitted when:
 - Cost grossly disproportionate to benefit
 - Residual risk is tolerable
 - Shorter design life allows for future adaptation



DECISION FRAMEWORK IN ACTION

- Authority required designers to develop adaptation measures
- Transparent evaluation of cost, risk reduction, and residual risk
- Authority governance structure is then triggered for decisions on adaptation measures and residual risks

Risk Rating	Action Required
Unacceptable	Risk must be reduced and managed
Undesirable	Risk is acceptable <i>only where</i> further risk reduction is impracticable. Authority decision at the executive level is required to accept residual risk.
Tolerable	Apply mitigations where reasonable practicable. Risk can be tolerated and accepted with adequate controls. Authority review at the SSOC level is required to accept residual risk.
Acceptable	No further risk reduction required.



OTHER EXAMPLES



Future flood water levels threaten acceptable freeboard for embankments



Future extreme heat requires stress test for rail expansion and tension on overhead lines



Future wildfire frequency and impact area threatens defensible space criteria



Future wildfire smoke impacts to station HVAC design



INSIGHTS FOR FUTURE GUIDANCE

- Middle ground approaches can be pragmatic and scalable
- Importance of risk tolerance definitions and decision triggers
- Embedding adaptation and fiscal accountability into design process, not as “nice to have”
- Agency-driven frameworks can serve as prototypes for future standards



B.2.1.6. Future Guidelines: Regulatory Case Study: NYC Waterfront Code; Stirling Moore

REGULATORY CASE STUDY: NYC WATERFRONT CODE

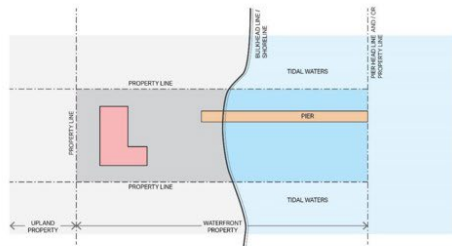
Stirling Moore, AIA, AECOM





INTRODUCTION

- The NYC waterfront is deemed to include all structures located on any “water front property”
- Per Chapter 52 of the NYC Charter, “water front property” is defined as “all property fronting on all the tidal waters in the port and city of New York and extending inshore to the property line of the first adverse owner and shall include such land under water extending offshore to the pierhead line or the property line, whichever extends the furthest offshore.”
- Current regulations do not completely address the design, construction, and maintenance requirements of structures located on waterfront properties



PROGRAM NEED & BENEFITS

Program Need

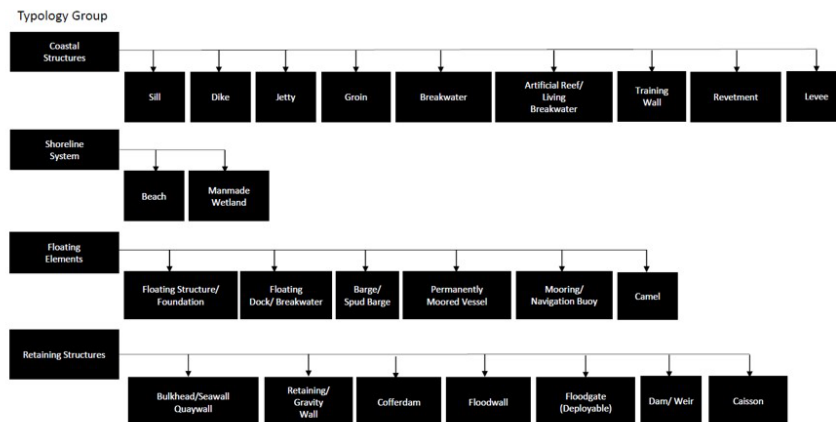
- Industry expressed need for an exclusive code to address waterfront structures
- No national or international model code available
- No clear definition of waterfront structure exists
- Plan Review & Inspection of waterfront properties currently under SBS jurisdiction

Benefits of Establishing a Waterfront Code

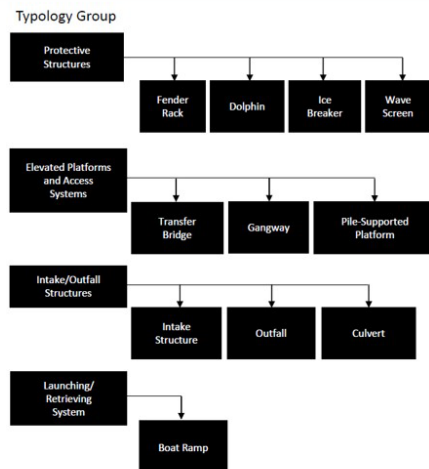
- Codifying standards will improve regulations, standard of practice, and consistency of permit application review
- Allows for oversight of existing and new licensees who work on waterfront projects
- Development of maintenance requirements will improve safety and longevity of waterfront structures



WATERFRONT TYPOLOGIES (1 OF 3)



WATERFRONT TYPOLOGIES (2 OF 3)

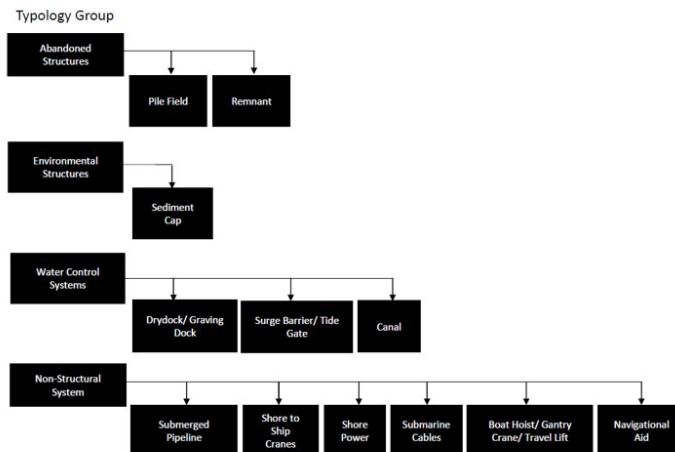


AECOM

129

NYC
Buildings

WATERFRONT TYPOLOGIES (3 OF 3)



AECOM

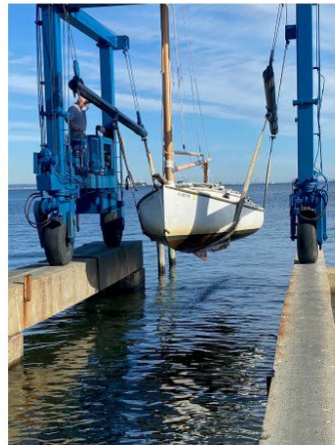
130

NYC
Buildings

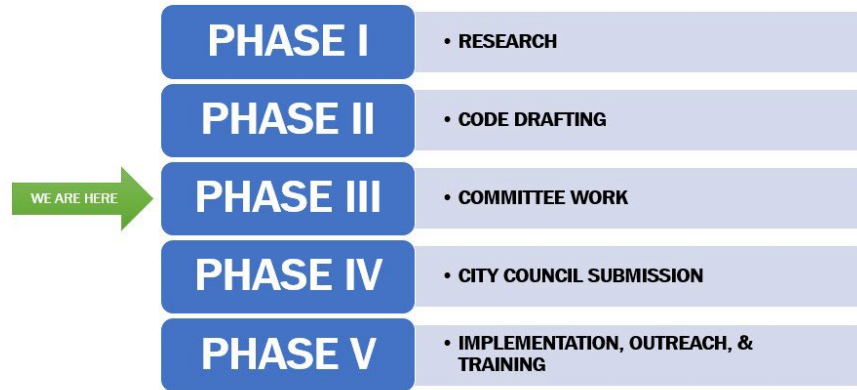


SCOPE OF WORK

- **Technical:** Research applicable standards, propose provisions, develop inspection requirements, introduce maintenance standards.
- **Communications:** Provide communications strategy, identify committee members, conduct outreach to industry stakeholders.
- **Operations:** Incorporate requirements and operational processes into DOB electronic systems.
- **Environmental Review:** Assess and research applicable CEQR requirements for Draft EAS.



WFC PHASES OF DEVELOPMENT



CODE PROVISIONS

- The proposed Waterfront Code provisions will be organized as a separate code, but complementary to the NYC Building Code provisions
- The Waterfront Code provisions will follow the NYC Building Code format, matching the BC chapter and section organization allowing each BC chapter and/or section to be adopted as is from the BC by direct reference; modified/replaced with specific content in the WFC; or appended with additional content in the WFC as required
- New waterfront typology-specific provisions will be added as a new Chapter 34 in the Waterfront Code; Chapter 34 in the Building Code will remain “Reserved”
- The scope of the Waterfront Code will be limited to non-building waterfront typologies. Enclosed, partially enclosed, and open buildings on waterfront property will continue to be addressed by the BC



WFC TABLE OF CONTENTS

Ch. No.	Chapter Name	Recommendation
1	Administration	Adopting NYCBC section with modification
2	Definitions	Adopting NYCBC section with modification
3	Use and Occupancy Classification	Adopting NYCBC section with modification
4	Special Detailed Requirements Based on Use and Occupancy	Adopting NYCBC section with modification
5	General Building Heights and Areas; Separation of Occupancies	Adopting NYCBC section with modification
6	Types of Construction	Adopting NYCBC section with modification
7	Fire and Smoke Protection Features	Adopting NYCBC section with modification
8	RESERVED Interior Finishes	Not applicable for Waterfront Code
9	Fire Protection Systems	Adopting NYCBC section with modification
10	Means of Egress	Adopting NYCBC section with modification
11	Accessibility	Adopting NYCBC section with modification
12	RESERVED Interior Environment	Not applicable for Waterfront Code
13	Energy Efficiency	Adopting NYCBC section with modification
14	RESERVED Exterior Walls	Not applicable for Waterfront Code
15	RESERVED Roof Assemblies and Rooftop Structures	Not applicable for Waterfront Code



WFC TABLE OF CONTENTS

16	Structural Design	Adopting NYCBC section with modification
17	Special Inspections and Tests	Adopting NYCBC section with modification
18	Soils and Foundations	Adopting NYCBC section with modification
19	Concrete	Adopting NYCBC section with modification
20	Aluminum	Adopting NYCBC section without modification
21	Masonry	Adopting NYCBC section with modification
22	Steel	Adopting NYCBC section with modification
23	Wood	Adopting NYCBC section with modification
24	Glass and Glazing	Adopting NYCBC section with modification
25	RESERVED Gypsum Board, Gypsum Panel Products and Plaster	Not applicable for Waterfront Code
26	Plastic	Adopting NYCBC section with modification
27	Electrical	Adopting NYCBC section with modification
28	Mechanical Systems	Adopting NYCBC section without modification
29	Plumbing Systems	Adopting NYCBC section with modification
30	RESERVED Elevators and Conveying Systems	Not applicable for Waterfront Code
31	Special Construction	Adopting NYCBC section with modification



WFC TABLE OF CONTENTS

32	Encroachments into the Public Right-of-Way	Adopting NYCBC section with modification
33	Safeguards During Construction or Demolition	Adopting NYCBC section with modification
34	Waterfront Design RESERVED	New Chapter
35	Reference Standards	Adopting NYCBC section with modification

App. No.	Appendix Name	Recommendation
Appendix A	RESERVED	Adopting NYCBC section without modification
Appendix B	RESERVED	Adopting NYCBC section without modification
Appendix C	RESERVED	Adopting NYCBC section without modification
Appendix D	Fire Districts	Adopting NYCBC section with modification
Appendix E	Supplementary Accessibility Requirements	Adopting NYCBC section with modification
Appendix F	Rodent-Proofing	Adopting NYCBC section with modification
Appendix G	Flood-Resistant Construction	Adopting NYCBC section with modification
Appendix H	Outdoor Signs	Adopting NYCBC section with modification
Appendix I	RESERVED	Adopting NYCBC section without modification
Appendix J	RESERVED	Adopting NYCBC section without modification
Appendix K	RESERVED—Modified Industry Standards for Elevators and Conveying Systems	Not applicable for Waterfront Code
Appendix L	RESERVED	Adopting NYCBC section without modification



WFC TABLE OF CONTENTS

Appendix M	RESERVED—Supplementary Requirements for One-And Two-Family Dwellings	Not applicable for Waterfront Code
Appendix N	Assistive Listening Systems Performance Standards	Adopting NYCBC section without modification
Appendix O	RESERVED	Adopting NYCBC section without modification
Appendix P	RESERVED	Adopting NYCBC section without modification
Appendix Q	Qualified National Standards for Automatic Sprinkler, Standpipe, Fire Pump, Fire Alarm, and Smoke Control Systems	Adopting NYCBC section with modification
Appendix R	RESERVED—Acoustical Tile and Lay-in Panel Ceiling Suspension Systems	Not applicable for Waterfront Code
Appendix S	RESERVED—Supplementary Figures for Luminous Egress Path Markings	Not applicable for Waterfront Code



ADDRESSING FUTURE UNCERTANTIES

- Our coastlines no longer follow the contours of Pangaea; we expect changes to occur over time that will inevitably affect coastal structures
- No year follows the exact same patterns from years before related to:
 - Seasonal conditions and extremes
 - Ice flows and harsh winters
 - Major storms, floods, and other disaster events
- We cannot predict certain types of failures and resultant impacts:
 - Atypical structural failures
 - Debris impacts
 - Vessel failures / impact on structures

So...

**What do
we do?**



ADDRESSING FUTURE UNCERTANTIES

- Develop a sound and robust code development process
- Leverage jurisdictional requirements that naturally help to address identifiable uncertainties
- Identify specialty studies that can address gaps found through research and code development
- Identify appropriate thresholds for reasonable worst-case design scenarios
- Design in flexible mechanisms to adjust codified requirements in the future if conditions change

**We design
for the
reasonable
worst-case
design
scenarios**



DEVELOP A ROBUST CODE DEVELOPMENT PROCESS

■ WFC Research Scope of Work: Code Development (CD)

- CD Task 1 – Identify and Evaluate Existing Waterfront Structures
- CD Task 2 – Categorize Structures
- CD Task 3 – Identify Activities for Additional Research
- CD Task 4 – Define Current Regulatory Framework
- CD Task 5 – Comparable Jurisdiction Regulatory Review
- CD Task 6 – Identify and Evaluate Existing National and International Standards
- CD Task 7 – Site-Specific Analysis
- CD Task 8 – Identify Maintenance Requirements
- CD Task 9 – Identify and Evaluate Maintenance Requirements Deficiencies
- CD Task 10 – Draft and Final Recommendations Reports



LEVERAGE JURISDICTIONAL REQUIREMENTS

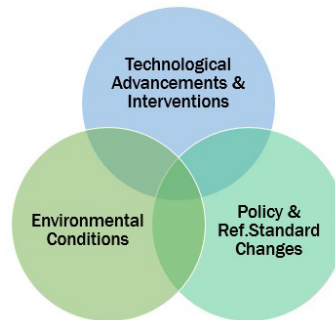
- NYC Formal Development Regulation / Code Development Processes
 - Dept. of Buildings
 - Legal Dept.
 - City Council
 - Many other NYC Agency Stakeholders
- NYC City Environmental Quality Review (CEQR) & Draft Environmental Assessment Study (EAS)
 - Mayor's Office of Environmental Coordination (MOEC)
- NYC Waterfront Revitalization Program (WRP)
 - Dept. of City Planning (DCP)



ADJUST THE DESIGN PROCESS AS YOU GO

- Identification of WFC specialty studies:
 - Floating Ice Loads
 - Debris Impact Loads
 - Load Combinations
- Identify appropriate thresholds for reasonable worst-case design scenarios
 - Induced development
 - Disaster events
 - Changing urban and natural conditions
- Design in flexible mechanisms to adjust codified requirements
 - Simplified code update processes
 - Planned periodic updates
 - Reference standard updates

Code design improvements can be based on:



AECOM

145

NYC
Buildings

THANK YOU

AECOM

NYC
Buildings

PANEL DISCUSSION WITH Q & A

Guidance Beyond Code and Standards

Moderator: Jayantha Obeysekera

- Rob Lempert, RAND Corporation
- Jack Hogan, P.E., Arup
- Stirling Moore, AIA, AECOM



LUNCH

12:15 – 12:45 pm

CONCLUSION of ZOOM Broadcast

Virtual attendees – PLEASE switch to next Zoom meeting



PLENARY DISCUSSION

12:45 pm – 1:30 pm



PLENARY: NEXT GENERATION GOALS FOR ENGINEERING DESIGN GUIDANCE

Next Generation Goals for Engineering Design Guidance – [45 mins.]; ALL

• Moderators: Jayantha Obeysekera, Terri McAllister

Discussion to prepare for breakouts

BREAKOUTS - DEVELOP RESEARCH AGENDA FOR FUTURE ENGINEERING DESIGN GUIDANCE

PROMPTS:

- 1) What do you wish you had for data, tools.
- 2) What are the next generation research needs.
- 3) Prioritize top 5 research needs. (Each written as a sentence.)

GOAL: What do you wish you had?

- **TOPIC a: Structural Capacity.**
 - What are the most impactful future conditions or effects on structural capacity?
 - What is needed to characterize future structural capacity and degradation effects?
- **TOPIC a: Future Guidance**
 - What is needed to address standard updates about future effects and performance criteria?
 - How should updates between code and standard cycles be addressed?
 - How should criteria beyond codes and standards be reviewed and published for design practice?



PLENARY: NEXT GENERATION GOALS FOR ENGINEERING DESIGN GUIDANCE

Discussion to prepare for breakouts

- [Terri to add bullets]



PLENARY: BREAKOUTS - DEVELOP RESEARCH AGENDA FOR FUTURE

PROMPTS:

- 1) What do you wish you had for data, tools.
- 2) What are the next generation research needs.
- 3) Prioritize top 5 research needs. (Each written as a sentence.)

GOAL: What do you wish you had?

- TOPIC 1: Structural Capacity
 - What are the most impactful future conditions or effects on structural capacity?
 - What is needed to characterize future structural capacity and degradation effects?
- TOPIC 2: Future Guidance
 - What is needed to address standard updates about future effects and performance criteria?
 - How should updates between code and standard cycles be addressed?
 - How should criteria beyond codes and standards be reviewed and published for design practice?



PLENARY: BREAKOUTS - DEVELOP RESEARCH AGENDA FOR FUTURE

PROMPTS:

- 1) *What do you wish you had for data, tools.*
- 2) *What are the next generation research needs.*
- 3) *Prioritize top 5 research needs. (Each written as a sentence.)*

GOAL: What do you wish you had?

- **TOPIC 1: Structural Capacity**
 - What are the most impactful future conditions or effects on structural capacity?
 - What is needed to characterize future structural capacity and degradation effects?
- **TOPIC 2: Future Guidance**
 - What is needed to address standard updates about future effects and performance criteria?
 - How should updates between code and standard cycles be addressed?
 - How should criteria beyond codes and standards be reviewed and published for design practice?

NOTE: Communication is important but this workshop is not about communication – it is technical roadmap for research/advancement, including social impacts!



PLENARY: CHARGE THE BREAKOUTS

SCHEDULE: BREAKOUT SESSIONS 1:45PM – 4:45 PM

1:45pm – 2:00 pm = Breakout Session Introductions
and Identify *Day 2 Reporter*

(THREE TOPICS for approximately 45-60 minutes each)

2:00pm – 2:45pm = *What do you wish you had for data, tools.*

2:45pm – 3:30pm = *What are the next generation research needs.*

3:30pm – 3:45pm = **BREAK**

3:45pm – 4:45pm = *Prioritize top 5 research needs.*



Asking for a
VOLUNTEER for
Day 2 Report Outs

GROUP: **NAME** Top 5 NEEDS

Identify the TOP 5 Priority Items and describe each in 1-2 complete sentences.

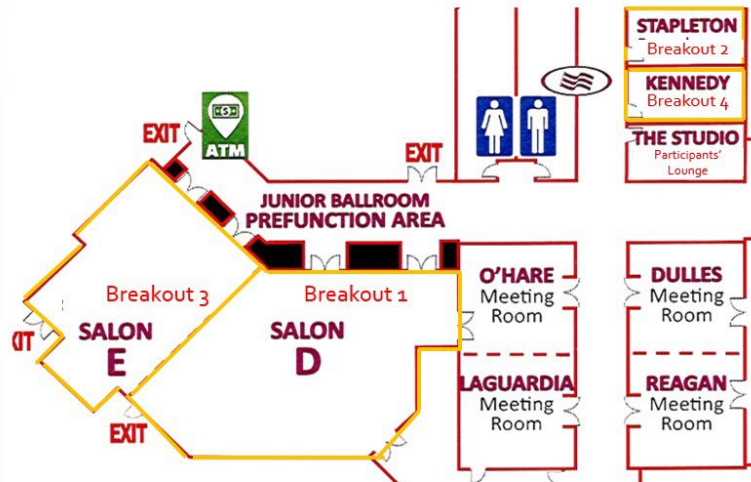
- 1.
- 2.
- 3.
- 4.
- 5.

- **TOPIC 1: Structural Capacity**
 - What are the most impactful future conditions or effects on structural capacity?
 - What is needed to characterize future structural capacity and degradation effects?
- **TOPIC 2: Future Guidance**
 - What is needed to address standard updates about future effects and performance criteria?
 - How should updates between code and standard cycles be addressed?
 - How should criteria beyond codes and standards be reviewed and published for design practice?



BREAKOUT GROUPS

Group	Room	Moderator	Note Takers
1 - Structural Capacity INPERSON	Salon D	Terri McAllister	Scott Jones/ Siamak Sattar
2 - Structural Capacity VIRTUAL	Stapleton	Joe Barsugli	Kevin Borth/ Marc Levitan/ Amanda McCarty
3 - Future Guidance INPERSON	Salon E	Sihan Li	Michel Ghosn/ Jennifer Helgeson
4 - Future Guidance VIRTUAL	Kennedy	Mari Tye	Joe Akroyd/ Jack Hogan



BREAKOUT SESSIONS

1:45 pm – 4:45 pm

FUTURE ENGINEERING DESIGN GUIDANCE

*The workshop presentations and discussion do not necessarily reflect
the views or policies of NIST or the United States Government.*

Sept. 25-26, 2025

SEI/NIST Forward Looking Codes and Standards Workshop #3



B.2.2. Day 2: Overview Presentation

FORWARD-LOOKING CODES AND STANDARDS: WELCOME

Jayantha 'Obey' Obeysekera, Ph.D., P.E.

Research Professor & Director, Sea Level Solutions Center,
Florida International University

Project Director, SEI/NIST Workshops



ASCE/NIST FORWARD LOOKING CODES & STANDARDS WORKSHOPS

1. **JUNE 4-5: Future hazards for design** – confidence/uncertainty in hazard projections, downscaling of global models, converting hazard projections to design criteria
2. **JULY 29-30: Future load effects on the built environment** – (a) load effects for future hazards, (b) changes in load effects relative to historical basis, (c) changes in structural performance, material properties, soils.
3. **SEPT. 25-26: Engineering design guidance and criteria** - non-stationary reliability, service life, design loads, resistance, deterioration
4. **OCT. 28-29: Adaptation and resilience** - buildings and infrastructure system assessment, material durability, mitigation, retrofit.



AGENDA

Digital Package

(password: futureloads)

- AGENDA
- Participant List
- Slide Decks

Day 2: Sep. 26, 9:00am – 12:00pm Eastern

8:30am-9:00am – NETWORKING CONTINENTAL BREAKFAST PROVIDED

9:00am-9:15am – Welcome

- Purpose and Goals of Day 2

9:15am-10:15am – Report Out

- Breakout Session Report out: [15 mins EACH + 10 mins. + 5 mins Q&A]

15-minute COFFEE BREAK

10:30am-11:45am – Prioritization

- Moderated Discussion of Breakout Reports [30 mins.]
Moderator: Jayantha Obeyesekere
- Prioritization of Research Needs – Survey [15 mins.]
- Discussion of Survey Results [30 mins.]

11:45am-12:00pm – Conclusion

- Summary and Adjourn Day 2

12:30-3:00pm – Workshop Steering Committee Meeting

REPORT OUT & PRIORITIZATION

9:15 am – 11:45 am



A.1.1.1. Breakout Session Reports

BREAKOUT ₁

Structural Capacity [In Person]



BREAKOUT GROUP #1

1:45PM – 2:00PM

MODERATOR: **Terri McAllister**
NOTE TAKER: **Siamak Sattar,**
Scott Jones
DAY 2 REPORTER: **Obey**

ATTENDEES:

1. Jim Harris
2. Jan Dale
3. Irem Efe
4. Mohammad Houshman
5. Mija Hubler
6. Kingsley Lau
7. Ming Liu
8. Aaron Newman
9. Sissy Nikalaou
10. Milad Roohi
11. Obey
12. Fabio Biondini

GROUP: **Structural Capacity (Breakout 1)**

Top 5 NEEDS

1. Codes and standards that address capacity degradation. Codes need to address frequent events that affect degradation as well as extreme events. This could be implanted through maps (e.g., ASCE Hazard tool) of future environmental conditions (e.g., temperature, humidity, CO₂ concentration) and associated reduction factors for degradation in structural design and evaluation.

2. Adaptive design methods. For DMDU approach, identify selection basis for scenarios, models, and stress tests for design that maintains an acceptable level of risk. Need thresholds values and time intervals for decision support, and a strong foundation for such thresholds. Develop societal requirements for structural design and expected performance and life cycle based on an economic model of cradle to cradle life cycle costs to deliver long service lives for critical structures.

3. Optimal, effective monitoring to assess new vs existing structures. Inexpensive tools for monitoring degradation, such as corrosion or delamination. Technology for nondestructive remote monitoring, including below surface – adapt existing technologies used by other disciplines (bridges, geotechnical, etc.). Need models to identify optimal monitoring frequency and locations based on degradation type, load paths and failure modes, spatial variability, and uncertainty.

4. Data driven life cycle models. Need degradation models that are well validated. Also need models that can be updated with structural monitoring data. Need to understand where, when, why degradation happens in structures to improve effectiveness of retrofits, improve designs, reliability assessments. Need data from existing structures and full-scale experimental testing to validate life cycle models.

5. Assessment of changing conditions and future hazards. Develop improved characterization of compounding (sequential) hazards and time-varying structural conditions. Study of relative impacts of future conditions, including extreme and frequent events, and their impact on structural capacity/degradation over time. Develop plausible scenarios for regions that designers might consider.



BREAKOUT 2

Structural Capacity [Virtual]



BREAKOUT GROUP 2 1:45PM – 2:00PM

MODERATOR: **Joe Barsugli**
NOTE TAKER: **Marc Levitan**
DAY 2 REPORTER: **Kevin Borth**

ATTENDEES:

1. Joe Barsugli
2. Kevin Borth
3. Alex Cannon
4. Eun J Cha
5. Elisabeth Gilmore
6. Amin Hariri
7. Marc Levitan
8. Amanda McCarty
9. Dan Rhee
10. Silky Wong



GROUP: #2 *Structural Capacity* Top 5 NEEDS

- TOPIC 1: Structural Capacity
 - What are the most impactful future conditions or effects on structural capacity?
 - What is needed to characterize future structural capacity and degradation effects?

1. Develop an open-source database including in-situ material characteristics and structural system behavior to calibrate performance models under hazard events. For example, information gathered during post-hazard assessments or upon demolition.
2. Evaluate durability characteristics of structural materials (e.g., concrete, steel, wood) and non-structural materials (e.g., coatings, sealants) with a focus on anticipated future effects and relating accelerated lab testing to real world long-term behavior.
3. Characterize effects due to concurrent or compounding material degradation modes that reflect real world behavior.
4. Better understanding of "micro to macro": how materials degradation impacts components and how this affects behavior of the structural system. For example, developing system reliability in lieu of, or in addition to, member reliability incorporating degradation to the components.
5. Develop guidelines to incorporate uncertainty in future structural capacity when evaluating designs for acceptable reasonable risk. For example, using decision making under uncertainty.



BREAKOUT₃

Future Guidance [In Person]



BREAKOUT GROUP #3

1:45PM – 2:00PM

MODERATOR: **Sihan Li**
NOTE TAKER: **Jeniffer Helgeson, Michel Ghosn**
DAY 2 REPORTER: **NAME** (ask for a volunteer)

ATTENDEES:

1. Abigail Beck
2. Chris Clavin
3. Michel Ghosn
4. Jennifer Helgeson
5. Ayse Hortascu
6. Katherine Johnson
7. Ann Kosmal
8. Ken Kunkel
9. Sihan Li
10. Ning Lin
11. Stirling Moore
12. Adam Reeder
12. Peter Vickery
13. Yating Zhang

GROUP: *Future Guidance*

Top 5 NEEDS

Identify the TOP 5 Priority Items and describe each in 1-2 complete sentences.

1. Research on implementation of adaptive design and whether the current risk categories are applicable for all types of hazards and asset size and number of users? Future guidance should include adaptation/adaptive capacity rating categories to extend the current four risk categories.
2. Research on the applicability of current methodology used for stationary conditions to the design of structures in nonstationary conditions?
3. Develop guidelines for monitoring existing structures and for determining appropriate criteria and thresholds for adapting existing assets to future conditions and to evaluate the performance of adaptive designs over time.
4. Research on assessing the effects of uncertainty in climate scenarios and associated uncertainties in the damaging effects of different hazards.
5. Updates between code and standard cycles might be promoted by applying performance-based design – There is a need to develop guidance/standards for data validation for interim updates.
 - 5.i. Guidelines for assessing existing structures for future conditions.
 - 5.ii. Procedure explaining how we can review and update established criteria in codes and standards?

• **TOPIC 1: Structural Capacity**

- What are the most impactful future conditions or effects on structural capacity?
- What is needed to characterize future structural capacity and degradation effects?

• **TOPIC 2: Future Guidance**

- What is needed to address standard updates about future effects and performance criteria?
- How should updates between code and standard cycles be addressed?
- How should criteria beyond codes and standards be reviewed and published for design practice?



BREAKOUT 4

Future Guidance [Virtual]



BREAKOUT GROUP 4 1:45PM – 2:00PM

MODERATOR: **MARITYE**
NOTE TAKER: **JOE ACKROYD, JACK HOGAN**
DAY 2 REPORTER: **NAME**

ATTENDEES:

1. Ahmed Abdelaal
2. Joe Ackroyd
3. Bill Coulbourne
4. Shideh Dashti
5. Keith Dixon
6. Matt Gilbertson
7. Emily Guglielmo
8. Jack Hogan
9. Abbie Liel
10. Roy Lobo
11. Kris May
12. Lauren Mudd
13. Manny Perotin
14. Mari Tye

GROUP: 4 Top 5 NEEDS

Identify the TOP 5 Priority Items and describe each in 1-2 complete sentences.

1. **Timely and Flexible Code Updates.** The current 3–6 year cycles for codes and standards are often too slow to incorporate rapidly evolving climate science and engineering research. Mechanisms are needed to publish vetted interim guidance or supplements without confusing practitioners or undermining the authority of codes. And also providing guidance for non-traditional entities that regulate development through local land use ordinances.
2. **Future-Oriented Hazard and Load Data.** Practitioners need authoritative, regularly updated datasets (e.g., precipitation, wind, flood) that reflect future conditions rather than outdated baselines like NOAA Atlas 14. Scalable methods (e.g., simple adjustment factors, ensembles) could provide usable interim tools until full datasets are refreshed.
3. **Uncertainty, Reliability, and Threshold Criteria.** Engineers require clearer ways to handle uncertainty in both climate projections and structural degradation. Establishing benchmark thresholds, reliability criteria (for research - e.g. number of papers or consensus of percentage increase), and peer-reviewed vetting processes would help ensure that updates are scientifically defensible and practical for design.
4. **Monitoring, Materials, and Degradation Research.** More research is needed on long-term performance of structures under future conditions—covering new materials, degradation mechanisms, and sensor-based monitoring of public and private infrastructure. Standardized protocols for instrumentation and data-sharing could make real-world data more accessible for codes and practice (and to ensure that data are used for good, no liability from providing entities further down the line).
5. **Performance-Based and Future Conditions Design Frameworks.** There is strong demand for performance-based approaches (e.g., for flooding) and methods to overlay current and future hazard conditions at the site level. These frameworks would allow codes and standards to evolve beyond prescriptive rules, enabling adaptation to compounding hazards and long-term climate shifts.
6. **Research Funding, Governance, and Dissemination Pathways.** The development of next-generation codes and standards requires clarity on how research is funded, coordinated, and translated into practice. Industry groups, insurers, standards bodies, and government agencies all play roles in shaping research priorities, publishing new standards, and influencing updates—yet stronger mechanisms are needed to ensure consistent dissemination of guidance not only to engineers, but also to planners, policymakers, and other decision-makers who shape the built environment.



COFFEE BREAK

10:15 – 10:30 am



MODERATED DISCUSSION OF BREAKOUT REPORTS

[45 mins]

• Moderator: Jayantha Obeysekera



PRIORITIZATION OF RESEARCH NEEDS

15 minutes



DISCUSSION – 30 MINUTES

Moderator:

Jayantha 'Obey' Obeysekera – Workshop Director

- Review of findings
- Discussion (ALL PARTICIPANTS)



SUMMARY & ADJOURN

11:45 am – 12:00 pm



ASCE/NIST FORWARD LOOKING CODES & STANDARDS WORKSHOPS

1. **JUNE 4-5: Future hazards for design** - confidence/uncertainty in hazard projections, downscaling of global models, converting hazard projections to design criteria
2. **JULY 29-30: Future load effects on the built environment** - (a) load effects for future hazards, (b) changes in load effects relative to historical basis, (c) changes in structural performance, material properties, soils.
3. **SEPT. 25-26: Engineering design guidance and criteria** - non-stationary reliability, service life, design loads, resistance, deterioration
4. **OCT. 28-29: Adaptation and resilience** - buildings and infrastructure system assessment, material durability, mitigation, retrofit.



STRUCTURAL
ENGINEERING
INSTITUTE

THANK YOU to all participants and
to the Workshop Steering
Committee!!!

SUMMARY & ADJOURN

12:00 pm

PLEASE recycle your Name Badges



Appendix C. Workshop Participants

Following is the list of workshop participants including their self-identified organization, listed in alphabetical order.

Ahmed	Abdelaal	SUNY Polytechnic Institute
Joe	Ackroyd	NYC Department of Building
John	Allen	Central Michigan University
Ahmed	Attar	National Research Council Canada
Michele	Barbato	University of California, Davis
Joe	Barsugli	University of Colorado
Abby	Beck	University of Houston
Fabio	Biondini	Politecnico di Milano
Philip	Blackmar	HDR Engineering, Inc.
Kevin	Borth	HGA
Alex	Cannon	Environment and Climate Change Canada
Eun	Cha	University of Illinois at Urbana–Champaign
Christopher	Clavin	NIST
Bill	Coulbourne	Coulbourne Consulting
Jan	Dale	RWDI Inc.
Shideh	Dashti	University of Colorado, Boulder
Keith	Dixon	NOAA
Lakshmana	Doddipatla	FM
Irem	Efe	NIST
Bruce R.	Ellingwood	Colorado State University
Graziano	Fiorillo	University of Manitoba
Matt	Gilbertson	Simpson Gumpertz & Heger
Elizabeth	Gilmore	Carleton
Michel	Ghosn	The City College of New York/CUNY
Jennifer	Goupil	ASCE–SEI

Emily	Guglielmo	Martin Martin
Ruohua	Guo	Reliability Equity LLC
Amin	Hariri	NIST
James R.	Harris	J. R. Harris & Company
Jennifer	Helgeson	NIST
Jack	Hogan	Arup
Ayse	Hortacsu	Applied Technology Council
Mija	Hubler	University of Colorado, Boulder
John	Ingargiola	FEMA
Katherine	Johnson	NIST
Scott Z.	Jones	NIST
Ann	Kosmal	Kosmal Partnership
Kenneth	Kunkel	Johns Hopkins University
Yuchuan	Lai	Tetra Tech
Kingsley	Lau	Florida International University
Robert	Lempert	RAND Corp.
Marc	Levitan	NIST
Sihan	Li	RWDI
Abbie	Liel	University of Colorado
Ning	Lin	Princeton University
Ming	Liu	NAVFAC-EXWC
Roy	Lobo	HCAI
Norma Jean	Mattei	The University of New Orleans
Kris	May	Pathways Climate Institute
Therese	McAllister	NIST
Amanda	McCarty	NOAA
Stirling	Moore	AECOM
Lauren	Mudd	Applied Research Associates

Aron	Newman	NIST
Sissy	Nikolaou	NIST
Jayantha	Obeysekera	Florida International University
Manny A.	Perotin	CDM Smith
Adam	Reeder	CDM Smith
Dan	Rhee	NIST
Milad	Roohi	University of Nebraska–Lincoln
Siamak	Sattar	NIST
Michael	Sukop	Florida International University
Tori	Tomiczek	U.S. Naval Academy
Mari	Tye	Johns Hopkins University
Peter	Vickery	Vickery Consulting
Silky	Wong	Dow Inc.
Xuebin	Zhang	Pacific Climate Impacts Consortium, University of Victoria
Yating	Zhang	