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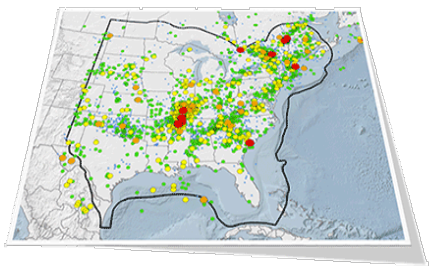
NIST GCR 23-041

Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States



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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

NIST Grant/Contractor Report
NIST GCR 23-041

Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States

Prepared for
U.S. Department of Commerce
Engineering Laboratory
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May 2023

U.S. Department of Commerce
Gina M. Raimondo, Secretary

National Institute of Standards and Technology
Laurie E. Locascio, NIST Director and Under Secretary of Commerce for Standards and Technology

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Preface

In 2021, the National Institute of Standards and Technology (NIST) awarded Contract 1333ND21PNB730567 to the Applied Technology Council (ATC) to identify research and practice needs to advance seismic design and construction practices for new and existing buildings and lifeline infrastructure in the Central and Eastern United States (CEUS). Based on a workshop held on the project theme, this resulting report provides a summary of current issues in CEUS seismic practice and recommended projects to address those issues. The plan provided can be used by NIST and other National Earthquake Hazards Reduction Program (NEHRP) agencies to develop future programmatic activities intended to improve the seismic performance of the built environment for a significant earthquake in the CEUS.

ATC is indebted to the leadership of Emily Guglielmo, Project Technical Director, and the members of the Project Steering Committee, consisting of Craig Davis, Julie Furr, Nathan Gould, James R. Harris, Sanaz Rezaeian, Karl Rubenacker, and Kent Yu, for their contributions in development of the workshop program and this report.

The Applied Technology Council also gratefully acknowledges John (Jay) Harris (Acting NEHRP Director and NIST Project Manager) for his input and guidance in the preparation of this report; Chiara McKenney for ATC project management; and Kiran Khan for ATC report production services.

Jon A. Heintz
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Chapter 1

Introduction

Much of the built environment in the Central and Eastern United States (CEUS) was not designed or built to resist earthquakes and could be damaged if affected by an earthquake of even moderate size. Though damaging earthquakes are rare events in the CEUS, the vulnerability of buildings and lifeline infrastructure makes the region susceptible to devastating consequences from earthquakes when they do occur. An earthquake with significant ground shaking that happens to strike a densely built-up region in the CEUS has the potential to result in a major loss of life, widespread damage of buildings, and lifeline infrastructure losses.

Disruptions caused by an earthquake with significant ground shaking in the CEUS could ripple out beyond the immediately affected area and impact operations around the nation. For example, pipeline damage could halt the flow of fuel, creating gasoline and jet fuel shortages that impact travel and distribution services across the nation. The impact of a cyberattack that shut down a major pipeline from Houston, Texas, to the southeastern United States for five days in 2021 (Englund and Nakashima, 2021) provides a glimpse into how regional and national interdependencies could be stressed by an earthquake in the CEUS. However, relative to a targeted attack on one pipeline, damage to the built environment from an earthquake in the CEUS would impact a wider range and number of systems, and the time to restore operations could be much longer.

Moderate earthquakes occur on a regular basis in the CEUS, such as the 2011 magnitude (M) 5.8 Virginia Earthquake (USGS, 2019a), the 2016 M5.8 Oklahoma Earthquake (Taylor et al., 2017), and the 2020 M5.1 Sparta Earthquake (Price and Lindstrom, 2020) in North Carolina (Figure 1-1). The lower population density of these recent earthquake locations limited the overall amount of damage, but three of the densest cities in the United States (New York, Philadelphia, and Boston) are in locations with a similar level of seismic hazard. At present, there is insufficient inventory data to paint the full picture of vulnerability of these major cities to earthquakes, but the typical characteristics of the building stock and lifeline infrastructure make obvious that vulnerability to earthquakes is high. Considering the high exposure of these major cities, even a moderate earthquake would jeopardize the safety of a large number of people and could cause major disruptions to the region and the nation.

Moderate earthquakes are not the only concern. Some of the largest known earthquakes in the contiguous United States occurred in the CEUS. In 1811 and 1812, several earthquakes between M7 and M8 struck the New Madrid Seismic Zone (Figure 1-2a), where six states meet in the Mississippi Valley (USGS, 2019b). Significant ground failure and impact to river navigability were observed in those events. In 1886, an M7 earthquake struck near Charleston, South Carolina (Chapman et al., 2016) and heavily damaged the port city (Figure 1-2b).

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(a) (b)

Figure 1-1 Examples of damage from recent moderate earthquakes in the CEUS.
(a) Chimney collapse in the 2011 M5.8 Virginia Earthquake (from USGS).
(b) Out-of-plane unreinforced masonry wall failure in the 2016 M5.8 Oklahoma Earthquake (from Ezra Jampole).

(a) (b)

Figure 1-2 Images of destruction following major 19th century earthquakes in the CEUS.
(a) Woodcut print depicting one of the New Madrid Earthquakes of 1811 to 1812.
(b) Widespread damage from the 1886 Charleston Earthquake (from USGS).

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To date, most fundamental research, applied research, practice-related projects, and development of codes and standards have focused on the seismic performance of the built environment in the Western United States (WUS). Data from these activities are applied to seismic practice in the CEUS, but a one-size-fits-all approach does not account for regional differences between the WUS and CEUS. Beyond that issue, practices essential for seismic safety are not always implemented in the design and construction of new buildings in the CEUS, and seismic retrofitting of vulnerable existing buildings is not viewed as a high priority in many jurisdictions of the CEUS.

Preventing an earthquake disaster in the CEUS will require determining the extent of vulnerabilities of existing buildings and lifeline infrastructure, addressing the identified vulnerabilities, and raising the standard for design and construction of new buildings and lifeline infrastructure. This report summarizes the issues presently impeding advancement of seismic practice in the CEUS and presents a roadmap of research and practice-related projects to address the identified issues. The benefit of addressing impediments to seismic resilience in the CEUS is incalculable. Better performing buildings and lifeline infrastructure during a significant earthquake will translate into saved lives, reduced injuries, avoided economic losses, lower insurance costs, reduced recovery costs, and faster recovery times. Completing the projects identified in this report will result in CEUS communities that are safer in and quicker to recover after earthquakes.

1.1 Project Approach

The project was guided by a steering committee and centered around a workshop held in October 2022. The steering committee was selected to represent relevant expertise in the subject matter. In advance of the workshop, the steering committee developed a preliminary list of issues in CEUS seismic practice to seed discussion at the workshop and organized those issues into three general topic areas: *Hazard Characteristics and Design Philosophies*, *Buildings*, and *Lifeline Infrastructure*. Topic areas are described in Section 1.2.

Topic papers on each of the major subjects were developed by the steering committee and circulated to workshop participants in advance of the workshop, along with a pre-workshop poll. The workshop was designed to expand and refine the steering committee's list of issues, develop a list of research and practice-related projects to address those issues, and identify the highest priority needs. This report provides a synthesis of the information gathered in advance of the workshop and during the workshop.

The two-day workshop, entitled *Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States*, was held on October 17 and 18, 2022. The workshop was attended by 43 invited participants from 14 states (Figure 1-3). Participants represented perspectives from engineering practice, academia, code development, Federal and State Government, lifelines operations, and non-profit organizations (Figure 1-4). The workshop was funded by the National Institute of Standards and Technology (NIST) and held at the Sheraton Charlotte Airport Hotel in Charlotte, North Carolina (Figure 1-5).

At the workshop, all participants attended the introductory and closing plenary sessions and the topic session on *Hazard Characteristics and Design Philosophies*. Participants divided into two tracks to participate in sessions covering the other topic areas: *Buildings* (25 people) and *Lifelines* (17 people). Each topic session included introductory presentations and breakout discussions. At the conclusion of the workshop, each identified issue was prioritized by the participants to determine the level of criticality for advancing seismic practice in the CEUS.

As a starting point for discussion, the Lifelines Track used the recommendations from three prior reports (published between 2014 and 2021) that identify research and practice needs for lifeline infrastructure on a national level. As the other two topic areas did not have analogous reports, seeds for discussion in those topic areas were developed by the steering committee.

After the workshop, the lists of issues and projects from the workshop were organized and distilled by the steering committee to consolidate similar items and highlight key themes.

The workshop agenda is provided in Appendix A. Presentation slides are provided in Appendix B.

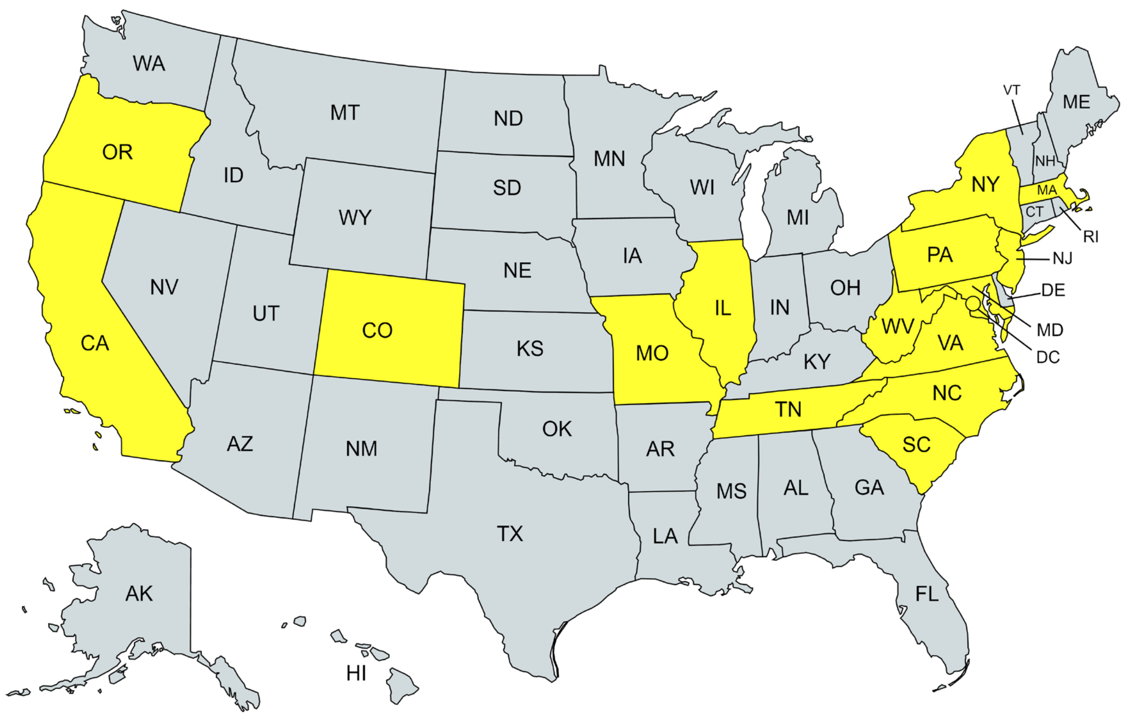

Figure 1-3 States represented in the group of workshop participants (including steering committee). Participants outside of the CEUS were selected for specific expertise needs.

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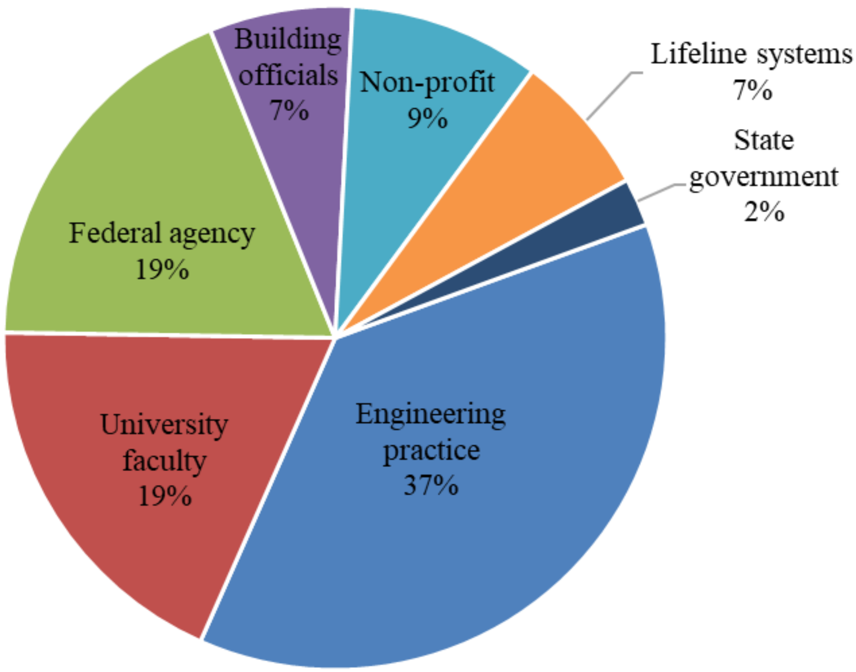

Figure 1-4 Workshop participants by sector.

Figure 1-5 Participants at the workshop.

1.2 Issues and Recommended Projects

This report describes existing issues in seismic practice in the CEUS and recommended projects to address those issues.

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Each *issue* is referenced by the section number of the report in which it is described (e.g., Issue 3.1 is described in Section 3.1 along with all projects recommended to address Issue 3.1). For each issue, a description is provided, along with a recommended approach to address the issue and the envisioned impact of addressing the issue.

Each *project* is referenced by the number of the issue that it addresses and a letter (e.g., Projects 3.1-A, 3.1-B, 3.1-C, and 3.1-D are recommended to address Issue 3.1 and described within Section 3.1). For each project, a description, a priority level (see Section 1.5), key steps, roles, and estimate time to complete are provided.

1.3 Topic Areas

The workshop and this report are organized into three major topic areas:

- *Hazard Characteristics and Design Philosophies* (Chapter 3) is a topic area that includes hazard modelling; geo- and multi-hazard considerations; design ground motions; and potential future recovery-based design philosophy.
- *Buildings* (Chapter 4) is a topic area that includes new building design; evaluation and retrofit of existing buildings; building codes, standards, and guideline development; and building code adoption and implementation.
- *Lifeline Infrastructure* (Chapter 5) is a topic area that includes existing and new infrastructure systems for water, wastewater, drainage, communication, electric power, gas and liquid fuels, transportation, and solid waste systems.

Most identified issues in the *Buildings* or *Lifelines Infrastructure* chapters are specific to that topic area, but all issues covered under *Hazard Characteristics and Design Philosophies* impact both the *Buildings* and *Lifeline Infrastructure* topic areas. Some issues covered under *Hazard Characteristics and Design Philosophies* are major issues in their own right within *Buildings*, such as those pertaining to design ground motions, seismic design category, and potential future directions for seismic design philosophy. To prevent duplication of information, such issues are addressed only in Chapter 3 but listed in the opening to Chapter 4.

1.4 Summary of Key Themes

Across more than twenty seismic practice issues that are described in the report, several key themes emerged:

- A greater understanding of seismic hazard characteristics in the CEUS is needed.
- The level of seismic safety targeted by current codes, which is based on WUS hazard, produces different levels of reliability in the CEUS because of how the natures of the hazard (i.e., event frequency, severity, and characteristics of the ground shaking) differ.
- Current seismic standards and guidelines do not address all building typologies and characteristics (e.g., materials) common in the CEUS.

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- Seismic provisions are perceived by some CEUS engineers as too complicated and some CEUS clients as too costly.
- Some jurisdictions are resistant to adopting and/or enforcing seismic provisions. Some jurisdictions are expected to be resistant to future seismic provisions if based on enhanced performance to address objectives beyond life safety (e.g., functional recovery).
- Barriers to retrofit include lack of data about and unique issues in the CEUS existing building stock.
- Earthquakes in the CEUS can have compounding effects from failure of energy infrastructure or levees/dam systems. They also have the potential to be multi-hazard events due to seasonal weather and environmental conditions.

Table 6-2 identifies common themes across the issues described in this report.

1.5 Prioritization of Recommended Projects

Each recommended project in the report is assigned a priority level, which was determined using input from the workshop participants. The workshop participants rated each project on a scale of moderately important (1) to critical (3). Participants only assigned priority levels to workshop sessions in which they took part (i.e., Buildings Track participants did not assign priority levels to projects discussed in the Lifelines Track and vice versa).

Priority levels were assigned using the average priority score across workshop participants, except in a few cases where projects identified at the workshop were divided or consolidated after the workshop. In those cases, the priority level was interpolated or inferred by the steering committee.

The importance of each recommended project in this report is categorized from lowest to highest levels as

- MODERATELY IMPORTANT (average score of 1.0 to 1.4),
- IMPORTANT (average score of 1.5 to 2.4), or
- CRITICAL (average score of 2.5 to 3.0).

The number in parentheses provided next to the priority level is the average priority score from workshop participants.

Priority levels can be compared across all recommended projects using Tables 6-3 to 6-5, which list all issues and recommended projects by chapter along with priority level. Table 6-3 covers Chapter 3, *Hazard Characteristics and Design Philosophies*. Table 6-4 covers Chapter 4, *Buildings*. Table 6-5 covers Chapter 5, *Lifeline Infrastructure*.

1.6 Report Organization and Content

This report summarizes issues in CEUS seismic practice for existing and new buildings and lifeline infrastructure, provides recommendations for future research and practice-related projects, and includes an order of magnitude estimate of the approximate level of effort. The plan is intended to be coordinated

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with other National Earthquake Hazard Reduction Program (NEHRP) partner agencies, representative industry organizations, and national model building codes and standards development organizations.

The remaining chapters of this report are organized as follows:

- Chapter 2 provides background information across all topic areas.
- Chapter 3 provides descriptions of issues and projects for the Hazard Characteristics and Design Philosophies Topic Area.
- Chapter 4 provides descriptions of issues and projects for the Buildings Topic Area.
- Chapter 5 provides descriptions of issues and projects for the Lifeline Infrastructure Topic Area.
- Chapter 6 provides cost estimation information and summary tables highlighting themes and priority levels.

The workshop agenda, the workshop presentations, a list of acronyms, references, and project participants are provided as appendices at the end of the report.

Chapter 2

Background

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This chapter provides background for the issues and recommended projects presented in Chapters 3 to 5. Background content for all three topic areas is presented in this chapter to accommodate major themes that bridge topic areas. Context is provided about the nature of the earthquake hazard in the CEUS, current state of seismic practice in the CEUS for lifelines and buildings, and expected future direction of seismic practice in the United States.

To date, most fundamental research, applied research, practice-related projects, and development of codes and standards has focused on the seismic performance of the built environment in the WUS, leaving the CEUS without adequate attention despite having areas of both moderate and high seismic hazard. Especially relevant to understanding CEUS seismic risks is understanding the ways in which the CEUS differs from the WUS. This chapter emphasizes those differences, as these variations contribute to the issues presented in Chapters 3 to 5.

2.1 Earthquake Hazard

The risk exposure and nature of earthquake hazard vary across the CEUS. Parts of the CEUS expected to be affected by large events with extreme or violent shaking include the area around Charleston, South Carolina, and the New Madrid Seismic Zone, where six states meet in the Mississippi Valley. The vulnerability of the built environment in these areas is driven by high hazard that is best exemplified by several earthquakes between M7 and M8 that struck the New Madrid region in 1811 to 1812 (USGS, 2019b) and the M7 Charleston Earthquake in 1886 (Chapman et al., 2016). Parts of the CEUS susceptible to moderate events of strong shaking include New York, Boston, and Philadelphia, three of the densest cities in the United States; the seismic risk of these moderate hazard areas is driven by large populations and high density. In general, hazard is highest for CEUS regions that have experienced large earthquakes in the past, as shown in the earthquake hazard map by the United States Geological Survey (USGS) in Figure 2-1.

Due to geological differences, an earthquake in the CEUS affects a wider geographical area than a similar magnitude earthquake in the WUS. Figure 2-2 compares the area over which an earthquake in the WUS was felt relative to three comparable or smaller earthquakes in the CEUS.

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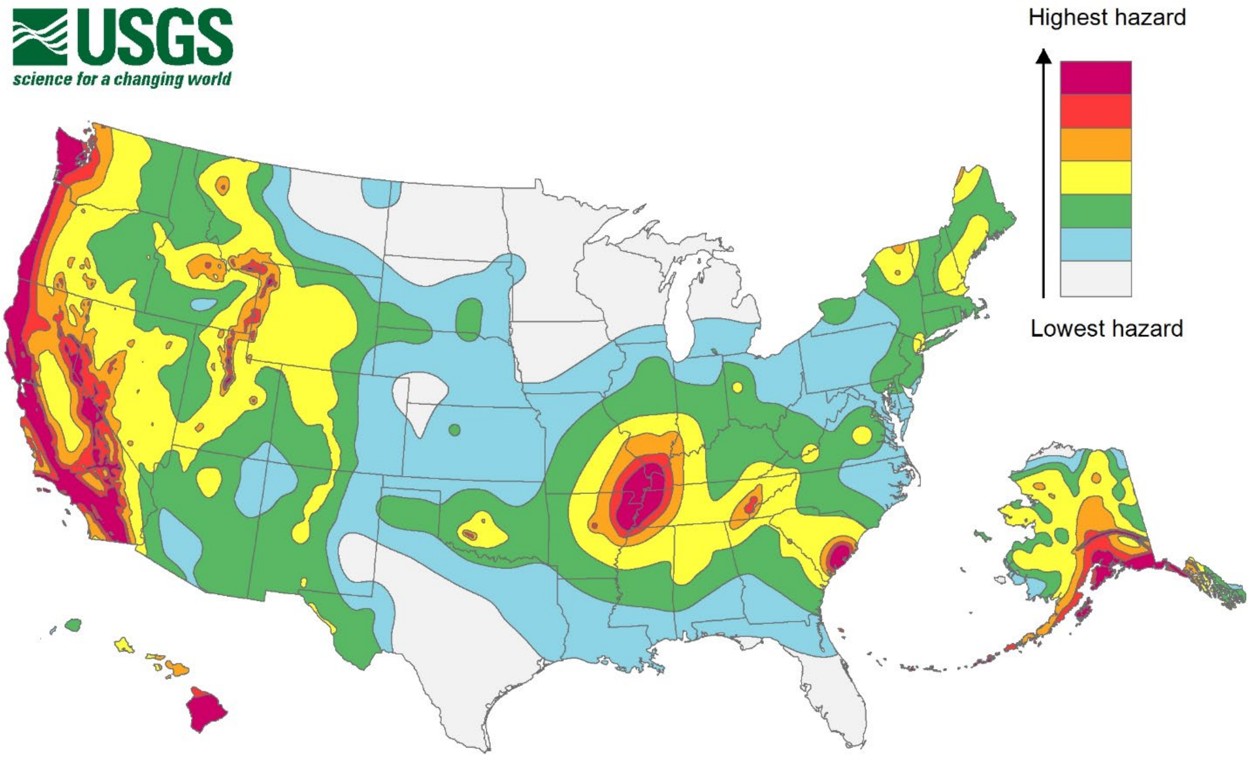

Figure 2-1 Earthquake hazard map of the United States (from USGS).

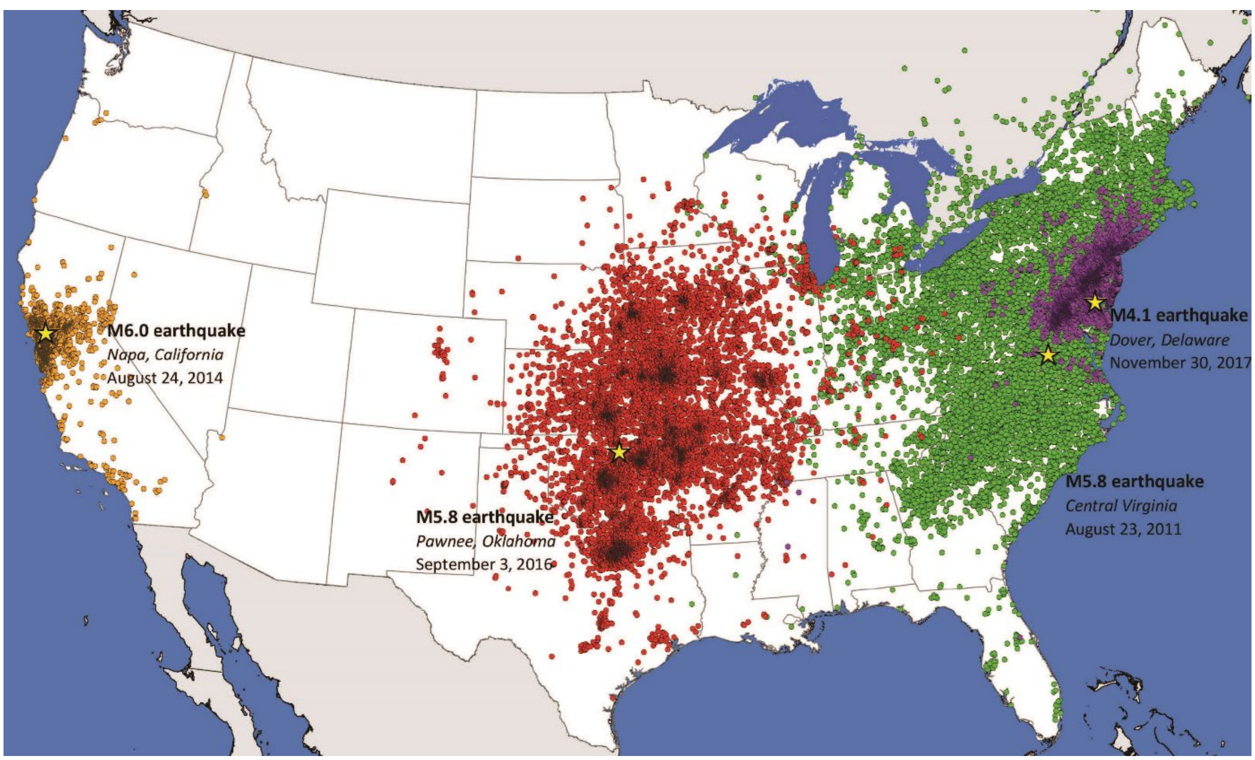

Figure 2-2 Map comparing the affected areas of an earthquake in the WUS to comparable and smaller earthquakes in the CEUS (from USGS).

2.1.1 History of Earthquake Hazard Modelling

The National Earthquake Hazards Reduction Program (NEHRP) was established in 1977 following the 1971 San Fernando Earthquake in California to "reduce the risks of life and property from future earthquakes in the United States through the establishment and maintenance of an effective earthquake hazards reduction program" (NEHRP, 2023). As a national program, NEHRP broadened the focus of seismic hazard mitigation to a nationwide scale, deliberately including both WUS and CEUS regions. However, research and tools used today for quantifying earthquake hazards are primarily based on WUS geology and criteria. These tools are extrapolated to the CEUS to quantify seismic hazards in known historically active regions but with a higher degree of uncertainty and lower confidence in the results due to the lower frequency of occurrence and other challenges to regionally testing the accuracy of the tools.

It was only in 2018 that a suite of ground motion models (GMMs) focused specifically on CEUS geology and characteristics was developed. This project, called the Next Generation Attenuation Relationships for Central & Eastern North-America (NGA-East), was coordinated by the Pacific Earthquake Engineering Research Center (PEER) and quantifies CEUS seismic hazards based on actual CEUS data (Goulet et al., 2018).

2.1.2 Current State of Earthquake Hazard Modelling

Hazard curves represent the probabilities of exceeding certain levels of ground motions. These curves are generated by combining information on seismic hazard sources and GMMs through probabilistic seismic hazard analyses (PSHA). This section summarizes existing relevant research and hazard models, as well as gaps in existing knowledge needed to develop hazard curves that are appropriate for CEUS sites, taking into account regional differences.

The border between the CEUS and WUS regions is defined by an attenuation boundary, which separates the two regions by seismicity catalog and which GMMs are used in PSHA. The attenuation boundary between the active tectonic WUS crust and the stable continental CEUS crust has traditionally gone through Colorado. As a result, there is a transition zone between 115- and 100-degrees west longitudes. This boundary is currently being updated by USGS based on new research (Figure 2-3) for the 2023 USGS National Seismic Hazard Model (NSHM).

Two types of seismic sources are defined in the CEUS: fault-based and repeating large-magnitude earthquake sources, such as the New Madrid and Charleston source zones, and grid or background seismicity sources that include smaller magnitude events, such as the East Tennessee seismic zone.

The 2014 NSHM updated the fault model for the New Madrid seismic zone, and the 2018 NSHM updated the earthquake catalog and rate models for the background seismicity (Petersen et al., 2020). Expected seismic source updates in the 2023 NSHM (Petersen et al., expected 2023) were presented at the workshop.

Induced earthquakes have been removed from long-term NSHMs because they are ephemeral features and change rapidly over short periods of time. USGS, however, has considered these earthquakes in

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several short-term (1-year) forecasts for the CEUS (Petersen et al., 2016). Figure 2-4 is a map of induced seismicity regions in the CEUS.

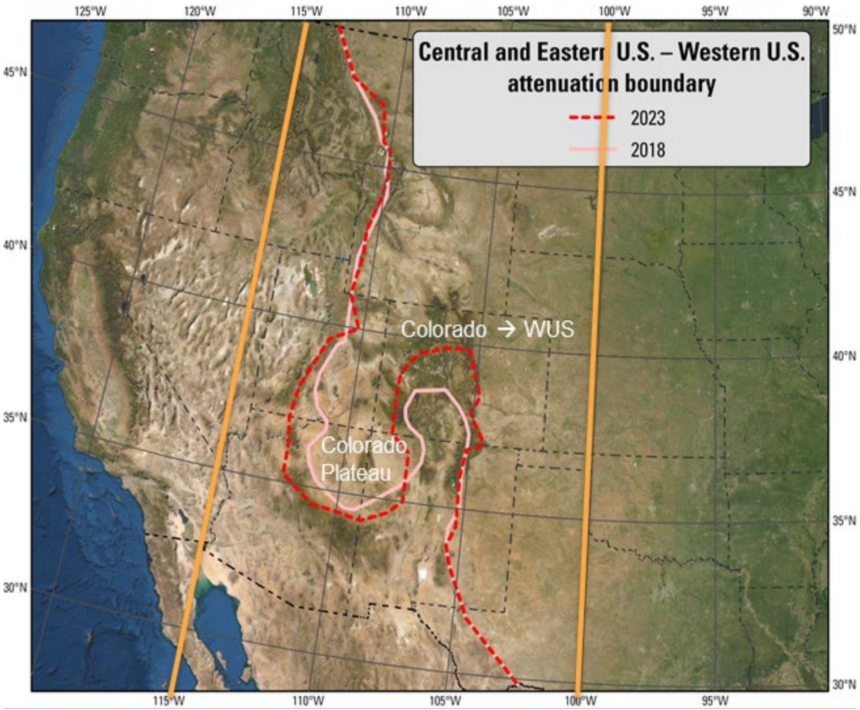

Figure 2-3 Updated boundary under consideration for the 2023 NSHM development in which areas of Colorado previously assigned to the CEUS would become part of the WUS (Peterson et al., expected 2023).

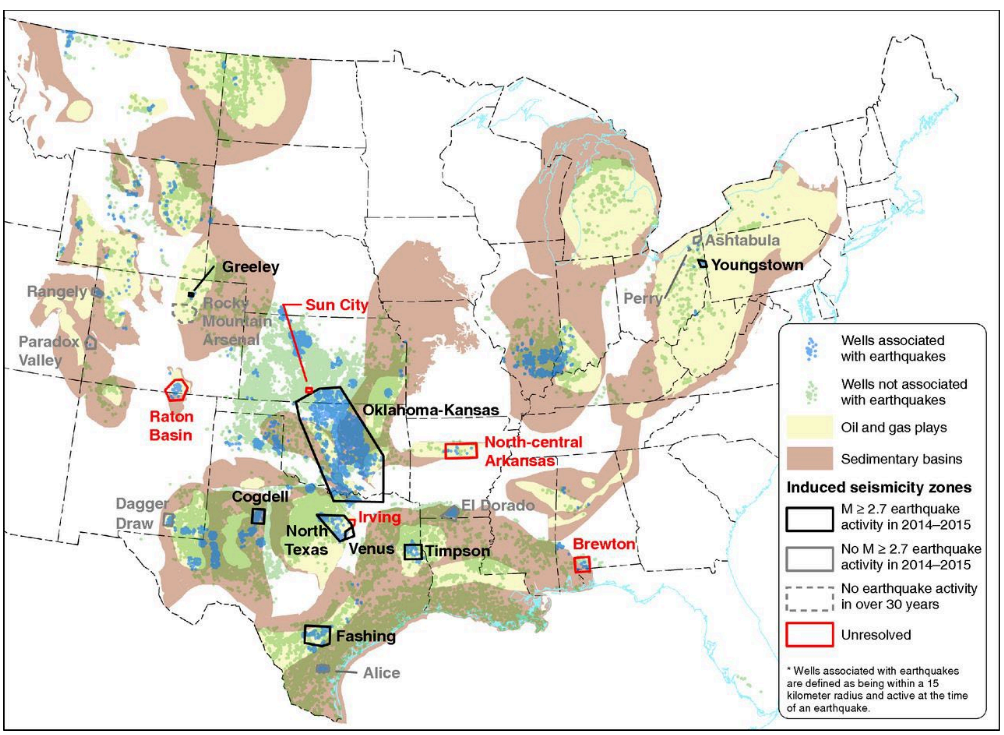

Figure 2-4 Induced seismicity zones (Petersen et al., 2016).

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In the 2018 NSHM, there were major updates to CEUS GMMs. Namely, 31 new GMMs replaced the 9 GMMs of the 2014 NSHM and provided significant improvements to the representation of the ground motion space (i.e., epistemic uncertainty). These included 17 GMMs from the NGA-East project (Goulet et al., 2018) and 14 updated seed GMMs (defined in Rezaeian et al., 2021), all developed for very hard rock site conditions (V_{S30}=3000 m/s) and periods between 0 seconds (i.e., peak ground acceleration, PGA) and 10 seconds. Single models for aleatory variability and site effects were applied to all GMMs (Rezaeian et al., 2021).

Since epistemic uncertainty on the median GMM improved significantly in the 2018 NSHM, addition of any new GMM is expected to make little difference in the mean hazard results. However, some questions remain regarding the current distribution of weights between NGA-East and updated seed GMMs (two-thirds and one-third respectively). Specifically, more research is needed to determine whether NGA-East GMMs properly represent the complexities seen in seed GMMs (e.g., reflection of seismic waves from the Moho boundary) and investigate possible overestimation of uncertainties around 60 to 100 kilometers (Figures 2-5 and 2-6).

The overall aleatory variability model that was applied to all GMMs gave 20% and 80% weights respectively to the NGA-East recommended model “2018 Updated EPRI” and an alternate model developed by a “2018 Working Group” to include CEUS site-to-site variability terms (Figure 2-7). More research is required to gain more confidence in the “2018 Working Group” model and consider its weight in future updates.

A CEUS-specific site effect model was implemented for the first time in the 2018 NSHM, a significant improvement over previous NSHMs. Figure 2-8 shows the magnitude-distance dependence of the overall implemented model in solid lines. However, more research remains to improve this model, and the appropriateness of current site parameters (i.e., top-30-meter shear wave velocity, V_{s30}, and the basin depth parameters, Z_1, $Z_{2.5}$) for CEUS should be investigated. The current site effect model should be modified for specific regions in the CEUS such as the Gulf and Atlantic coastal plains or within CEUS basins such as the eastern Great Lakes. Some ongoing recent research is available (Boyd et al., 2020), but not yet implemented in practice. However, it is being considered for implementation in a logic tree of the 2023 NSHM update (Petersen et al., expected 2023).

USGS NSHMs only consider shaking hazards from earthquakes. There are other kinds of hazard such as liquefaction and lateral spreading that present potential risks from earthquakes in the CEUS. These geohazards have not been studied in detail in the CEUS national context. Some work has been done in local urban hazard mapping efforts, and efforts are underway to apply a national crustal model (Boyd et al., 2020) to perform a national assessment of site response and liquefaction hazard.

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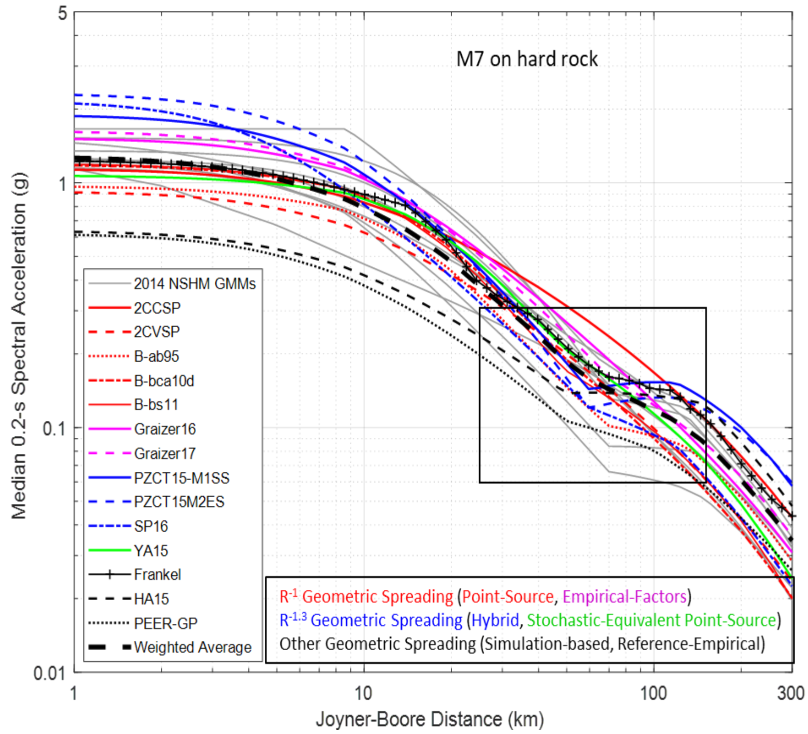

Figure 2-5 The fourteen updated seed GMMs in the CEUS in 2018 NSHM compared to the nine 2014 NSHM GMMs (Rezaeian et al., 2021). The irregularity in the box is discussed in Rezaeian et al. (2021).

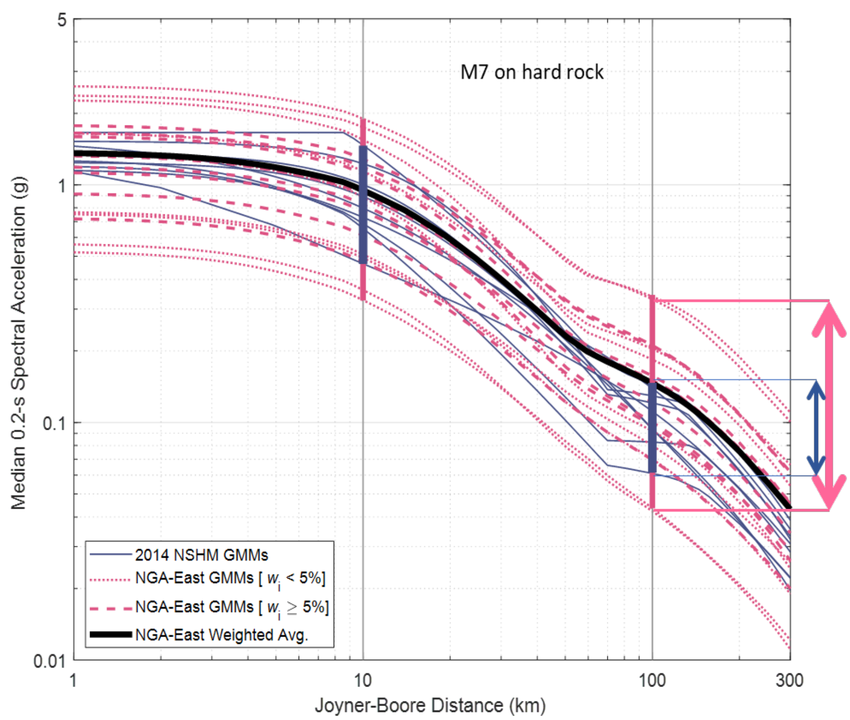

Figure 2-6 The seventeen NGA-East GMMs in the CEUS in 2018 NSHM compared to the nine 2014 NSHM GMMs. Epistemic uncertainty range is indicated by the arrows (Rezaeian et al., 2021). For more detailed discussion on uncertainty ranges see Rezaeian et al. (2021)

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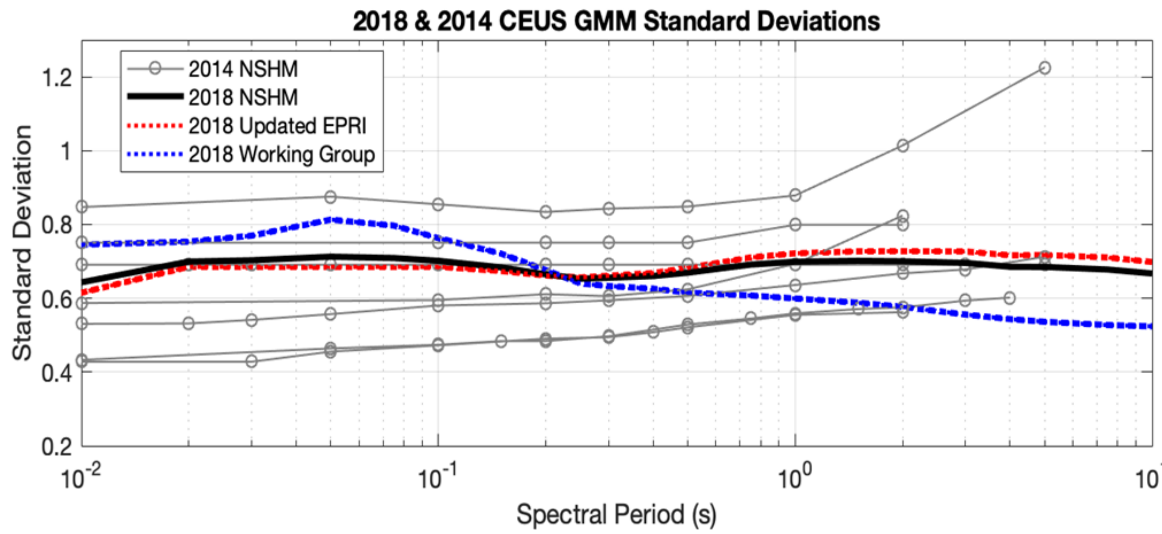

Figure 2-7 The aleatory variabilities from 2014 and 2018 NSHMs (Rezaeian et al., 2021).

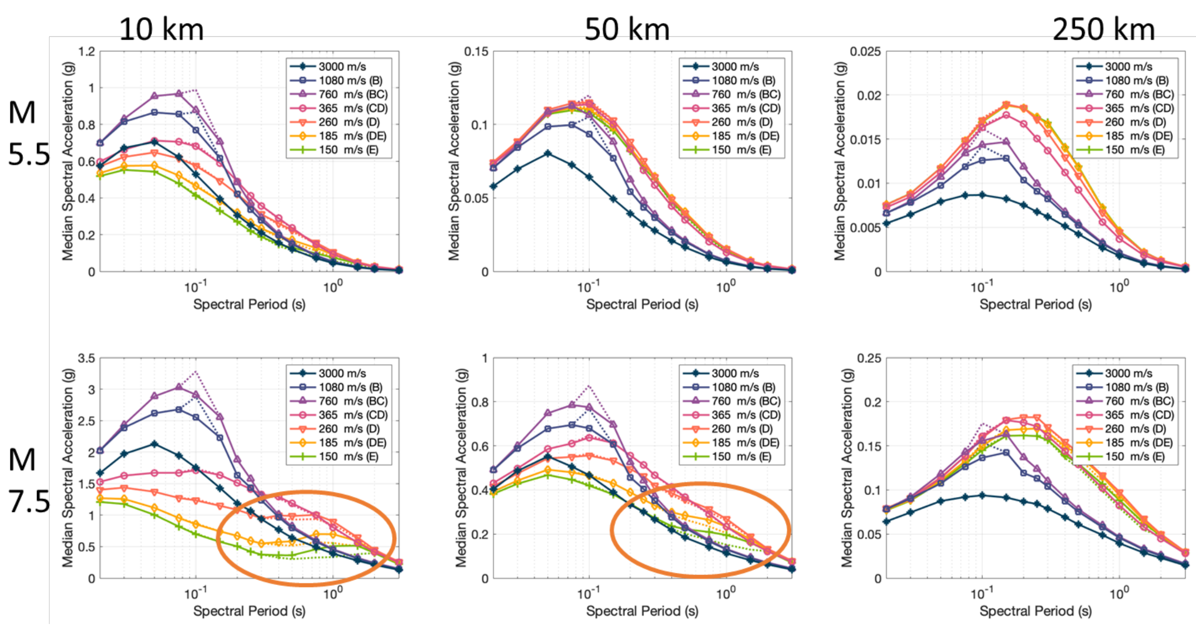

Figure 2-8 The site effect model used in the 2018 NSHM (Rezaeian et al., 2021).

2.1.3 *Design Ground Motions*

Seismic design methodologies are strongly influenced by empiricism, and nearly all the modern U.S. experience is from earthquakes in the WUS. Ground motions for the design of new buildings per ASCE/SEI 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE, 2022), and the *International Building Code* (IBC) (ICC, 2020a) are calculated by integrating the hazard curves with structural fragility functions to achieve a certain risk level for collapse. Therefore, the shape of the hazard curve is important in computing the level of ground motion used for design. Figure 2-9 shows hazard curves for several locations in the CEUS and one for downtown San Francisco. Notice the difference in shape; at low probabilities of exceedance, the motions in the high hazard portions of the

CEUS could exceed those for San Francisco; yet at higher probabilities (i.e., lower mean recurrence intervals), the motions in those same locations are far less than the corresponding motions in San Francisco. The target reliability for buildings with ordinary occupancies has been defined based on experience at WUS sites. The target is substantially higher (i.e., less safe) than that for other loads important in structural design, such as wind. Particularly for lower hazard areas and for dense cities, this concept of a higher target risk for seismic safety deserves further study. The risk-targeted ground motion in the very high hazard portions of the New Madrid region is deterministically capped, again based on the philosophy developed for WUS sites, although the amount of area affected by deterministic capping is less in the CEUS than the WUS. Alternative approaches to deterministically capping have been explored (Stewart et al., 2020; Luco et al., 2017), but not yet implemented in practice.

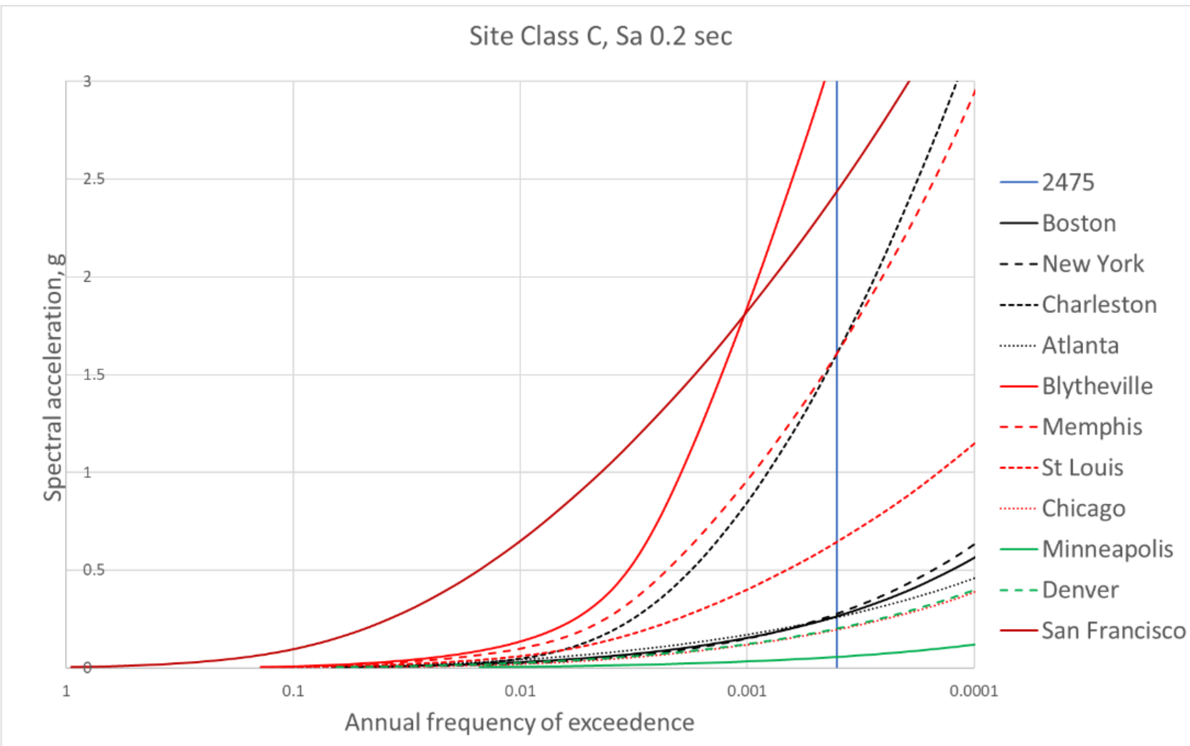

Figure 2-9 Hazard curves for CEUS sites compared with San Francisco.

2.1.4 Design Spectra Shapes

Multi-period response spectra (MPRS), the newest procedure in ASCE/SEI 7 for characterizing ground motions for design, makes use of an acceleration response spectrum specified at 22 periods of vibration, which provides a spectrum capable of more accurately representing geological site conditions. However, the two-parameter spectrum based upon response acceleration at two periods of vibration (0.2 s and 1.0 s) is still the basis for many important design provisions. Figure 2-10 shows that the typical CEUS spectrum exceeds the design value for the short period portion of the spectrum by a substantial amount. A decision to ignore those high values at very short periods for the purpose of building design by the widely used Equivalent Lateral (static) Force method was made about 25 years ago, based upon engineering judgment, and is deserving of more detailed study.

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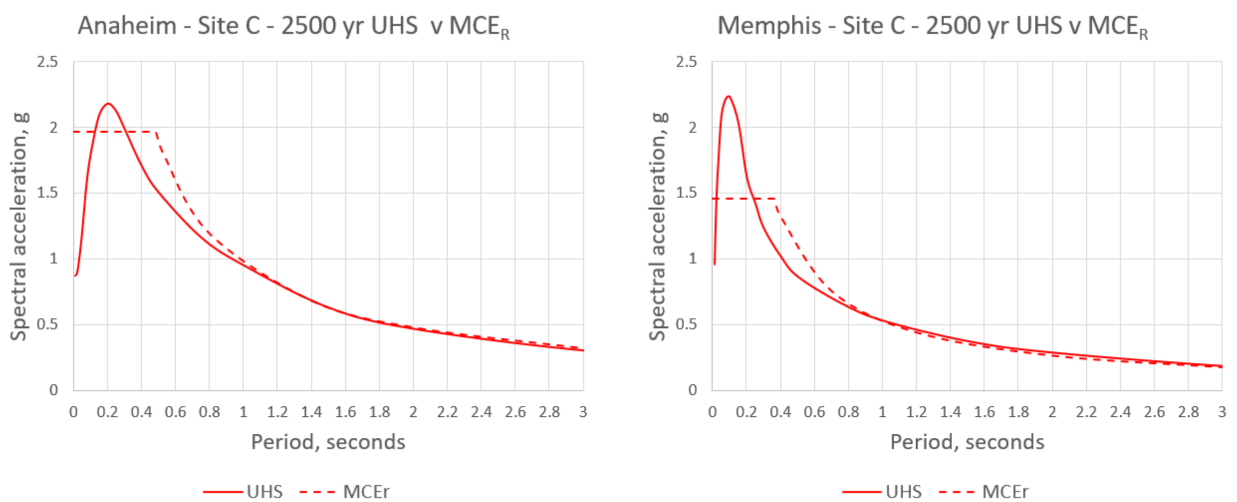

Figure 2-10 Comparison of spectral shape between a site in the WUS (Anaheim) and a site in the CEUS (Memphis). For these sites, the 2500 year mean recurrence interval uniform hazard spectra (UHS) is close to the MCE$_R$ multi-period spectra.

Other parameters of design spectrum development that need to be made CEUS-specific are maximum direction factors and the long period parameter, T_L.

2.2 Building Code Provisions

Most U.S. standards, codes, and guidelines currently used in seismic practice were developed in the context of hazard and building characteristics typical of the WUS. In the CEUS, adoption, enforcement, and implementation of seismic code provisions were considered a low priority, primarily due to less frequent seismic activity.

2.2.1 History of Development

The Uniform Building Code (UBC) was the earliest model building code in the United States to clearly codify seismic design and detailing requirements for use by engineers and planners. Voluntary seismic provisions were introduced in the 1927 UBC, refined and improved over time, and in later editions made mandatory. These early seismic design requirements were developed by WUS engineers. The seismic provisions of the UBC were adopted primarily by jurisdictions in the WUS. Beginning in 1959, the Structural Engineers Association of California published “Recommended Lateral Force Requirements.” That document was updated regularly and became the basis for the seismic requirements in subsequent editions of the UBC.

Advancement of UBC seismic provisions was driven by actual building failure mechanisms observed during earthquakes in the WUS and around the world. In the CEUS, the historically predominant model building codes were the Standard Building Code (SBC) and the Building Officials and Code Administration (BOCA) Basic Building Code. The SBC and BOCA did eventually include seismic provisions, but for many years those model codes contained escape clauses. Few jurisdictions utilizing those model codes required any seismic provisions in design or construction. For example, up until the 1987 BOCA and SBC codes, provisions in those codes provided an exemption from the consideration of

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earthquake loads "…where local experience or the records of the USGS do not show loss of life or damage or property, regardless of zone" (BOCA, 1984; SBCCI, 1984). Given the limited population in the New Madrid and Charleston regions during the time of the large seismic events, this was an easy out for many designers. Because earthquakes were less likely to happen in the CEUS, there was little justification to support extensive and sometimes costly seismic code requirements and less incentive for engineers to push for their development and implementation.

Underpinned by NEHRP and using the UBC as the vehicle of implementation, stakeholders in the WUS delved into the underlying cause and magnitude of expected seismic hazards and began to develop the means to accommodate the resulting ground motion with design provisions focused on minimizing loss of life and protecting the public health and welfare. In the early 1990s, NEHRP-supported seismic provisions were adopted by the SBC and BOCA, as well as the general structural loading standard ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures.*

With the merger of the regional building codes (UBC, SBC, BOCA) into the International Code Council (ICC), the ICC set of national model building codes ("I-Codes") have become the basis for the overwhelming majority of state and local building codes (ICC, 2020a; 2020b, 2020c). The I-Codes are developed on a national level rather than a regional or local level. The seismic events, consequences, and community needs in the WUS tend to dominate the I-Code seismic design provisions.

2.2.2 Adoption, Implementation, and Enforcement

As seismic design provisions continue to advance in the I-Codes and associated standards, the CEUS lags behind the WUS with respect to adoption, implementation, and enforcement of specific code versions and the respective seismic provisions. In some CEUS jurisdictions, I-Code seismic design provisions are consciously and deliberately reduced through local amendments. Some jurisdictions in the CEUS still question if seismic design should be required at all. The resulting discrepancies between the performance objectives behind the current provisions and the likely performance of the building stock during a seismic event in the CEUS will have real life consequences to the building occupants, owners, and impacted communities.

A frequently cited impediment to adoption is the 3-year code publication cycle that can be at odds with the jurisdictional adoption process timelines. Jurisdictional structures vary between states and between state and local municipalities and include hybrid variations of exempt jurisdictions under state level umbrellas. The adoption processes may require interaction between state, county, and local levels, resulting in adoption timelines of approximately 3 years from start to finish. This may cause the adopted code to come into effect at approximately the same time a new national model building code is published. Specific local environmental, societal, and economic concerns add to the practical timing and technical issues to further stymie broad efforts to facilitate uniform code adoptions within the CEUS.

Adopted building code versions and local amendments vary widely between CEUS jurisdictions. In some locations, jurisdictions may not explicitly adopt a code and it is left up to the engineer to select an appropriate version. In other locations, jurisdictions may adopt a commercial code only, without including a residential code.

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CEUS adoption of residential building codes varies significantly because of local amendments and some exempt jurisdictional structures that do not require residential code compliance. In particular, seismic provisions for small residential structures are frequently reduced or eliminated altogether, justified by the argument that the increased cost is not warranted due to the low probability of a damaging earthquake occurring or that the seismic provisions in the International Residential Code (IRC), which addresses one- and two-family dwellings and low-rise multi-unit dwellings, are overly conservative and will impede development. Although only a subset of the overall code adoption discussion, the voices of the residential development community influence both residential and commercial adoptions. Some of the objections raised at local and state levels deserve focused consideration to address the issues raised with residential codes. Such focused consideration will have the added benefit of differentiating between residential and commercial code provisions. This differentiation is critical in CEUS code adoption discussions to separate commercial and residential codes, because commercial codes are sometimes rejected due to concern by some groups over the residential provisions.

The seismic provisions of IRC have been modified each cycle without a comprehensive analysis and review of the collective impact of the provisions. The wind and seismic wall bracing provisions of the IRC were last systematically reviewed and updated in the 2009 edition, with the update effort led by the ICC Ad Hoc Wall Bracing Committee. Collectively there may be room for updating and streamlining the seismic provisions for small residential buildings and thus reducing cost impact to new housing projects.

Among the challenges to ensuring proper and uniform enforcement of building code provisions in the CEUS are building department staff qualifications, review processes, and available resources and enforcement tools. CEUS code officials and staff do not all have Professional Engineer (PE) licenses. Of the licensed PEs on staff, only a small percentage are structural engineers and/or well versed in seismic provisions. This results in uneven enforcement between jurisdictions, which generates resistance to new seismic provisions that change the status quo or add perceived cost to a structure. Code officials that have an in-depth understanding of the intent and function of seismic provisions tend to be more stringent in document reviews and construction enforcement. Where code officials have a less in-depth understanding, document reviews tend to be less stringent and rely heavily upon a presumption of knowledge held by the Engineer of Record (EOR); construction enforcement tends to be limited to easily observable requirements clearly detailed in the construction drawings, with less scrutiny of embedded requirements and compliance items that are listed in construction drawing notes or specifications.

Peer reviews are occasionally required in a few larger metropolitan CEUS jurisdictions for specific building types (e.g., hospitals). However, smaller CEUS jurisdictions rarely impose peer review or similar requirements that would engage a review of the design by an independent qualified engineer. The result is that code officials and their staff provide the only review of construction drawings prior to approval for construction outside of the original design firm.

Across the nation, code enforcement resources are stretched thin and routinely directed to the most immediate needs. Many CEUS jurisdictions have deemed seismic design requirements as a low priority relative to other hazards, thus limiting the resources allocated for seismic design and enforcement. Outside support and incentives from state and/or federal programs have supported local code enforcement departments in compliance with flood provisions and could be similarly beneficial in encouraging compliance with current seismic provisions.

Nonstructural seismic anchorage falls within a grey area of responsibility, and code enforcement frequently lacks clear information from the construction documents on the requirements. In the CEUS, structural engineers may consider this anchorage to be within the scope of the appropriate discipline engineer (i.e., mechanical, electrical, plumbing, or fire), whereas some of those engineers consider the anchorage within the scope of structural engineers. (Fire protection engineers typically incorporate this anchorage for their systems within their design scope.) This results in nebulous requirements that may not be understood, cannot be enforced, or are simply overlooked by enforcement jurisdictions.

The wide variations in jurisdictional organizations, presence of multiple jurisdictions, and lack of knowledge on how each jurisdiction works impedes a coordinated effort to educate, train, and update official and practitioners in the CEUS to the latest available national model building code versions.

2.2.3 Existing Building Stock

The ongoing challenges in the CEUS with adoption, enforcement, and implementation of seismic code provisions for existing buildings are even greater than for new buildings. Many older buildings in the CEUS were designed without consideration for earthquake forces. The collective existing building stock of the CEUS will, for an indeterminate timeframe, remain at a higher level of seismic risk than is expected from compliance with current national model building code seismic provisions.

CEUS jurisdictions collectively are tasked with making use of current seismic provisions to reduce this higher level of building stock vulnerability through new code-compliant construction and modifications to existing construction. The need for simplified approaches for evaluating and rehabilitating seismic hazards in existing buildings is even greater in the CEUS than the WUS. Further, existing CEUS buildings present issues that are different in scope or ubiquity than in existing buildings in WUS practice. As a result, there is insufficient guidance incorporated in current relevant standards, such as ASCE/SEI 41, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2017), and guidelines for some typical existing CEUS building types and characteristics.

2.3 Lifeline Infrastructure

Lifeline infrastructure is systems that are critical to the functioning of a modern society, such as water, wastewater distribution and treatment, storm and sewer drainage, communication, electric power, natural gas and liquid fuels, transportation, and solid waste collection and storage systems (Duke and Moran, 1975). Communities are unable to recover after an earthquake until these systems can operate at a level to provide their basic services. As a result, it is important for lifeline infrastructure systems to be designed, constructed, operated, and maintained in a manner such that they will recover to provide the critically needed services to users in a rational and reliable manner after a seismic event. Lifeline infrastructure systems are often designed, constructed, and maintained by a privately-owned business; in some sectors a system may be regulated by a government entity. In other cases, a government entity governs all aspects of a system. The extent of regulatory authority varies between sectors and jurisdictions, as well as the

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type of regulation provided (e.g., protecting consumers vs. economic regulation). Development of design and construction standards and their enforcement can also vary.

There are conditions unique to the CEUS pertaining to the design and construction of lifeline infrastructure systems for earthquakes. These conditions include low awareness of the seismic risks, methods and policies for design and construction, differences between perceptions of expected seismic performance and how they may actually perform, and competing priorities for funding to address many other hazards the CEUS is exposed to (e.g., floods, tornadoes, hurricanes, severe storms).

2.3.1 History of Research

Over the past 50 years, there has been intermittent attention to the advancement of design and construction of U.S. lifeline infrastructure systems to improve ability to withstand the effects of and recover services after an earthquake or other natural hazard event (NIST, 2014; 2016). The extensive damage to engineered transportation, electric power, water, and other lifeline systems and components caused by the M6.6 San Fernando Earthquake in 1971 gave rise to the field of lifeline earthquake engineering and inspired engineering professionals to raise the standards of lifeline infrastructure system performance in earthquakes across the United States.

Established in 1977 following the 1971 San Fernando Earthquake, NEHRP set the stage for subsequent creation of key institutions, including a national earthquake engineering research center to help move forward the field of lifeline earthquake engineering. In 1985, the Federal Emergency Management Agency (FEMA) commissioned the Building Seismic Safety Council (BSSC) of the National Institute of Building Sciences (NIBS) to develop a plan for abating seismic hazards to lifeline infrastructure systems, and concluded that abating the risk to lifeline infrastructure systems from earthquakes and other hazards could be best approached by a nationally coordinated and structured program. The NEHRP Re-authorization Act of 1990 required FEMA (with support of NIST) to establish a detailed plan for developing and adopting seismic design standards for lifeline infrastructure systems. Leveraging the knowledge and practice of lifeline earthquake engineering developed over the two decades after the San Fernando Earthquake, FEMA and NIST developed the plan, focusing on improving system-level functionality of lifeline infrastructure systems. Following some of the recommendations in the plan, FEMA funded the American Lifelines Alliance (ALA) in 1998, a public-private partnership first managed by ASCE (1998 to 2001) and later by the Multi-hazard Mitigation Council of NIBS (2002 to 2005), to facilitate development, adoption, and implementation of design and retrofit guidelines to improve the performance of lifeline infrastructure systems in the event of natural hazards. Following the terrorist attacks on September 11, 2001, the scope of ALA was expanded to included man-made threats. ALA successfully created more than a dozen design and/or assessment guidelines related to electric power, oil, natural gas, water, and wastewater systems before it dissolved in 2005, due to shifts in hazard priorities and funding cuts in the NEHRP budget.

In 2008, the San Francisco Planning and Urban Research Association (SPUR) started a multi-year initiative called *The Resilient City* (SPUR, 2009) to ensure that San Francisco will be able to recover rapidly following earthquakes to meet social and economic needs of community members. From 2010 to

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2012, the State of Oregon and the State of Washington used the methodology of *The Resilient City* to develop state-wide 50-year resilience plans to prepare for a future Cascadia Subduction Zone earthquake and tsunami. During the same period, NEHRP agencies, the National Research Council, and Presidential Policy Directive 21 called for improvement of buildings and lifeline infrastructure systems to achieve community resilience. In 2012, NIST started to develop a 10-year research, development, and implementation roadmap for producing new model earthquake-resilient design and construction standards for key lifeline infrastructure systems and components (NIST, 2014). In 2013, NIST took a multi-hazard approach to develop a community resilience planning guide for buildings and infrastructure systems (NIST, 2015) so that communities across the nation can effectively prepare for, respond to, and recover from natural, technological, and human-caused hazards. In 2018, Congress reauthorized NEHRP, with new emphasis on functional recovery of the built environment to support community resilience. As part of the reauthorization, FEMA and NIST jointly convened a Committee of Experts to develop options to improve the built environment for post-earthquake functional recovery times and in 2021 submitted to Congress the FEMA P-2090/NIST SP-1254 report, *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time* (FEMA-NIST, 2021).

2.3.2 Past Research and Practice Needs Reports

Three existing reports that identify lifeline infrastructure systems research and practice needs, which had already been completed before the start of this project, served as an ideal starting point for establishing research and practice needs in the CEUS:

- NIST GCR 14-917-33, *Earthquake-Resilient Lifelines: NEHRP Research, Development, and Implementation Roadmap* (2014)
- NIST GCR 16-917-39, *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery* (2016)
- FEMA P-2090/NIST SP-1254, *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time* (2021)

These three reports (Figure 2-11) served as the basis of identification of issues and recommended projects in the lifeline infrastructure topic area and are described in more detail in Section 5.1.

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Figure 2-11 Covers of three reports that describe research and practice needs for lifeline infrastructure in the United States.

2.3.3 Past CEUS Studies

There have been limited seismic studies of lifeline infrastructure systems in the CEUS. In 1988, FEMA funded ATC to complete a macroscopic investigation of seismic vulnerability and impact of disruption of lifeline infrastructure systems at the national level to develop a better understanding of the impact of disruption of lifeline infrastructure systems from earthquakes and assist in the identification and prioritization of hazard mitigation measures and policies (FEMA, 1991). As part of this study, scenario events were identified for three regions in the CEUS: M7.0 Cape Ann Earthquake for the Northeastern Region, M7.5 Charleston Earthquake for Southeastern Region, and M7.0 and M8.0 New Madrid Earthquakes for the Central Region. Based on seismic vulnerability of selected lifeline infrastructure systems (electric power, water, gas and oil pipelines, highways and bridges, airports, railroads, and emergency service facilities), direct damage and indirect economic losses were estimated. As the CEUS did not have a significant history of lifeline infrastructure system seismic design for major earthquakes, their seismic economic impact as summarized in the report was enormous. Between the late 1980s and early 1990s, the National Center for Earthquake Engineering Research (NCEER) carried out many projects to examine seismic performance and associated impact of energy distribution systems (oil and natural gas), transportation system, and water supply systems in the CEUS. Key findings were summarized in *Lifeline Earthquake Engineering in the Central and Eastern U.S.* (ASCE, 1992). In 2007, FEMA funded the Mid-America Earthquake Center to complete a multi-phased study to understand the impact of earthquakes on the eight-state region around the New Madrid Seismic Zone in the Central United States (Elnashai et al., 2008). This study considered a total of ten scenarios associated with three seismic zones: the New Madrid Seismic Zone, the Wabash Valley Seismic Zone, and the East Tennessee Seismic Zone. It leveraged the best available inventory of essential facilities and critical lifeline infrastructure systems (including multi-modal transportation system, electric power facilities, oil and natural gas, communication, water treatment facilities, and dams and levees) to estimate direct damage and social and economic impact on the Central United States. The study found that earthquake impact on the CEUS would likely be catastrophic, especially after a major earthquake on the New Madrid fault. Damage to major natural gas and oil transmission lines would lead to service disruption as far away as New England.

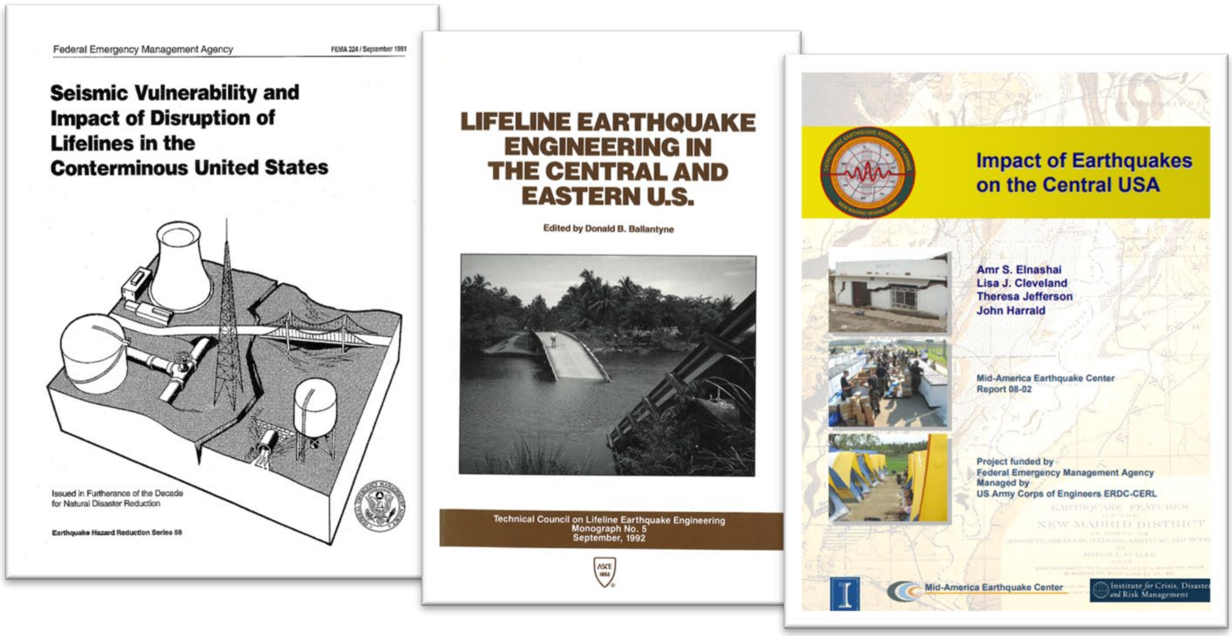

Figure 2-12 Covers of three reports that present studies about seismic performance of lifeline infrastructure systems in the CEUS.

2.4 Future Direction of Seismic Design

National model building codes, specifically seismic provisions, have historically been focused on minimizing loss of life and life-threatening injuries, and protecting the public health and welfare. Colloquially referred to as "life-safety provisions," the basic aim of this philosophy is to allow the building to remain standing and substantially intact during the earthquake and for long enough to allow the occupants to evacuate. It has long been understood among the design community that buildings designed to these life-safety provisions may sustain significant damage and even require demolition after a design-level earthquake. Similarly, the development of guidelines and standards for the design of lifeline infrastructure system components has also historically focused on life safety, but without regard to impacts to customers from the loss of services at the system level. This limited focus can result in the components protecting life and property but can also result in those components not being usable after an earthquake, and even the loss of services from an entire lifeline infrastructure service after an earthquake.

In addition to showing the importance of safety performance of our existing built environment, recent events such as the 2018 Alaska Earthquake (Hassan et al., 2021), the 2019-2020 Puerto Rico Earthquake sequence (Wall, 2023), and the 2019 Ridgecrest Earthquake (EERI, 2020) have demonstrated substantial direct and indirect economic losses and displaced peoples. These events have highlighted the need for communities to consider what parts of the built environment should be designed for enhanced

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performance that goes beyond life-safety target levels. The resources and funding required in clean-up, recovery, and reconstruction after these events are massive and may not be economically or socially sustainable. Improved planning, design, construction, and management practices are being studied to mitigate such losses. Following hazard events, the general populace looks to the authorities to ensure they can survive the immediate aftermath, which requires shelter, water, and food at a minimum. Subsequently, the general populace looks to professional design and construction communities to fully restore the infrastructure to the more comfortable and operational state that is expected for everyday use. For a community to recover, it is becoming more necessary for building codes to provide provisions and lifeline infrastructure system design standards to consider the time period between the event and full recovery to minimize long-term consequences to communities and society.

Functional recovery and resilience are terms coined to describe "beyond life-safety" goals. These definitions describe the terms as they are used in this report:

- **Functional recovery**: "a post-earthquake performance state in which a building or lifeline infrastructure system is maintained, or restored, to safely and adequately support the basic intended functions associated with the pre-earthquake use or occupancy of a building, or the pre-earthquake service level of a lifeline infrastructure system" (FEMA-NIST, 2021).
- **Resilience:** The capability of an organization or community to withstand, respond to, and recover from an earthquake in order to return its livelihood to a measure of its pre-earthquake state in a timely, nondisruptive manner, while also minimizing the consequences of a future hazard event.

While the concepts are generally agreed upon, specific definitions are highly variable and dependent upon the individual or organization using these terms. This variability in expectations increases the level of complexity that code and standards development committees face as they attempt to define and write specific code provisions to achieve these enhanced performance goals.

A few jurisdictions in the WUS are beginning to address the functional recovery design concept. As WUS engineers and jurisdictions take leadership roles in developing functional recovery-based seismic provisions, CEUS engineers and jurisdictions have not been as involved. If the CEUS does not become more involved, future provisions may not be reflective of the needs of the nation as a whole or applicable across all jurisdictions.

Given that CEUS implementation of current life-safety seismic design provisions has lagged the WUS by many years, a similar lag may also occur with functional recovery provisions. Unlike life-safety code provisions that can be easily isolated to specific buildings or structures, true functional recovery of a community is dependent on the performance of lifeline infrastructure elements, which may extend beyond jurisdictional boundaries. The functional recovery of a lifeline infrastructure system is dependent upon the return of basic services to all customers. As such, any lag in the CEUS implementation will have a direct and immediate impact on operations in the WUS due to the interdependencies between regions (e.g., disruption of distribution systems or supplies).

Current initiatives to control damage to provide functional recovery of individual facilities or improved community resilience are new concepts in the CEUS. The nature of the hazard curves and the built environment in the CEUS are both different from the WUS. Introduction of the new concepts to the CEUS will require careful study and planning. As national model building codes and design standards begin to look beyond life-safety goals toward functional recovery and community resilience, the regional lag between the CEUS and the WUS in adoption, implementation, and enforcement of the most current seismic code provisions and design standards will become even more impactful in the event of strong earthquakes.

In this report, the consideration of seismic risk goes beyond total or partial collapse of a building and loss of life or life-threatening injuries to building occupants or the public-at-large. This report looks ahead to the future of seismic design to consider interruption of building function or agency mission, either short- or long-term, and direct economic losses from damage to the building and/or its contents and indirect losses by absence of provided services.

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Chapter 3

Topic Area: Hazard Characteristics and Design Philosophies

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This chapter provides an overview of current seismic practice issues in the CEUS within the topic area of *Hazard Characteristics and Design Philosophies*. Issues addressed include seismic hazard curves (i.e., probabilities of exceeding certain levels of ground motions); design ground motions for safety and enhanced performance objectives; and considerations related to geology, geotechnical conditions, and climate. For each issue within the topic area, research, and practice-related projects to address the needs are provided. General background information relevant to this topic area is provided in Chapter 2.

Each section in this chapter provides an overview of one issue. The recommended projects to address that issue are provided in the same section. Table 3-1 lists the issues covered in this chapter. Table 6-3 lists all issues and recommended projects covered in this chapter and includes the priority level of each project.

The motivation for addressing issues in this topic area includes better characterization of CEUS seismic hazards and better recognition of these characteristics in the development of improved design philosophies and provisions for the CEUS.

Table 3-1 Issues Covered in Chapter 3

Section	Title
3.1	Insufficient Accuracy of Hazard Modelling
3.2	Design Motions for Seismic Safety Based on WUS Hazard
3.3	Insufficient Understanding of Site Characteristics
3.4	Sensitivity of Seismic Design Category Thresholds
3.5	Insufficient Understanding of Geohazard and Multi-Hazard Considerations
3.6	Need for CEUS Involvement in Development of Resilience and Functional Recovery-based Provisions

3.1 Insufficient Accuracy of Hazard Modelling

Less information is known about seismic hazards in the CEUS compared to the WUS because earthquakes are less frequent and fewer events rupture the surface than in the WUS. The uncertainty about faults, area sources, historical seismicity, and ground motions in the CEUS impact the accuracy of seismic hazard modelling for the CEUS. Other areas requiring attention include induced seismicity, the long-period transition period, T_L, maximum direction ground motion models, and uncertainty approximation.

To address this issue, hazard models for the CEUS should be improved by including induced seismicity (***Project 3.1-A***), improving seismic source models (***Project 3.1-B***), improving ground motion models (GMMs) (***Project 3.1-C***), developing CEUS-specific maximum direction factors (***Project 3.1-D***) and long-period transition period (***Project 3.1-E***), and improving hazard uncertainty approximations (***Project 3.1-F***).

The envisioned impact of addressing this issue is that there will be a more accurate representation of the seismic hazard in the CEUS and more effective application of the regional hazard in seismic design and construction practices, leading to reduced seismic risk and increased resilience.

Project 3.1-A	**Include Induced Seismicity in Long-Term Hazard Models**
Description	Include induced seismicity in hazard models. Determine how to address induced seismicity in practice.
Priority level	IMPORTANT (1.7)
Key steps	1. Investigate inclusion of induced earthquakes in short-term and long-term hazard models. Determine if induced and long-term maps should be combined or used separately by engineering practitioners. 2. Perform outreach with jurisdictions affected by induced seismicity and other user bases, including insurance industries. 3. Increase awareness of induced seismicity and disseminate relevant products and procedures. Study what special wind regions have done in the past (region-specific seismic maps) on how to do outreach and dissemination.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 3.1-B	**Improve Seismic Source Modeling**
Description	More accurately characterize seismic hazard by improving CEUS seismic sources to address unknowns about faults, area sources and background seismicity. These efforts should be encouraged and implementation of new findings in the USGS National Seismic Hazard Models (NSHM) must be supported through future research.
Priority level	CRITICAL (2.5)
Key steps	1. Coordinate with NRC (Nuclear Regulatory Commission) and Electric Power Research Institute (EPRI) and other agencies/organizations that have developed previous seismic source models in the CEUS to determine the shortcomings of such models. 2. Improve source characterization of historic large magnitude earthquakes. 3. Improve representation of background seismicity, de-clustering of the earthquake catalog, and smoothing algorithms. 4. Implement findings the USGS NSHMs.
Roles	Government; University/Research Organizations
Estimated time	4 to 5 years

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Project 3.1-C	**Improve Ground Motion Models**
Description	Improve CEUS GMMs and logic tree weights for incorporation into the USGS NSHMs. Perform validation studies and updates, incorporation of aleatory variability, and improvement of site effects.
Priority level	CRITICAL (2.5)
Key steps	1. Validate the current NGA-East models used by the USGS and NRC in hazard modeling. Investigate the necessity of additional Seed GMMs as described by the USGS due to the shortcomings of the NGA-East models. 2. Investigate inclusion of new GMMs by independent researchers/modelers since NGA-East was developed and quantify the sensitivity of the final hazard values to the addition of these GMMs. 3. Support studies on the quantification of epistemic uncertainty. (The current USGS approach of assigning logic tree weights is subjective; more systematic approaches should be explored but need additional research.) 4. Develop NGA-East2 non-Senior Seismic Hazard Analysis Committee (SSHAC) GMMs. (The SSHAC process of NGA-East caused some restrictions including the site-effects model being developed separately from the GMMs). 5. Develop CEUS-specific site effect models simultaneously.
Roles	Government; University/Research Organizations
Estimated time	1 to 3 years

Project 3.1-D	**Develop and Implement Maximum Direction Factors**
Description	Develop and implement CEUS-specific maximum direction factors for use in developing CEUS ground motions for design. Some models have been developed but are not yet implemented in building codes, which still use WUS-specific max direction factors.
Priority level	IMPORTANT (1.9)
Key steps	1. Implement the existing CEUS-specific models in hazard calculations. 2. Engage with codes and standards organizations to update policy and guidelines on max direction factors for the CEUS. 3. Investigate the appropriateness of RotD100 for various structure types common to the CEUS but not the WUS. 4. Encourage development of more max direction models that are specific to CEUS for epistemic uncertainty and if more data becomes available.
Roles	Government; Code/Standard Organizations; University/Research Organizations
Estimated time	Less than 1 year

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Project 3.1-E	Update the Long-Period Transition Period T_L and Displacement Spectrum
Description	Update the long-period transition period, T_L, for CEUS and replace the outdated T_L maps in building codes. This parameter will be important in investigating the relations between the displacement spectrum and the new Multi-Period Response Spectra (MPRS) concept.
Priority level	IMPORTANT (1.9)
Key steps	1. Update the T_L maps in building codes. 2. Investigate development of displacement spectrum and relations with MPRS.
Roles	University/Research Organizations; Government; Code/Standard Organizations
Estimated time	Less than 1 year

Project 3.1-F	Improve Hazard Uncertainty Estimation
Description	Investigate the appropriateness of mean hazard and whether other percentiles of hazard should be considered in practice. Uncertainty approximation is critical in the CEUS given the many unknowns that exist in the estimation of hazard. The effects of uncertainties in source models and ground motion models on the mean hazard estimate may be small, but they become significant if hazard uncertainty is considered by code officials.
Priority level	IMPORTANT (1.8)
Key steps	1. Investigate the appropriateness of mean hazard and the effects of uncertainty on the full distribution of hazard. 2. Reach out to code officials to consider other percentiles of hazard in addition to the mean.
Roles	University/Research Organizations; Government; Code/Standard Organizations
Estimated time	4 to 5 years

3.2 Design Motions for Seismic Safety Based on WUS Hazard

The nominal level of safety level set as a target by codes across the nation for seismic hazards is fundamentally based upon experience in high seismicity regions of the WUS. When compared with safety levels for wind and other environmental hazards, the stated reliability targets are much lower for seismic than for wind. In large measure this discrepancy exists because the cost of equivalent performance becomes unbearable in areas with very high seismic hazards. There is some reason to believe that the public in such areas accepts the higher risk of collapse in earthquakes, in comparison to other structural risks. Many portions of the CEUS, especially many densely populated urban areas, have a relatively low seismic hazard, and the proposition that the public there would accept higher risk of unsafe performance from earthquake than from windstorm has not been validated. Recent research findings showing that designs satisfying current codes provide less reliability than the code target where the ground motions are very high might imply that designs by current codes perform better than the target where the ground motions are low. While many parts of the CEUS are resistant to increases in construction cost due to government regulation, there is also limited evidence that cost increases to design for moderate levels of seismic hazard are not large, and there may be reasons that cost increases for higher design requirements in low hazard areas will be minimal. A related issue is that the generic structural fragility relation used to develop the design ground motions is based upon structural systems common in the high hazard portions of the WUS, and there is a greater variety of low performance systems in the CEUS. Another related issue is the nature of the seismic hazard in the CEUS: the design requirements in current codes truncate the acceleration level for short period structures much more significantly than in the WUS.

To address this issue, research should be conducted to establish structural fragility relations appropriate for the range of construction and the range of ground motions found in the CEUS and to assess the effect differing fragility relations on ground motions for various risk levels (***Project 3.2-A***); applied research should be conducted to establish cost impacts for increasing the seismic resistance of various structural types at low hazard levels (***Project 3.2-B***); applied research should be conducted to determine the vulnerability of short period structures (***Project 3.2-C***); research should be conducted to quantify the effects of density of construction and population on the consequences of damage from strong ground shaking (***Project 3.2-D***); applied research should be conducted to develop reliability targeted ground motions for existing structures (***Project 3.2-D/E***), and applied research should be conducted to test methods of modifications to design codes to account for such effects.

The envisioned impact of addressing this issue is that seismic safety will be more closely aligned with structural safety from other natural hazards and with public expectations, along with a more rational expenditure of resources.

Project 3.2-A	**Examine Seismic Structural Fragility Relations**
Description	Examine the current generic fragility relation used in the development of the risk-targeted maximum considered earthquake (MCE_R) ground motions to see if they are appropriate for the types of construction commonly found in the CEUS and for the levels of ground motion found in the CEUS, especially in areas with low to moderate seismic hazards. Use the improved fragility relations to develop revised MCE_R ground motions for multiple risk levels for selected CEUS locations and compare with current ground motions in current codes.
Priority level	CRITICAL (2.5)
Key steps	1. Derive statistics for types of construction expected for the future in the CEUS. 2. Test a selection of such types for conformance to the generic fragility relation currently used for development of MCE_R ground motions, considering ground motion records considered typical for the CEUS. 3. Develop improved relations where so indicated. Use improved relations to develop revised MCE_R motions at several selected reliability targets, including reliability targets that vary with the amplitude of the predicted ground motion.
Roles	Government; University/Research Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

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Project 3.2-B	Perform Cost and Benefit Studies
Description	Develop a methodology to fairly examine costs and benefits of changes in seismic design levels; apply the methodology for a selected set of structural types in selected CEUS locations to illustrate the effects of potential changes in to align seismic risk levels in low and moderate hazard areas with risks presented by other hazards.
Priority level	CRITICAL (2.5)
Key steps	1. Convene a working group of stakeholders to define the scope of the methodology. (The NIST Applied Economics Office would be a likely candidate for development of a cost methodology. Benefit analysis methodology will require a broad oversight panel. Different stakeholders will have different opinions on how to weigh benefits.) 2. Focus on methods to solicit input, to vet, and to promote acceptance of the methodology. (Illustrative test applications will be essential for success.)
Roles	Government; University/Research Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

Project 3.2-C	Determine Vulnerability of Short Period Structures
Description	Determine vulnerability of short period (low rise and stiff) structures in CEUS, making use of ground motions with frequency contents expected in the CEUS. Uniform hazard response spectra for the CEUS typically have a different shape than those in the WUS. The design requirements truncate predicted high response accelerations at periods below 0.2 seconds. This truncation, which is much more significant for the CEUS than the WUS was made without a substantial analytical basis, and better tools for such analysis are available today. Recent research on short period structures in high hazard areas of the WUS demonstrated that improved nonlinear response analysis predicted results in line with empirical observations, but that study was based upon ground motion records from the FEMA P-695, *Quantification of Building Seismic Performance Factors* (FEMA, 2009), which are appropriate for the WUS, but do not capture the short period amplifications seen in the CEUS GMMs.
Priority level	CRITICAL (2.5)
Key steps	1. Develop representative set of ground motions to realistically represent expected CEUS ground motions that develop peak response accelerations at periods less than 0.2 seconds. 2. Develop representative set of building archetypes characteristic of very short period CEUS structures, including structural types thought to be relatively brittle and test using the FEMA P-695 methodology, but with the alternative ground motions developed in step 1 and for varying levels of ground motion. 3. Develop alternative designs based upon deformability (e.g., upgrade from ordinary to intermediate detailing) and develop criteria that will deliver desired and expected performance.
Roles	Government; University/Research Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

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Project 3.2-D	**Consider Density of Built Environment**
Description	Develop methods and models to predict performance with an emphasis on life safety of dense clusters of buildings and infrastructure and examine the costs and benefits of requiring differing levels of seismic performance depending on the density.
Priority level	IMPORTANT (2.0)
Key steps	1. Using current research on community resilience as a base, study the effects on life safety of potential cascading failures (emergency response and rescue as well as collapse prevention) of densely built clusters. Include representative essential facilities. 2. Study the effects, both cost and benefit, of raising the required resistance of such densely built clusters.
Roles	Government; University/Research Organizations; Professional/Trade Organizations.
Estimated time	1 to 3 years

Project 3.2-E	**Develop Reliability Targets for Existing Structures**
Description	Study the feasibility of developing reliability targeted ground motions for evaluation and rehabilitation of existing structures. This will require structural fragility relation appropriate for existing construction in the CEUS, and therefore is related to Project 3.2-A.
Priority level	IMPORTANT (2.4)
Key steps	1. Extend seismic structural fragility relations to capture typical existing structures in the CEUS, as well as commonly used rehabilitation techniques. 2. Study how seismic risk targets compare to other hazards in the CEUS. Make recommendations for revision based on the results. 3. Study different risk targets for different ground motions for existing buildings. For example, may protect against a moderate event, but use a lower threshold. 4. Determine risk targets directly relevant to existing buildings for representative sample of CEUS locations. 5. Study alternative reliability targets that vary with the level of seismic hazard.
Roles	Government; University/Research Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

3.3 Insufficient Understanding of Site Characteristics

Site characteristics in the CEUS are fundamentally different from the WUS and not well understood. CEUS-specific site amplifications have been implemented in the USGS hazard models, but the approach is relatively simple. There is room for improvement in research and implementation. USGS NSHMs only consider shaking hazards from earthquakes, but there are other kinds of hazard such as liquefaction and lateral spreading that present potential risks from earthquakes in the CEUS, for which there has been insufficient research to date. It remains to be determined if the current site parameters in building codes such as V_{s30} are appropriate for the CEUS and to develop more region-specific models in the CEUS.

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To address this issue, hazard models in the CEUS should be improved by updating the site-specific analysis parameters (***Project 3.3-A***) and developing guidelines for site-specific response analysis guidelines (***Project 3.3-B***).

The envisioned impact of addressing this issue is that a more accurate representation of hazard in the CEUS would provide a more effective application of the regional hazard in seismic design and construction practices.

Project 3.3-A	**Determine Site Response Analysis Parameters**
Description	Determine the site response analysis parameters for the CEUS and complexity of site response analysis in this region. V_{s30} has been the main parameter used for site response analysis in California and is effective in the WUS. The effects of V_{s30} on site response in CEUS are important, yet the V_{s30} parameter is less impactful in CEUS compared to WUS. Other factors have been proposed as affecting CEUS site response such as depth to a geologic contact (Boyd, 2020) and site frequency.
Priority level	IMPORTANT (2.2)
Key steps	1. Conduct research to evaluate depth effects on site response that are consistent with the way the V_{s30} effects were considered (non-reference site approach) so that the depth-effect models are compatible with GMMs. 2. Evaluate site frequency effects on site response. Develop models that can accommodate one or more of these parameters, including nonlinear effects. 3. Investigate the site-to-site uncertainty that accompanies site response modeling with different numbers of site parameters.
Roles	Government; University/ Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 3.3-B	**Develop Guidelines for Site-Specific Response Analysis**
Description	Develop guidelines for site-specific response analysis.
Priority level	IMPORTANT (2.3)
Key steps	1. Determine how engineers are doing the site response analysis in the CEUS when it is required (e.g., according to building code, performing site specific procedures) and when it is being done to achieve a lower seismic design category (SDC). 2. Develop site-specific guidelines specific to the CEUS to improve hazard and reach a relatively uniform level of safety in design of structures in the region.
Roles	Government; Code/Standard Organizations; Professional/trade Organizations; Industry
Estimated time	1 to 3 years

3.4 Sensitivity of Seismic Design Category Thresholds

Seismic Design Categories (SDC) and associated design rules are not well-tailored for a variety of hazards and risks in the CEUS because they were designed for the WUS. SDCs impose requirements that can affect both cost and performance for the structures and nonstructural elements. The dependence on

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site conditions means that there can be many SDCs in a single city. Changes in design hazards from one edition of national standards to another have resulted in the SDC for a given site changing repeatedly. The dependence on risk category in the lower hazard areas is inconsistent with high hazard areas. All these factors disproportionally affect the CEUS. The practice of soliciting opinions from geotechnical consultants about site classification with the objective of finding a lower SDC is more common in the CEUS than WUS because of the lower levels of seismicity.

To address this issue, research should be conducted to quantify performance and cost differences (***Project 3.4-A***), current thresholds should be reviewed (***Project 3.4-B***), and standardization efforts should be undertaken to make the seismic requirements rely more on scalable quantities and less on step functions (***Project 3.4-C***).

The envisioned impact of addressing this issue will be less resistance to adoption of the most current standards and codes, fewer instances of "shopping" for a geotechnical site evaluation that promises a lower SDC, and improvements in both performance and efficiency.

Project 3.4-A	**Assess Cost of Seismic Design Category Requirements in CEUS**
Description	Conduct an economic analysis to quantify real changes in the cost of design and construction of buildings and their nonstructural elements created by a shift in SDC without a change in the level of ground motion demand. The analysis should be broad enough to capture changes from SDC A to B, B to C, and C to D across a representative sample of cities in the CEUS. Note: the study could be broadened to include various types of lifeline structures.
Priority level	IMPORTANT (2.0)
Key steps	1. Convene a panel of engineers, construction cost experts, and economists to define the scope of locations, structure types, and site conditions to be included in the study. The scope must cover the significant step function requirements imposed because of SDC. 2. Compile cost data from real projects. 3. Prepare conceptual designs and cost estimates for selected prototypical structures and compare with Step 2. Reconcile any differences. Expand to cover the necessary categories of change (i.e., from SDC A to B, B to C, C to D for the defined occupancies, building and structure types, and CEUS regions). 4. Prepare economic summaries useful for defining the cost of SDC steps for various regions of the CEUS and for common building occupancies and structural types. 5. Disseminate the results.
Roles	Government; University/Research Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

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Project 3.4-B	Review Thresholds for Seismic Design Categories
Description	Conduct a study to compare and contrast how SDC is assigned for buildings, bridges, and other lifelines, to evaluate the manner in which site response effects are considered in that process.
Priority level	CRITICAL (2.6)
Key steps	1. Assemble a team to decide how many lifeline standards should be included. 2. Summarize and compare the categories used for general buildings (International Building Code), small residential buildings (International Residential Code), bridges (AASHTO, AREMA), water, sanitary, and storm water systems, electrical power systems, natural gas systems, raw and refined petroleum systems, and other lifeline systems as appropriate. 3. Summarize and compare the parameters used to define the category boundaries, including ground motions, site characteristics and effects, risk, or importance categories
Roles	University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	Less than 1 year

Project 3.4-C	Improve Seismic Design Categories
Description	Improve SDC to be better correlated with actual demand and performance and to reduce the stepwise features of the current standard.
Priority level	CRITICAL (2.5)
Key steps	1. Compile available empirical and controlled test data on performance of structures. Make use of FEMA P-58, *Development of Next Generation Performance-Based Seismic Design Procedures for New and Existing Buildings* (FEMA, 2018), to supplement, as necessary. Correlate with ground motion and site response parameters available in standard procedures for design. 2. Evaluate decoupling step functions inherent in existing application of SDCs to make each requirement dependent on the measure of demand best correlated to desired performance associated with that particular requirement. 3. Evaluate simplification by possibly reducing the number of SDCs. 4. Compile alternative recommendations, convene a workshop to vet.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	4 to 5 years

3.5 Insufficient Understanding of Geohazard and Multi-Hazard Considerations

There are environmental, geological, and multi-hazard considerations in CEUS that differ from the WUS. These considerations are not well understood and require study.

To address this issue, research should be conducted to better understand, within the CEUS context, the effect of environmental changes such as flooding, hurricanes, and climate change on earthquake hazard (***Project 3.5-A***), wave propagation demands on pipelines (***Project 3.5-B***), liquefaction characteristics (***Project 3.5-C***), and multi-hazard and compounding events (***Project 3.5-E***). A CEUS geophysical database should also be compiled (***Project 3.5-D***).

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The envisioned impact of addressing this issue is that a more accurate representation of hazard in the CEUS would provide a more effective application of the regional hazard in seismic design and construction practices, leading to reduced seismic risk and increased resilience.

Project 3.5-A	**Study Impact of Environmental Changes on Earthquake Hazard**
Description	Investigate how environmental changes such as flooding, hurricanes, and climate change impact soil properties and site response. Climate change, hurricanes, and flood events could impact water tables and site response. As other hazards increase due to climate change, earthquake safety is potentially affected. For example, it should be considered if and how hazards such as flooding or long-term effects of climate change impact the soil properties that control site response or earthquake probabilities.
Priority level	IMPORTANT (1.7)
Key steps	1. Identify the relevant environmental changes. 2. Assess their potential impact on earthquake hazard (e.g., on soil properties controlling site response). 3. Assess their impact on earthquake probabilities and shaking intensity.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 3.5-B	**Study Wave Propagation Demands on Pipelines**
Description	Investigate the strain demands imposed on pipelines by ground shaking for laterally varying CEUS conditions given the frequency content of surface waves from hazard-controlling events. Determine if surface waves moving across strong contrasts in laterally varying subsurface properties can generate large strains and failure in subsurface infrastructure. Distributed lifelines systems are vulnerable to disruption when they experience seismic ground strains. Those strains can come from a variety of sources, including ground motions, fault rupture, and ground failure (liquefaction, landslides). Note: This project does not include ground failure.
Priority level	IMPORTANT (1.8)
Key steps	1. Establish a team of experts on distributed lifelines and site response. 2. Investigate the strain demands imposed on pipelines for laterally varying CEUS site conditions. 3. Make recommendations on ground motion demands for pipelines and other similarly distributed infrastructure.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

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Project 3.5-C	**Develop CEUS Liquefaction Guidelines and Maps**
Description	Identify how the Next Generation Liquefaction (NGL) database and models should be adapted to better characterize liquefaction characteristics in the CEUS. Based on these findings, as well as geospatial liquefaction models in literature and that are being developed in NGL, develop liquefaction vulnerability maps across CEUS to identify areas where liquefaction is possible and detailed studies would be justified to evaluate site-specific hazards. There are unique geological conditions in the CEUS that make the liquefaction problem different from California. Among these is the common occurrence of residual soils that can have pronounced aging effects that increase liquefaction resistance.
Priority level	IMPORTANT (2.3)
Key steps	1. Identify areas in the CEUS vulnerable to liquefaction. 2. Define conditions unique to the CEUS related to liquefaction. 3. Develop liquefaction maps for CEUS. 4. Develop consistent and uniform guidelines for CEUS liquefaction analysis.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 3.5-D	**Compile CEUS Geophysical Database**
Description	Compile the existing CEUS geophysical database. Shear-wave velocity profiles and additional subsurface geophysical information are available for CEUS locations and need to be compiled. The lack of accessibility of site information needed for site response studies is a major impediment to progress in site response and other topics in CEUS. In NGA-East, only a very small fraction of ground motion recording sites had V_{s30} values developed from site-specific measurements.
Priority level	IMPORTANT (2.4)
Key steps	1. Form a project to add V_S data and horizontal-to-vertical spectral ratio (HVSR) data to the V_S profile database (https://www.vspdb.org), which is now mainly populated with data from California sites. 2. Start by collecting reliable data from public sources like building departments and departments of transportation. 3. Assess the needs for further site characterization work at priority sites, such as ground motion stations with earthquake recordings. 4. Support exploration programs to develop site characterization data for such sites.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 3.5-E	Identify Multi-Hazard and Compounding Event Types
Description	Identify multi-hazards and compounding events unique to CEUS. CEUS has a broad spectrum of seasonal weather and environmental conditions that can impact seismic resilience. An example is freeze events following seismic events that could mean that shelter and maintenance of habitability will be more critical than in more moderate temperature seasons. These other environmental issues can exacerbate post-earthquake recovery (e.g., temporary housing options become more difficult when dealing with cold weather or snow).
Priority level	IMPORTANT (2.2)
Key steps	1. Identify multi-hazards and compounding events unique to CEUS. 2. Understand the perspective of various communities regarding resilience (e.g., outages) due to one hazard and multiple hazards. For example, consider what a community is willing to pay for resilience from one hazard versus multi-hazards. 3. Work on resolving specific problems identified in previous steps.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	4 to 5 years

3.6 Need for CEUS Involvement in Development of Resilience and Functional Recovery-based Provisions

Knowledge of what seismic resilience is and how it can be developed is an emerging field. Current development is mostly based on WUS seismic conditions and expectations, and much of that has made use of the design earthquake ground motion defined in ASCE/SEI 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE, 2022). Communities in the CEUS that are working on resilience are typically more focused on flood and wind hazards, rather than seismic. The difference in the nature of the seismic hazard in the CEUS means that the mean return interval for the ASCE/SEI 7 design earthquake in the CEUS is typically a much longer time that in the WUS, and that fact will reduce the appetite for developing seismic resilience in the CEUS, because it will be more difficult to show a reasonable balance of current costs with the present value of future losses avoided.

The issue of resilience is complex, and the optimum balance of costs against benefits for protection of a community system need not be based on the same level of ground motion for all the elements of the system. Advancement of seismic resilience in the CEUS will require methods that recognize the characteristics of the built environment and the seismic hazard in the CEUS as well as integration with and capitalization on efforts to provide resilience against other hazards, which are sometimes more pressing concerns. Efforts to develop new seismic code provisions should be planned with substantial participation from the CEUS. Additional focused research and outreach is required within the CEUS to inform development of actionable functional recovery code provisions and incorporate them into adoptable and enforceable building code formats. In the CEUS context, addressing functional recovery in terms of multi-hazard risks and benefits will likely result in more productive discussions and would be better received than focusing discussions only on one specific hazard (e.g., earthquake). Stakeholders in the CEUS are interested in participating in functional recovery discussions and development of the provisions. If the provisions are applicable to and inclusive of CEUS, they are more likely to be adopted

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and enforced in the future. In the CEUS context, addressing functional recovery in terms of multi-hazard risks and benefits will result in more productive discussions and would be better received than focusing discussions only on one specific hazard (e.g., earthquake).

To address this issue, an integrated system of classification of seismic performance levels that captures the importance of elements and structures to the resilience of a system as a whole should be developed (***Project 3.6-A***). Research should be conducted to develop seismic damage fragilities, as opposed to collapse fragilities, for integrated systems of buildings and lifelines that are based on the CEUS built environment (***Project 3.6-B***); risk-targeted strategies should be developed for both new construction and for assessment of existing conditions (***Project 3.6-C***); measures that simultaneously improve resilience for multiple hazards should be developed (***Project 3.6-E***); CEUS stakeholders should be surveyed and encourage to participate in the development of provisions for seismic resilience (***Project 3.6-F***), and tentative provisions for the CEUS should be developed (***Project 3.6-D/F/G***).

The envisioned impact of addressing this issue is that seismic resilience will be improved across the United States, rather than being ignored in wide portions of the CEUS, even where the density of construction creates significant vulnerability from even moderate earthquakes. Ensuring that the CEUS is well represented across the board in functional recovery discussions will build regional support for the resulting provisions when it is time to adopt and enforce new ideas. Input on preferred and workable concepts that may be specific to the CEUS will provide invaluable information in the development of the functional recovery provisions that will minimize if not eliminate a future lag on CEUS adoption and enforcement, similar to the current state of life-safety code provisions. Conscious, explicit, and highly visible outreach to the CEUS will avoid the perception that new functional recovery provisions are WUS requirement being imposed on the CEUS by engineers in the WUS and thus preempt many of the common objections voiced against life-safety seismic code provisions in the CEUS.

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Project 3.6-A	**Develop Integrated Seismic Performance Classification System**
Description	Develop a way to quantify and compare performance of the elements of complex systems, especially in terms of the effect of damage or loss of an element to function on the system as a whole. The end goal of a unified classification system is probably a very long-term series of projects, but this project will develop key pieces applicable in the CEUS by building on seismic limit state definitions present in standards for new and existing buildings (ASCE/SEI 7 and ASCE/SEI 41), in evaluation methodologies for buildings, such as the FEMA P-58 methodology, and for additional infrastructure elements in various design standards (e.g., AASHTO, API 650), and the INCORE platform under development at the NIST-sponsored Center of Excellence for Risk-Based Community Resilience Planning. The objective is an integrated system of classification of seismic performance levels that captures the importance of elements and structures to the resilience of a system as a whole.
Priority level	IMPORTANT (2.0)
Key steps	1. Collect limit state performance definitions from available standards, codes, guidelines and methodologies for buildings and lifeline systems. 2. Compare and contrast the available information and select one or more sets. Combine the set(s) with available seismic damage fragility relations to represent one (or more) hypothetical CEUS community subject to multiple hazards. 3. Select a few scenario seismic events at different hazard levels and compute the response of the overall system; include at least one where the seismic event occurs during cold or hot weather in which survival and recovery of function is more complex than in benign weather. 4. Develop a potential ranking of performance needs for the various elements of lifelines and buildings. 5. Convene a workshop to vet the potential ranking and recommend improvements for eventual development of a performance classification system. 6. Update as better fragility relations are developed and as performance objectives are clarified based upon cost and benefit studies.
Roles	Government; University/Research Organizations; Professional/Trade Organizations
Estimated time	More than 5 years

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Project 3.6-B Develop Seismic Damage Fragility Relations

Description Build on seismic damage fragilities for buildings and building elements present in the FEMA P-58 methodology and ASCE/SEI 41 plus those for additional infrastructure elements in the INCORE platform under development at the NIST-sponsored Center of Excellence for Risk-Based Community Resilience Planning to achieve a comprehensive set of relations that cover the variety of types and densities of construction common in the CEUS.

Priority level CRITICAL (2.6)

Key steps

1. Develop a reasonable inventory of seismic damage fragility relations for use in CEUS risk assessment, for buildings and lifelines.
2. Compile available experimental/field/simulation data to establish a database documenting seismic behavior and limit state progression.
3. Identify critical knowledge gaps that need to be filled with additional experiments and simulations
4. Conduct targeted projects to fill identified knowledge gaps.
5. Use the expanded database of structural behavior and limit states to develop damage state relations.

Roles Government; University/Research Organizations; Professional/Trade Organizations

Estimated time 1 to 3 years

Project 3.6-C Define Seismic Performance Expectations for Resilience

Description Extend the study of costs and benefits defined in a related study for minimum safety levels in the CEUS (*Project 3.2-B*) to define costs and benefits for protection against more frequent ground shaking than used as a basis for life-safety provisions in building codes. The objective is to define a suite of levels of ground motion for damage control than can be used in conjunction with the varying performance objectives for buildings and lifelines to establish design criteria that are compatible with the nature of CEUS seismic hazards, buildings, and infrastructure. The current definition of a design earthquake ground motion used for control damage as two-thirds of the motion used for the collapse prevention limit state results in a wide variety of mean return intervals for that ground motion across the United States, typically being higher in the CEUS than in the WUS. This project is a key step in achieving design ground motions that will deliver a consistent reliability target for resilient performance. It is not expected that the mean recurrence interval will be the for same different elements of the built environment nor for different locations.

Priority level CRITICAL (2.6)

Key steps

1. Evaluate alternative design criteria for resilience for effectiveness and economy. Alternative criteria should include design for a damage limit state at: (a) a ground motion level tied to some fraction of the risk-targeted MCE_R level used for collapse prevention (the current ASCE/SEI 7 method); (b) design for a damage limit state at a ground motion level tied to a constant mean recurrence interval (similar to the existing building criteria in ASCE/SEI 41); and (c) design for a damage limit state at a ground motion selected to deliver a specified reliability (e.g., a 10% chance of failure in 50 years).
2. Compare results and procedures in terms of ease of use, costs and benefits, and feasibility.
3. Convene workshops in various CEUS regions and focused on various sectors of the built environment to vet the findings and recommendations and develop plans for future work.

Roles Government; University/Research Organizations; Professional/Trade Organizations

Estimated time 4 to 5 years

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Project 3.6-D Develop Tentative Provisions for Seismic Resilience in the CEUS

Description Bring together well vetted performance objectives and more complete and robust fragility relations, together with cost and benefit studies, to develop a set of design, construction, operation, and quality assurance provisions at the pre-standardization level that could deliver various levels of resilience to the CEUS built environment.

Priority level CRITICAL (2.6)

Key steps

1. Following development and review of Projects 3.6-A, 3.6-B, and 3.6-C, assemble a team to refine performance objectives and limit states, fragility relations, and hazard levels/performance expectations. The project will need very broad participation, and very likely multiple workshops at intermediate stages to develop something that will find acceptance and use in the CEUS.
2. Develop a graduated set of provisions for application to small and large systems, low to high seismic hazard areas, and sparsely populated to dense urban environments. The end need is for a relatively simple set of provisions for what is clearly a complex issue, and it would be expected that communities that find the costs too high would elect to perform more detailed and specific studies to focus the resources where the return is the highest.

Roles Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry

Estimated time 4 to 5 years

Project 3.6-E Quantify the Benefits of a Multi-Hazard Approach to Functional Recovery

Description Develop a cost benefit study to quantify the collective benefits of seismic provisions that also improve function/performance for other hazards (e.g., snow, wind, flood), in comparison with the selective benefits of seismic provisions that only improve function/performance during a seismic event. The study should be based on the current national model building code and life-safety provisions. Because functional recovery provisions are in their infancy, a chapter in the study report could be focused on specific potential functional recovery requirements and the anticipated benefits.

Priority level CRITICAL (2.8)

Key steps

1. Pull together a project team with in-depth knowledge of CEUS standard design and construction practices, with familiarity of all common environmental hazard design and detailing requirements.
2. Identify common building archetypes that best represent CEUS practices.
3. Complete design drawings for each archetype.
4. Identify hazard-specific (e.g., seismic, wind, snow) code requirements that only provide benefits for that particular hazard.
5. Estimate cost of each design drawing set, breaking out the cost of requirements identified in Step 4.
6. Estimate the potential cost benefit of the proposed functional recovery provisions for each archetype.
7. Peer review/affirm results.
8. Develop and publish a report outlining the process, assumptions, procedures, and results.
9. Reference/share this report in code adoption and functional recovery discussions.

Roles Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry

Estimated time 1 to 3 years

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Project 3.6-F	**Determine Publication Methodology for Functional Recovery Provisions**
Description	Conduct a survey to identify the majority of regional preferences on where, how, and in what format functional recovery provisions should be included as building code requirements. The survey should be all inclusive and representative of multiple interest groups in addition to code enforcement officials, engineers and architects, and municipal planners.
Priority level	IMPORTANT (2.0, 2.3)
Key steps	1. Conduct a survey to determine a preference for one of the following: a. Incorporate functional recovery provisions into the current codes (i.e., IBC, IRC), without explicit delineation between life-safety and functional recovery. This may include revising current code provisions to achieve functional recovery performance in lieu of adding new provisions. b. Incorporate functional recovery provisions into the current codes (i.e., IBC, IRC), with explicit delineation between life-safety and functional recovery. This may include creating a separate functional recovery appendix/chapter, or explicitly identifying functional recovery requirements separately from life-safety provisions. c. Develop a separate code specifically for functional recovery that could be used in conjunction with current codes. Current codes would provide life-safety requirements, the new code would provide additional functional recovery requirements to improve performance and resiliency. 2. Group survey results by interest groups and identify the prevailing preference within each group. 3. Compare results between interest groups and assess the underlying cause/conflicts/point of view if vastly different. 4. Share results with the survey participants for consideration and discussion. Hold a workshop to discuss the preferences and attempt to identify a consensus. 5. Conduct a follow-up survey to see if any responses changed after the discussion. 6. Share results with committees and interest groups actively developing functional recovery provisions.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	Less than 1 year

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Project 3.6-G	**Develop Practical Functional Recovery Provisions for CEUS**
Description	Evaluate if increasing the strength of a structure in the CEUS would be as effective and simpler than increasing the ductility. Traditionally building performance has been improved by increasing the ductility of structural systems through the use of special detailing. Although effective, this approach increases the cost and complexity of the structure design and construction. Where seismic events occur fairly frequently, the increased cost and complexity is justifiable and extends the life of the building. However, for buildings that are expected to withstand only a smaller seismic event, alternate but simpler approaches to achieving similar performance and continued function should be investigated.
Priority level	IMPORTANT (2.3)
Key steps	1. Pull together a project team to develop and test alternate design and detailing concepts focused on structural robustness in lieu of ductility. 2. Develop alternate concepts and vet ideas with material/design experts. 3. Test concepts for performance and vulnerabilities, including the effect of higher in-building floor accelerations on nonstructural components and systems 4. Develop a report summarizing the results. 5. Collaborate with professional committees involved in code writing to develop proposed code provisions.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	4 to 5 years

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Chapter 4

Topic Area: Buildings

This chapter provides an overview of current seismic practice issues in the CEUS within the topic area of *Buildings*, which addresses new building design; evaluation and retrofit of existing buildings; building codes, standards, and guideline development; and building code adoption and implementation. For each issue within the topic area, research and practice-related projects to address the needs are provided. General background information relevant to this topic area is provided in Chapter 2.

Each section in this chapter provides an overview of one issue. The recommended projects to address that issue are provided in the same section. Table 4-1 lists the issues covered in this chapter. Table 6-4 lists all issues and recommended projects covered in this chapter and includes the priority level of each project.

The motivation for addressing issues in this topic area is that there would be more effective application of regional hazard in CEUS seismic design and construction practice, leading to reduced seismic risk and increased resilience. Seismic provisions would be more consistently adopted and enforced in the CEUS.

Table 4-1 Buildings Issues Covered in Chapter 4

Section	Title
4.1	Perception that ASCE/SEI 7 Standard is Complicated and/or Not Reflective
4.2	Perception that Seismic Design is Expensive
4.3	Lack of Access to Training Resources for Engineers
4.4	Unknown Impact of Delegated Design on Seismic Performance
4.5	Lack of Building Stock Inventory Data
4.6	Lack of Best Practices for CEUS-Specific Existing Building Characteristics
4.7	Perception that ASCE/SEI 41 Standard is Complicated and/or Not Reflective
4.8	Challenges in Adoption of Seismic Code Provisions
4.9	Challenges in Seismic Code Provision Enforcement
4.10	Large Amount of Building Stock Needing Seismic Retrofit

Several issues presented in *Hazard Characteristics and Design Philosophies* are also issues in their own right within the *Buildings* topic area. To avoid duplication, those issues are presented only in Chapter 3. Specifically, these three issues overlap topic areas:

- Design Motions for Seismic Safety Based on WUS Hazard (Section 3.2)
- Sensitivity of Seismic Design Category Thresholds (Section 3.4)
- Need for CEUS Involvement in Development of Resilience and Functional Recovery-based Provisions (Section 3.6).

4.1 Perception that ASCE/SEI 7 Standard is Complicated and/or Not Reflective

There is the perception in the CEUS that the seismic provisions in ASCE/SEI 7 Standard, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE, 2022), are too complicated for the design of buildings in lower seismic design categories (SDC) and that a simplified approach would encourage the inclusion of seismic design as part of the overall structural design of these structures. There is also a perception that ASCE/SEI 7 seismic provisions do not adequately reflect some building systems and features that are common in the CEUS, because they were based on WUS building types, construction techniques, and practicalities.

To address the issue, CEUS structural engineers should be surveyed on the shortcomings of ASCE/SEI 7 seismic provisions in CEUS applications, especially as they relate to complexity and representation of common building characteristics (***Project 4.1-A***). If issues with complexity are substantiated, standard developers should develop additional alternative simplified procedures that meet the needs to CEUS engineers (***Project 4.1-B***). If missing CEUS building characteristics are identified, standard developers should add those characteristics to the standard (***Project 4.1-C***). If the survey identified a specific issue with overuse of “R=3” lateral load-resisting steel systems, standard developers should convene a working group to address the concern (***Project 4.1-D***).

The envisioned impact of addressing this issue is that the ASCE/SEI 7 Standard will be reflective of typical CEUS practice, better received by CEUS engineers, and more consistently applied in new building design regardless of the region.

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Project 4.1-A	Conduct a Survey of Engineers about ASCE/SEI 7 Seismic Provisions
Description	Conduct a survey of engineers in the CEUS who design structures in regions of moderate or moderately high seismicity about the ASCE/SEI 7 seismic provisions. Specifically, determine their perception of the complexity of the ASCE/SEI 7 seismic provisions, what methods they currently use to mitigate the complexity of the provisions, and if there are building systems and features that are common in the CEUS that they feel are not adequately represented in the ASCE/SEI 7 seismic provisions. For example, pose questions regarding: how the complexity of the seismic provisions does or does not inhibit their use on relatively simple building projects; ask if engineers resort to using the "R=3" approach when design the lateral load-resisting systems for steel building to avoid the more complicated requirements in ASCE/SEI 7 (and by reference in the AISC seismic provisions) for structural steel systems with higher R values; ask if engineers know about and use the existing simplified seismic provisions in ASCE/SEI 7 Section 12.14 .
Priority level	IMPORTANT (2.0)
Key steps	1. Identify areas of moderate and moderately high seismicity to focus on for survey. 2. Prepare a questionnaire to be sent to structural engineering professionals who practice in the areas identified in Step 1. 3. Collect the questionnaire information and review the questions to determine if there is an issue with the code complexity and if so, determine potential solutions. 4. Identify groups of representative structural engineers in the CEUS to focus on for survey. 5. Prepare a questionnaire to be sent to structural engineering professionals who practice in the areas identified in Step 1. 6. Collect the questionnaire information and review the questions to determine what building systems and/or features are commonly identified as not be adequately addressed by the current ASCE/SEI 7 seismic provisions.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

Project 4.1-B	Develop Alternative Simplified Procedures
Description	If the survey developed in Project 4.1-A determines that the complexity of the current seismic provision is an impediment for their use in the design of simple buildings, and the current simplified seismic design criteria in ASCE/SEI 7-16, Section 12.14 is either not being used or is not applicable to many of the simple building designs, convene a working group to develop new or modified simple seismic design criteria.
Priority level	IMPORTANT (2.0)
Key steps	1. Review data from Project 4.1-A and determine if there is an issue with the complexity of the code. 2. If so, work with BSSC, ASCE, and other organizations to stand up a working group to further examine the issue of simplified seismic design.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

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Project 4.1-C	Add Missing Buildings Systems and Characteristics
Description	If Project 4.1-A determines that there are building systems and/or features that are commonly used in the design of buildings in the CEUS that are not adequately addressed in the current ASCE/SEI 7 seismic provisions, convene a working group to develop additional or modified code language to address identified shortcomings.
Priority level	IMPORTANT (2.0)
Key steps	1. Review data from Project 4.1-A and identify building systems and/or features commonly used in the design of buildings in the CEUS that are not adequately addressed in the current ASCE/SEI 7 seismic provisions. 2. Work with BSSC, ASCE/SEI 7 Seismic Subcommittee, and other organizations to stand up a working group to develop potential modifications to the provisions to address the issues.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

Project 4.1-D	Review of Use of "R=3" Lateral Systems
Description	If the survey developed in Project 4.1-A determines that there are a large number of structural engineers in the CEUS using "R=3" lateral load-resisting steel systems, even when that system may not be the most appropriate option, convene a working group to examine if the continued inclusion of the "R=3" option in higher seismic regions is appropriate.
Priority level	IMPORTANT (2.0)
Key steps	1. Review data from Project 4.1-A and determine if there is an issue with the use (or misuse) of "R=3" lateral load-resisting systems for steel buildings. 2. If so, work with BSSC, ASCE, AISC, and other organizations to stand up a working group to further examine if changes should be made to how the "R=3" option may be utilized by designers.
Roles	Code/Standard Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

4.2 Perception that Seismic Design is Expensive

There is a perception in the CEUS that seismic design provisions make projects more expensive without imparting equitable value. Except for a cost comparison study done in Memphis, Tennessee between the 1999 SBC and the 2009 IBC (NIST, 2013), there is little documentation that quantifies potential cost increases based on new code provisions. The perceived increase in cost is attributed to: encouragement of new and proprietary products which may also require specialized design; additional detailing and design requirements imposed for higher SDCs; increasing or changing step function requirements as seismic ground motion maps oscillate geographical locations between SDC B and C and SDC C to D (See Section 3.4); relative seismic hazard and likelihood of occurrence in the CEUS when compared with snow, wind, or flood, and perception that requirements that are not readily applicable within CEUS standard practices.

To address the issue, cost-benefit studies should be conducted on CEUS building archetypes, including common nonstructural elements, with a focus on the impact of changes in seismic design and detailing provisions. Cost comparison studies should compare different code versions ***(Project 4.2-A)*** or impacts of

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different SDC requirements ***(Project 4.2-B)*** within the same code. The benefits of seismic provisions that also improve performance for other hazards (e.g., snow, wind, flood) should be considered in comparison with the selective benefits of seismic provisions that only improve performance during a seismic event.

The envisioned impact of addressing this issue is that credible cost and cost-benefit studies will provide information to all parties when evaluating new building codes and inform decision making. Such studies will inform municipalities of the anticipated impacts and benefits of new codes while providing guidance to designers and developers on what impacts to expect on the projects and budgets.

Project 4.2-A	**Study Cost Impact of Seismic Design Provisions**
Description	Develop a cost comparison study for multiple CEUS building archetypes with typical nonstructural elements to identify and substantiate cost increases/reductions between building code versions. The study should be designed to separate out cost changes specifically due to changes in seismic provisions.
Priority level	MODERATELY IMPORTANT (1.2)
Key steps	1. Pull together a project team with in-depth knowledge of CEUS standard design and construction practices, in addition to seismic specific code provisions. 2. Identify building archetypes and nonstructural elements that best represent CEUS practices. 3. Complete design documents for each code and archetype. 4. Estimate the cost of each design. Peer review and affirm the results. 5. Develop and publish a report outlining the process, assumptions, procedures, and results.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 4.2-B	**Determine Cost Impact of SDC Step-functions in Seismic Design Provisions**
Description	Develop a cost comparison study for multiple CEUS common building archetypes to identify and substantiate anticipated cost increases/reductions as a result of seismic design and detailing requirements between SDC B and C, and SDC C to D. Separate out costs due to seismic provisions.
Priority level	MODERATELY IMPORTANT (1.2)
Key steps	1. Pull together a project team with in-depth knowledge of CEUS standard design and construction practices, in addition to seismic specific code provisions in both low and high SDCs. 2. Identify common building archetypes that best represent CEUS practices. “Locate” the building archetypes in different SDCs. 3. Complete design drawings for each code and building archetype in each SDC. 4. Estimate the cost of each design. Peer review/affirm results. 5. Develop and publish a report outlining the process, assumptions, procedures, and results.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

4.3 Lack of Access to Training Resources for Engineers

Seismic code provisions have become more complex and detailed, requiring a greater understanding by the engineer of the underlying intent, need, and development of the provisions. Absent this understanding, seismic code provisions may be incorrectly applied, overlooked, or even ignored by engineers. Engineers are limited by available time and billable needs, and need access to training on seismic topics that can speed up their learning. To further exacerbate knowledge requirements, newer technologies and systems (e.g., solar, green roofs, tall mass timber structures) come with their own unique design considerations. There is a need for comprehensive educational resources on seismic design provisions that engineers, code officials, and others can readily access at a reasonable rate to apply the code provisions fully and properly. Alternately, simplified seismic design provisions available for less complex buildings may be unfamiliar or unknown and therefore remain unused by engineers. WUS client demand provides incentive for engineers to delve into the seismic code provisions, including the underlying rationale and research behind them, given the relatively frequent occurrence of seismic events. In contrast, with a low occurrence of seismic events and limited resultant damage if any, client demand in the CEUS prioritizes simplicity and cost savings over faithful compliance with the full complexity of seismic provisions. Resources such as ASCE/SEI 41, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2017), and FEMA P-154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards* (FEMA, 2015),were developed predominantly by WUS designers in response to frequent seismic events necessitating evaluation, repair, and rehabilitation of buildings. With less frequent seismic events in the CEUS, these resources are not as commonly used. As a result, CEUS designers are less conversant in the full in-depth requirements of these resources, resulting in a hesitation to use them due to a lack of knowledge and familiarity. There is a need for low cost comprehensive educational resources on seismic design provisions that engineers, code officials, and others can readily access to fully and properly apply the code provisions. Resources such as ASTM E2026 (seismic risk assessments) and E2557 (probable maximum loss evaluations) were developed for specific financial industry requirements in response to a need to assess the potential risk of a property in seismically active areas. Although these types of resources appear simple to use, they require a depth of knowledge in seismic design requirements and building vulnerabilities during seismic events, that will inform final evaluation results.

To address this issue, engineers and building officials should be surveyed about their present challenges in seismic requirements (***Project 4.3-A***) and comprehensive CEUS-tailored educational resources on the application and background behind seismic design provisions should be developed (***Project 4.3-B***). Such material should be focused on the CEUS region to address provisions that seem obvious to WUS designers but are infrequently used and thus more opaque to CEUS designers. Training about new technologies should also be developed and disseminated at little or no cost (***Project 4.3-C***).

The envisioned impact of addressing this issue is that collective engineering knowledge about seismic provisions will increase in the CEUS and facilitate compliance with code provisions. Further, the increased understanding by CEUS engineers will prompt greater support of the design provisions among the design community.

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Project 4.3-A	**Conduct a Survey of Engineers and Building Officials about Seismic Requirements**
Description	Survey CEUS practicing engineers and code/building officials to identify specific seismic provision requirements that are most frequently challenging to understand and/or implement.
Priority level	IMPORTANT (2.2)
Key steps	1. Plan regional workshops of engineers to develop a list of specific seismic code provisions that are challenging to understand and/or implement. 2. Prepare a survey for engineers to prioritize the seismic code provision list. 3. From the survey results, compile a master prioritization list of seismic code provisions identified by engineers as needing/wanting additional education. 4. Begin development of educational materials on the specific seismic provisions identified by the engineers.
Roles	Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 4.3-B	**Adapt Existing Guidelines and Training Materials**
Description	Adapt existing guidelines and training materials (e.g., FEMA P-154) for the CEUS context.
Priority level	IMPORTANT (2.2)
Key steps	1. Identify specific resources and gaps in currently available guideline and training material. 2. For each resource: Develop a training outline and circulate it among CEUS engineers for feedback on appropriate knowledge levels and base assumptions. 3. Using the outline and feedback, develop training material on the selected resource. 4. Publish/advertise educational training material.
Roles	Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	4 to 5 years

Project 4.3-C	**Provide Training to Engineers about New Technologies**
Description	Develop focused education/training on newer technologies and systems (e.g., solar, green roofs, tall mass timber structures) which come with their own unique design considerations.
Priority level	MODERATELY IMPORTANT (1.3)
Key steps	1. Develop focused educational materials on the seismic needs and considerations of specific newer technologies and systems. 2. Note: this can be an education topic under Project 1.
Roles	Government; University/Research Organizations
Estimated time	Less than 1 year

4.4 Unknown Impact of Delegated Design on Seismic Performance

Use of delegated design in the CEUS is on the rise and may impact the quality of seismic design and construction, especially where delegated design is used for critical elements of the lateral force-resisting system such as connections and splices or other key elements (e.g., stairs, facades, equipment anchorage).

To address this issue, a survey of CEUS structural engineers should be conducted to understand the prevalence and impact of delegated design and its impact on construction in the CEUS (***Project 4.4-A***). If the data suggest that delegated design is widely used for critical building elements in the CEUS, further investigation by researchers and codes/standards committees should be undertaken to determine if there is a potential negative impact on the seismic performance of buildings in the CEUS due to delegated design (***Project 4.4-B***).

The envisioned impact of addressing this issue is that any gaps in seismic design quality caused by delegated design will be understood and addressed.

Project 4.4-A	**Conduct a Survey of Engineers about Delegated Design**
Description	Conduct a survey of engineers in the CEUS who design structures in regions of moderate or moderately high seismicity to understand how often and for which elements delegated designed is being utilized. Develop questions to better understand the interaction of the Engineer of Record (EOR) and the engineer providing the delegated design. Include questions to better understand if the EOR and the Authority Having Jurisdiction (AHJ) are reviewing the delegated design to ensure compliance with the project requirements.
Priority level	IMPORTANT (2.0)
Key steps	1. Identify areas of moderate and moderately high seismicity to focus on for survey. 2. Prepare a questionnaire to be sent to structural engineering professionals who practice in the areas identified in Step 1. 3. Collect the questionnaire information and review the questions regarding the prevalence of delegated design in the CEUS and understand which building elements are most often designed through this process.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations
Estimated time	1 to 3 years

Project 4.4-B	**Quantify the Impact of Delegated Design on the Expected Seismic Performance**
Description	If the survey developed in Project 4.4-A determines that delegated design is being widely used for the design of critical and/or major building elements in the CEUS, convene a working group of seismic experts representing the design community, industry groups, building officials, and researchers to better understand the impact of delegated design on the expected seismic performance of buildings in the CEUS.
Priority level	IMPORTANT (2.0)
Key steps	1. Review data from Project 4.4-A and determine if there is actually widespread use of delegated design the CEUS for building elements that could impact the seismic performance of the building. 2. If there is widespread use of delegated design in the CEUS, work with BSSC, ASCE, ICC, AISC, ACI, and other organizations to stand up a working group to further examine the impact of delegated design.
Roles	Government; Code/Standard Organizations; Professional/Trade Organizations
Estimate time	1 to 3 years

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4.5 Lack of Building Stock Inventory Data

The CEUS lacks sufficient information about its existing building stock to properly develop CEUS-specific programs, ordinances, and seismic provisions.

To address the issue, building stock data collection should be conducted in key regions (***Project 4.5-A***), common building typologies should be identified (***Project 4.5-B***), and a literature review of historical building codes should be conducted (***Project 4.5-C***). The survey should also quantify the number and type of structures that are used for low-income housing in the respective communities. It should be determined if a disproportionate number of seismically vulnerable structures in the selected cities are used for housing in economically disadvantaged areas (***Project 4.5-D***). If is determined that there is a disproportionate seismic risk to the housing stock in economically disadvantaged areas, initiatives may be undertaken with local, state and federal stakeholders to reduce the seismic risk to the impacted communities (***Project 4.5-E)***.

The envisioned impact of addressing this issue is that data about CEUS existing building stock are readily available to code writers, government officials, and engineers to improve the knowledge and practice of CEUS existing building safety. Data regarding the potential seismic risk of low-income housing can be evaluated to better understand prevalence of seismically at-risk housing in selected major metropolitan areas as well as the most common type of structures used for this purpose.

Project 4.5-A	**Collect Building Stock Data**
Description	Determine a mechanism for ongoing data collection regarding building characteristics, codes used, building materials, and structural systems in the CEUS.
Priority level	MODERATELY IMPORTANT (1.5)
Key steps	1. Determine where data should live (live webpage/database) and who will host/maintain data. 2. Identify which metrics should be collected for each building. 3. Provide a mechanism for input (ideally automated) data from permitting process in key jurisdictions to collect key metrics.
Roles	Government, University/ Research Organizations
Estimated time	4 to 5 years

Project 4.5-B	**Identify Common Building Typologies**
Description	Conduct a survey of the CEUS, with focus on high density areas, to understand typical CEUS building typologies. For example, unreinforced masonry buildings are more prevalent on the CEUS.
Priority level	CRITICAL (2.5)
Key steps	1. Identify and prioritize high density areas of the CEUS for surveying. 2. Engage in surveying of building typologies in specific regions. 3. Generate a list of common building typologies, with descriptions and classifications.
Roles	Government, University/Research Organizations
Estimated time	4 to 5 years

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Project 4.5-C	**Conduct Literature Review of Historical Building Codes for Lateral Force Design**
Description	It is important to understand, for our existing building stock in key areas, what building code the building was designed under and if there was any seismic design performed. In addition, if there was a wind design requirement and to what level of wind load was the building designed for.
Priority level	MODERATELY IMPORTANT (1.5)
Key steps	1. Select specific geographic regions for study. 2. Perform a survey of typical buildings based on age and assumed code during time of design/ construction. 3. Compile a list of modifications made to the seismic provisions of historic codes by different jurisdictions in the CEUS. 4. Group building ages/ codes applied based on regions. 5. Leverage other research projects (i.e., ATC-146: *Steel Buildings in the Central and Eastern United States Designed for Controlling Wind Loads to Evaluate their Seismic Performance*) to correlate building age/code design under to expected building performance.
Roles	Government, University/ Research Organizations
Estimated time	4 to 5 years

Project 4.5-D	**Determine if There is a Disproportionate Seismic Risk to Low Income Housing**
Description	Conduct a study in several major metropolitan areas in the CEUS that have at least a moderate seismic risk to determine if there is a disproportionate seismic risk to the low-income housing in those areas. Utilize tools such as the National Risk Index (NRI) (FEMA, 2023c) and Hazus (FEMA, 2023a), in conjunction with current census and housing data to quantify the problem. The study should also highlight potential negative post-earthquake impacts in the areas with a high concentration of vulnerable housing stock.
Priority level	IMPORTANT (2.0)
Key steps	1. Identify metropolitan areas with moderate and/or moderately high seismic risk to focus on for survey. 2. Perform in-depth data mining in the selected communities and then refine key metrics using the NRI and Hazus tools. 3. Presentation of the findings including a detailed discussion of the impact of the disproportionate seismic risk in the impacted communities both during and following a major seismic event.
Roles	Government; University/Research Organizations
Estimated time	1 to 3 years

Project 4.5-E	Develop a Strategy to Mitigate the Disproportionate Seismic Risk to the Housing Stock in Low Income Areas
Description	If the above study determines that there is a disproportionate seismic risk to the housing stock in low-income areas of major metropolitan areas in the CEUS, develop a coordinated plan to mitigate the risk.
Priority level	IMPORTANT (2.0)
Key steps	If the conclusion of Project 4.5-D is that there is a disproportionate seismic risk to the housing stock in low-income areas of major metropolitan areas in the CEUS, engage key stakeholders to develop options for the mitigation of the risk posed by the housing stock. It is anticipated that mitigation options may take many forms including both structural retrofit of existing housing and replacement housing.
Roles	Government; University/Research Organizations
Estimated time	1 to 3 years

4.6 Lack of Best Practices for CEUS-Specific Existing Building Characteristics

Existing CEUS buildings present issues that are different in scope or ubiquity than in WUS practice, such as widespread existence of party wall buildings, adjacent buildings, multi-tenant buildings, prevalence of older buildings, and buildings that have degraded over time. As a result, the seismic performance of such characteristics is not well understood.

- Party wall buildings typically consist of a single URM structure spanning multiple ownership lots and separated by party walls at the lot lines. In addition to structural support, the party walls provide fire separation, essential in post-seismic fires. Party walls were typical to cities developed on the eastern seaboard since the 1800s and still represent a significant number of buildings from Portland, Maine to Savannah, Georgia. As such the study is of high relevance to CEUS. Presently there is no structural standard addressing this ubiquitous type of construction. The advantage of the attached units participating in common to the environmental loads has not been considered thus far in building codes.
- Adjacent lot line buildings typically consist of buildings designed and constructed prior to seismic requirements and may include buildings with unreinforced masonry walls and wood framed floors, mercantile buildings with iron or steel columns and proprietary floor systems, transitional steel frame buildings, non-ductile reinforced concrete buildings. Include mid-block as well as corner buildings.

To address this issue, the seismic performance considerations for each unique characteristics of CEUS buildings should be studied, any needed technical and legal information to address them should be identified, and relevant codes, standards, and guidelines should be updated to reflect this knowledge. The unique characteristics to cover include party wall buildings (***Project 4.6-A***), adjacent lot line buildings (***Project 4.6-B***), multi-tenant buildings (***Project 4.6-C***), and material degradation (***Project 4.6-D***).

The envisioned impact of addressing this issue is that design and construction of seismic retrofits in the CEUS will be made more consistent and be designed on the basis of relevant technical knowledge.

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Project 4.6-A Develop a Framework for Party Wall Buildings

Description	Study the seismic performance of buildings separated by party walls and the implications of alterations to party wall buildings. Develop the engineering and propose a legal framework to improve the seismic resiliency of these buildings. Presently there is no structural standard addressing this common type of construction.
Priority level	CRITICAL (2.5)
Key steps	1. Survey to identify how large is the stock of existing party wall buildings, the rate of alterations and seismic retrofits to these buildings, and the frequency of new party wall buildings being constructed. 2. Study the seismic performance of existing buildings with party walls, including row houses. These typically include buildings with unreinforced masonry walls and wood framed floors. Include mid-block as well as corner buildings. To this day, there are still newly developed party wall buildings, but these might not be URM, and one can assume they meet recent seismic standards. 3. Study the effect of alterations and seismic retrofits one lot at a time. 4. Study the effect of demolition of a building on a lot belonging to a group. 5. Develop concepts and strategies for alterations and retrofits to party wall buildings, including the end goal of the desired level of seismic resiliency, which may happen over a long timeframe of decades or centuries. 6. Identify the utility of retrofits constructed on one side of a party wall (i.e., to only a portion of the total structure) and what steps can be taken to improve the seismic performance prior to the entire structure being upgraded. 7. Investigate and clarify the typical legal issues with work in buildings with party walls, such as access to neighboring spaces for investigation or work, required treatment of the party wall during demolition and construction, allowable vertical and lateral loads imposed on the party wall, required loads supported or received from the party wall. 8. Develop retrofit solutions which minimize or eliminate work in adjacent lots of building structures connected with party walls. 9. Postulate innovative methods to encourage and fund coordinated retrofits throughout the party wall connected structures. This might include direct funding, tax credits, alleviation of certain zoning regulations. 10. Develop standards and code language implementing the findings.
Roles	University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	More than 5 years

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Project 4.6-B	Develop a Framework for Construction in Adjacent Buildings
Description	Study the seismic implications and performance of alterations to buildings that are immediately adjacent to existing neighboring buildings. These buildings typically consist of "pre-seismic" existing buildings which have lot line walls, often multiple buildings comprising an entire block. There may also be a mixture of lot line and party walls. Develop the engineering and legal framework to improve the seismic performance of these buildings.
Priority level	CRITICAL (2.5)
Key steps	1. Study the seismic performance of buildings with adjacent lot line walls. 2. Study the effect of alterations and seismic retrofits one lot at a time. 3. Develop concepts and strategies for alterations and retrofits to adjacent buildings, including the end goal of the retrofits which may happen over a long timeframe. Identify what steps can be taken to improve the seismic performance of adjacent buildings where only one side may be under construction and able to be improved against pounding effects. 4. Investigate and clarify the typical legal issues with work in buildings with adjacent lot line walls. 5. Develop standards and code language implementing the findings.
Roles	University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	4 to 5 years

Project 4.6-C	Develop a Framework for Seismic Alterations on Multi-tenant Buildings
Description	Investigate the desire to allow seismic alterations to the space of one tenant in a multi-tenant building.
Priority level	CRITICAL (2.5)
Key steps	1. Investigate the potential for seismic retrofits on portions of existing buildings occupied by a single tenant, without working in adjacent tenant spaces. 2. Prepare proposed standards or code language to reflect the findings. 3. Evaluate and compare the efficiency and end result of the application of each of the three International Existing Building Code (IEBC) methods (i.e., prescriptive, work area, performance compliance) in multi-tenant buildings.
Roles	University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

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Project 4.6-D	Account for Effect of Material Degradation
Description	Determine how and to what extent the material degradation of existing buildings in the CEUS affects their seismic performance, and what measures should be taken to incorporate the degradation in seismic retrofits. Degradation refers to loss of original structural capacity due to wear and tear or chemical decomposition resulting from weathering in CEUS areas.
Priority level	IMPORTANT (2.0)
Key steps	1. Identify common existing CEUS building materials or structural systems that are typically subject to deterioration due to age, weathering, settlement, creep and which are also relevant to the seismic resistance of those structures. 2. Develop a procedure for condition assessment of existing buildings which will identify the relevant potentially degraded materials or structural systems. 3. Develop testing procedures as relevant for these degraded materials and systems. 4. Develop default material or system properties, and rules to reduce the recognized strength, stiffness, or ductility of these based on the field observations and testing. 5. Prepare a design methodology for seismic rehabilitation and retrofit which includes consideration of existing conditions. 6. Write standards and code language which implements the findings of the above steps.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	More than 5 years

4.7 Perception that ASCE/SEI 41 Standard is Complicated and/or Not Reflective

The ASCE/SEI 41 Standard, *Seismic Evaluation and Retrofit of Existing Buildings*, is perceived by some as WUS-focused and/or difficult to use. Some typical existing CEUS building types (e.g., 19th century brownstones) and characteristics (e.g., material properties) are not well reflected in ASCE/SEI 41. Benchmark buildings provided are not accurate for CEUS, due to the use of other codes in the region (e.g., SBC, BOCA), variability in adoption dates across jurisdictions, and modifications made to codes by selected jurisdictions during their code adoption process. ASCE/SEI 41 and performance-based design are perceived as too complicated by some CEUS engineers for small upgrades to simple buildings that either present a low seismic risk or whose design is controlled by other lateral loads such as wind.

To address this issue, ACSE/SEI 41 should be expanded to include relevant information about CEUS existing building types and characteristics. Vulnerable building types presently not addressed (***Project 4.7-A***), CEUS-specific benchmarks (***Project 4.7-B***), and CEUS-specific material properties (***Project 4.7-C***) should be added. For example, masonry of the Midwest is different than in the WUS, there may be highly variable lime mortar, with much of the lime leached away leaving sand. Identification may include material type, location, or vintage. Lastly, simple, prescriptive methods for identified low-risk CEUS building types, materials, layouts should be added (***Project 4.7-D***).

The envisioned impact of addressing this issue is that technical information in existing building codes and standards will be more applicable to practice in the CEUS and that retrofits will increase in the CEUS.

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Project 4.7-A Add Vulnerable Building Types Not Currently Represented

Description Identify vulnerable building types in the CEUS

Priority level CRITICAL (2.6)

Key steps

1. Identify what are typical existing building types in the CEUS with particular attention to building types or vintages that are prevalent in the CEUS but not in the WUS.
2. Of the CEUS building types that have been identified, identify the seismically vulnerable types.
3. Based on Project 4.5-A, categorize and quantify the vulnerable existing buildings.
4. Identify what kinds of buildings are being built today in the CEUS that may not perform well in seismic events. For instance, buildings in Seismic Design Category A.
5. Review "new" kinds of construction, such as cross laminated timber structures, for their seismic performance. Consider construction issues such as which trade erects them.
6. Develop retrofit solutions for typical seismically vulnerable existing buildings in the CEUS.

Roles University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry

Estimated time More than 5 years

Project 4.7-B Determine Benchmark Buildings

Description Determine benchmark buildings for the CEUS.

Priority level IMPORTANT (2.2)

Key steps

1. Identify the components of ASCE/SEI 41 that work well or do not work well in the CEUS. Identify if these can and should be refined.
2. Establish benchmark building tables for CEUS.
3. Address the question of whether to require documentation that buildings were built by code.

Roles University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry

Estimated time 1 to 3 years

Project 4.7-C Improve Representation of Typical Material Properties

Description Improve ASCE/SEI 41 to represent CEUS values for older materials.

Priority level IMPORTANT (2.0)

Key steps

1. Identify which materials may be different in the CEUS than in WUS.
2. Implement testing of these identified typical CEUS materials to provide values.
3. Publish the material values that are found, and include in ASCE/SEI 41 (along with the requisite factors to transition between expected and minimum values), so they can be used.

Roles University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry

Estimated time 1 to 3 years

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Project 4.7-D	Develop Simplified Method for Use on Small Projects
Description	Prepare simplified method for ASCE/SEI 41 use in CEUS for certain simple projects.
Priority level	CRITICAL (2.7)
Key steps	1. Identify a list of structures which may benefit from a simplified ASCE/SEI 41 approach. 2. Develop simple, prescriptive methods for these identified low-risk CEUS building types, materials, layouts. 3. Verify the simplified procedure with full ASCE/SEI 41 analysis. Identify limitations to the simplified methodology, such as seismic zone, building size, material, or usage. 4. Publish or reference the simplified procedure in ASCE/SEI 41 or similar standard.
Roles	University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	4 to 5 years

4.8 Challenges in Adoption of Seismic Code Provisions

Adopted building code versions and local amendments vary widely between CEUS jurisdictions and rarely include the latest available national model building code version. A frequently cited impediment to adoption is the 3-year code cycle in combination with jurisdictional adoption process timelines. In addition to practical timing limitations imposed by jurisdictional structures, the 3-year code cycle discourages engineers from learning new requirements. CEUS adoption of residential building codes varies significantly because of local amendments and exempt jurisdictional structures that do not require residential code compliance. In particular, seismic provisions in the model codes are frequently reduced or eliminated

To address this issue, research focused on CEUS regions should be conducted to identify and document how jurisdictions are organized and structured, state government jurisdictional oversight (if present), adoption processes and timelines, minimum required code official qualifications and/or credentials, and specific local concerns. Encourage a regional coalition focused on providing information, support, resources, and networking opportunities for jurisdictions that adopt building codes.

The envisioned impact of addressing this issue is that a collective repository of jurisdictional information will be available to help inform ongoing regional efforts in training, coordination, and consensus building within the CEUS region. This repository will be built on publicly available information consolidated into one location that can be referenced by engineers, researchers, code officials, municipal/state officials, and other parties interested in code adoptions.

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Project 4.8-A	**Identify Jurisdictions that Adopt and Enforce Building Codes**
Description	Identify jurisdictions in the CEUS that adopt and enforce building codes and document organizational structures, adoption processes, and timelines.
Priority level	IMPORTANT (2.1)
Key steps	1. Define CEUS states. 2. Identify states with statewide only code adoption jurisdictions. 3. Identify major municipal code adoption jurisdictions in each state, where applicable. 4. Identify regional anchor jurisdictions that influence surrounding jurisdictions. 5. Prepare a questionnaire regarding the jurisdiction code adoption process and timelines to be sent to code enforcement officials within the identified jurisdictions. 6. Review the questionnaire responses to categorize jurisdictions and jurisdiction processes and timelines.
Roles	Government; University/Research Organizations; Code/Standard Organizations
Estimated time	Less than 1 year

Project 4.8-B	**Form Regional Coalition to Support Code Adoption**
Description	Survey code/building officials in the identified jurisdictions on specific challenges and impediments they face in adopting the latest national model building code version. Identify most commonly cited challenges to determine if there is an underlying common factor that can be addressed on a regional basis. Note that the surveys should be limited to code/building officials only to limit bias and should not be inclusive of engineers, politicians, or other groups that are not directly involved with the AHJ adoption and enforcement process.
Priority level	IMPORTANT (2.1)
Key steps	1. Prepare a short questionnaire regarding specific challenges and impediments to be sent to code/building officials. The questionnaire should include a question regarding their interest in developing a regional coalition to work toward uniform adopted codes, and multi-hazard topics including seismic hazards. 2. Plan a regional workshop of code/building officials to discuss a regional code adoption coalition. 3. Support development of an ongoing regional coalition that will provide resources for code/building officials and networking between jurisdictions with a specific focus on working toward uniform adopted codes across the CEUS. Note: this may also fit as a subgroup within existing code/building official organizations.
Roles	Government; University/Research Organizations; Code/Standard Organizations
Estimated time	1 to 3 years

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Project 4.8-C	**Evaluate Residential Seismic Provisions**
Description	Design a shake table test scale model of representative CEUS wood-framed residential single-family dwellings to determine the effectiveness, cost, and impact of full compliance with the 2021 IRC seismic provisions.
Priority level	IMPORTANT (1.8)
Key steps	1. Select: a. Single-family dwelling floor plans representative of CEUS construction. b. Design firms to design the plans per the IRC. c. Construction firms to price and provide input on field construction practices. d. Code officials to provide input on common local or regional interpretations of IRC provisions. 2. Complete the designs per the latest IRC, assuming a high seismic region (SDC D_0 or D_1). 3. Construct scale models of the designs. 4. Test the scale models and record the findings. 5. Produce a report on the findings and costs. Include recommendations on specific seismic provisions that are critical, have minimal impact, or are duplicative.
Roles	Government; University/Research Organizations; Code/Standard Organizations, Industry
Estimated time	1 to 3 years

Project 4.8-D	**Survey Contractors and Owners about Resistance to Seismic Provisions**
Description	Hold two workshops (1 commercial-specific, 1 residential-specific) with contractors, owners, and other development financial stakeholders to discuss/identify specific sources of resistance to seismic provisions.
Priority level	IMPORTANT (2.4)
Key steps	1. Select workshop steering committees and organize the workshops. 2. Focus on clear communication and outreach to attendees to ensure broad and accurate representation of the targeted professions. 3. Hold workshops. 4. Produce a report from each workshop on specific seismic provisions/impacts of concern and potential solutions. Solutions could include code revisions, focused education on implementation of the code provisions, a summary of topics outside the engineering professions to be addressed by insurance/banking/other. 5. Inform appropriate organizations of report findings and recommended actions that could be taken.
Roles	Government; University/Research Organizations; Code/Standard Organizations, Industry
Estimated time	1 to 3 years

4.9 Challenges in Seismic Code Provision Enforcement

The CEUS has challenges to ensuring proper and uniform enforcement of building code provisions that stem from staff qualifications, review processes, and available resources and enforcement tools.

To address the issue, surveys of buildings officials about qualifications and enforcement (***Project 4.9-A, Project 4.9-C***) and training about critical seismic features, construction practices, and nonstructural bracing and anchorage should be conducted (***Project 4.9-B, Project 4.9-D, Project 4.9-E***).

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The envisioned impact of addressing this issue is that a collective repository of code enforcement knowledge, abilities, and current processes will be available as a resource to avoid duplication or contradiction of current efforts, while also providing a reference point of understanding to help inform ongoing regional efforts in training, coordination, and consensus building within the CEUS region. This repository can be referenced by engineers, researchers, code officials, municipal/state officials, and other parties interested in code adoptions.

Project 4.9-A	**Conduct a Survey of Building Officials about Qualifications**
Description	Survey code/building officials on minimum required staff qualifications and actual staff qualifications (e.g., Professional Engineer, PE, or General Contractor, GC). Include general questions to gage seismic-specific knowledge, document review processes, and construction enforcement approaches. Identify most common ability and knowledge level to use as a common regional benchmark if possible.
Priority level	CRITICAL (2.6)
Key steps	1. Define CEUS code enforcement jurisdictions. 2. Catalogue minimum required staff qualifications, including licensed PEs and the PE discipline. 3. Identify impediments to hiring licensed PEs. 4. Catalogue general document review processes. Identify successful and non-successful commonalities between jurisdictions. 5. Catalogue general construction enforcement processes such as required EOR inspection letters, special inspections, field inspections by staff knowledgeable in specific disciplines or general staff based on availability, etc. 6. Identify impediments and objections to more thorough review and comprehensive inspections.
Roles	Government; Code/Standard Organizations, Industry
Estimated time	Less than 1 year

Project 4.9-B	**Provide Training to Code Officials about Critical Seismic Features**
Description	Develop and provide educational materials tailored to code officials and their staff that identify critical seismic features of the project design, discuss the function of these features and how they work, and outline the benefits and consequences of proper/improper construction of the critical features. Include materials on special inspections and certifications and what would be deemed compliant for these features.
Priority level	IMPORTANT (2.1)
Key steps	1. Identify critical seismic features for common building archetypes. 2. Develop educational materials based on input from code officials on beneficial formats and teaching approach. 3. Distribute/promote educational materials to CEUS jurisdictions. 4. Support continuing education by updating materials with new code provisions and ongoing promotion to build awareness of the resources.
Roles	Government, University/Research Organizations
Estimated time	1 to 3 years

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Project 4.9-C	Conduct a Survey of Building Officials about Enforcement
Description	Survey CEUS code/building officials on inspection requirements to ensure compliance and quality control and identify invalid presumptions that current seismic inspection provisions are predicated on. Specific topics to cover should include special inspections, general EOR inspections, code enforcement inspections, and steps required to ensure non-compliant deficiencies are corrected. Under special inspections, identify if third party inspections are a requirement, who hires the inspectors (owner or contractor), and do these inspections work?
Priority level	IMPORTANT (2.4)
Key steps	1. Complete survey to identify current practice by CEUS jurisdictions. a. General inspections by Registered Design Professional (RDP), staff, third party. b. Special inspections required and by whom? Third party? Who hires the inspectors? c. What type of reinspection and/or documentation is required to ensure corrective action was performed? d. Identify differences between written enforcement procedures and practical implementation and enforcement. Survey code officials to determine their understanding of why any discrepancy exists. 2. Review current seismic inspection provisions in national model building codes and common/major material standards and identify underlying presumptions that conflict with survey results (e.g., presumption that the inspector is a licensed PE; the requirement that the inspector be hired by the owner, not the contractor). 3. Categorize the identified presumptions and/or inspection requirements as: a. Practically enforceable with additional education to code enforcement staff. b. Practically enforceable and still effective with minor revisions to the requirements. c. Not practically enforceable given standard inspection practice in the CEUS. d. Not practically enforceable given CEUS code enforcement staff qualifications and technical knowledge regarding seismic design provisions. e. Other 4. In conjunction with the surveyed code officials, develop general potential solutions for the items identified in Step 3. 5. Develop educational material for Step 3a. 6. Work with professional organizations on potential revisions for Step 3b. 7. Identify alternate means of compliance and quality control for Step 3c. 8. Develop alternate inspection requirements based on technical knowledge levels for Step 3d. 9. Produce a report outlining the findings under Step 3, and the potential recommendations under Step 4. The report should be made available to code officials and code writing organizations as a reference and guideline when contemplating future seismic inspection provisions. The report should emphasize and make clear practical CEUS impediments to absolute compliance with seismic inspection provisions as written.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	More than 5 years

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Project 4.9-D	**Provide Training to Engineers and Code Officials about Masonry Grout**
Description	Provide training to engineers and code officials about proper installation of masonry grout. Proper grouting of concrete masonry units (CMU) is difficult to inspect and verify, yet CMU shafts/cores and shear walls commonly comprise part of the lateral force-resisting systems in the CEUS. Common grouting deficiencies include reinforcement coverage within cells and uniform properly laid grout beds between units.
Priority level	IMPORTANT (1.7)
Key steps	1. Develop educational material focused on proper grouting techniques and inspection techniques. Techniques should be tailored to CEUS construction practices, with input from regional professional masonry organizations. 2. Educational materials should be usable by inspectors of all technical knowledge and credential levels, assuming a basic field experience level. Materials could include: publications, webinars; on-demand video recordings; in-person seminars available upon request; lab-based tests and demonstrations. 3. Publicize and disseminate information regarding the available educational materials to engineering organizations, jurisdictions, masonry trade groups, and code writers of inspection requirements. 4. Periodically review and update educational material based on new information or products.
Roles	Government; University/Research Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 4.9-E	**Improve Nonstructural Component Seismic Lateral Restraint and Anchorage**
Description	Improve accountability for nonstructural lateral restraint and anchorage and disseminate education materials to code enforcement jurisdictions and engineering organizations.
Priority level	CRITICAL (2.5)
Key steps	1. Review current national model code requirements and identify critical seismic nonstructural component lateral restraint and anchorage provisions. 2. For each identified provision, recommend a designated RDP that is responsible for ensuring compliance for that provision has been included within the construction documents. 3. Develop a publication summarizing the critical provisions and recommended RDP. 4. Subsequent publications could be developed with educational material on means and methods that could be used to ensure compliance of the critical provisions. 5. Publicize and disseminate information regarding the available educational materials to code enforcement jurisdictions and engineering organizations. 6. Periodically review and update educational material based on new information or products.
Roles	Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

4.10 Large Amount of Building Stock Needing Seismic Retrofit

The prevalence and quality of seismic retrofits should be increased in the CEUS. The reasoning, justification, clarity, and economy of seismic retrofit requirements can and should be improved to aid in this goal. The reasoning, justification, and goals of seismic retrofits need to be communicated to both

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building Owners and others in the design community, along with the utility of retrofits and the technical basis for them.

To address this issue, retrofit design methodologies and building code requirement needs to be improved (***Project 4.10-A***), voluntary and mandatory retrofit programs should be encouraged (***Project 4.10-B***, ***Project 4.10-C***) especially those pertaining to nonstructural falling hazards (***Project 4.10-D***), and cost-benefit studies should be conducted (***Project 4.10-E***).

The envisioned impact of addressing this issue is that most building stock in the CEUS was constructed prior to the implementation of seismic design requirements, and these structures will likely be utilized for a long time, so a clear retrofit strategy will over time improve the seismic resiliency of the CEUS.

Project 4.10-A	**Respond to the Prevalence of Pre-seismic Buildings**
Description	Improve retrofit design methodologies and building code requirements to reflect the reality that the majority of existing buildings in the CEUS were designed and constructed prior to the incorporation of seismic considerations into the governing building codes.
Priority level	IMPORTANT (2.3)
Key steps	1. Improve implementation of codes which lead to seismic retrofits, such as the IEBC. Review these codes to determine what level of seismic retrofit actually occurs and if improvement to the code is warranted to increase seismic upgrades. 2. Review the circumstances under which using the default Site Class D is appropriate and where it can be revised. This may be especially relevant for small buildings. Do this by developing databases and mapping of localized default seismic site class, which aggregate the results of prior geotechnical investigations for densely constructed neighborhoods. Clarify and explain the need for geotechnical investigations for existing buildings to obtain an appropriate site class and then seismic design category. 3. To facilitate seismic improvements, may wish to create delineation in the triggering code language for small existing buildings and building age, and incorporate into codes how to retrofit older buildings and smaller buildings with greater allowance for their age and difficulty of upgrades.
Roles	University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	4 to 5 years

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Project 4.10-B	Increase Prevalence of Voluntary Seismic Retrofits
Description	Increase the occurrence of voluntary seismic retrofits in the CEUS.
Priority level	IMPORTANT (1.7)
Key steps	1. Identify incentives to encourage voluntary seismic upgrades (e.g., credits, tax rebates, and grants for seismic upgrades; federal aid funding to AHJs using latest codes, including IEBC; grants; leverage historic preservation and sustainability initiatives). 2. Probe how to relieve compounding actions from seismic retrofits (e.g., allow voluntary seismic retrofits to occur but not trigger follow-on requirements such as accessibility upgrades). Study how frequently voluntary seismic retrofits trigger accessibility, energy code, and other updates. 3. Identify parameters under which voluntary seismic retrofit can be expanded. Determine if, when, and how they may be used. 4. Identify what aspects of current voluntary upgrade procedures are west coast based, and not necessarily relevant to CEUS practice. 5. Prepare voluntary upgrade methodologies whose seismic resiliency targets are more in line with CEUS needs and practical retrofit procedures.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	More than 5 years

Project 4.10-C	Improve Mandatory Seismic Retrofits
Description	Improve the relevance and the use of code-required retrofits in the CEUS.
Priority level	IMPORTANT (2.3)
Key steps	1. Study how and under what circumstances retrofit triggers in existing model codes do not capture vulnerable CEUS buildings or alterations (e.g., unreinforced masonry (URM) buildings which are not changing occupancy, stiffness, or mass). Determine magnitude of problem and identify how to close loopholes. 2. Identify where and under which circumstances the current retrofit triggers, for instance in the IEBC, are not being adhered to, or upgrades not done. Identify the reasons, such as political or industry pressure. 3. Review local codes and code provisions and identify areas where their provisions may be beneficially incorporated into national model codes. And, vice versa, which aspects of the national model codes may be used to improve seismic practice in the remaining local code. 4. Provide outreach and education of code officials so they are aware of required triggers/ thresholds.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	4 to 5 years

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Project 4.10-D	Increase Retrofit of Potential Falling Hazards
Description	Improve identification and mitigation of and potential falling hazards.
Priority level	IMPORTANT (2.4)
Key steps	1. Identify which are the most hazardous potential falling hazards on the exterior of existing buildings (e.g., chimneys, stonework, brick veneers, parapets, cantilevers) 2. Identify which are the most hazardous potential falling hazards on the interiors of existing buildings (e.g., suspended equipment, ceilings, piping, lighting). 3. Identify what can be done about these identified falling hazards (e.g., inspections, retrofits, replacements, requirements for new construction in existing buildings)
Roles	Government; Professional/Trade Organizations; Industry
Estimated time	1 to 3 years

Project 4.10-E	Establish Prioritization Framework for Seismic Retrofits
Description	Determine how seismic upgrades can be prioritized.
Priority level	IMPORTANT (2.2)
Key steps	1. Establish prioritization for existing buildings to be upgraded, beyond what is required by current building codes (e.g., should the owner spend money to upgrade when the building may statistically be gone by the time the earthquake hits). 2. Prepare methodologies for determining when to voluntarily upgrade a building. The methodology should be soundly based on economics, hazards, and social needs to help determine if a retrofit or upgrade is worthwhile, and not simply fall on the design engineer to make a value judgement. 3. Establish a rubric for communities to establish where resources should be spent on voluntary seismic upgrades. 4. To better understand the need for seismic retrofits, prepare a series of sample studies of building types specific to CEUS (e.g., flat plate moment frame) to determine when the building system is vulnerable and at what level of ground shaking (e.g., ground shaking threshold for URMs). 5. Establish fragility curves for existing CEUS buildings.
Roles	Government; University/Research Organizations; Code/Standard Organizations; Professional/Trade Organizations; Industry
Estimated time	More than 5 years

Chapter 5

Topic Area: Lifeline Infrastructure

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This chapter provides an overview of current seismic practice issues in the CEUS within the topic area of *Lifeline Infrastructure*. This topic area includes planning, analysis, design, and construction of lifeline infrastructure systems and addresses both new and existing systems. For each issue within the topic area, research and practice-related projects to address the needs are provided. General background information relevant to this topic area is provided in Chapter 2.

As introduced in Section 2.3.2, three existing reports that outline research and practice needs for lifeline infrastructure at a national level served as a starting point for developing a list of issues tailored to the CEUS context. Section 5.1 presents the prioritization of the recommendations in those reports based on the input from workshop participants in the Lifelines Track.

Additional issues for the CEUS context were identified beyond those in the existing reports; those issues and the recommended projects to address them are provided in Sections 5.2 to 5.5. Table 5-1 lists the issues covered in this chapter. Table 6-5 lists all issues and recommended projects covered in this chapter and includes the priority level of each project.

The motivation for addressing issues in this topic area is that seismic performance of lifeline infrastructure will improve and post-earthquake service recovery time will decrease. The effect of addressing these issues would also go beyond earthquakes, with opportunities to improve day-to-day reliability and reduce service restoration times after other natural hazard events.

Table 5-1 Lifeline Infrastructure Issues Covered in Chapter 5

Section	Title
5.1	Prioritization of the Prior Lifeline Infrastructure System Recommendations
5.2	Insufficient Understanding of Social and Economic Consequences from Service Outage
5.3	Insufficient Understanding of Risk Posed by Earthquake Hazards and Multi-Hazards
5.4	Insufficient Understanding of Dependencies and Interdependencies
5.5	Need for a National Lifeline Infrastructure System Component Database

5.1 Prioritization of the Prior Lifeline Infrastructure System Recommendations

Three existing reports provide lists of general seismic research and practice needs at a national level for specific lifeline infrastructure systems. The recommendations from these reports were used as a starting point to obtain a CEUS perspective on these existing recommendations.

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The reports are:

- NIST GCR 14-917-33, *Earthquake-Resilient Lifelines: NEHRP Research, Development, and Implementation Roadmap* (2014),
- NIST GCR 16-917-39, *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery* (2016), and
- FEMA P-2090/NIST SP-1254, *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time* (2021).

The priority research and practice tasks for the CEUS were identified through workshop discussions on the following four categories:

- anticipated performance of existing lifeline infrastructure systems during earthquakes and the societal needs and expectation for recovery timeframes of these systems,
- multi-hazard approaches to improving lifeline infrastructure systems,
- dependencies and potential impact on response and recovery, and
- lifeline infrastructure system analysis, design, codes, and standards.

From the prior 82 task recommendations in NIST (2014), NIST (2016), and FEMA-NIST (2021), 45 task recommendations were grouped into the above four categories and presented for discussion in three breakout sessions at the workshop. The order in which the topics were presented is provided in Appendix B. Lifeline system-specific topics (e.g., water) were not included because the workshop participants was diversified across lifeline systems and time was limited. In addition, consistent with the approach for NIST (2016), lifeline-specific research needs are considered important but not as high a priority as for topics that can address multiple or all lifeline infrastructure systems. The general planning, education, and financial resources topics and other topics that did not fit within the above four listed categories were not discussed due to time constraints in order to allow for greater discussion to generate and rank new CEUS-specific recommended topics. Two topics from NIST (2016) were identified as duplicates from NIST (2014), leaving 43 topics that were prioritized. The topics that were not reviewed or ranked during the workshop are marked in Tables 5-2 to 5-10 as "Not reviewed" in the *CEUS Priority* column.

The following three subsections summarize the recommendations for lifeline infrastructure system research and practice provided respectively in NIST (2014), NIST (2016), and FEMA-NIST (2021) and provide the background for review and deliberation about their importance to the CEUS. The priority ranking for the CEUS context is also provided.

5.1.1 NIST GCR 14-917-33, *Earthquake-Resilient Lifelines: NEHRP Research, Development, and Implementation Roadmap*

This report entitled *NIST GCR 14-917-33, Earthquake-Resilient Lifelines: NEHRP Research, Development, and Implementation Roadmap* (Roadmap) was prepared with the intention to guide investments made by NIST and other NEHRP agencies in generating national performance and restoration goals in concert with the development of guidelines, manuals, and standards for key lifeline

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infrastructure systems and components. It also addresses lifeline infrastructure system interdependencies and institutional research and implementation priorities that are needed to support resilient lifeline infrastructure system practices and improved performance during extreme events. High priority needs for industry practice and adoption as well as guidelines and consensus-based standards are included in the Roadmap.

Overall, the Roadmap identifies 28 research, development, and implementation topics, grouped into four main program elements (and six program element subgroups), and identified with a "highest," "high," or "medium" priority ranking. Each topic has a one-page description including cost, duration, and potential funding that can be found in NIST (2014).

The framework for the Roadmap consists of four key program elements that define the range of proposed priority topics for research, development, and implementation to be pursued over the next decade, as well as a consensus-based prioritization scheme for completing the work. The program elements are as follows:

- Program Element I. Establish national lifeline system performance and restoration goals.
- Program Element II. Develop lifeline system specific performance manuals, guidelines, standards, and codes.
- Program Element III. Conduct problem focused research for various lifeline systems.
- Program Element IV. Enable the adoption and implementation of lifeline system performance goals and standards.

The Roadmap is not a static arrangement of priorities. It is a framework that includes dynamic interactions. It is intended for research topics in Program Element III to emerge from work undertaken in Program Elements I, II, and IV. As work is accomplished to establish national lifeline infrastructure system performance and restoration goals in conjunction with the development of guidelines and standards, gaps in knowledge and fundamental uncertainties will emerge, requiring further research.

Program Element I is the foundational element of the Roadmap. Its objective is to establish a national framework of seismic performance and restoration goals for lifeline infrastructure systems that reflects the evolving nature of communities, technology, business, and government. Its purpose is to help transition from current utility-specific crisis management practices to a more integrated and consistent approach to interdependent lifeline infrastructure systems performance improvement and integrated community resilience enhancement. Program Element I also provides input and guidance for the rest of the program elements.

Table 5-2 summarizes the recommended research topics with priorities in Program Element I. Program Element I is defined by two complementary subgroups, a Performance Framework subgroup that is focused on establishment of lifeline infrastructure system restoration goals driven by societal needs and expectations and a modeling-based Needs Assessment subgroup. The goal of the Performance Framework subgroup is to develop performance and restoration goals that are broadly applicable to all interdependent lifeline systems throughout earthquake-prone regions of the United States with consideration of current

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utility best practices. Such a framework must reflect realistic system evolution that is aligned with national and local community resilience priorities.

The goal of the Needs Assessment subgroup is to provide modeling methods to assess specific functionality levels and restoration times achievable with enhanced best practices. This subgroup also addresses current shortfalls in performance related to the absence of measures that account for lifeline infrastructure system interdependencies and focuses on the need to align lifeline infrastructure system services with societal expectations.

Table 5-2 summarizes the priority topics for research, development, and implementation in these subgroups. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

Table 5-2 Summary of Lifeline System Research and Implementation Element I Priorities (NIST, 2014) with CEUS Priority Added

No.	Topic	CEUS Priority
	SUBGROUP I.1. Develop a Framework for the Establishment of Lifeline System Performance and Restoration Goals	
1	Develop an overarching framework for national lifeline performance and restoration goals	Critical (3)
2	Assess current societal expectations of acceptable lifeline performance levels and restoration times informed by the phases of response and recovery	Critical (3)
3	Establish procedures to quantify hazards over spatially distributed lifeline systems	Critical (3)
	SUBGROUP I.2. Develop Methods for Lifeline System Performance and Restoration Needs Assessment	
4	Develop modeling tools to support design approaches, planning, and restoration for interdependent lifeline systems	Critical (3)
5	Develop tools to quantify and rank the societal benefits and costs of different lifeline system performance levels and restoration times, as well as prioritize lifeline upgrades and investments	Important (2)

Program Element II of the Roadmap focuses on the development of guidelines, manuals of best practice, and standards to improve system reliability. Since the 1971 San Fernando Earthquake, many seismic guidelines and standards have been developed to cover gaps resulting from the paucity of codes and standards for lifeline infrastructure systems in use prior to that earthquake. Existing best practice manuals and guidelines include those produced for different lifeline infrastructure systems by the American Lifelines Alliance (ALA), the Technical Council on Lifeline Earthquake Engineering (TCLEE) of the ASCE, and other organizations.

Existing lifeline-specific guidelines and standards need to be expanded and updated to address advances in research, construction, and operational experience. They need to reflect better recent technological advances, as well as address the national performance and restoration goals developed as part of the Roadmap. They must include consideration of lifeline infrastructure system interdependencies.

Table 5-3 summarizes the priority topics for research, development, and implementation to address lifeline infrastructure system performance and reliability. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

Table 5-3 Summary of Lifeline System Research and Implementation Element II Priorities (NIST, 2014) with CEUS Priority Added

No.	Topic	CEUS Priority
6	Develop guidelines for the analysis, design, and planning of electric power infrastructure in seismically vulnerable regions	Not reviewed
7	Develop guidelines for improving telecommunication system resilience under earthquake conditions	Not reviewed
8	Develop water system seismic guidelines and standards	Not reviewed
9	Develop wastewater system seismic guidelines and standards	Not reviewed
10	Develop a manual of best seismic practices for gas and liquid fuel transmission pipelines	Not reviewed
11	Develop a manual for improving the seismic performance of natural gas distribution systems	Not reviewed
12	Develop guidelines for mitigating damage to lifelines from tsunamis and other flood-related hazards	Moderately important (1)
13	Develop guidelines for post-earthquake lifeline assessment, response, and recovery	Moderately important (1.5)
14	Develop geohazard guidelines for owners and contractors for engineering, procurement, and construction of pipelines	Moderately important (1.5)
15	Develop seismic qualification standards for lifeline components and systems	Critical (3)

Program Element III identifies priority topics that are organized in two main areas: (1) priorities related to research across lifeline infrastructure systems, and (2) priorities related to research for specific lifeline infrastructure systems.

The recommended topics for this program element attempt to fill gaps in knowledge and/or advance the state-of-the-art in lifeline infrastructure system risk and resilience assessment and management. However, as noted earlier, these topics should be regarded as a starting point for an emerging dynamic and interactive process, with new topics being identified on the basis of work in other program elements.

New lifeline infrastructure system network paradigms are emerging in response to increased demands for energy, renewal of aging lifeline infrastructure systems, planning and operations for sustainability, and innovations in computational methods for complex networks. Lifeline infrastructure risk and resilience methods need to advance across systems to meet the challenges and opportunities created by these changes.

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Table 5-4 summarizes the priority topics related to research across lifeline infrastructure systems and for specific lifeline infrastructure systems. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

Table 5-4 Summary of Lifeline System Research and Implementation Element III Priorities (NIST, 2014) with CEUS Priority Added

No.	Topic	CEUS Priority
	SUBGROUP III.1. Priorities Related to Research Across Lifelines	
16	Evaluate the feasibility of new interdependent lifeline system configurations	Important (2)
17	Develop methods for analysis and mitigation of damage from fire following earthquakes and hazardous material releases	Important (2)
18	Improve and extend methods for mitigating the effects of earthquake-induced ground displacement on underground pipelines, conduits, and cables	Critical (3)
	SUBGROUP III.2. Priorities Related to Research for Specific Lifeline Systems	
19	Evaluate distributed power generation and energy storage to reduce earthquake/natural hazard effects on electric power systems	Not reviewed
20	Develop a multi-hazard, multi-modal dynamic transportation network risk assessment model	Not reviewed
21	Develop water and wastewater system evaluation methods for earthquake impacts	Not reviewed
22	Develop tensile and compressive strain limits for welded steel pipelines in permanent ground displacement zones	Not reviewed

Program Element IV focuses on the research, development, and implementation priorities necessary to advance the adoption and implementation of lifeline infrastructure system performance goals and standards and sustain lifeline infrastructure system reliability and seismic resilience over time. It is organized into two subgroups: (1) priorities to enable adoption and implementation of lifeline infrastructure system performance goals and standards, and (2) priorities for long-term earthquake resilience.

Table 5-5 summarizes the priority topics for research, development, and implementation to enhance the capacity and willingness of lifeline infrastructure system owners and operators to adopt and implement system- and component-level performance goals and standards and to help sustain lifeline infrastructure system reliability and seismic resilience. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

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Table 5-5 Summary of Lifeline System Research and Implementation Element IV Priorities (NIST, 2014) with CEUS Priority Added

No.	Topic	CEUS Priority
	SUBGROUP IV.1 Priorities to Enable Adoption and Implementation of Lifeline System Performance Goals and Standards	
23	Develop tools, guidance, incentives, and funding mechanisms for voluntary adoption and implementation of lifeline seismic resilience programs and earthquake-resilient design and construction standards	Critical (2.5)
24	Develop strategies and techniques for the public and key customers to engage lifeline system providers to define acceptable performance levels and restoration timeframes	Moderately important (1.5)
	SUBGROUP IV.2. Priorities for Long-Term Earthquake Resilience	
25	Assess the direct and indirect socioeconomic consequences and financial implications of different lifeline performance levels and restoration timeframes	Critical (3)
26	Implement post-earthquake information and response services for lifeline systems	Critical (2.5)
27	Develop and deploy intelligent lifeline monitoring, advanced sensors, and emergency response and restoration decision support systems	Not reviewed
28	Develop and deploy better tools, training, and guidance for emergency operation planning, response, and restoration of lifeline systems	Not reviewed

5.1.2 NIST GCR 16-917-39, *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery*

This study was born from the NIST (2014) Element I Topic 2 shown in Table 5-2, undertaken to better understand societal needs during recovery, and conducted as part of the NIST Community Resilience Program (NIST, 2015). The primary purpose was to assess current societal expectations of acceptable lifeline infrastructure system performance levels and restoration timeframes that are informed by the phases of response and recovery, distinguishing those that are hazard independent and those that are specific for seismic (including tsunami), wind (including hurricane and tornado), flood, snow/ice, and wildfire hazard events. An additional goal of the study was to identify gaps between the desired and anticipated performance of lifeline infrastructure systems.

Assessment broadly examined the societal considerations and interdependencies associated with the performance of lifeline infrastructure systems. Each assessment summarizes current codes, standards, guidelines, manuals, and performance requirements as well as societal considerations and critical infrastructure interdependencies. Each assessment also describes system performance, summarizes disaster lessons, discusses key gaps and deficits between anticipated lifeline system performance and the performance required to support societal needs, and makes recommendations for improvements.

Based on the results of the assessments, 33 recommendations were organized in four areas: Lifeline Codes, Standards, and Guidelines; Research; Modeling; and Lifeline Infrastructure System Operations, summarized in Tables 5-6 to 5-9. In NIST (2016), each recommendation has a one-paragraph description. There are no estimates of cost or duration for the research, and no variation in priorities identified, although all recommendations were identified as having high priority.

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Lifeline Codes, Standards, and Guidelines: This study reveals critical gaps in the codes, standards, and guidelines that govern the design, construction, and performance of various lifeline infrastructure systems and system components.

Table 5-6 lists the resulting recommended topics reflecting organizational and framework needs, available information, new knowledge needs, guidelines and standards development needs, and scoping breadth, with recommendations that pertain to broad issues and improving community resilience considered higher priorities than recommendations for specific lifeline infrastructure systems. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

Table 5-6 Summary of Needs Assessment Recommendations - Lifeline Codes, Standards, and Guidelines (NIST, 2016) with CEUS Priority Added

Rec.	Topic	CEUS Priority
A1	Identify or establish an organization and process for advocating, harmonizing, and unifying the consensus procedures for lifeline guidelines and standards development.	Critical (3)
A2	Develop more consistent terminology for lifeline standards.	Important (2)
A3	Develop an up-to-date and complete suite of codes, standards, and guidelines for all lifeline systems to reflect the current state of practice, knowledge, and performance requirements.	Not reviewed
A4	Develop a methodology to combine component-based design criteria into system level performance targets.	Important (2)
A5	Develop lifeline system performance requirements that relate to community resilience and better reflect societal considerations.	Critical (3)
A6	Develop consensus-based guidelines and standards for the design of new lifelines and the retrofit of existing lifelines that reflect community resilience performance requirements and societal considerations.	Critical (3)
A7	Develop guidelines to inform the design, interoperability, and upkeep of lifeline system dependencies. Establish procedures to quantify hazards over spatially distributed lifeline systems	Critical (2.5)
A8	Reduce inconsistencies in the compendium of codes and standards that guide design, construction, and resilience of the built environment, such as fire codes, building codes, and lifelines codes, standards, and guidelines.	Important (2)
A9	Develop consistent policy and standards on accessing information and databases about critical infrastructure systems that is coordinated with Department of Homeland Security critical infrastructure activities.	Not reviewed
A10	Provide updated guidance for evaluating gas and liquid fuel pipeline and facility response to seismic hazards, floods, coastal storms, and tsunami-related inundation.	Not reviewed

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Research: The study identified a number of gaps in data and knowledge necessary to improve the fundamental understanding of acceptable lifeline infrastructure system performance.

Table 5-7 lists 15 recommendations with respect to systematic study and research needs. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

Table 5-7 Summary of Needs Assessment Recommendations - Research (NIST, 2016) with CEUS Priority Added

Rec.	Topic	CEUS Priority
B1	Gather information on and systematically study the relationships between service disruptions, and societal impacts and expectations to better understand lifeline system performance.	Critical (3)
B2	Develop and conduct a targeted research program to assess societal expectations associated with lifeline system performance.	Critical (2.5)
B3	Systematically study and compare the array of design approaches and methods for addressing societally-based performance requirements within current codes, standards, and guidelines for lifeline systems.	Moderately important (1)
B4	Investigate the differential vulnerability among social groups to lifeline system outages.	Critical (3)
B5	Systematically collect and review various “proxies” and secondary evidence for societal expectations of lifeline performance and restoration timeframes.	Important (2)
B6	Assess the various lifeline performance programs and practices for public safety and develop guidance on their application to other critical lifelines, including multiple, interdependent systems and collocated facilities.	Not reviewed
B7	Conduct research on needed service restoration times, including how system operability as a performance metric supports community resilience.	Critical (3)
B8	Study lifeline system operator organizational issues and how they affect community-scale lifeline performance and resilience planning.	Not reviewed
B9	Enhance the understanding of infrastructure-related failures and cascading effects resulting from low-probability/high-consequence events.	Critical (3)
B10	Develop post-disaster data collection protocols to assess lifeline system recovery and restoration timeframes and improve the understanding of restoration processes across individual and interdependent lifeline systems.	Critical (2.5)
B11	Develop tools to identify interdependent infrastructure systems and services along with their restoration criteria.	Critical (2.5)
B12	Establish procedures to quantify hazards for spatially distributed systems.	Repeat of 3 in Table 5-2
B13	Enhance the understanding of lifeline system supply sources and end-point facilities and their role in system performance, restoration, and community and regional recovery with the goal of improving databases and modeling of such sources and facilities.	Critical (2.5)
B14	Perform studies on changes in water demand considering an array of hazards as well as seasonal and longer-term climate variability, like drought.	Moderately important (1)
B15	Improve knowledge, databases, and modeling for the impact of widespread flooding and storm damage on regional fuel supplies.	Moderately important (1.5)

Modeling: There is a growing body of modeling methodologies for lifeline infrastructure systems and their interdependencies that can be leveraged to improve resilience across lifeline infrastructure systems,

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but there are also notable limitations in scope, outputs, integration, and validation that need to be addressed. Table 5-8 lists the three modeling related recommendations. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

Table 5-8 Summary of Needs Assessment Recommendations - Modeling (NIST, 2016) with CEUS Priority Added

Rec.	Topic	CEUS Priority
C1	Aggregate the existing suite of infrastructure modeling tools and create a user-friendly interface so communities can properly assess their lifeline-related system performance and restoration risks, including uncertainty.	Critical (3)
C2	Develop first-generation models and practical tools to analyze community resilience that account for lifeline system dependencies and interdependencies.	Critical (3)
C3	Improve numerical modeling of water and wastewater systems, with emphasis on validation of models, developing the most effective simulation procedures, and applications in real systems.	Not reviewed

Lifeline Infrastructure System Operations: The study also identifies a number of needs related to lifeline infrastructure system operations and operational design. These also must be addressed in order to improve community resilience and bridge the gap between the post-event capabilities of lifeline infrastructure systems and the societal expectations of their performance and restoration.

Table 5-9 lists the five recommendations. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

Table 5-9 Summary of Needs Assessment Recommendations - Lifeline System Operations (NIST, 2016) with CEUS Priority Added

Rec.	Topic	CEUS Priority
D1	Develop a process for major utilities to conduct self-assessments of their preparedness for various natural hazard events, as a basis for prioritizing improvement to system robustness and post-event response.	Not reviewed
D2	Develop guidance for lifeline service providers on how to engage and collaborate with communities, including emergency management agencies and other key community institutions, in developing resilience strategies and preparing system restoration and contingency plans.	Critical (2.5)
D3	Develop guidance for local planning (e.g., for fuel delivery to emergency responders and critical infrastructure).	Critical (2.5)
D4	Develop guidance for lifeline service providers to evaluate the effects of system component failures, both in isolation and in combination, and considering upstream and downstream dependencies.	Important (2)
D5	Design protocols for lifeline service providers, working with emergency management and other community institutions, to communicate to the public the likely impacts of different hazard events on service provision and disruption.	Not reviewed

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5.1.3 FEMA P-2090/NIST SP-1254, *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time*

This FEMA-NIST report (2021) provides a set of options in the form of recommendations, tasks, and alternatives for improving the built environment (buildings and lifeline infrastructure systems), which have been developed and assessed by the Committee of Experts jointly convened by FEMA and NIST. The report provides a total of 7 recommendations, 17 tasks, and 9 alternatives. Lifeline infrastructure systems are addressed in the two following recommendations:

- **Recommendation 1**: *Develop a Framework for Post-Earthquake Reoccupancy and Functional Recovery Objectives.* A framework for reoccupancy and functional recovery is needed to provide a national consensus on policies and technical criteria necessary to define what services must be in place and the design requirements needed for a building or lifeline infrastructure system to be occupiable or functionally recoverable within a specified timeframe after an earthquake.
- **Recommendation 4**: *Design, Upgrade, and Maintain Lifeline Infrastructure Systems to Meet Recovery-Based Objectives.* To improve the performance of lifeline infrastructure systems in a major earthquake, a recovery-based approach for the design of new systems and the upgrade and maintenance of existing systems is needed. Because the operation of a lifeline infrastructure system depends on numerous components, designed and built over time, using a variety of standards, procedures, and material types, the recovery-based design, upgrade, and maintenance of a system are combined and considered under a single recommendation.

The following three recommendations covering planning, education, and financing also pertain to lifeline infrastructure systems:

- **Recommendation 5**: *Develop and Implement Pre-Disaster Recovery Planning Focused on Recovery-Based Objectives.* Pre-disaster recovery planning involves making decisions before a disaster about how a community will recover after a disaster. Pre-disaster recovery planning by federal, state, local, tribal, and territorial governmental authorities, building owners and managers, and lifeline infrastructure system owners and operators is needed to improve reoccupancy and functional recovery times beyond what is achievable by design and construction alone.
- **Recommendation 6**: *Provide Education and Outreach to Enhance Awareness and Understanding of Earthquake Risk and Recovery-Based Objectives.* Many people underestimate the risks associated with earthquakes and do not understand the performance that building codes are intended to provide. Education and outreach are needed to enhance awareness and understanding of earthquake risk and recovery-based objectives, and to enable communities to make rational decisions about how the built environment should be designed and constructed.
- **Recommendation 7**: *Facilitate Access to Financial Resources Needed to Achieve Recovery-Based Objectives*. The probability of mitigation increases as the financial resources needed to facilitate mitigation are created and made available. A shift to focus on recovery-based objectives will cost money. Those who will bear these costs will need to have access to additional financial resources needed to make such a shift. Existing mechanisms to facilitate access to financial resources should be augmented with newly developed and implemented mechanisms.

Table 5-10 lists the recommendations, tasks, and alternatives. The priority levels for CEUS, as determined by Lifelines Track participants, are also included in the table.

Table 5-10 Summary of Recommendations, Tasks, and Alternatives Associated with Lifelines (FEMA/NIST, 2021) with CEUS Priority Added

Rec.	Task	Alt.	Lifeline System Operations	CEUS Priority
1			**Develop a Framework for Post-Earthquake Reoccupancy and Functional Recovery Objectives**	
	1.1		Develop a Policy for Recovery-Based Objectives	Critical (3)
	1.2		Develop Design Criteria for Achieving Recovery-Based Objectives	Critical (2.5)
	1.3		Determine Appropriate Hazard Levels for Recovery-Based Objectives	Critical (2.5)
4			**Design, Upgrade, and Maintain Lifeline Infrastructure Systems to Meet Recovery-Based Objectives**	
	4.1		Provide National Guidance on Regulatory Authority Across Lifeline Infrastructure Sectors	Not reviewed
	4.2		Evaluate the Ability of Lifeline Infrastructure Systems to Meet Recovery-Based Objectives	Not reviewed
	4.3		Develop National Seismic Design Standards to Meet Recovery-Based Objectives for Lifeline Infrastructure Systems	Not reviewed
	4.4		Create Regional Lifelines Councils	Critical (3)
		4-1	Mandate the Design of New and Upgrade of Existing Lifeline Infrastructure Systems to Meet Recovery-Based Objectives	Not reviewed
		4-2	Encourage the Voluntary Design of New and Upgrade of Existing Lifeline Infrastructure Systems to Meet Recovery-Based Objectives	Not reviewed
		4-3	Trigger the Upgrade of Existing Lifeline Infrastructure Systems to Meet Recovery-Based Objectives	Not reviewed
5			**Develop and Implement Pre-Disaster Recovery Planning Focused on Recovery-Based Objective**	
	5.1		Develop and Implement Pre-Disaster Recovery Plans	Not reviewed
	5.2		Create and Promote Seismic Continuity Programs	Not reviewed
	5.3		Expand and Improve Criteria, Guidelines, and Procedures for Post-Earthquake Assessments and Evaluations	Not reviewed
	5.4		Plan for Sufficient Staffing to Expedite Post-Earthquake Recovery	Not reviewed
6			**Provide Education and Outreach to Enhance Awareness and Understanding of Earthquake Risk and Recovery-Based Objectives**	
	6.1		Educate Building and Lifeline Infrastructure System Stakeholders about Earthquake Risk and Recovery-Based Objectives	Not reviewed
	6.2		Educate Design and Construction Industry Professionals about Earthquake Risk and Recovery-Based Objectives	Not reviewed
7			**Facilitate Access to Financial Resources Needed to Achieve Recovery-Based Objectives**	
	7.1		Develop and Deploy Pre-Disaster Financial Mechanisms to Achieve Recovery-Based Objectives	Not reviewed
	7.2		Develop and Deploy Post-Disaster Financial Mechanisms to Achieve Recovery-Based Objectives	Not reviewed

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5.2 Insufficient Understanding of Social and Economic Consequences from Service Outage

The social and economic consequences of service outages and long-duration service restoration times are not well understood and may be devastating and ripple across the United States. The CEUS has specific problems related to how to address compounding consequences from coincidental and/or sequential hazards (e.g., unrelated or related multiple hazards that occur during the same disaster, response and recovery period); damage of their energy infrastructure and potential impact on large populations (in the Northeastern states) as their energy sources and transmission either originate or pass through seismic regions; and equity and social justice.

To address this issue, research and analyses should be undertaken to improve the understanding of the consequences resulting from earthquake-induced lifeline infrastructure systems service outages and how these systems and their components can be designed and/or upgraded to mitigate social and economic impacts. Specific studies should address compounding hazard impacts (***Project 5.2-A***), damage of energy infrastructure (***Project 5.2-B***), and social equity (***Project 5.2-C***).

The envisioned impact of addressing this issue is reduced social and economic seismic risk.

Project 5.2-A	**Assess Effect of Compound Climatic and Earthquake Hazards on Services**
Description	Perform an assessment of lifeline infrastructure system services that are needed during common CEUS hazards and the consequences from not having those services. Assess how different earthquake scenarios may impact the provision of these services and identify strategies for mitigating compounding impacts resulting from climatic hazards occurring concurrent with earthquake recovery (e.g., severe cold or rain).
Priority level	CRITICAL (3)
Key steps	1. Identify common climatic hazards in different CEUS regions. 2. Identify the lifeline services needed during these climatic hazards and consequences of not having the services to different portions of the populations. 3. Assess how earthquakes in the CEUS will damage lifeline systems and impact ability to provide the needed services. 4. Identify how to mitigate the consequences of service outages through user adaptations, lifeline system adaptations, and improving the system performance by reducing their fragilities.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	More than 5 years

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Project 5.2-B	**Assess Regional Consequences of Energy Infrastructure Failure**
Description	Assess the vulnerability of electric power, natural gas, and oil infrastructure systems to earthquakes in the CEUS and resulting consequences across the entire CEUS region from potential service outages. The assessment should include an estimate of the duration to restore the services.
Priority level	CRITICAL (3)
Key steps	1. Identify/update the inventory of electric power, natural gas, and oil infrastructure systems supplying the CEUS, including their source origination and transmission lines. 2. Assess the earthquake hazard exposure for each of the different energy systems and their fragilities to the hazards. The earthquake hazards need to include all potential transient and permanent ground deformations. 3. Identify the potential for system damages and resulting service outage durations from future expected earthquake scenarios. 4. Estimate the social and economic consequences across the CEUS from the service outages and ripple effects across the United States. 5. Identify potential mitigation options and complete their benefit-cost assessments.
Roles	Government; University/ Research Organizations; Lifelines Organizations
Estimated time	More than 5 years

Project 5.2-C	**Identify Ways to Ensure Social Equity in Service Restoration**
Description	Seismic design for new (or enhancement of existing) infrastructure systems needs to include consideration of equity and social justice. There is an inequity issue in the CEUS on the reliability of lifeline infrastructure system services to vulnerable populations. Many older communities have much more fragile infrastructure which will be more severely damaged and take much longer to restore after an earthquake and can aggravate existing social and economic issues. A study should be undertaken to identify how to properly design new and mitigate existing lifeline infrastructure systems to ensure equity of post-earthquake service restoration throughout communities.
Priority level	IMPORTANT (2.0)
Key steps	1. Assess lifeline infrastructure system service needs in communities across a city. It may be best to select an example city or find generalizations across a number of cities. 2. Identify potential inequity gap by investigating relative fragility of infrastructure serving the neighborhoods and relative consequences of the service outages to various social classes in a community. 3. Develop near-term and long-term solutions to mitigating potential inequities in various neighborhoods including improvement of infrastructure and adaptations that may be useful to close an inequity gap.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	4 to 5 years

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5.3 Insufficient Understanding of Risk Posed by Earthquake Hazards and Multi-Hazards

The CEUS lacks information on some earthquake-related hazards and how they impact lifeline infrastructure systems; how to synergistically enhance performance of lifeline infrastructure systems for earthquake while dealing with multiple other hazards; how to design lifeline infrastructure systems for coincidental and/or sequential hazards, even those hazardous events that may occur infrequently; and how to address compounding consequences during the same disaster response and recovery period.

To address this issue, research and analyses should be undertaken to improve understanding of the issue and how lifeline infrastructure systems can be designed for individual hazards and multi-hazards including the consequences resulting from the design procedure. Methods should be developed for multi-hazard risk evaluation (***Project 5.3-A***), landslide risk assessment (***Project 5.3-B***), and liquefaction risk assessment (***Project 5.3-C***). Studies about seismic behavior of localized soils in the CEUS (***Project 5.3-D***), earthquake scenarios (***Project 5.3-E***) and potential impact to navigability of rivers (***Project 5.3-F***) should be conducted.

The envisioned impact of addressing this issue is that synergistic designs will be implemented that cost efficiently mitigate impacts from multiple hazards.

Project 5.3-A	**Develop Multi-hazard Evaluation Guideline for Seismic Risk Mitigation**
Description	Develop a systematic evaluation method to understand and quantify risks and benefits associated with cross-hazard mitigation in evaluating the business case for earthquake mitigation of lifeline infrastructure systems.
Priority level	CRITICAL (2.5)
Key steps	1. Collect and assess common and best practices, from design, construction, operations, and maintenance perspectives, for mitigating common, non-seismic risks of lifeline infrastructure systems in various CEUS regions. 2. Identify practices that could improve or worsen seismic performance of lifeline infrastructure systems. 3. Collect and assess common and best practices for seismic risk mitigation of lifeline infrastructure systems and identify practices that could worsen performance or increase risk exposure of lifeline infrastructure systems for all other hazards. 4. Develop a multi-hazard evaluation guideline for lifeline system owners so that risks and benefits of seismic mitigation of lifeline systems relative to other common hazards can be effectively evaluated, resulting in “do no harm” to performance and recovery of lifeline systems for all other hazards while improving performance for one hazard.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	More than 5 years

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Project 5.3-B	Develop Method to Assess Earthquake-Induced Landslide Risk
Description	Earthquake-induced landslides can damage lifeline infrastructure systems locally from the ground deformation and create debris collected into rivers that flows downstream and causes damage to downstream communities. A method is needed to assess the local infrastructure system risks to damage from earthquake-induced landslides and potential downstream impacts from the mass wasting.
Priority level	CRITICAL (2.5)
Key steps	1. Identify practices that can identify potential earthquake-induced landslides and map out locations and probabilities of ground movement magnitudes. 2. Identify potential impacts to lifeline infrastructure systems within or in the vicinity of the potential landslide locations. Include direct impacts from vulnerable components at the landslide sites and potential loss of services impacting customers throughout the service area. 3. Investigate immediate and longer-term impacts from landslides moving into water courses which may restrict or dam up water flow, result in mass wasting of debris into the water course, and/or result in debris such as human-made structures and geologic materials deposited into the water course. Longer-term impacts may result from erosion of the ground over time causing sedimentation issues in the water courses. 4. Assess riverine impacts from mass wasting and sedimentation which may change the navigation of the water course, use of water as an intake for potable water supply, use of water for disposal of treated wastewater, and potential damage to downstream levees, locks, piers, wharfs, bridge crossings, or other related issues.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	More than 5 years

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Project 5.3-C	Develop Method to Assess Effects of Liquefaction on Levees and Dams
Description	Earthquake-induced liquefaction can severely impact the performance of water retaining levees and dams, potentially resulting in a catastrophic release of water and longer-term inability to control flooding. Rivers in the CEUS are managed through a system of levees and dams. Depending on the size of the dams, they may or may not be regulated. Catastrophic releases of water result in devastating impacts on downstream communities. Additionally, damage to levees and dams removes the ability to control flooding even from a normal annual flow, resulting in potential flooding of cities and agricultural lands as well as loss of navigation capabilities. Systematic methodologies for assessing the risks from liquefaction-induced damages to dams and levees, incorporating the resulting societal consequences along the rivers, need to be developed.
Priority level	CRITICAL (3)
Key steps	1. Identify practices that can identify potential earthquake-induced liquefaction and map out locations and probabilities of damage to levees and dams. 2. Identify potential impacts from catastrophic releases of water and longer-term inabilities to manage flooding from annual flows. Include societal impacts that go beyond the immediate damage to the levees and dams that involve the (a) social and economic consequences to downstream land uses, (b) inhibiting emergency response and recovery activities in the immediate and short-term aftermath of the earthquake, and (c) dependencies of other lifeline infrastructure systems (e.g., transportation, oil and gas pipelines, water intakes, wastewater discharges).
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	More than 5 years

Project 5.3-D	Characterize Behavior of Specialized Soils
Description	The seismic behavior of localized soils in the CEUS are not well understood and need better characterization to understand how their performance may affect the performance of lifeline infrastructure systems.
Priority level	CRITICAL (2.5)
Key steps	1. Identify soil types unique to the CEUS like varved clay and loess that need improved seismic behavior characterization. 2. Investigate existing testing that may help characterize the CEUS soils. 3. Undertake field and laboratory investigations of the soils, including specialized sampling and testing methods, to confirm if any existing methodologies can be used to calibrate the soil performance and if any new methodologies need to be developed to characterize the soils behaviors.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	1 to 3 years

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Project 5.3-E	Develop Earthquake Scenarios to Assess Expected Performance
Description	CEUS scenario studies are needed with updated data on potential lifelines losses and associated social and economic impacts. Existing studies are limited to some CEUS high seismic zones and are not sufficiently comprehensive to fully address the impacts from damage of all lifeline infrastructure systems and their dependencies and interdependencies.
Priority level	CRITICAL (3)
Key steps	1. Develop plausible and realistic earthquake rupture scenarios for all significant CEUS seismic zones incorporating aftershocks and earthquake sequences. The scenarios should include all potential multi-hazard effects including surface fault rupture, landslide, liquefaction, ground settlement, etc. 2. Develop and utilize CEUS lifeline infrastructure system component fragilities. 3. Include expected performance of all lifeline infrastructure system, loss of services and recovery times, efforts and associated costs to make full repairs, dependencies and interdependencies, and resulting social and economic impacts from potential service outages, including impact on downstream communities outside seismic affected area (e.g., impact on northeastern states from oil pipeline rupture in the New Madrid Seismic Zone).
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	More than 5 years

Project 5.3-F	Study Potential Impacts of Earthquakes on Ability to Navigate Rivers
Description	Several rivers, including the Mississippi River and Ohio River, are important transportation corridors for CEUS. Earthquakes can (1) shift and/or damage river channels, obstruct river channels with collapsed bridges, and damage locks and ports; (2) create debris that falls into rivers causing damage downstream; and (3) impact the drainage infrastructure for agriculture. Studies are needed to understand how an earthquake can impact the ability to navigate rivers and identify potential methods for mitigating impacts.
Priority level	CRITICAL (2.5)
Key steps	1. Identify all the means by which river navigation may be impacted by earthquake including permanent ground deformations, long-term sediment erosion, and damage to interdependent infrastructure. 2. Identify potential mitigation strategies to reduce the navigational impacts.
Roles	Government; University/Research Organizations; Lifelines Organizations, Industry
Estimated time	1 to 3 years

5.4 Insufficient Understanding of Dependencies and Interdependencies

Lifeline infrastructure systems are interconnected and dependent upon each other (e.g., water system requiring electric power to operate). The issue becomes more complicated when the systems are interdependent (e.g., electric power requires water for generation of power while delivery of water requires power to operate the water pumping station). Dependencies and interdependencies are not well understood or documented resulting in difficulty for lifelines organizations to fully account for their impacts on the system post-earthquake performance, especially for emergency response and recovery (e.g., lack of fuel supplies due to transportation damages exacerbates power outages). Current methodologies for assessing dependencies and interdependencies are insufficient and difficult to implement into practice. The continued practice of lifeline infrastructure systems operating in silos inhibits the ability to better understand the existing dependencies and interdependencies, account for them in system seismic assessments, and mitigate or manage their impacts to minimize potential cascading effects during recovery.

To address this issue, improved methodologies should be developed for assessing and incorporating lifeline infrastructure system dependencies and interdependencies into practice. The first step of this process will be to evaluate the barriers for identifying and mitigating dependencies (***Project 5.4-A***). Lessons from the COVID-19 Pandemic will be leveraged (***Project 5.4-B***), an emergency communications plan for lifeline infrastructure systems will be developed (***Project 5.4-C***), and an interdependent socio-technical digital twin computational models will be created (***Project 5.4-D***).

The impact of addressing this issue will be improved emergency response and recovery, reduced service losses from earthquake, and rapid recovery of social and economic activities following earthquakes and other hazards.

Project 5.4-A	**Evaluate Barriers for Identifying and Mitigating Dependencies**
Description	The project focuses on the identification of barriers that inhibit the identification and mitigation of dependencies. Barriers may include legal, security, levels of satisfaction, compatibility/interoperability of platforms, communication, and interaction between agencies, among other things.
Priority level	CRITICAL (3)
Key steps	1. Undertake studies to identify dependencies and interdependencies among lifeline infrastructure systems and with other societal and economic systems. This should include thorough literature review to summarize known issues. Interviews with lifeline infrastructure owners and/or operators are recommended. Example study areas may also be selected to identify how the dependencies and interdependencies may change by geographical area and hazard types. 2. Identify the barriers to addressing dependencies and interdependencies. 3. Identify possible solutions to removing the barriers and when they may apply.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	4 to 5 years

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Project 5.4-B	Leverage Lessons on Interdependencies Learned from the COVID-19 Pandemic
Description	Specific to the COVID pandemic, there is information available on supply chain and work force shortage disruptions. There are tensions between private sector interests (businesses) and public health interests (COVID-related), emergency response needs (disaster-related), or individual post-disaster decision-making (evacuation due to disaster). Studies to investigate and document these issues will improve the knowledge of certain types of dependencies associated with the planning and operation of lifeline infrastructure systems during multiple types of hazard strikes. This type of study will highlight the less studied societal and organizational types of dependencies as opposed to the dependencies related to the physical infrastructure.
Priority level	CRITICAL (3)
Key steps	1. Perform literature survey and conduct interviews to identify the issues noted in the above description associated with the COVID-19 pandemic. 2. Identify lessons learned and effective strategies associated with mitigation of dependencies and interdependencies. 3. Compile the lessons learned and how they can be used to improve lifeline infrastructure systems organizational behaviors to reduce dependency and interdependency impacts.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	1 to 3 years

Project 5.4-C	Design and Implement Plan for Post-Earthquake Information Infrastructure to Facilitate Coordination Among Utilities
Description	Develop emergency communications plan for lifeline infrastructure systems that may be damaged or non-functional following an event to speed up emergency response and recovery. Note: This project is related to Topic 26 in NIST (2014).
Priority level	CRITICAL (2.5)
Key steps	1. Identify dependencies within and among local lifeline infrastructure systems. 2. List the information needed for different systems for them to be able to properly undertake emergency response operations. 3. Knowing the needs from other lifeline infrastructure systems during emergency response, identify platforms and options for, and then develop an emergency communications plan useful for coordination across lifeline infrastructure systems.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	1 to 3 years

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Project 5.4-D	**Create Interdependent Socio-Technical Digital Twin Computational Models**
Description	A socio-technical digital twin is a computational model that integrates the technical built infrastructure and the human interaction necessary for providing services to customers. It includes decision-making processes needed to operate, maintain, and implement post-earthquake repairs and operations. An interdependent socio-technical digital twin is a computational model that incorporates the dependencies and interdependencies between lifeline infrastructure systems. This project encourages the development of multiple models covering the flow and socio-technical aspects of all lifeline infrastructure systems that can simulate the interaction between all of the systems at the human and built infrastructure levels.
Priority level	CRITICAL (3)
Key steps	1. Develop practical multi-modal computational models using a common platform for all lifeline infrastructure systems. Models currently exist for all lifeline infrastructure systems so this step may entail the assurance the models are all able to communicate with each other and provide consistent input and output. It is important that each model is based on common definitions like functionality and operability [e.g., one model should not define functionality restored when all repair are made as an output and another defined as when services are restored to customers (while other repairs are still being made) as input from the other model]. Inconsistent definitions result in misleading results. 2. Develop models for lifeline infrastructure system that include the required human interaction for operational purposes and decision making. These types of lifeline infrastructure system models do not currently exist, at least not at the level needed for the digital twin. 3. Integrate the models together using a common platform. 4. Validate the digital twin using ongoing lifeline infrastructure system performance and case studies from past earthquakes.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	More than 5 years

5.5 Need for a National Lifeline Infrastructure System Component Database

Lifeline infrastructure systems are large complex geospatial systems built with different materials and design specifications as well as specialized components over long periods of time. There is no database incorporating all the information needed to understand their seismic performance. In many cases, the lifeline infrastructure system owners and operators do not have complete records of their own assets. The key information is also limited or non-accessible to researchers who can undertake critical assessments on the seismic performance.

To address this issue, a national database of lifeline infrastructure system components, including their connectivity, should be created (***Project 5.5-A***).

The impact of addressing this issue is that broad-reaching assessments of lifeline infrastructure system performances in earthquakes and other hazards (i.e., similar to those undertaken by the Mid-America Earthquake Center) which will inform service providers and users of the potential damages, loss of services, and the social, economic, and environmental consequences.

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Project 5.5-A	Develop and Maintain a National Lifeline Infrastructure System Component Database
Description	Identify an organization for creating and maintaining a database of national lifeline infrastructure systems and their components. Undertake research to identify the extent and level of details for the systems and their components to be included in the database. Leverage the efforts accomplished by the New York University - Unification for Underground Resilience Measures (NYU-UNUM).
Priority level	CRITICAL (3)
Key steps	1. Identify an organization who will create and maintain the database and be included from the onset of the project. 2. Identify the lifeline infrastructure systems in the CEUS to be included in the database. This may start with regional systems and then incorporate local systems. 3. Work with the lifeline infrastructure system owners and operators to populate the database. 4. Develop methods for assuring legal and security matters are managed. 5. Develop a typology for infrastructure components and their fragilities. Existing typologies can be drawn upon for this step. 6. Undertake periodic and ongoing efforts to identify and log information on components that do not have existing records.
Roles	Government; University/Research Organizations; Lifelines Organizations
Estimated time	More than 5 years

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Chapter 6

Summary Tables

This chapter provides a cost estimate for the recommended projects at the topic area-level and tables that summarize the issues and recommended projects presented in Chapters 3 to 5. The summary tables are intended to present the issues and recommended projects such that themes across issues and level of priorities are easy to retrieve for planning purposes.

A cost estimate to implement all projects in each topic area is provided in Table 6-1. These cost estimates are based on expenditures for similar projects funded by the Federal Government in the past. It is estimated that implementation of this program will require up to $42M. It is assumed that experimental testing is minimal. It is anticipated that NIST will conduct cost estimating exercises as part of the procurement process to confirm and update the estimates as the program is implemented.

Table 6-1 Cost Estimate for Recommended Projects

Chapter	Topic Area	Cost estimate ($ Million)
3	Hazard Characteristics and Design Philosophies	13
4	Buildings	19
5	Lifeline Infrastructure[1]	10
	Total	**42**

[1] Estimate does not include items from the prior reports described in Section 5.1.

Groupings of issues by theme can be generated using Table 6-2, which assigns each issue to one or more themes. The eight themes are fundamental research, perception of seismic requirements, social impacts, multi-hazard considerations, enhanced seismic performance, education or training, code development, and code adoption or enforcement.

Priority levels can be compared across all recommended projects using Tables 6-3 to 6-5, which list all issues and recommended projects by chapter along with priority, from moderately important to critical. Table 6-3 covers Chapter 3, *Hazard Characteristics and Design Philosophies*. Table 6-4 covers Chapter 4, *Buildings*. Table 6-5 covers Chapter 5, *Lifeline Infrastructure*. See Section 5.1 for more information about how priority levels were determined.

Table 6-2 Assignment of Themes to Issues

Section and Issue Title	Fundam. research	Perception	Social Impacts	Multi-hazard	Enhanced Perform.	Education/ Training	Code Develop.	Code Adopt. & Enforce.
3.1 Insufficient Accuracy of Hazard Modelling	✓							
3.2 Design Motions for Seismic Safety Based on WUS Hazard	✓						✓	
3.3 Insufficient Understanding of Site Characteristics	✓							
3.4 Sensitivity of Seismic Design Category Thresholds							✓	
3.5 Insufficient Understanding of Geohazard and Multi-Hazard Considerations	✓			✓				
3.6 Need for CEUS Involvement in Develop. of Resilience and FR-based Provisions	✓		✓		✓		✓	
4.1 Perception that ASCE/SEI 7 Standard is Complicated and/or Not Reflective		✓				✓		✓
4.2 Perception that Seismic Design is Expensive		✓						✓
4.3 Lack of Access to Training Resources for Engineers						✓		
4.4 Unknown Impact of Delegated Design on Seismic Performance		✓				✓		✓

Table 6-1 Assignment of Themes to Issues (continued)

Section and Issue Title		Fundam. research	Perception	Social Impacts	Multi-hazard	Enhanced Perform	Education/ Training	Code Develop.	Code Adopt. & Enforce.
4.5	Lack of Building Stock Inventory Data	✓		✓				✓	
4.6	Lack of Best Practices for Unique Existing Building Characteristics						✓		
4.7	Perception that ASCE/SEI 41 Standard is Complicated and/or Not Reflective		✓					✓	✓
4.8	Challenges in Adoption of Seismic Code Provisions		✓						✓
4.9	Challenges in Seismic Code Provision Enforcement		✓						✓
4.10	Large Amount of Building Stock Needing Seismic Retrofit			✓					✓
5.1	Prioritization of the Prior Lifeline Infrastructure System Recommendations					✓			✓
5.2	Insufficient Understanding of Social & Economic Conseq. from Service Outage			✓		✓			
5.3	Insufficient Understanding of Risk Posed by Earthquake Hazards and Multi-Hazards	✓			✓	✓			
5.4	Insufficient Understanding of Dependencies and Interdependencies	✓				✓			
5.5	Need for a National Lifeline Infrastructure System Component Database	✓							

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Table 6-3 Issues and Recommended Projects: Hazard Characteristics and Design Philosophies

Issue	Project	Title	Priority
3.1		**Insufficient Accuracy of Hazard Modelling**	
	3.1-A	Include Induced Seismicity in Long-Term Hazard Models	Important (1.7)
	3.1-B	Improve Seismic Source Modeling	Critical (2.5)
	3.1-C	Improve Ground Motion Models	Critical (2.5)
	3.1-D	Develop and Implement Maximum Direction Factors	Important (1.9)
	3.1-E	Update the Long Period Parameter T_L and Displacement Spectrum	Important (1.9)
	3.1-F	Improve Hazard Uncertainty Approximation	Important (1.8)
3.2		**Design Motions for Seismic Safety Based on WUS Hazard**	
	3.2-A	Examine Seismic Structural Fragility Relations	Critical (2.5)
	3.2-B	Perform Cost and Benefit Studies	Critical (2.5)
	3.2-C	Determine Vulnerability of Short Period Structures	Critical (2.5)
	3.2-D	Consider Density of Built Environment	Important (2.0)
	3.2-E	Develop Reliability Targets for Existing Structures	Important (2.4)
3.3		**Insufficient Understanding of Site Characteristics**	
	3.3-A	Determine Site Response Analysis Parameters	Important (2.2)
	3.3-B	Develop Guidelines for Site-Specific Response Analysis	Important (2.3)
3.4		**Sensitivity of Seismic Design Category Thresholds**	
	3.4-A	Assess Cost of Seismic Design Category Requirements	Important (2.0)
	3.4-B	Review Thresholds for Seismic Design Categories	Critical (2.6)
	3.4-C	Improve Seismic Design Categories	Critical (2.5)
3.5		**Insufficient Understanding of Geohazard and Multi-Hazard Considerations**	
	3.5-A	Study Impact of Environmental Changes on Earthquake Hazard	Important (1.7)
	3.5-B	Study Wave Propagation Demands on Pipelines	Important (1.8)
	3.5-C	Develop Liquefaction Guidelines and Maps	Important (2.3)
	3.5-D	Compile Geophysical Database	Important (2.4)
	3.5-E	Identify Multi-Hazard and Compounding Event Types	Important (2.2)
3.6		**Need for CEUS Involvement in Development of Resilience and FR-based Provisions**	
	3.6-A	Develop Integrated Seismic Performance Classification System	Important (2.0)
	3.6-B	Develop Seismic Damage Fragility Relations	Critical (2.6)
	3.6-C	Define Seismic Performance Expectations for Resilience	Critical (2.6)
	3.6-D	Develop Tentative Provisions for Seismic Resilience in the CEUS	Critical (2.6)
	3.6-E	Quantify the Benefits of a Multi-Hazard Approach to FR	Critical (2.8)
	3.6-F	Determine Publication Methodology for FR Provisions	Important (2.0, 2.3)
	3.6-G	Develop Practical Functional Recovery Provisions for CEUS	Important (2.3)

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Table 6-4 Issues and Recommended Projects: Buildings

Topic	Project	Title	Priority
4.1		**Perception that ASCE/SEI 7 Standard is Complicated and/or Not Reflective**	
	4.1-A	Conduct a Survey of Engineers about ASCE/SEI 7 Seismic Provisions	Important (2.0)
	4.1-B	Develop Alternative Simplified Procedures	Important (2.0)
	4.1-C	Add Missing Buildings Systems and Characteristics	Important (2.0)
	4.1-D	Review of Use of "R=3" Lateral Systems	Important (2.0)
4.2		**Perception that Seismic Design is Expensive**	
	4.2-A	Study Cost Impact of Seismic Design Provisions	Moderately important (1.2)
	4.2-B	Determine Cost Impact of SDC Step-functions in Seismic Design Provisions	Moderately important (1.2)
4.3		**Lack of Access to Training Resources for Engineers**	
	4.3-A	Conduct a Survey of Engineers and Building Officials about Seismic Requirements	Important (2.2)
	4.3-B	Adapt Existing Guidelines and Training Materials	Important (2.2)
	4.3-C	Provide Training to Engineers about New Technologies	Moderately important (1.3)
4.4		**Unknown Impact of Delegated Design on Seismic Performance**	
	4.4-A	Conduct a Survey of Engineers about Delegated Design	Important (2.0)
	4.4-B	Quantify the Impact of Delegated Design on the Expected Seismic Performance	Important (2.0)
4.5		**Lack of Building Stock Inventory Data**	
	4.5-A	Collect Building Stock Data	Moderately important (1.5)
	4.5-B	Identify Common Building Typologies	Critical (2.5)
	4.5-C	Conduct Literature Review of Historical Building Codes for Lateral Force Design	Moderately important (1.5)
	4.5-D	Determine if There is a Disproportionate Seismic Risk to Low Income Housing	Important (2.0)
	4.5-E	Develop a Strategy to Mitigate the Disproportionate Seismic Risk to the Housing Stock in Low Income Areas	Important (2.0)
4.6		**Lack of Best Practices for CEUS-Specific Existing Building Characteristics**	
	4.6-A	Develop a Framework for Party Wall Buildings	Critical (2.5)
	4.6-B	Develop a Framework for Construction in Adjacent Buildings	Critical (2.5)
	4.6-C	Develop a Framework for Seismic Alterations on Multi-tenant Buildings	Critical (2.5)
	4.6-D	Account for Effect of Material Degradation	Important (2.0)

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Table 6-4 Issues and Recommended Projects: Buildings (continued)

Topic	Project	Title	Priority
4.7		**Perception that ASCE/SEI 41 Standard is Complicated and/or Not Reflective**	
	4.7-A	Add Vulnerable Building Types Not Currently Represented	Critical (2.6)
	4.7-B	Determine Benchmark Buildings	Important (2.2)
	4.7-C	Improve Representation of Typical Material Properties	Important (2.0)
	4.7-D	Develop Simplified Method for Use on Small Projects	Critical (2.7)
4.8		**Challenges in Adoption of Seismic Code Provisions**	
	4.8-A	Identify Jurisdictions that Adopt and Enforce Building Codes	Important (2.1)
	4.8-B	Form Regional Coalition to Support Code Adoption	Important (2.1)
	4.8-C	Evaluate Residential Seismic Provisions	Important (1.8)
	4.8-D	Survey Contractors and Owners about Resistance to Seismic Provisions	Important (2.4)
4.9		**Challenges in Seismic Code Provision Enforcement**	
	4.9-A	Conduct a Survey of Building Officials about Qualifications	Critical (2.6)
	4.9-B	Provide Training to Code Officials about Critical Seismic Features	Important (2.1)
	4.9-C	Conduct a Survey of Building Officials about Enforcement	Important (2.4)
	4.9-D	Provide Training to Engineers and Code Officials about Masonry Grout	Important (1.7)
	4.9-E	Improve Nonstructural Component Seismic Anchorage	Critical (2.5)
4.10		**Large Amount of Building Stock Needing Seismic Retrofit**	
	4.10-A	Respond to the Prevalence of Pre-seismic Buildings	Important (2.3)
	4.10-B	Increase Prevalence of Voluntary Seismic Retrofits	Important (1.7)
	4.10-C	Improve Mandatory Seismic Retrofits	Important (2.3)
	4.10-D	Increase Retrofit of Potential Falling Hazards	Important (2.4)
	4.10-E	Conduct Cost-Benefit Studies for Seismic Retrofits	Important (2.2)

Table 6-5 Issues and Recommended Projects: Lifeline Infrastructure

Topic	Project	Title	Priority
5.1		**Prior Lifeline Infrastructure System Recommendations**	
	N/A	NIST GCR 14-917-33, *Earthquake-Resilient Lifelines: NEHRP Research, Development, and Implementation Roadmap*	See 5.1.1
	N/A	NIST GCR 16-917-39, *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery*	See 5.1.2
	N/A	FEMA P-2090/NIST SP-1254, *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time*	See 5.1.3
5.2		**Insufficient Understanding of Social and Economic Consequences from Service Outage**	
	5.2-A	Assess Effect of Compound Climatic and Earthquake Hazards on Services	Critical (3)
	5.2-B	Assess Regional Consequences of Energy Infrastructure Failure	Critical (3)
	5.2-C	Identify Ways to Ensure Social Equity in Service Restoration	Important (2)
5.3		**Insufficient Understanding of Risk Posed by Earthquake Hazards and Multi-Hazards**	
	5.3-A	Develop Multi-hazard Evaluation Guideline for Seismic Risk Mitigation	Critical (2.5)
	5.3-B	Develop Method to Assess Earthquake-Induced Landslide Risk	Critical (2.5)
	5.3-C	Develop Method to Assess Effects of Liquefaction on Levees and Dams	Critical (3)
	5.3-D	Characterize Behavior of Specialized Soils	Critical (2.5)
	5.3-E	Develop Earthquake Scenarios to Assess Expected Performance	Critical (3)
	5.3-F	Study Potential Impacts of Earthquakes on Ability to Navigate Rivers	Critical (2.5)
5.4		**Insufficient Understanding of Dependencies and Interdependencies**	
	5.4-A	Evaluate Barriers for Identifying and Mitigating Dependencies	Critical (3)
	5.4-B	Leverage Lessons on Interdependencies Learned from the COVID-19 Pandemic	Critical (3)
	5.4-C	Design and Implement Plan for Post-Earthquake Information Infrastructure to Facilitate Coordination Among Utilities	Critical (2.5)
	5.4-D	Create Interdependent Socio-Technical Digital Twin Computational Models	Critical (3)
5.5		**Need for a National Lifeline Infrastructure System Component Database**	
	5.5-A	Develop and Maintain a National Lifeline Infrastructure System Component Database	Critical (3)

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Appendix A

Workshop Agenda

ATC-NIST Workshop on
Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States (CEUS)

October 17-18, 2022
Sheraton Charlotte Airport Hotel, *Ballroom AB*

Workshop Objectives:

- Identify problems with current seismic design practices as applied to new buildings, existing buildings, and lifeline infrastructure in the CEUS.
- Identify differences in regional construction types and construction methods for new and existing buildings and lifeline infrastructure systems in the CEUS.
- Consider a balance between technical and social needs, and economic costs and benefits.
- Develop a list of research and practice needs, describe potential research tasks and their expected impacts, estimate time and effort, and prioritize recommendations.

DAY 1 AGENDA: Monday, October 17
Registration and refreshments starting at 12:30pm
Technical program: 1:00pm – 5:30pm

Time	Group	Location	Subject
12:30pm		*Ballroom AB*	*Registration and light refreshments*
1:00pm (20 min)	Plenary	Ballroom AB	Welcome (ATC) • Introductory Remarks (NIST) • Workshop Agenda and Objective (E. Guglielmo)
1:20pm (60 min)	Plenary	Ballroom AB	Brief overview of current state of practice and known issues • Buildings (N. Gould, J. Furr, K. Rubenacker) • Lifelines (K. Yu, C. Davis)
2:20pm			15 min break *(light refreshments)*
		Hazard Characteristics and Design Philosophy Session	
2:35pm (90 min)	Plenary	Ballroom AB	Presentations • Hazard (S. Rezaeian, J. Stewart, O. Boyd) • Design Philosophy (J. Harris, N. Luco, S. Pezeshk)
4:05pm (60 min)	Breakout	Ballroom AB, Degaulle, Heathrow	Guided discussions
5:05pm (20 min)	Plenary	Ballroom AB	Report out: Issues/research tasks (E. Guglielmo)
5:25pm (5 min)	Plenary	Ballroom AB	Day 1 closing remarks (E. Guglielmo)
5:30pm			Adjourn for the day

(Flip page for Day 2)

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DAY 2 AGENDA: Tuesday, October 18
Light breakfast available at 7:30am
Technical program: 8:00am – 4:00pm

Start	Group	Location	Subject	
7:30am	*N/A*	*Ballroom AB*	*Beverages and light refreshments available*	
8:00am (15 min)	Plenary	Ballroom AB	Welcome (ATC) • Agenda review (Day 2) (E. Guglielmo) • Setting the stage for breakout discussions (E. Guglielmo)	
8:15am			5 min break (go to track)	
			<u>*Buildings Track*</u> Location: Ballroom AB (J. Furr, N. Gould, K. Rubenacker)	<u>*Lifelines Track*</u> Location: Degaulle/Heathrow (K. Yu, C. Davis)
8:20am (15 min)	Full track		Building topic session #1 presentation	Lifeline topic session #1 presentation
8:35am (55 min)	Breakouts		Guided discussions	Guided discussions
9:30am (20 min)	Full track		Report out: Issues/tasks	Report out: Issues/tasks
9:50am			20 min break *(light refreshments)*	
10:10am (15 min)	Full track		Building topic session #2 presentation	Lifeline topic session #2 presentation
10:25am (55 min)	Breakouts		Guided discussions	Guided discussions
11:20am (20 min)	Full track		Report out: Issues/tasks	Report out: Issues/tasks
11:40am			Lunch in Junior Ballroom	
12:40pm (15 min)	Full track		Building topic session #3 presentation	Lifeline topic session #3 presentation
12:55pm (60 min)	Breakouts		Guided discussions	Guided discussions
1:55pm (20 min)	Full track		Report out: Issues/tasks	Report out: Issues/tasks
2:15pm			20 min break *(light refreshments)*	
2:35pm (55 min)	Full track		Prioritization	Prioritization
3:30pm			5 min break (go to plenary)	
3:35pm (25 min)	Plenary	Ballroom AB	Closing remarks	
4:00pm			Adjourn workshop	

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Appendix B

Workshop Presentations

B.1 Day 1 Opening Plenary Session

B.2 Hazard Characteristics and Design Philosophy Plenary Session

B.3 Day 1 Closing Plenary Session

B.4 Day 2 Opening Plenary Session

B.5 Parallel Track Sessions

B.5.1 Buildings Track

B.5.1 Lifeline Infrastructure Track

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ATC-NIST Workshop on Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States (CEUS)

October 17-18, 2022
Charlotte, North Carolina

Welcome!

1

Workshop Context

- Who are we?
  - NIST-funded ATC-156 Project on Seismic Practice Needs in the CEUS
- Who are you?
  - Participants from practice, research, code development, and government
  - Representing a range of disciplines
  - From across the Central and Eastern United States

2

Workshop Context

- Workshop Objectives
  - Identify problems with current seismic design practice in the CEUS.
  - Develop a prioritized list of research and practice needs and describe potential projects to address those needs.

.... not <u>solving</u> any problems today!
...staying focused on the <u>CEUS</u>!

3

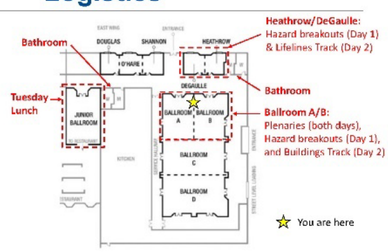
Workshop Context

- Workshop Outcomes
  - NIST report to published in early 2023
  - To be used by NIST as guide for future research and funding
  - Will be released publicly as a reference for others to consider in their own research and funding priorities

4

Logistics

- Over the next day and a half



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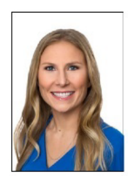
Introductions

Jay Harris
Acting NEHRP Director
Research Structural Engineer, NIST



Emily Guglielmo
Chair of the ATC-156 Project Steering Committee
Principal, Martin/Martin Consulting Engineers

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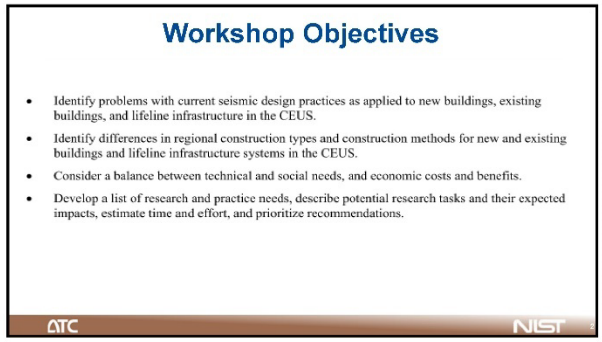

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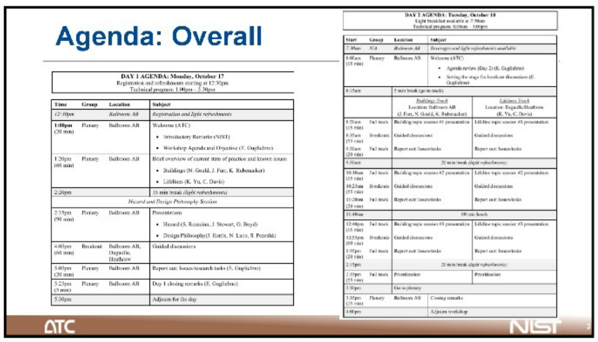

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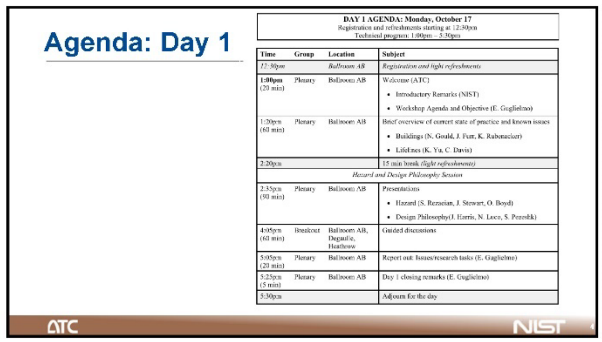

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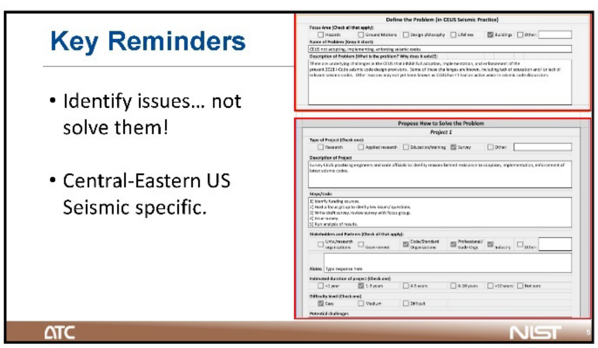

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Current Issues Impacting the Seismic Design and Construction of Buildings in the CEUS

Julie Furr, P.E.
Nathan Gould, D.Sc., P.E., S.E.
Karl Rubenacker, P.E., S.E., CWI, F.SEI

October 17, 2022

1

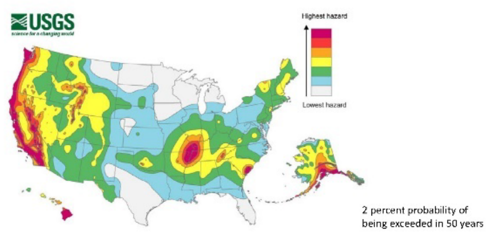
Topics

1. Central and Eastern US Seismicity
2. Evolution of Seismic Design in the CEUS
3. Impediments to CEUS Seismic Requirements
4. Breakout Sessions
   a. Implementation of Current Seismic Code Provisions
   b. Seismic Codes: CEUS Design and Construction
   c. Existing CEUS Building Stock

…Functional Recovery…

2

Central and Eastern US Seismicity



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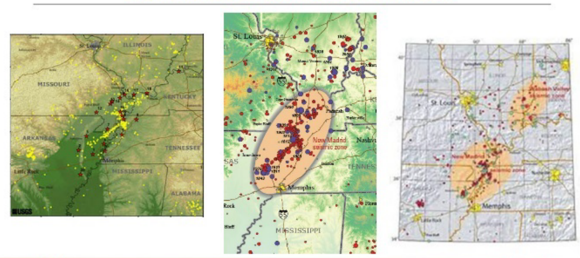
New Madrid Seismic Zone



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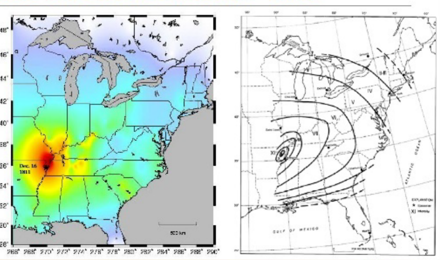
New Madrid Seismic Zone

The 1811-1812 New Madrid sequence consisted of three large earthquakes:

- M~7.5 on December 16, 1811
- M~7.3 on January 23, 1812
- M~7.5 on February 7, 1812



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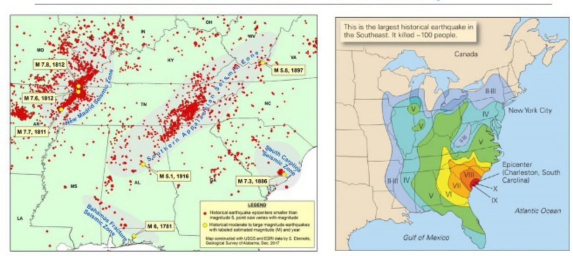
Southeast US Seismicity



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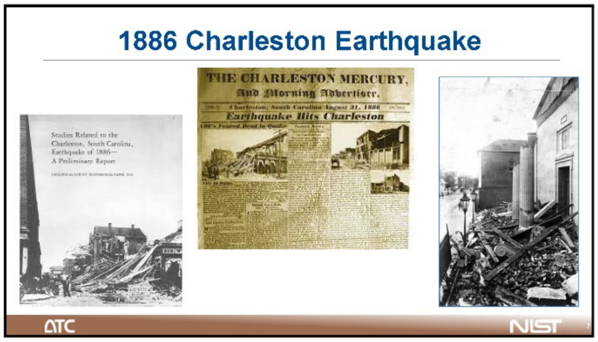

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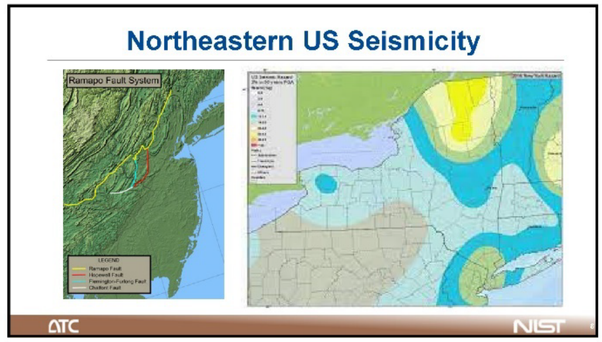

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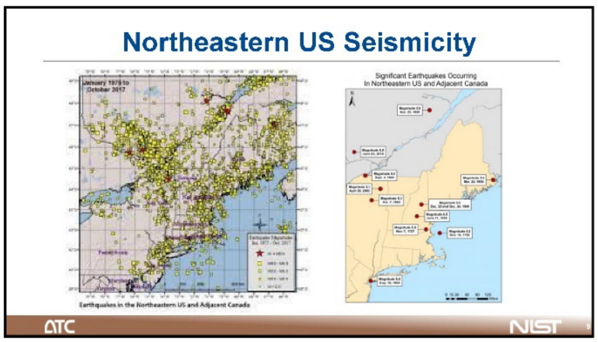

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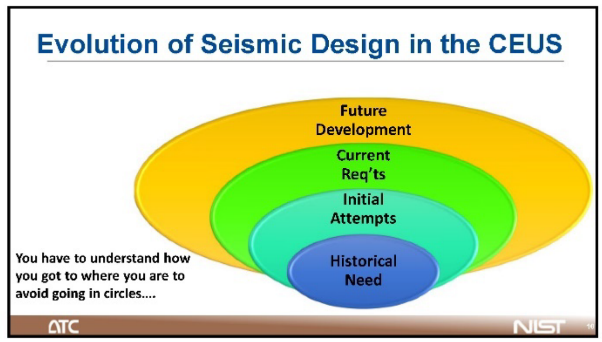

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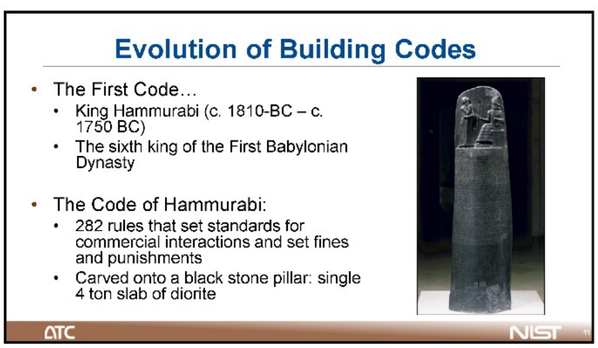

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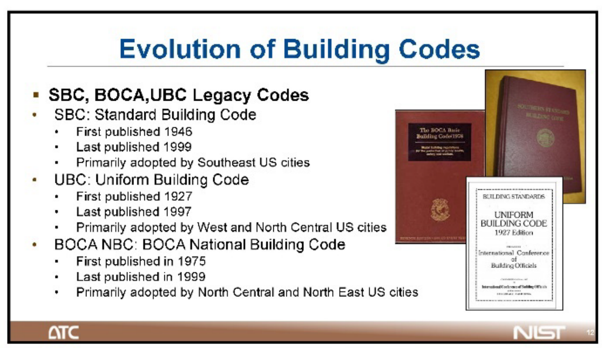

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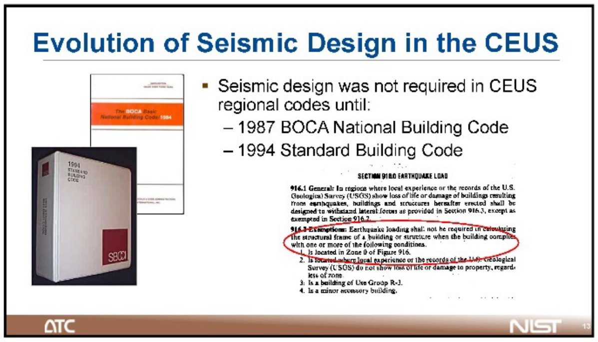

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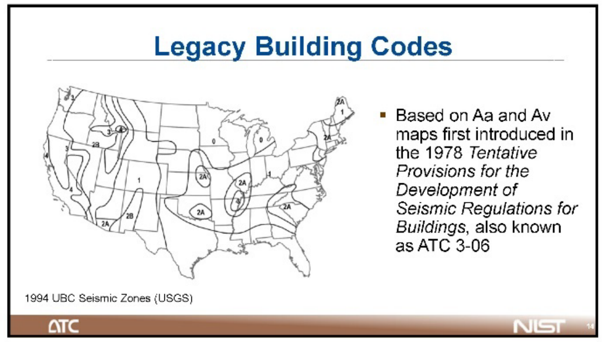

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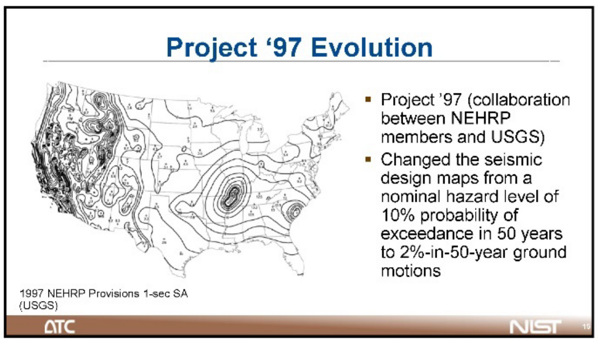

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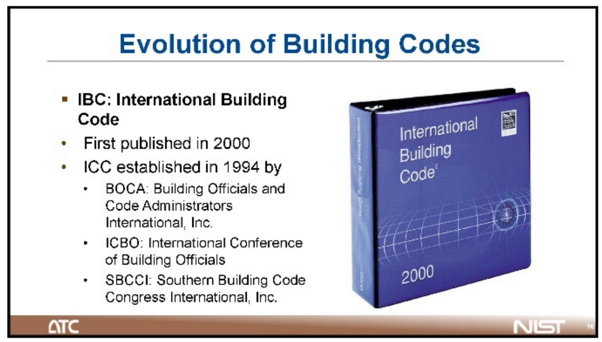

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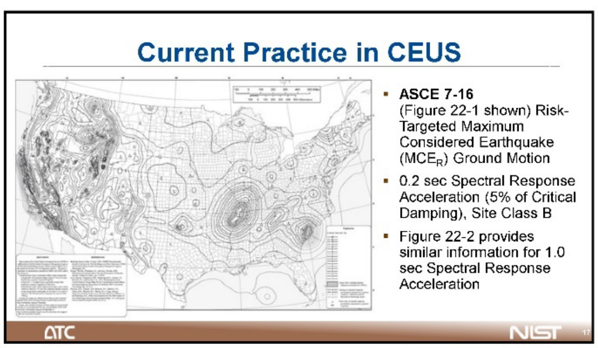

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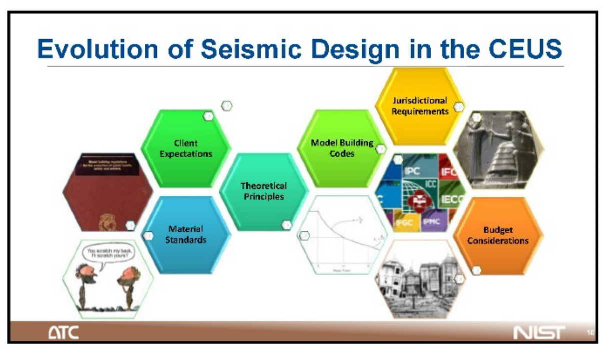

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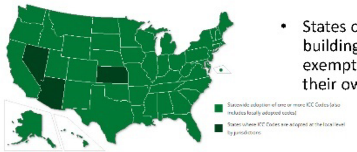
Evolution of Seismic Design in the CEUS

- **States/Counties/Cities**
- States can adopt their own codes without Federal Interference
- Not all states have a state wide building code



- States can have a state wide building code with smaller exempt jurisdictions that adopt their own codes like Tennessee

*STRUCTURAL DESIGN

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Evolution of Seismic Design in the CEUS

LOCAL AMENDMENTS - Residential

- Tennessee
  - West Tennessee IRC amendment replaces all IRC seismic provisions
  - Same being considered at state level right now
- Mississippi
  - North MS counties have adopted West TN IRC amendment
- North Carolina
  - 13 Counties assigned to SDC C. All others are SDC A or B.
  - IRC only applies to townhouses in SDC C.
  - All one and two family structures are exempt from seismic provisions.
  - Deleted and replaced with their own version:
    - All bracing tables, sections applying to D0, D1, or D2, and connection sections in chapter 6
  - Deleted all cold formed steel provisions

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Evolution of Seismic Design in the CEUS

LOCAL AMENDMENTS - Residential

- South Carolina
  - Recent formal recommendations to the State:
    - Implement 2018 IRC SDC maps where SDC will reduce in 2018
    - Keep 2015 IRC SDC maps where SDC will increase in 2018
    - Replace SDC E with SDC D_2
    - Perform additional research on PSHA maps to develop a state map
      - Add time-dependent branches back in the ground motion
      - Perform additional research to investigate the evidence that the magnitude of the 1886 earthquake may have been significantly smaller that currently assumed in USGS
      - Determine more accurate site factors across the state

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Evolution of Seismic Design in the CEUS

LOCAL AMENDMENTS - Existing

- South Carolina
  - Eliminated site specific study requirement for specific short period structures
  - Reinstated 2012 Chapter 34 in lieu of IEBC
- Kentucky
  - State wide ground motion values assigned by county (less than USGS)
- Georgia
  - Reinstated 2012 Chapter 34 in lieu of IEBC

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Evolution of Seismic Design in the CEUS

LOCAL AMENDMENTS - Commercial

- Arkansas
  - Exempt from seismic requirements (1999):
    - wood or metal constructed business occupancies of 4,000 sf or less
    - business occupancy < 40
    - mercantile occupancy < 100
    - Storage occupancy
  - Reduced seismic requirements (2016)
    - Category I and II: industrial, manufacturing, public works
    - Seismic base shear shall not be less than 1997 SBC
    - ~30%-50% of the ASCE 7 base shear

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Evolution of Seismic Design in the CEUS

- Arkansas

STEEL MOMENT FRAME STRUCTURE

Basic Assumptions

30' Tall Structure

Moment Frame System: OMF (SBC), IMF (IBC)

IBC 2012 vs. SBC 1999 Design Base Shears

Location	1997/1999 SBC				IBC 2012 (ASCE 7-10)				
	Av	Aa	Cs	Vb (lbs)	Sds	Sd1	Cs	Vb (lbs)	
Zone 1 (Little Rock)	0.100	0.050	0.028	2,800	0.399	0.234	0.089	8,900	31%
Zone 2 (Forrest City)	0.200	0.100	0.056	5,600	0.754	0.411	0.168	16,800	33%
Zone 3 (Jonesboro)	0.300	0.200	0.111	11,100	0.955	0.501	0.212	21,200	52%

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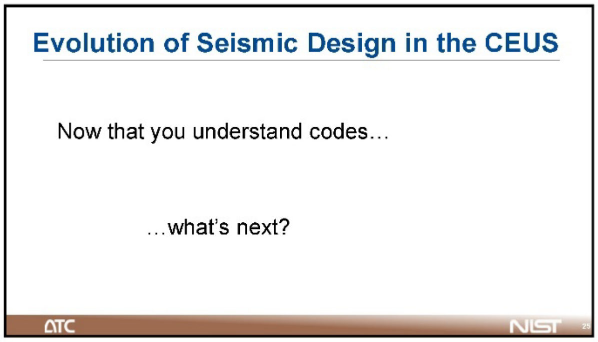

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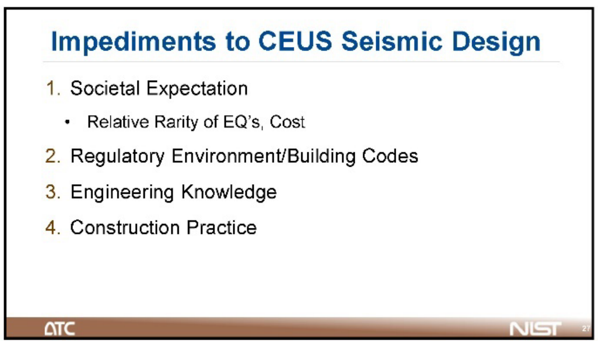

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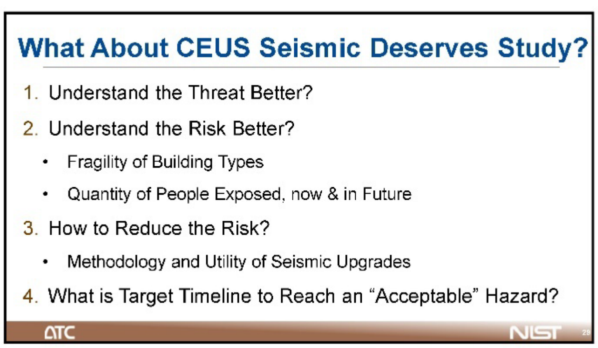

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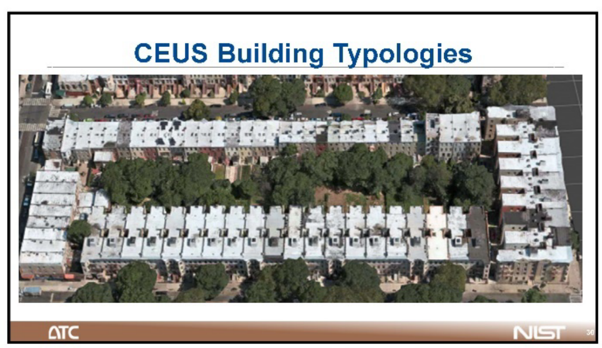

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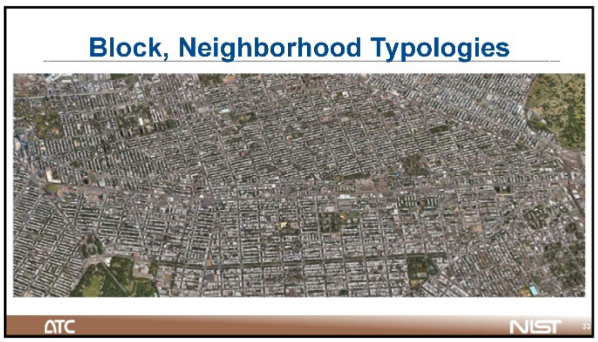

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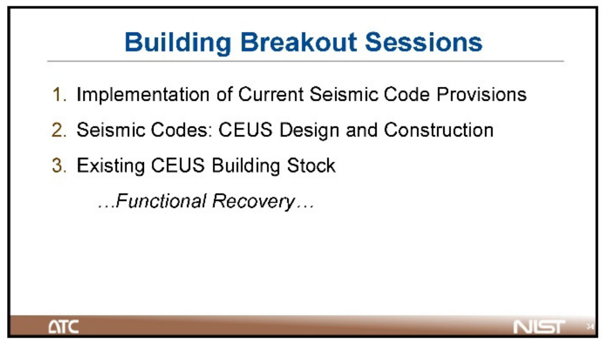

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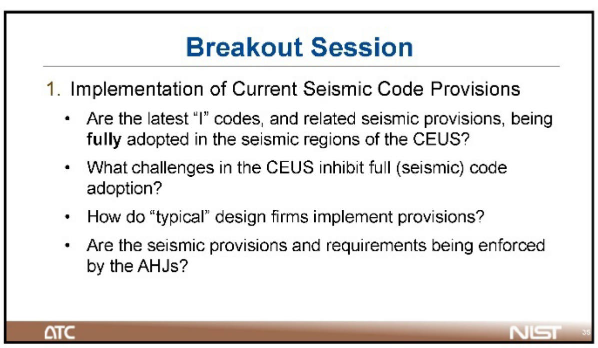

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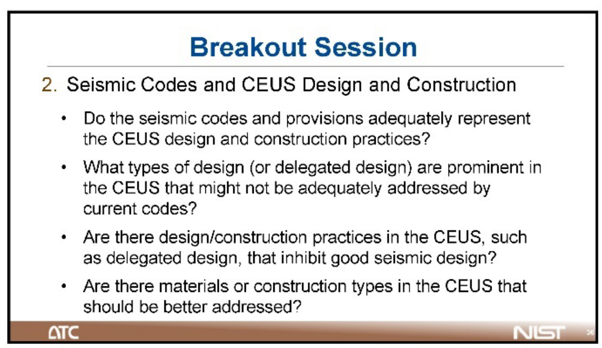

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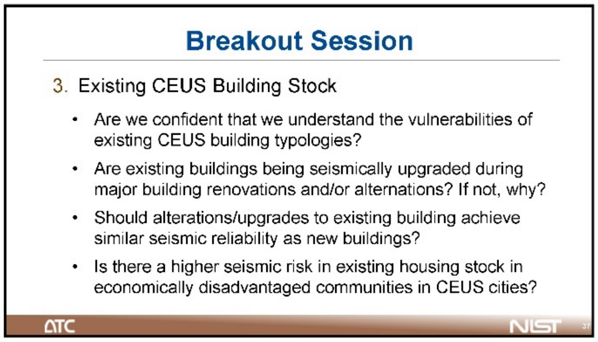

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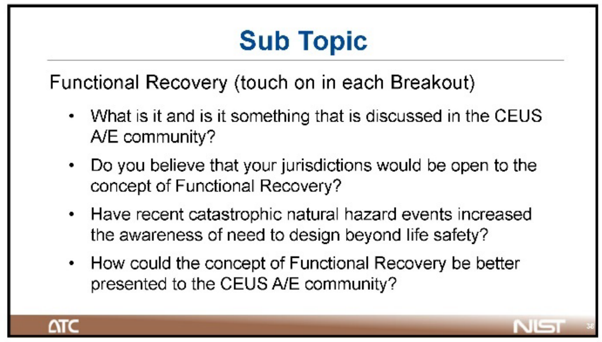

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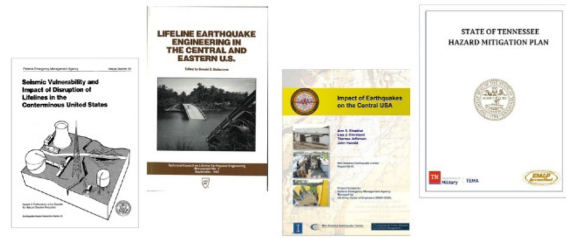
Lifeline Infrastructure Systems

Craig Davis, PhD, PE, GE
Kent Yu, PhD, PE, SE
October 17, 2022

1

Lifeline Infrastructure Systems



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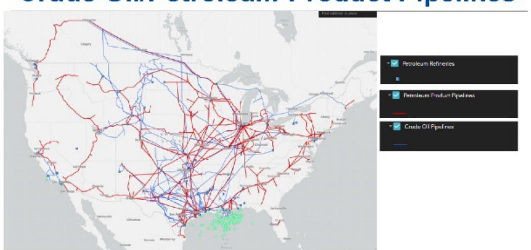
Crude Oil/Petroleum Product Pipelines



https://www.fractracker.org/2020/02/national-energy-petrochemical-map/

3

Lifeline Infrastructure Systems

- Infrastructure Systems = the physical and organizational structures needed for the operation of a society or enterprise
- Lifeline Infrastructure Systems:
  - Electric Power
  - Gas and Liquid Fuels
  - Transportation
  - Water & Wastewater (storm water)
  - Communication
  - Solid Waste

4

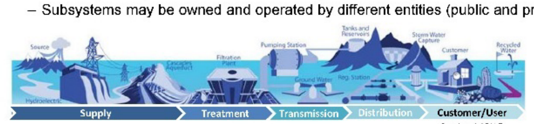
Lifeline Infrastructure Systems Overview

- Large geographically distributed systems
  - Some cover multiple regions, states, or countries
- Made of numerous interlinked specialized components
  - Designed & built over long timeframes
- Interdependent & Co-located
  - Performance of one affects the others
  - Proximity means failure of one can result in unintended damage to others
- Systems need intimate coordination
  - Yet tend to operate in silos

5

System of Systems & Services for Services

- Lifelines are systems within broader technical and social systems
- All Lifelines provide services
- Lifeline systems are made up of subsystems
  - All must coordinate to provide services to end users
- Each subsystem provides services used by other subsystems
  - Subsystems may be owned and operated by different entities (public and private)



Courtesy LADWP

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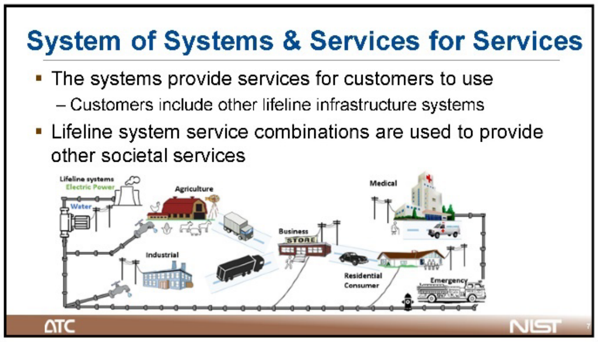

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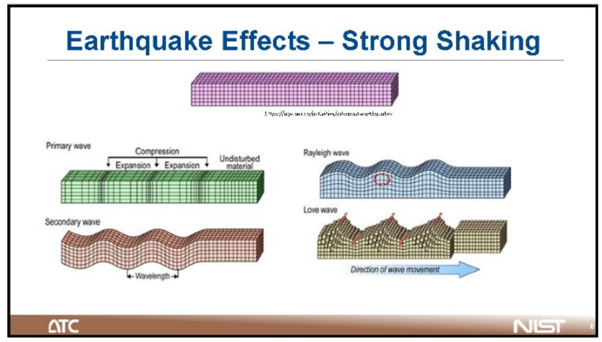

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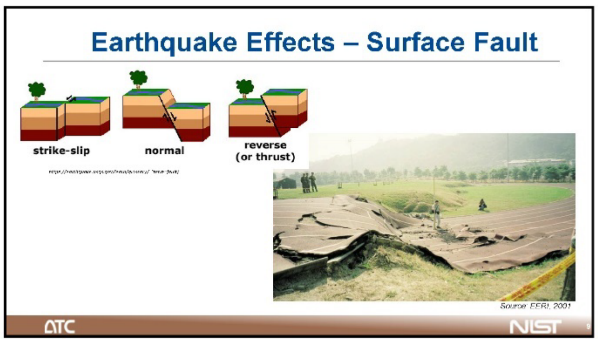

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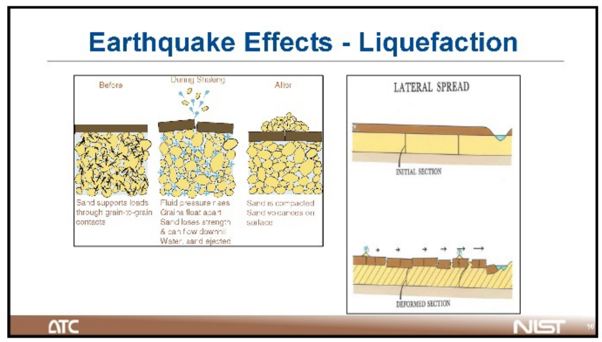

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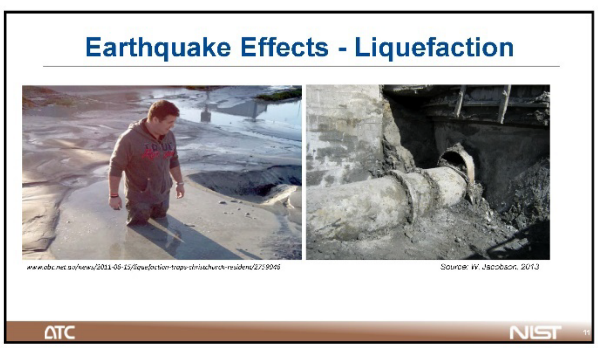

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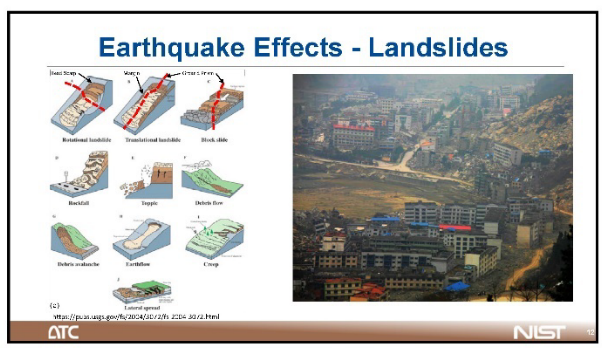

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Lifeline Infrastructure Systems Overview

- Failures in a single system can cause
  - Cascading failures in other systems
  - Public health and safety concerns
    - Flooding
    - Explosion
    - Fire
    - Electrocution
    - Contaminated water
    - Blocking mobility or communication
    - Wide loss of services

Photo: Balboa Blvd. 1994 Northridge Earthquake, damages to multiple lifelines (road, water, gas, electric power) – cascading failures and hazards

13

Lifeline System Services

- Need to recognize that not all lifeline infrastructure systems are used for a single purpose. Each may also provide different levels and types of service.

For example

- A single water system can be used to provide water for irrigation, sanitation, fire fighting, human consumption, and other purposes.

Recognizing the multiple service categories lifelines systems provide is critical for addressing their importance for supporting community resilience

14

History of Lifeline Earthquake Engineering

- 2021 is the 50-year anniversary of Lifeline Earthquake Engineering
- On February 9, 1971 a M6.6 earthquake struck the northern San Fernando Valley.
- Damage was wide-spread in Los Angeles and nearby cities
  - Schools
  - Hospitals
  - Homes
  - Other buildings
  - All lifeline systems

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San Fernando Earthquake – Lifeline Systems

Fault rupture in Interstate 210 – Caltrans photo

Scarp at Foothill Nursing Home – USGS Photo

16

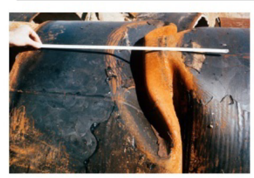
San Fernando Earthquake – Lifeline Systems

Upper San Fernando Dam showing movement of parapet wall – LADWP photo

Lower San Fernando Dam – remains of crest after upstream slope failure – LADWP photo

17

San Fernando Earthquake – Lifeline Systems



Damaged Section of the 49.5 inch diameter Granada Trunkline in the Utility Corridor – LADWP photo

Buckle in the 2- million gallon Sesnon Tank where steel plate thickness changed from 9/16-inch to 7/16-inch – LADWP photo

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San Fernando Earthquake – Lifeline Systems


Damaged Power Equipment at Sylmar Switching Station – LADWP photos

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San Fernando Earthquake – Lifeline Systems

Gas pipe taken from the shear-thrust zone across Glenoaks Boulevard – USGS photo

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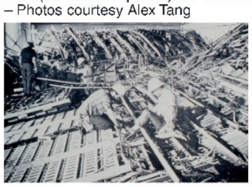
San Fernando Earthquake – Lifeline Systems

GTE (General Telephone) CO sustained extensive damage to the equipment – Photos courtesy Alex Tang



Service persons trying to sort out the line to transfer to San Fernando

Electro-mechanical equipment collapsed

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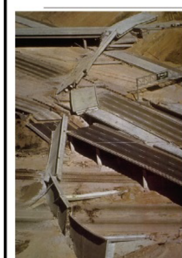
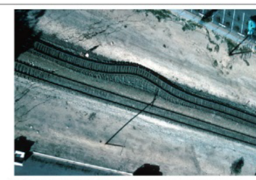
San Fernando Earthquake – Lifeline Systems





Displaced Southern Pacific Railroad tracks near Los Angeles County Juvenile Hall. – USGS Photo

Highway Bridge Collapse – Caltrans Photo

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History of Lifeline Earthquake Engineering

- ASCE TCLEE (now part of ASCE Infrastructure Resilience Division)
  - pioneered the development of lifeline earthquake engineering
  - Post-earthquake investigations
  - Best practices, guidelines, standards
- From onset Lifelines recognized the need for rapid return to service in order support the community.
  - Many lifeline systems have been addressing engineering resilience before we understood it by this term
  - Significant progress has been made, but not nearly enough – much remains to be done

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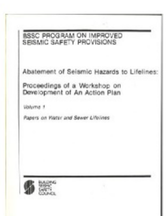
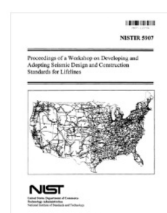
History of Lifeline Earthquake Engineering





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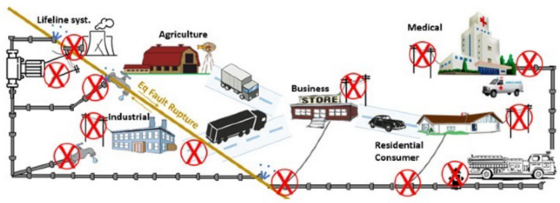
Lifeline System Earthquake Damage



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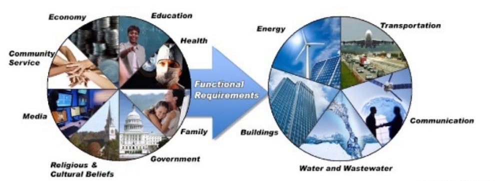
Lifeline System Earthquake Damage

- Lifeline service losses threatens livelihood and inhibits the providing of other societal services
- Timely restoration of lifeline services is critical to emergency response and community recovery – defining the **need for resilient infrastructure systems**
- **The disaster resilience of a community is completely linked to the resilience of lifeline systems**

26

System of Systems & Services for Services

- Social/economic needs of community after a disaster drive infrastructure performance requirements



Source: NIST, 2016

27

NEHRP-Sponsored Lifeline Research

28

NIST GCR 14-917-33 Lifelines Roadmap

- 28 research, development and implementation topics, grouped in 4 program elements.
  - Element I. Establish national lifeline system performance and restoration goals
  - Element II. Develop lifeline system specific performance manuals, guidelines, standards, and codes
  - Element III. Conduct problem focused research for various lifeline systems
  - Element IV. Enable the adoption and implementation of lifeline system performance goals and standards

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NIST GCR 16-917-39 Societal Expectations

- To understand societal needs during recovery
- 33 recommendations in 4 areas.
  - A. Lifeline Codes, Standards, and Guidelines
  - B. Research
  - C. Modeling
  - D. Lifeline Infrastructure System Operations

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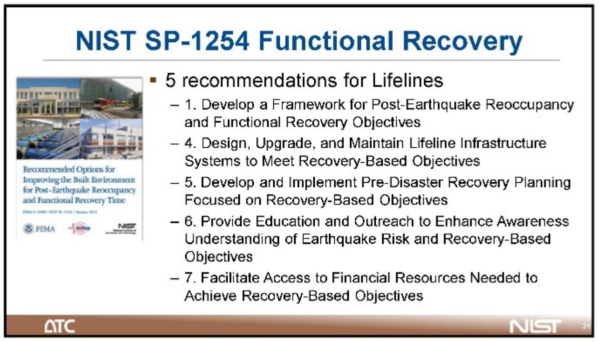

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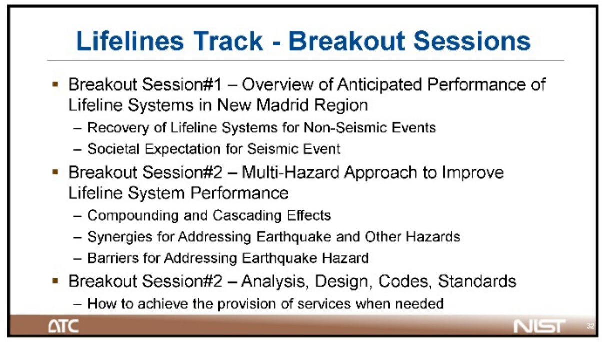

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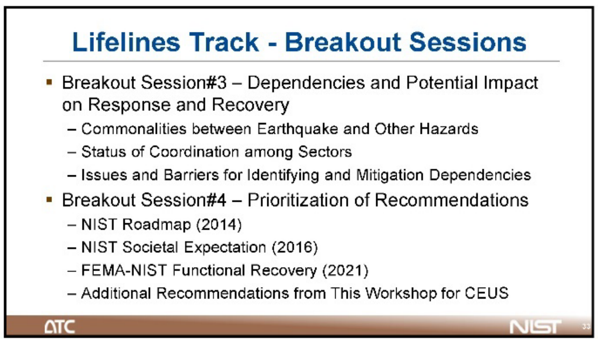

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Introduction to Hazard and Design Philosophy Issues

Jim Harris
October 17, 2022

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1

CEUS Ground Motion Hazards

- Historically low frequency of occurrence
  - Less confidence in the hazard modeling – higher uncertainty
  - What are the implications for existing structures – not the same as California
- Significant portion of the hazard in most areas is from relatively low magnitude event located close to the site
  - Is our design response spectrum appropriate?
  - Are our design parameters (R factors) appropriate?
- Middle Mississippi Valley hazard of a "swarm" of large events
  - Are our design parameters and damage control provisions good enough?

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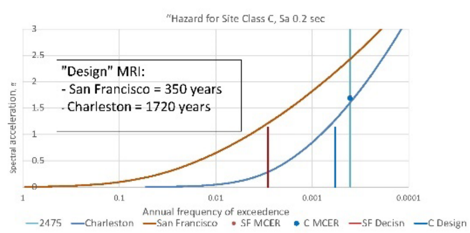
"Design" ground motion for damage?



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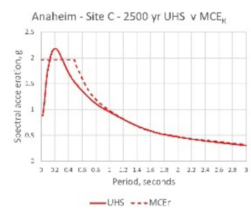
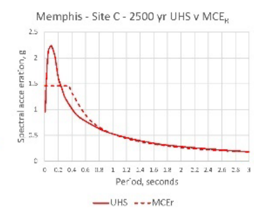
Look at spectral shape for design





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Agenda

- Sanaz Rezaeian, USGS on NSHM
- Jon Stewart, UCLA on Site Effects & Geohazards
- Oliver Boyd, USGS on Coastal Plain Amplifications
- Jim Harris, J R Harris & Co on Design Philosophy
- Nicholas Luco, USGS on Risk Targets for CEUS
- Shahram Pezeshk, U Memphis on Max Direction & T_L

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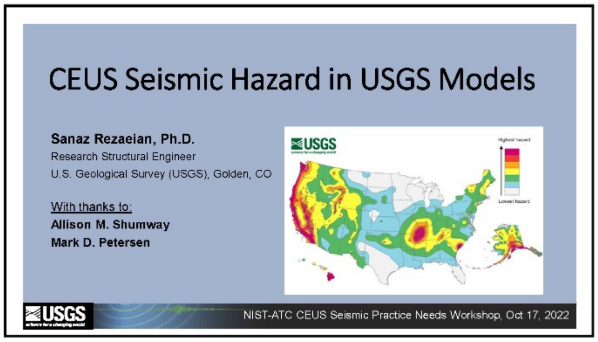

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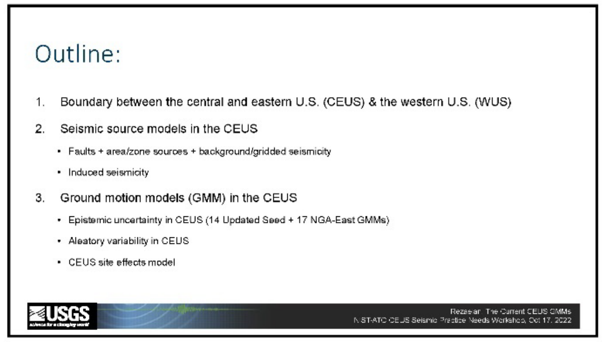

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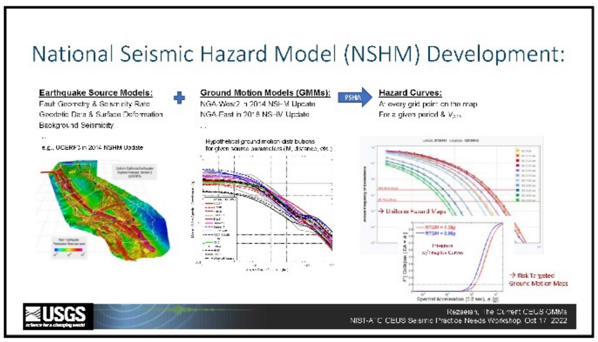

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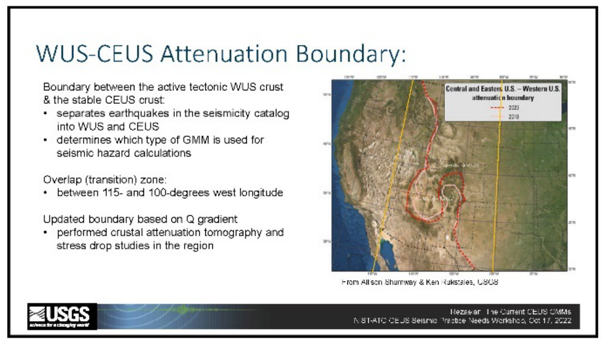

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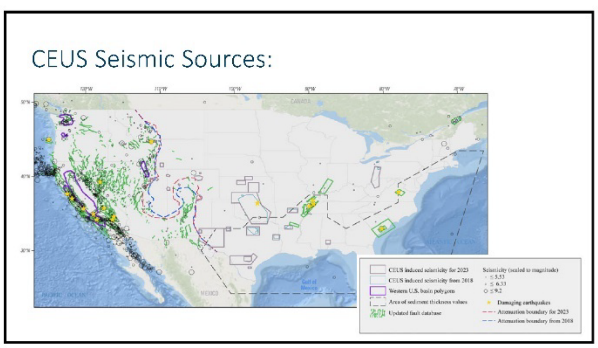

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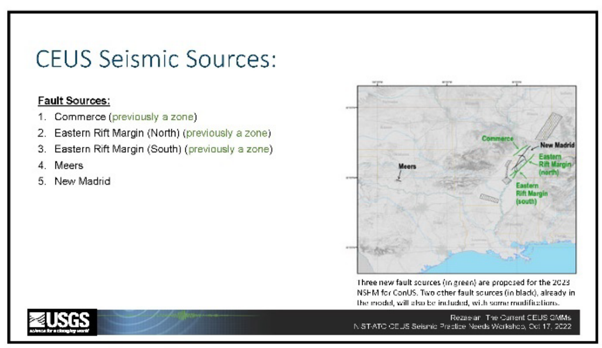

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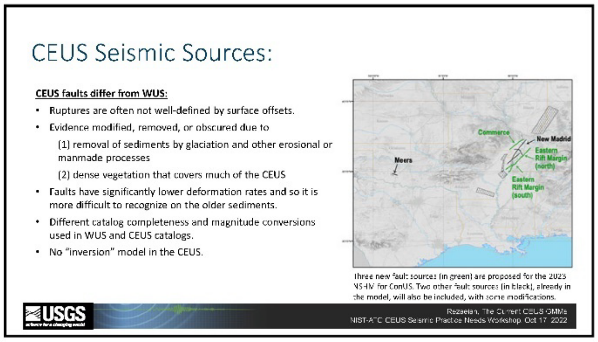

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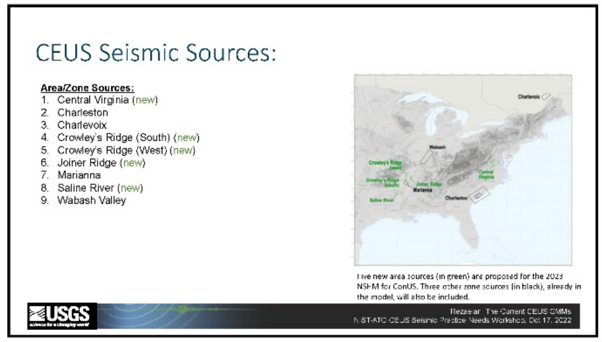

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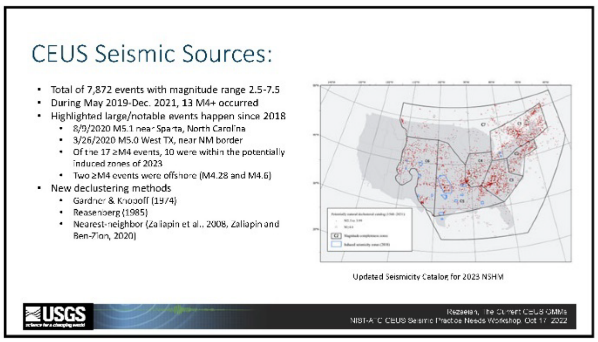

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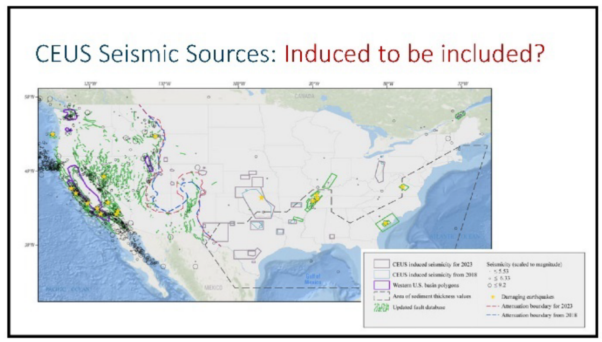

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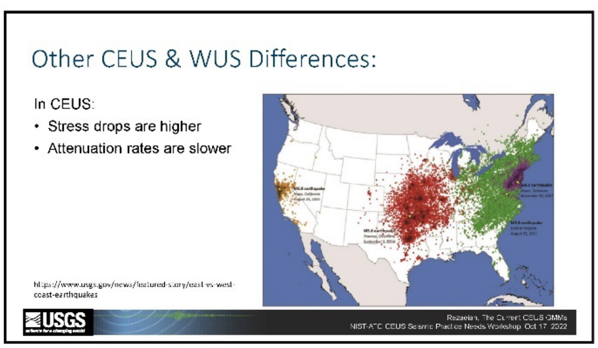

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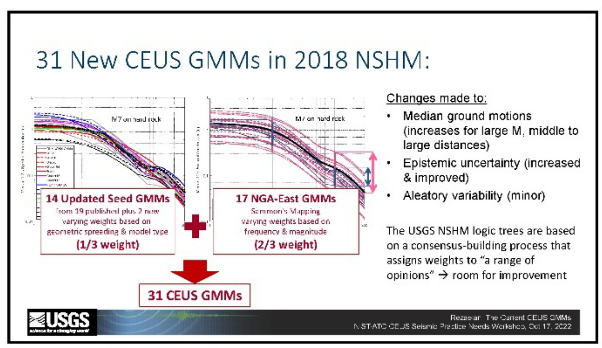

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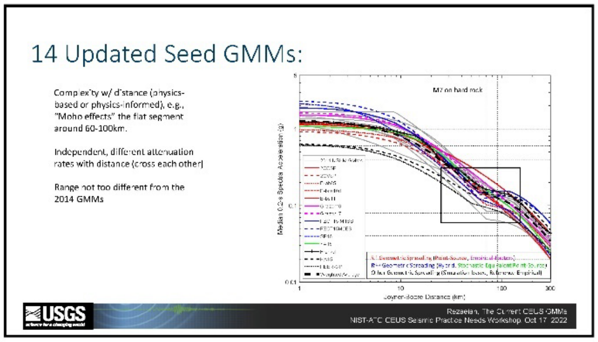

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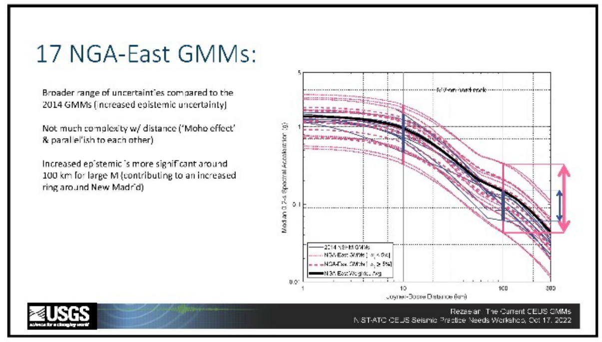

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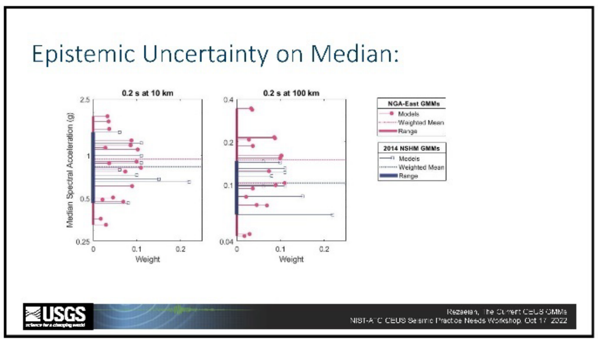

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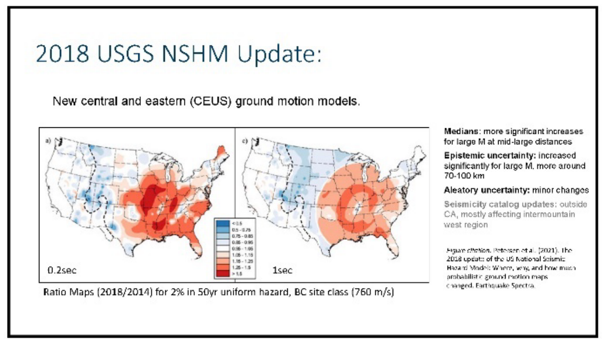

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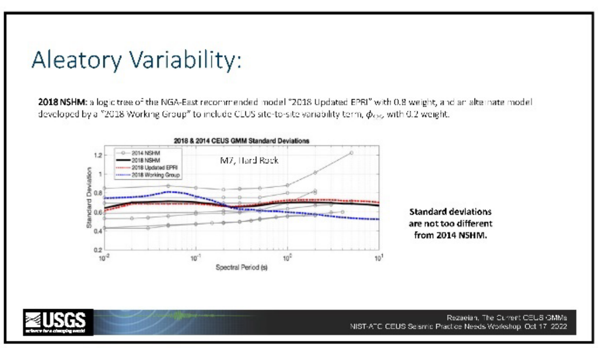

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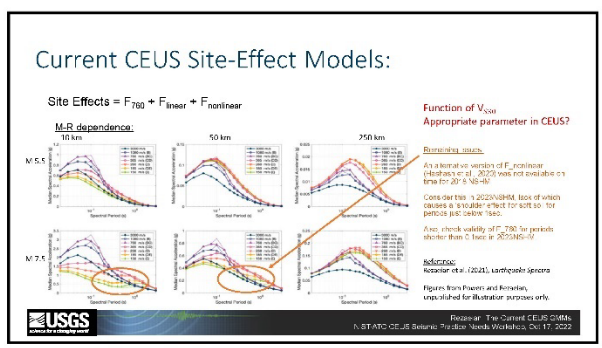

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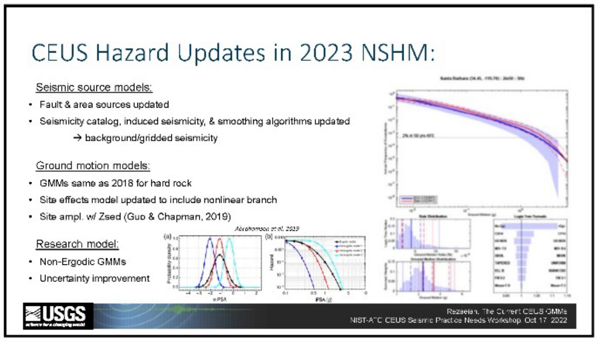

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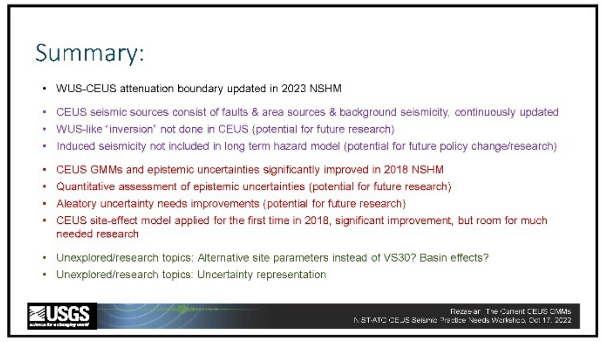

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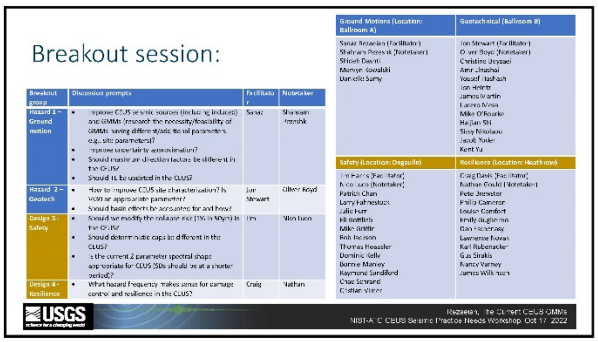

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CEUS Site Effects & Geohazards

Jonathan P. Stewart
UCLA Samueli Engineering

UCLA Samueli School of Engineering NIST ATC

ATC-NIST CEUS Workshop
October 17-18, 2022

1

Outline

- Current CEUS site factors
- Possible near term changes to site factors
- Longer-term research opportunities
- Liquefaction issues

2

CEUS Site Factors

Site parameters

- Simple metrics of site condition that should relate to site response physical processes
- Examples: V_{S30}, depth, site frequency (f_0)

Seldom measured in CENA

Correlated to geology, glaciation, location in basin

Applies in basins

Recently available from USGS (Boyd and others)

Useful for sites with large impedance contrasts

Captures site resonances

3

CEUS Site Factors

Site parameters

- Simple metrics of site condition that should relate to site response physical processes
- Examples: V_{S30}, depth, site frequency (f_0)

Currently used

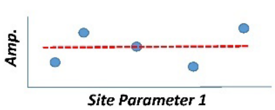
4

CEUS Site Factors

Site parameters

Ground motion *scaling* with site parameters

- Refers to how ground motion changes with a parameter



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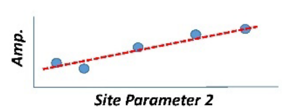
CEUS Site Factors

Site parameters

Ground motion *scaling* with site parameters

- Refers to how ground motion changes with a parameter



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CEUS Site Factors

Site parameters

Ground motion *scaling* with site parameters

- Refers to how ground motion changes with a parameter
- Predictive power of a parameter judged by the strength of scaling

7

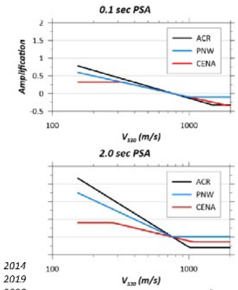
CEUS Site Factors

Site parameters

Ground motion *scaling* with site parameters

Regionalization of V_{S30}-scaling

- ACR > PNW > CEUS
- Largest differences at long periods



Seyhan and Stewart, 2014
Parker et al. 2019
Parker and Stewart, 2022

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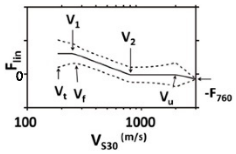
CEUS Site Factors

Current model, sum of:

- F_{lin}: V_{S30}-scaling model referenced to 760 m/s



Parker et al. (2019); Stewart et al. 2020

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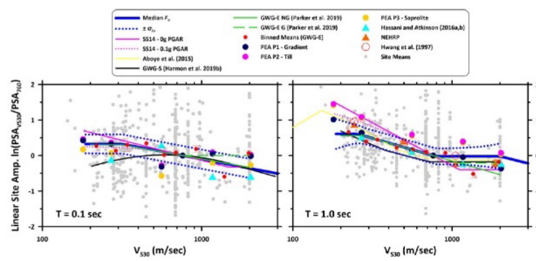

Stewart et al. 2020

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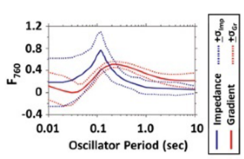
CEUS Site Factors

Current model, sum of:

- F_{lin}: V_{S30}-scaling model referenced to 760 m/s
- F_{760}: amplification of 760 m/s sites relative to 3.0 km/s



Stewart et al. 2020

11

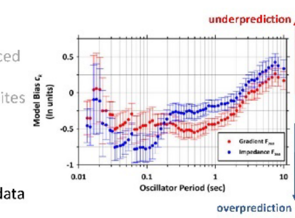
CEUS Site Factors

Current model, sum of:

- F_{lin}: V_{S30}-scaling model referenced to 760 m/s
- F_{760}: amplification of 760 m/s sites relative to 3.0 km/s

Model development not synchronized with GMM

- Bias when compared to CEUS data
- Currently being checked with expanded data set



Ramos-Sepulveda et al. 2022

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Possible Near-Term Changes

Adjustment of GMM constant term or F_{760} to remove bias

Introduction of depth adjustments within ACP and GCP domains (Boyd et al.)

13

Longer-Term Research Opportunities

NGA-East2 (non SSHAC) with combined development of GMMs and amplification models

Adding f_0-based parameters into regional models

- Replace or supplement V_{S30}
- Data needs: V_S profiles (measure-disseminate), HVSR data (measure-disseminate)

14

Outline

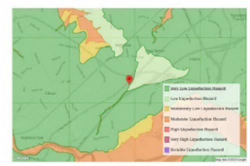
- Current CEUS site factors
- Possible near term changes to site factors
- Longer-term research opportunities
- **Liquefaction issues**

15

CEUS Liquefaction

State maps

- Liquefaction susceptibility
- Liquefaction potential



New Jersey Liquefaction map

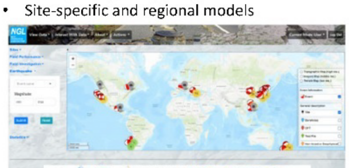
Map compilation in ATC -71

16

CEUS Liquefaction

Improved liquefaction models: NGL project

- Open database
- Susceptibility – triggering – manifestation
- Site-specific and regional models



www.nextgenerationliquefaction.org

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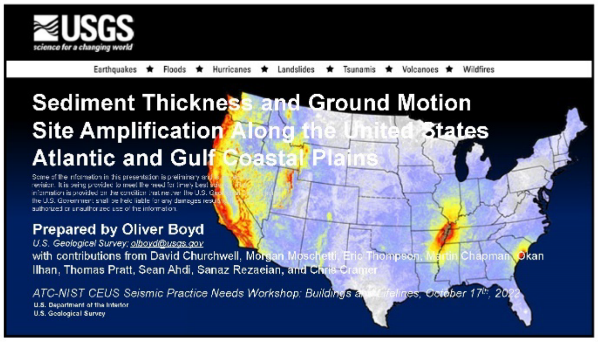

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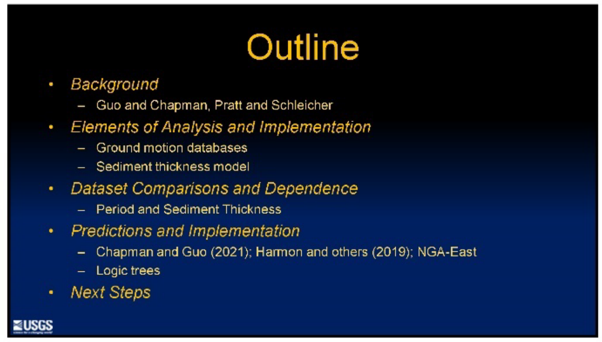

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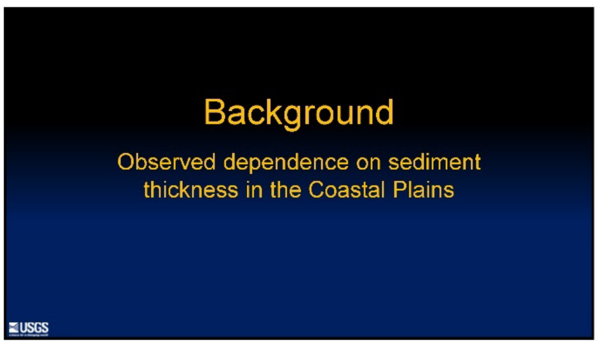

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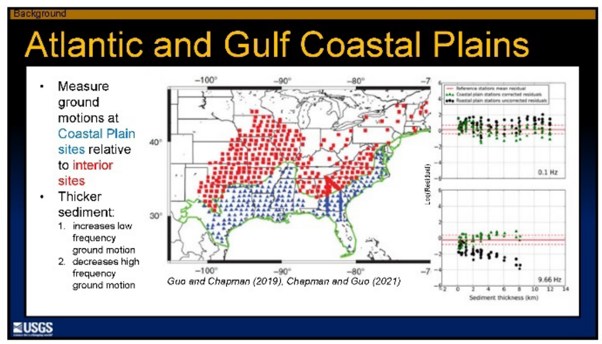

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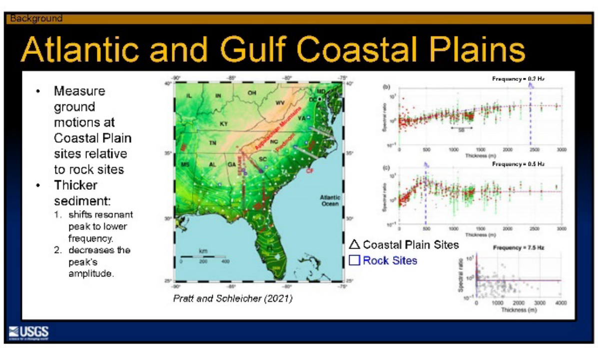

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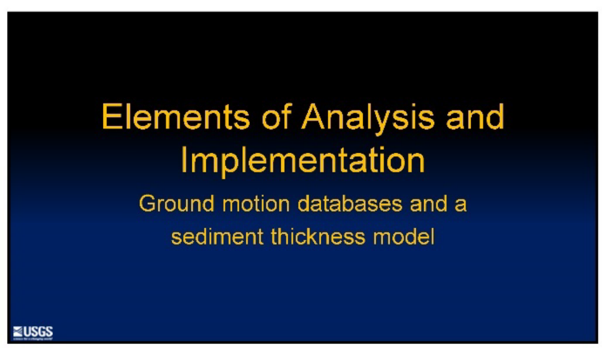

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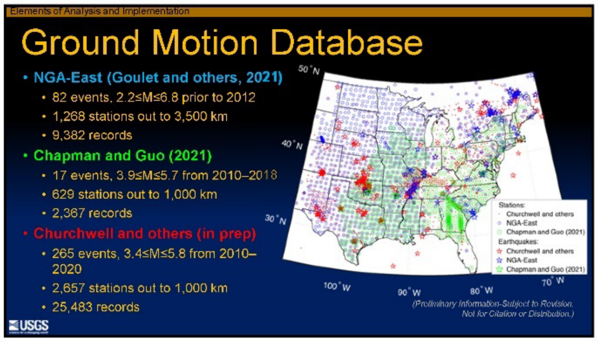

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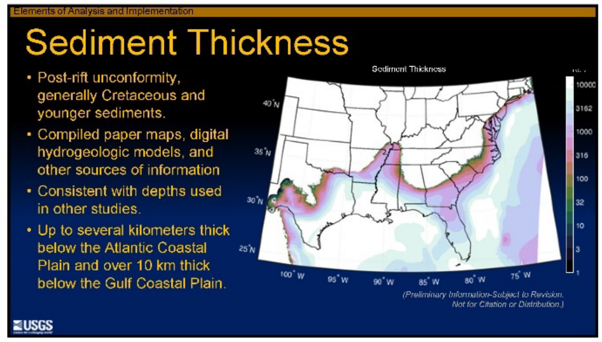

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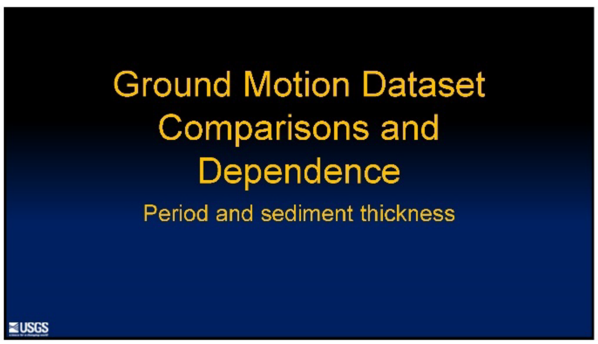

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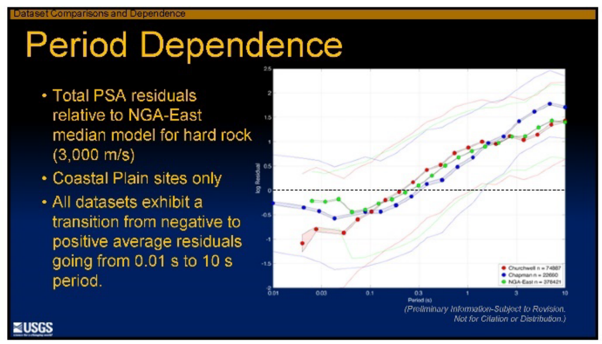

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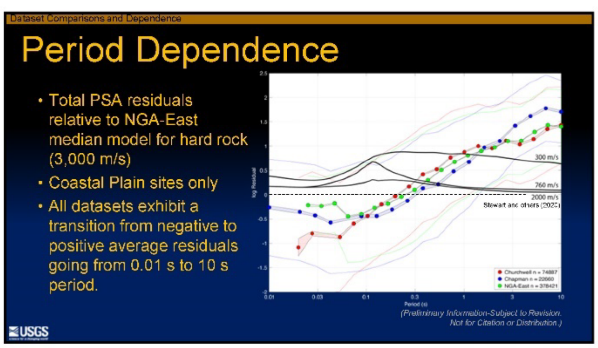

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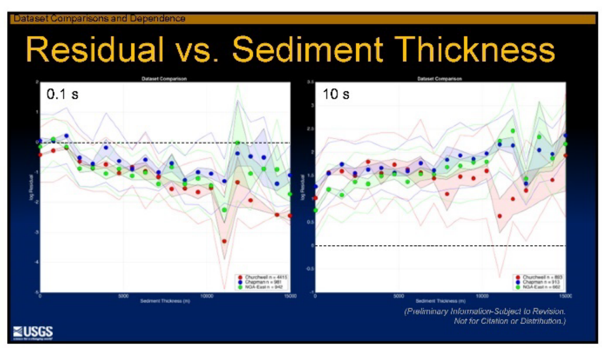

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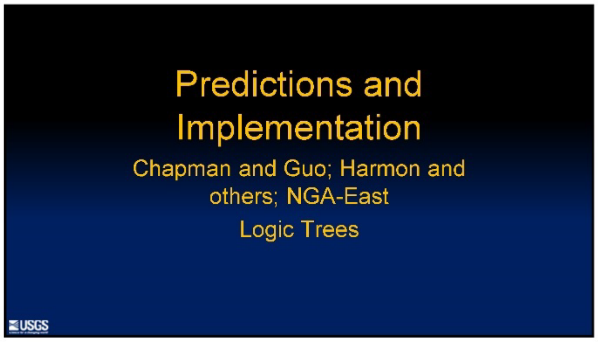

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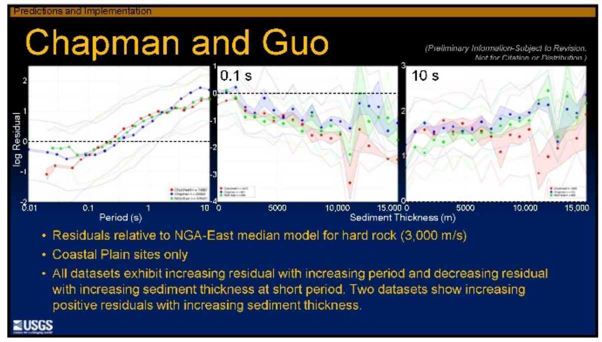

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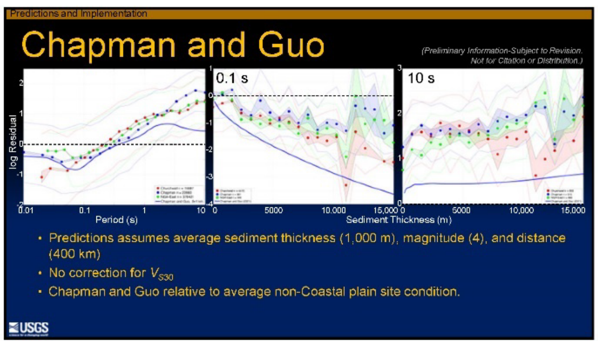

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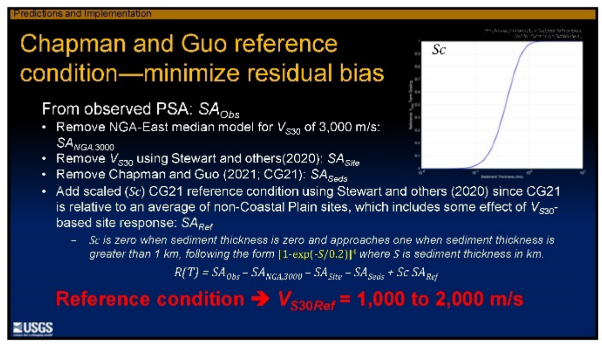

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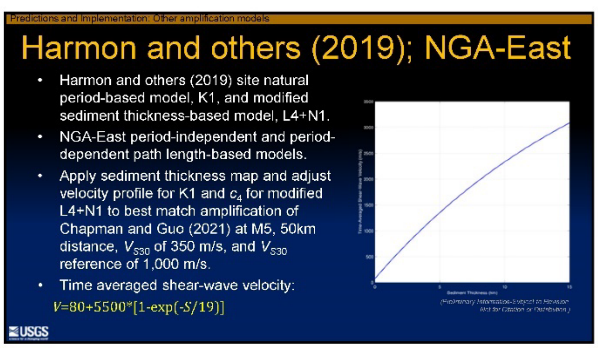

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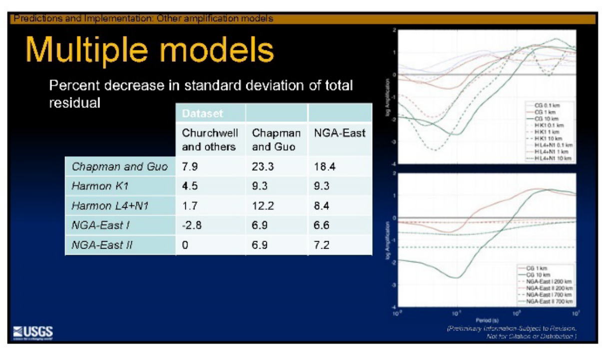

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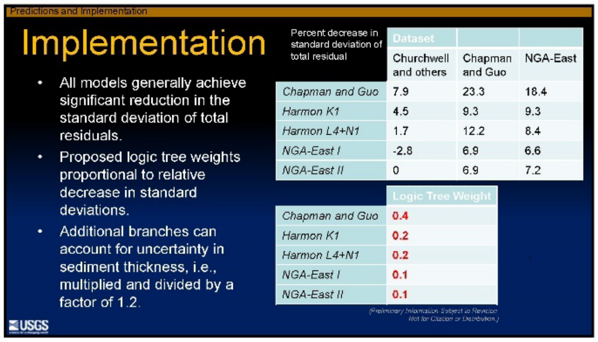

Percent decrease in standard deviation of total residual	Dataset		
	Churchwell and others	Chapman and Guo	NGA-East
Chapman and Guo	7.9	23.3	18.4
Harmon K1	4.5	9.3	9.3
Harmon L4+N1	1.7	12.2	8.4
NGA-East I	-2.8	6.9	6.6
NGA-East II	0	6.9	7.2

	Logic Tree Weight
Chapman and Guo	0.4
Harmon K1	0.2
Harmon L4+N1	0.2
NGA-East I	0.1
NGA-East II	0.1

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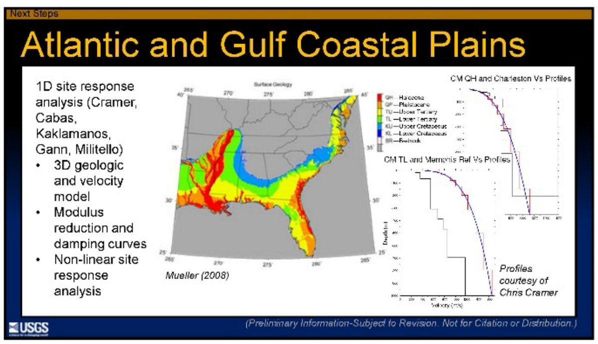

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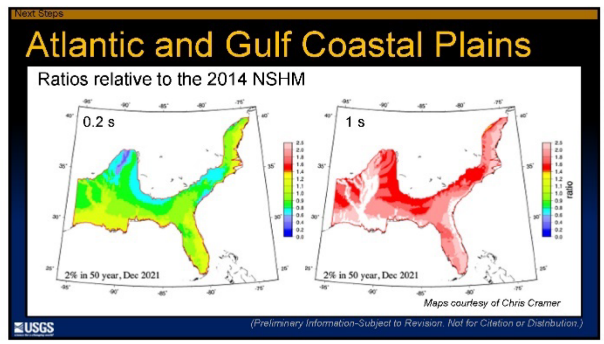

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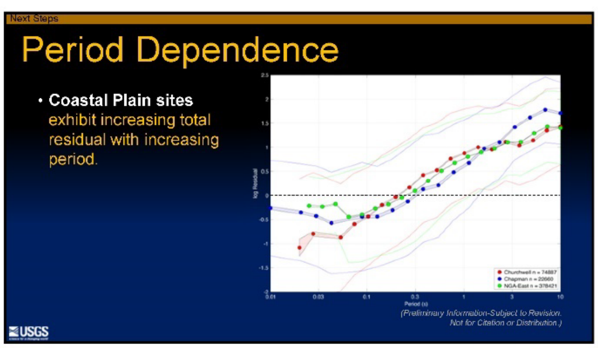

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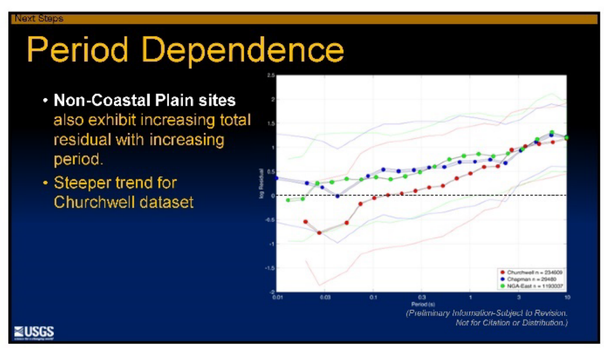

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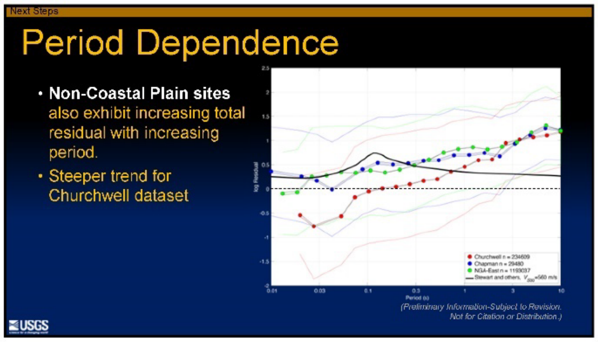

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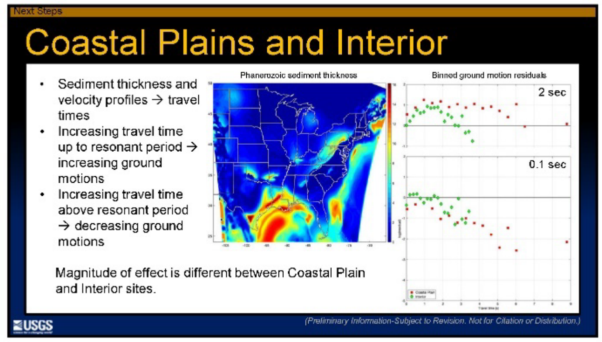

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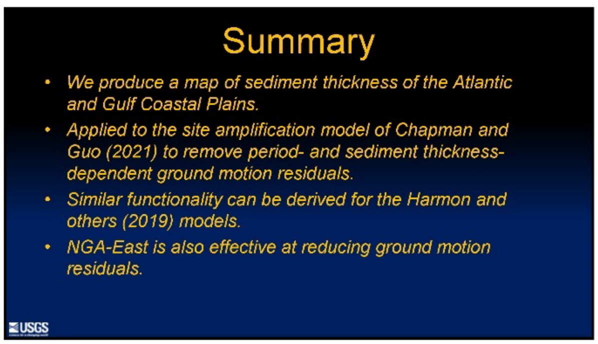

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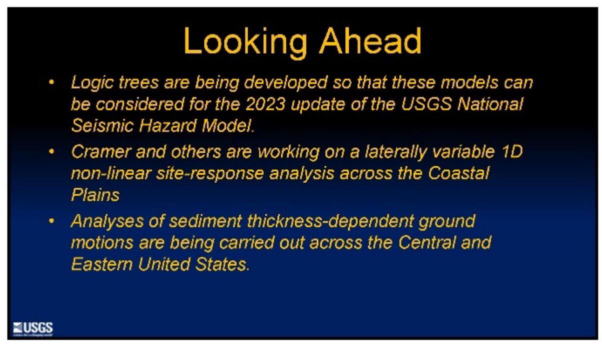

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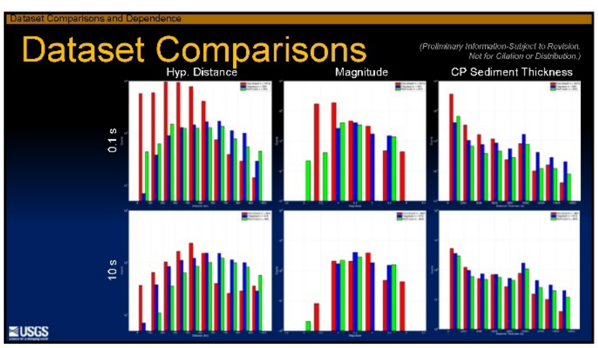

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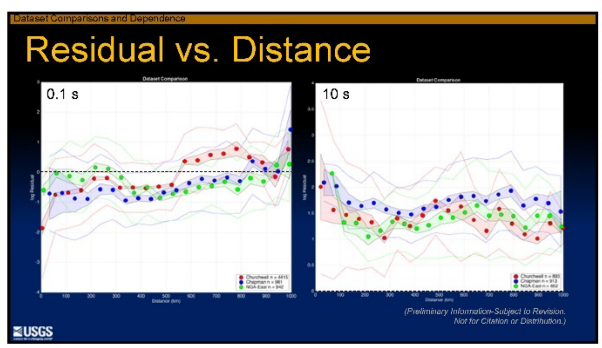

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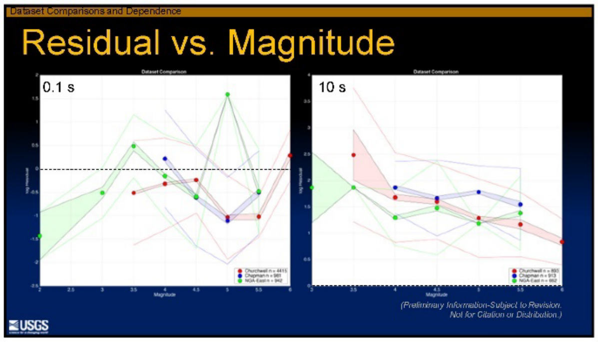

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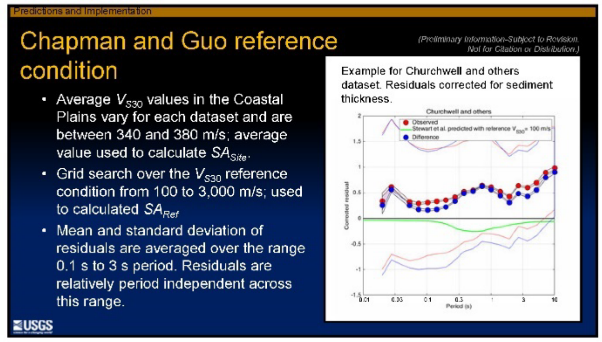

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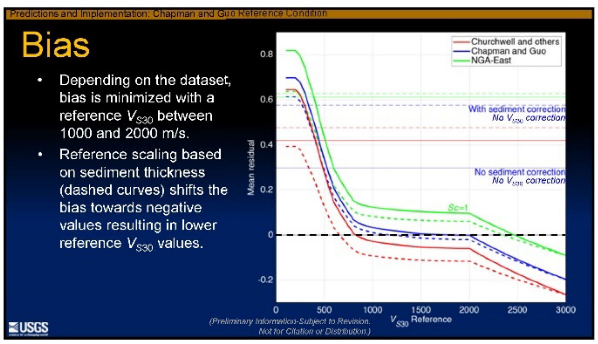

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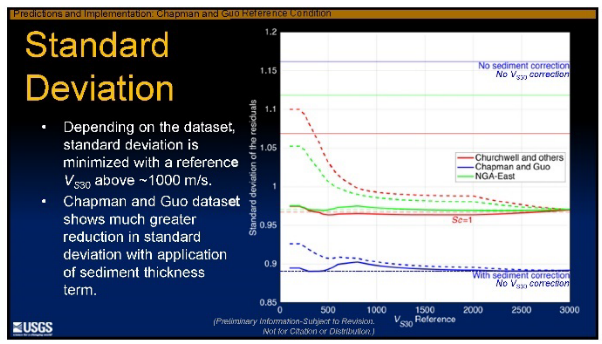

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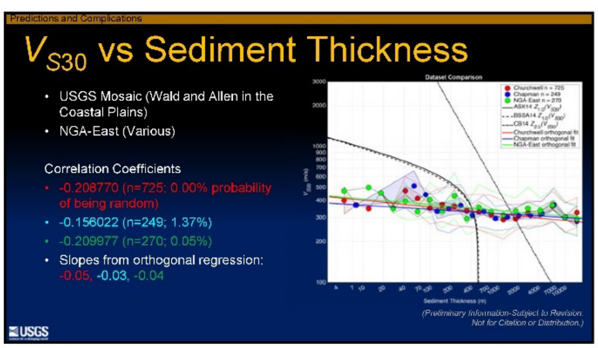

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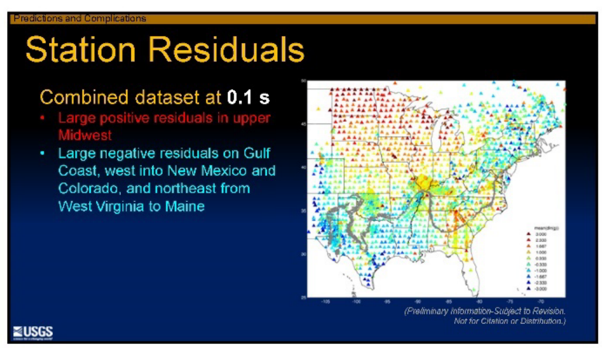

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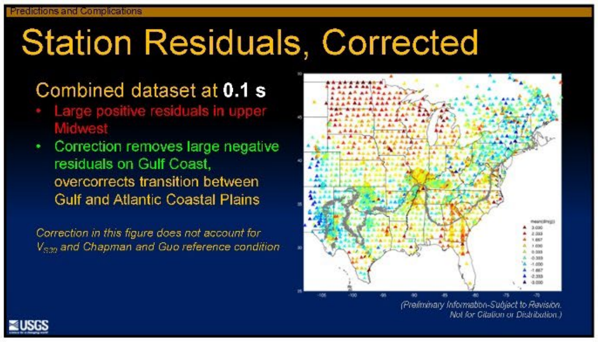

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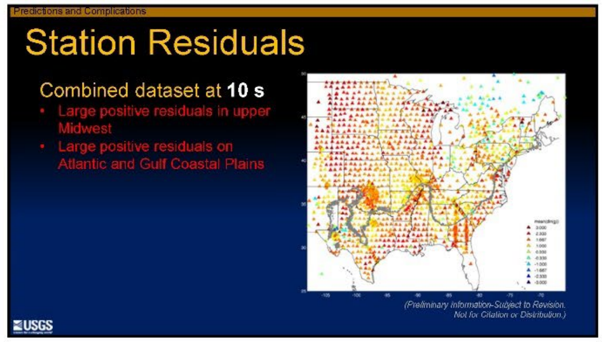

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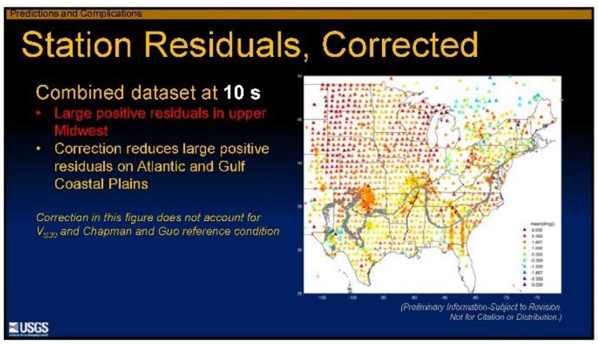

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CEUS vs WUS Hazard Curves, Spectral Shapes, SDCs & TL: Should the Design Philosophy Be Adjusted?

Jim Harris

October 17, 2022

ATC

1

Life Safety Design Criteria

- Conditional Probability of Collapse < 10% *given MCE_R motion*
- General MCE_R: deliver 1% probability of collapse in 50 years, when probabilistic hazard is integrated with a generic fragility
- Exception: MCE_R defined in semi-deterministic fashion (very high hazard locations)
- Conditional Probability of Failure of "Noncritical Members" < 25% *given MCE_R motion*
- *Note: probability of failure of primary structural member or connection ~ 0.1% in 50 years for wind or snow loads*
- Interstory Drift Ratio < 2% (over 4 stories) or 2.5% (shorter) at $\frac{2}{3}$ MCE_R which is defined at the Design Earthquake (DE)

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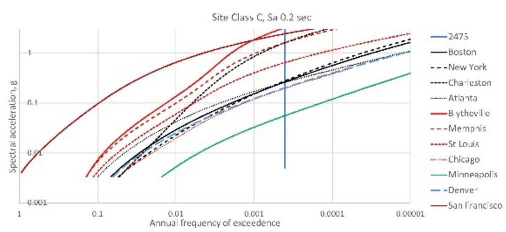
2

A Few Hazard Curves



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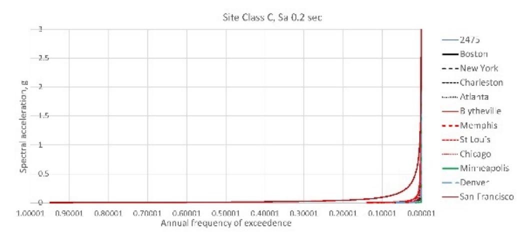
A Second View



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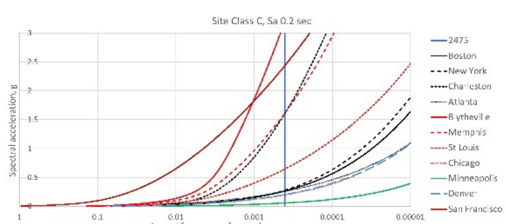
A Third View



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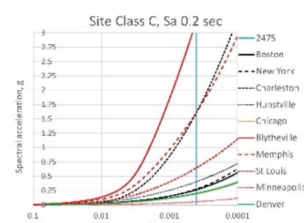
Seismic Design Categories



Range of Sa	SDC
Sa < 0.25	A
0.25 < Sa 0.5	B
0.5 < Sa <0.75	C
0.75 < Sa < 1.5	D
1.5 < Sa	"E"

Note that the boundary between A and B is identical for all Risk Categories (Why?)

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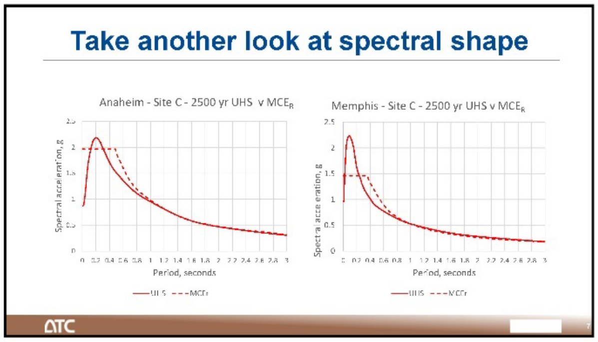

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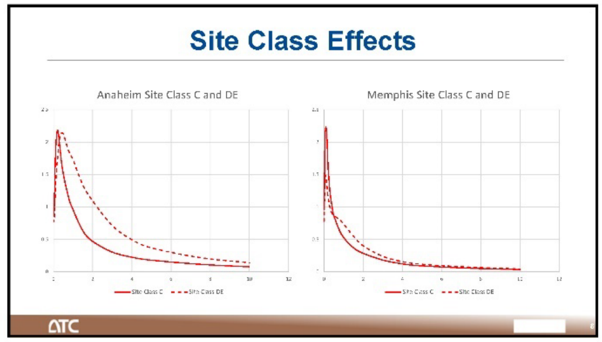

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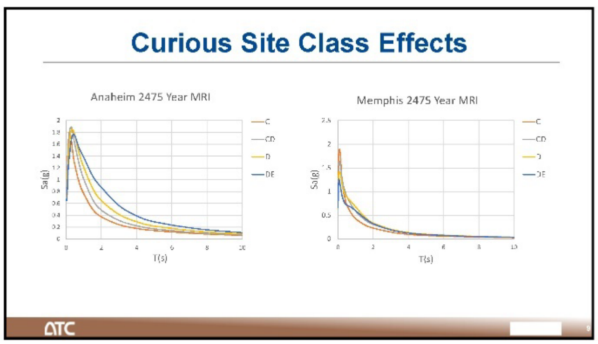

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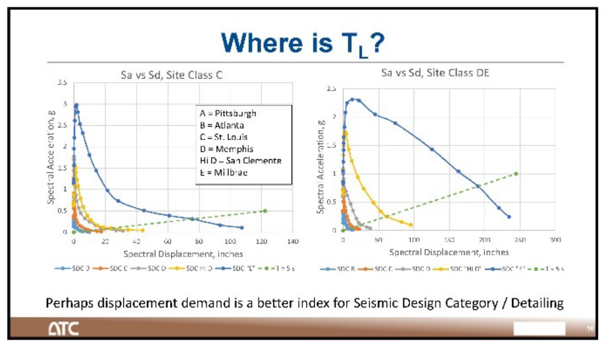

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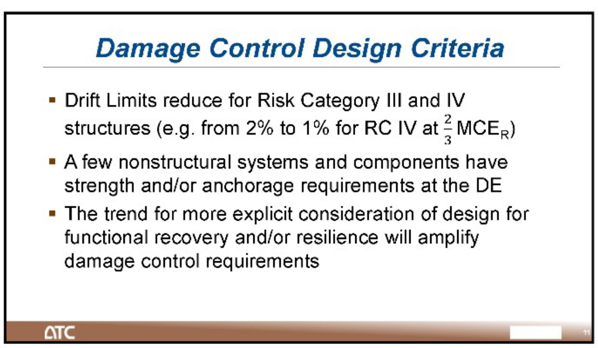

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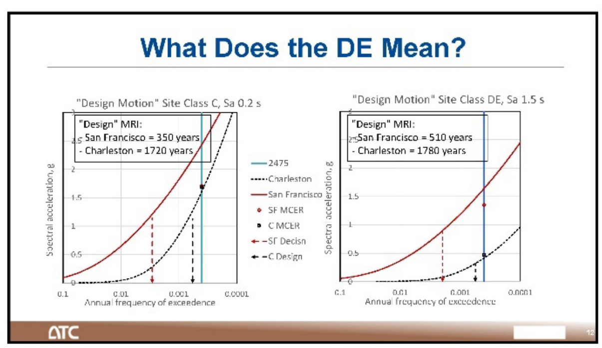

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Economics in CEUS

- Appropriate discount rate (NIST Office of Applied Economics?)
- Seismic Design Category boundaries & Risk Categories
- Should the reliability level be more like that for other hazards?
  - There is a "voluntarily assumed" risk in high hazard areas
  - It probably does not exist in lower hazard areas
  - Therefore why the big disconnect with seismic?

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13

Risk Depends on …

Consequences of failures, therefore should we consider

- Density of built environment
- Interdependencies
- Climate
- …?

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14

Summary

- Re-examine basic life safety criterion in low to moderate hazard areas
- Why is the cutoff to "A" the same for RC II and IV?
- Look again at short period cutoff
- CEUS site class effects very different than WUS
- 22 period spectra don't show the effect of T_L
- Redefine the "design earthquake" – need serious cost-benefit analysis

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Collapse Risks resulting from Current Design Ground Motions in the CEUS vs. WUS

ATC-NIST Workshop on Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the CEUS

Nicolas Luco, PhD
Research Civil Engineer

USGS

Geologic Hazards Science Center
Golden, Colorado

1

Summary

- Due to deterministic capping, current collapse risks are higher than the target 1%-in-50yrs in some higher-hazard areas of the WUS.
- As an alternative to deterministic capping, higher target risks could be set in higher-hazard areas of the WUS ***and CEUS***.
- Correspondingly, in lower-hazard areas, lower target risks could be set.
- Accepting higher risks in higher-hazard areas, and requiring lower risks in lower-hazard areas, could be consistent with cost-benefit analysis.

2

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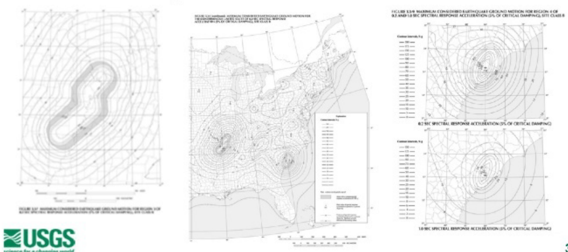
Since the 1997 NEHRP Provisions …

Design Ground Motions = 2/3 * MCE GMs



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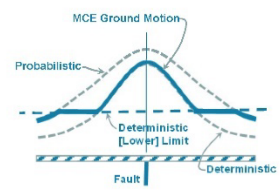
Deterministic Capping

MCE Ground Motions = max(Probabilistic GMs, Deterministic GMs)



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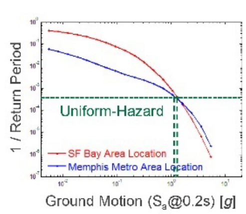
Before the 2009 NEHRP Provisions …

Probabilistic Ground Motions = Uniform-Hazard GMs



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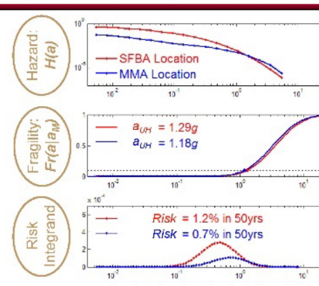
Uniform Hazard ≠ Uniform Risk



$$R = \int_0^\infty \frac{dFr(a|a_M)}{da} \cdot H(a)\, da$$

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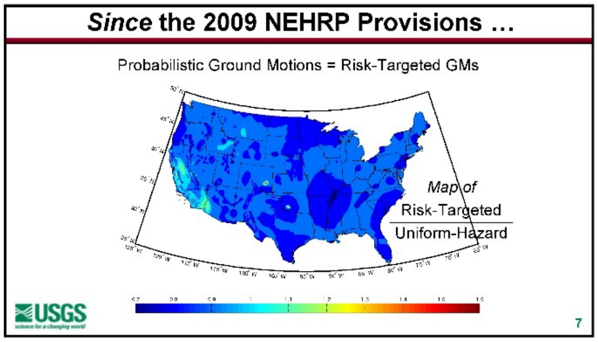

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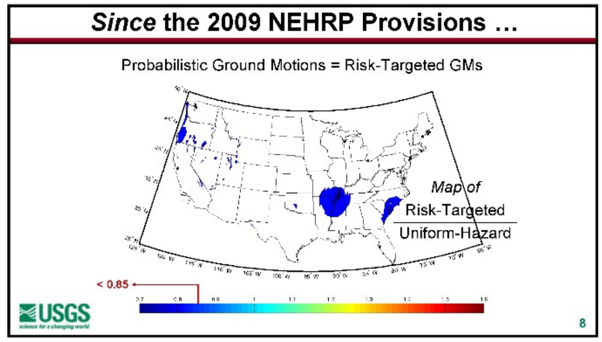

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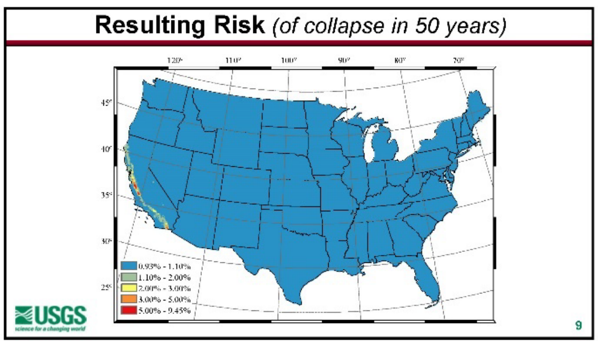

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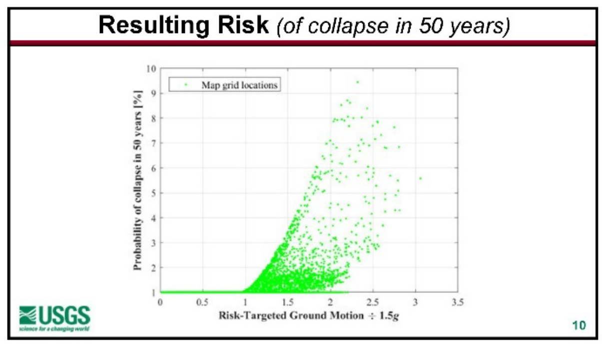

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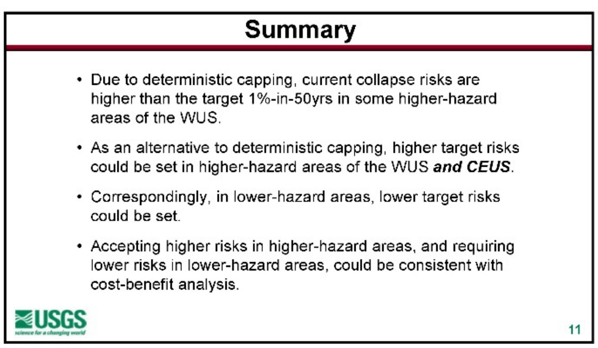

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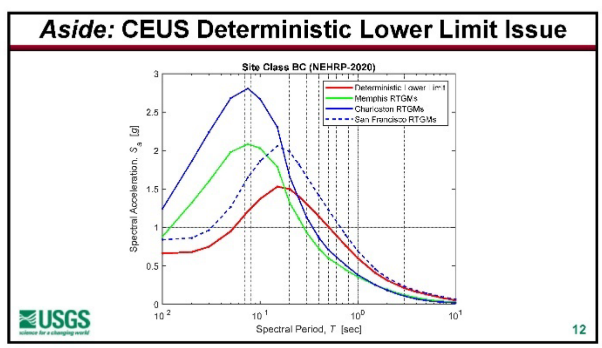

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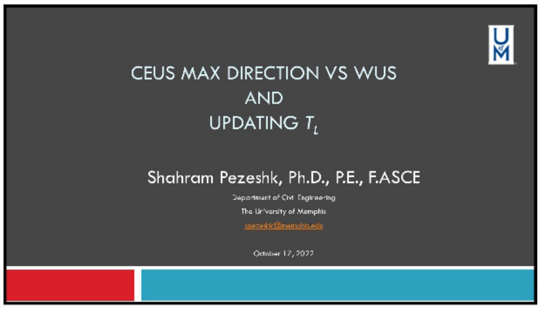

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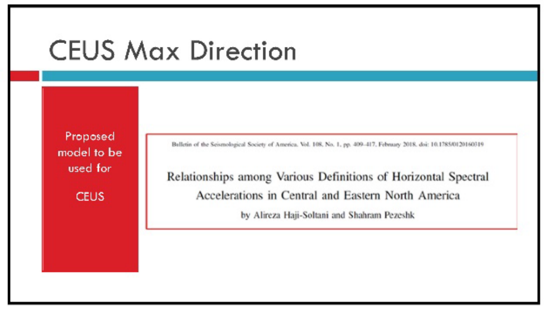

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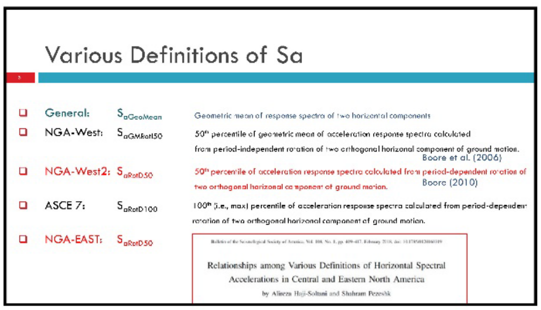

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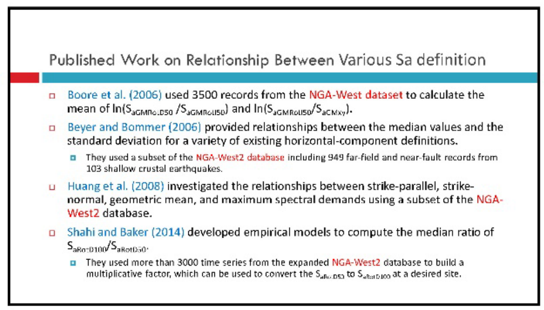

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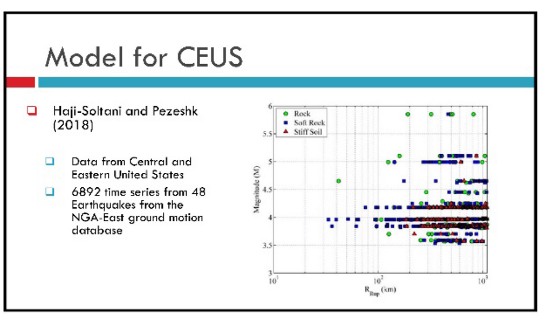

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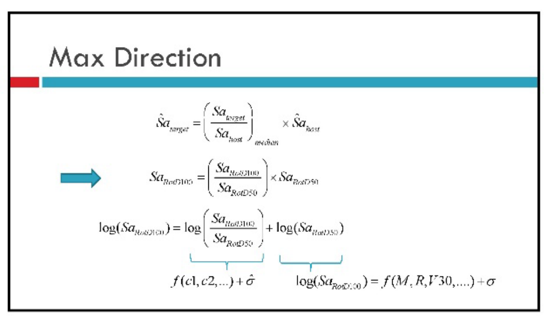

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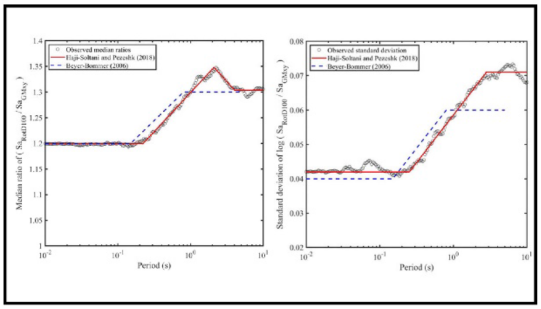

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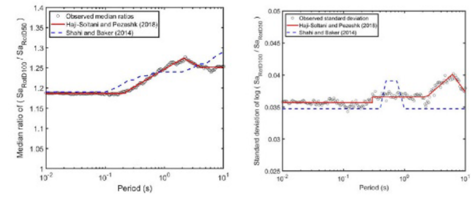
Recommendation:

Use Shahi and Baker (2014) for WUS

Use Haji-Soltani and Pezeshk (2018) for CEUS



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T_L Update

A Seismological Method for Estimating the Long-Period Transition Period T_L in the Seismic Building Code

Earthquake Spectra

9

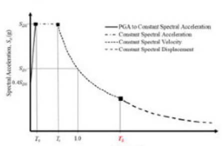
T_L Background

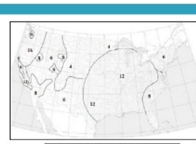
- T_L: defined as the corner period that marks the transition from the constant velocity to the constant displacement segments of the design response spectrum.
- Many changes have been made to the design response spectrum used in the ASCE 7 Standard in recent years.
- Since its introduction in FEMA 450-1/2003 the long-period transition period parameter, T_L, has remained unchanged.

10

T_L in ASCE 7-05 to 7-16 Standard

- Crouse et al. (2006):
  - $T_L = T_{L(NEHRP)} \approx T_c \approx 10^{-1.25+0.3M_w}$





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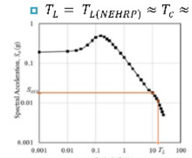
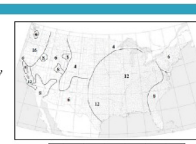
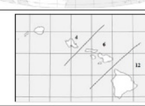
T_L in ASCE 7-22 Standard

- Estimation is unchanged
- Crouse et al. (2006):
  - $T_L = T_{L(NEHRP)} \approx T_c \approx 10^{-1.25+0.3M_w}$







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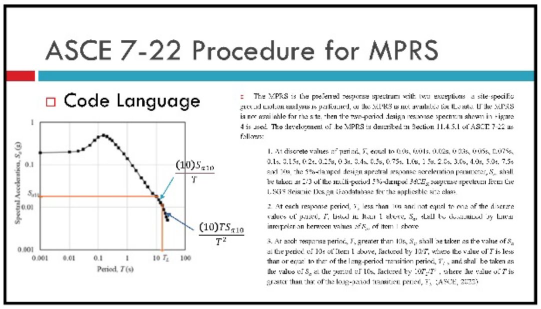

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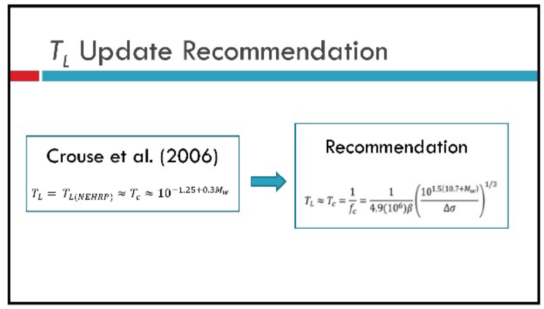

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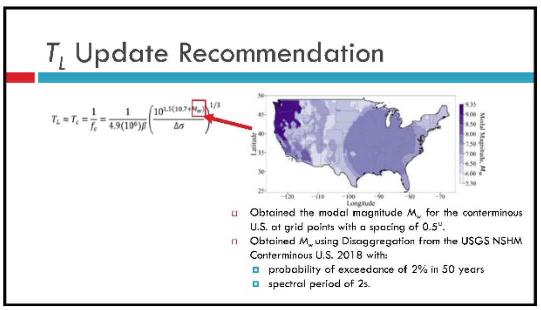

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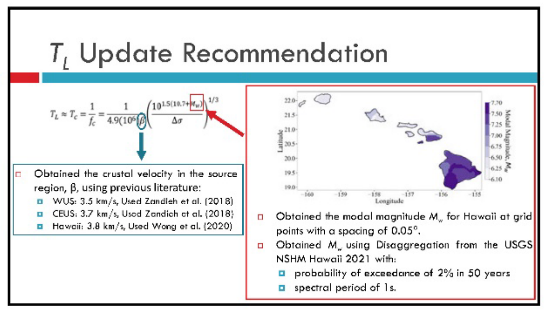

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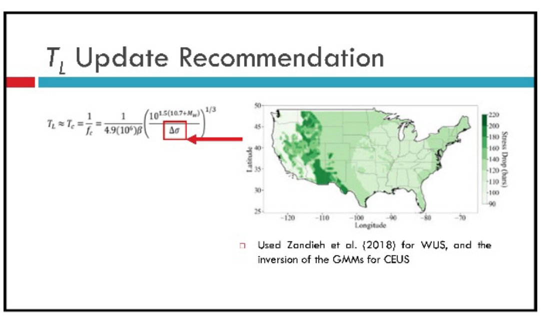

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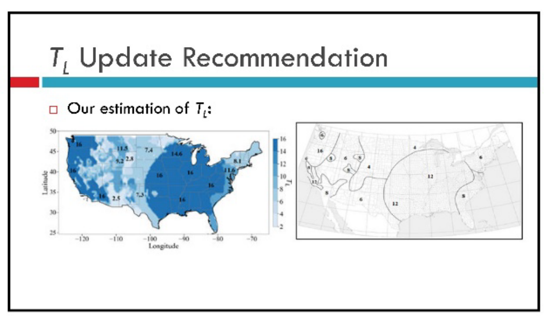

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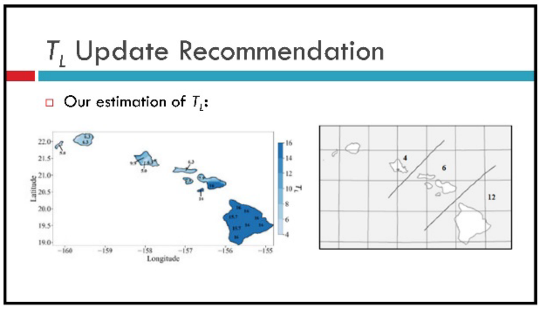

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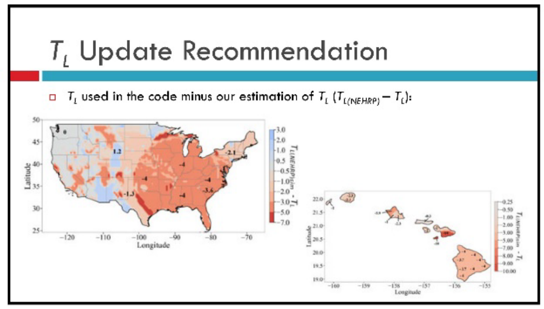

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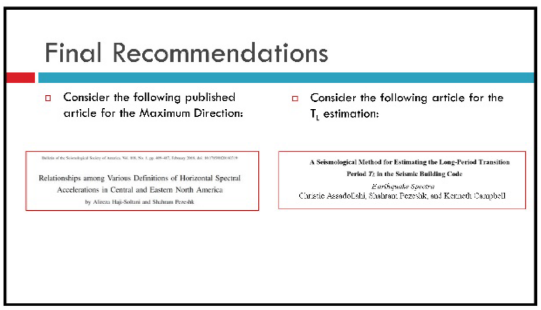

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ATC-NIST Workshop on Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States (CEUS)

October 17-18, 2022
Charlotte, North Carolina

ATC NIST

1

Questions to Ponder for Day 2

- Buildings
  - What are your current challenges with implementing present seismic code provisions?
  - Which seismic code provisions do you perceive as applicable only to western US design/construction practice and not applicable to CEUS design/construction practice?
  - What are practical impediments to improving existing buildings in the CEUS?
  - Is your jurisdiction open to the idea functional recovery/resilience concepts?

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Questions to Ponder for Day 2

- Lifelines

  NIST GCR 14-917-33, *Earthquake-Resilient Lifelines: NEHRP Research, Development, and Implementation Roadmap*, NIST (2014)

  NIST GCR 16-917-39, *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery*, NIST (2016)

  - Which of the problem statements/research projects in these reports are most applicable to CEUS?
  - Which are the highest priority?

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Thank You!

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ATC-NIST Workshop on Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States (CEUS)

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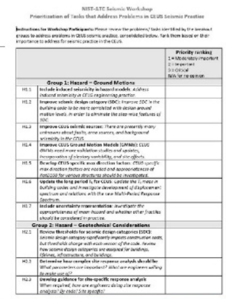
Day 1 Recap

- Ground Motions, Design Philosophies: Thank you!
- Problem/ Project Notes Worksheets
- Prioritization Worksheets



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2

Day 2 Agenda

Reminders:

- Identify issues… not solve them!
- Central-Eastern US Seismic specific.

		Buildings Track Location: Ballroom AB (J. Furr, N. Gould, K. Rubenacker)	*Lifelines Track* Location: Degaulle/Heathrow (K. Yu, C. Davis)
8:20am (15 min)	Full track	Building topic session #1 presentation	Lifeline topic session #1 presentation
8:35am (55 min)	Breakouts	Guided discussions	Guided discussions
9:30am (20 min)	Full track	Report out: Issues/tasks	Report out: Issues/tasks
9:50am		20 min break *(light refreshments)*	
10:10am (15 min)	Full track	Building topic session #2 presentation	Lifeline topic session #2 presentation
10:25am (55 min)	Breakouts	Guided discussions	Guided discussions
11:20am (20 min)	Full track	Report out: Issues/tasks	Report out: Issues/tasks
11:40am		Lunch in Junior Ballroom	
12:40pm (15 min)	Full track	Building topic session #3 presentation	Lifeline topic session #3 presentation
12:55pm (60 min)	Breakouts	Guided discussions	Guided discussions
1:55pm (20 min)	Full track	Report out: Issues/tasks	Report out: Issues/tasks
2:15pm		20 min break *(light refreshments)*	
2:35pm (55 min)	Full track	Prioritization	Prioritization
3:30pm		5 min break (go to plenary)	
3:35pm (25 min)	Plenary	Ballroom AB	Closing remarks
4:00pm		Adjourn workshop	

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Track Assignments

Buildings (Ballroom AB) – *Stay here*

Philip Cameron
Patrick Chan
Dan Eschenasy
Larry Fahnestock
Julie Furr
Eli Gottlieb
Nathan Gould
Mike Griffin
Emily Guglielmo
Jim Harris
Thomas Heausler
Rob Jackson
Dominic Kelly
Mervyn Kowalski
Bonnie Manley
James Martin
Lawrence Novak
Shahram Pezeshk
Sanaz Razaein
Karl Rubenacker
Chad Schrand
Gus Sirakis
Nancy Varney
Cristian Vimer
James Wilkinson

Lifelines (DeGaulle/Heathrow) – *Across the hall*

Christine Beyzaei
Oliver Boyd
Pete Brewster
Louise Comfort
Shideh Dashti
Craig Davis
Jon Heintz
Nico Luco
Lucero Mesa
Sissy Nikolaou
Mike O'Rourke
Raymond Sandiford
Haijian Shi
Jonathan Stewart
Danielle Sumy
Jacob Yoder
Kent Yu

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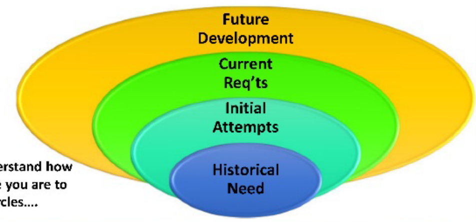
CEUS Buildings Breakout Session #1
Challenges in Implementation of Current Seismic Provisions

Facilitators:
Julie Furr, P.E.
Karl Rubenacker, P.E., S.E., CWI, F.SEI

Note Takers:
Nathan Gould, D.Sc., P.E., S.E.
Emily Guglielmo, S.E., P.E., F.SEI

1

Breakout Session Goals



You have to understand how you got to where you are to avoid going in circles....

2

Question: Breakout Session #1

What are your current CEUS challenges with implementing present seismic code provisions?

3

Breakout Session Goals

1. Start: Problems that discourage implementation of current seismic provisions
2. Identify: Underlying issues that cause the problems
3. Suggest: Potential solutions to fix the issues

...Specific to buildings in the CEUS...

4

Breakout Session Goals

1. Start: Problems that discourage implementation of current seismic provisions
   a. Adoption
   b. Implementation
   c. Enforcement

...Specific to buildings in the CEUS...

5

Breakout Session Goals

2. Identify: Underlying issues that cause the problems
   a. Social/community perceptions of code requirements
   b. Difficulty in following/applying/understanding code requirements
   c. Construction/field conflicts

...Specific to buildings in the CEUS...

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Breakout Session Goals

3. Suggest: Potential solutions to fix the issues
   a. "Research Areas & Topics"
      i. ***What can be done or what still needs to be learned?***
   b. Difficulty To Accomplish
   c. Time Frame for the Research
   d. How Critical To Achieve

...Specific to buildings in the CEUS...

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Potential Issue Topics

1. Resistance to seismic provisions or progressive codes in general?
2. Do challenges change when considering individual buildings vs communities?
3. Technical issues with seismic design procedures?
4. Non-technical issues with seismic provisions (design community, code officials, contractors, and society understanding?)
5. Clients frequently push consultants for concessions such as shopping for favorable geotech reports to reduce SDC?
6. Specific cost barriers that discourage adoption of current building codes? (Not just general "it cost too much" complaints.)
7. Same or different issues for seismic provisions in existing buildings vs new buildings?

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Sub-Question

...Functional Recovery...

- What is it and is it something that is discussed in the CEUS A/E community?
- Do you believe your jurisdictions would be open to the concept of Functional Recovery?
- Have recent catastrophic natural hazard events increased the awareness of need to design beyond life safety?
- How could the concept of Functional Recovery be better presented to the CEUS A/E community?

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Sub-Question: Breakout Session #1

Will your jurisdictions be open to the idea of including Functional Recovery and/or Resilience provisions in the National Model Building Code?

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Breakout group assignments

Group 1	Group 2
Philip Cameron	Shahram Pezeshk
Dan Eschenasy	Mervyn Kowalski
Larry Fahnestock	Patrick Chan
Mike Griffin	Eli Gottlieb
Jim Harris	Thomas Heausler
Rob Jackson	Sanaz Razaein
Dominic Kelly	Chad Schrand
Bonnie Manley	Gus Sirakis
James Martin	James Wilkinson
Lawrence Novak	Cristian Vimer
Nancy Varney	

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CEUS Buildings Breakout Session #2 Gaps and Incongruities in Applying Current Code to Practice

Facilitators:
Nathan Gould, D.Sc., P.E., S.E.
Julie Furr, P.E., S.E.

Note Takers:
Karl Rubenacker, P.E., S.E., CWI, F.SEI
Emily Guglielmo, S.E., P.E., F.SEI

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Goals of Breakout Session

1. Identify CEUS Seismic Building Issues
2. Identify Potential Research Areas & Topics
   a. Difficulty To Accomplish
   b. Time Frame for the Research
   c. How Critical To Achieve

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Initial Questions

Seismic Codes and CEUS Design and Construction

- Do the seismic codes and provisions adequately represent the CEUS design and construction practices?
- What types of design (or delegated design) are prominent in the CEUS that might not be adequately addressed by current codes?
- Are there design/construction practices in the CEUS, such as delegated design, that inhibit good seismic design?
- Are there materials or construction types in the CEUS that should be better addressed?

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CEUS Seismic Design – Potential Topics

- Are the current seismic design provisions appropriate for the CEUS and are they being applied as intended?
  - Delegated Design
  - "R = 3" Lateral System Designs
  - "Shopping" for better site soils characterization to transition from SDC D to SDC C
  - Nonstructural Elements

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Material and Construction - Potential Topics

- Are there materials and/or construction practices found in the CEUS that are not adequately addressed?
  - Tilt-Up Construction with steel roof systems
  - Use of pre-engineered building systems for RC III and IV structures
  - Construction and Inspection of key elements in the lateral force-resisting system (are contractors and fabricators knowledgeable regarding "special" systems like BRBFs?)

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Breakout Session Flow

1. Identify CEUS Seismic Building Issues related to the design and construction practices in the CEUS.
2. Describe the issues and focus on key elements that need to be addressed
3. Suggest potential projects, research or other investigation to address the issue

❖Initial thoughts on potential solutions are OK but not required

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Breakout group assignments

Group 1	Group 2
Philip Cameron	Shahram Pezeshk
Dan Eschenasy	Mervyn Kowalski
Larry Fahnestock	Patrick Chan
Mike Griffin	Eli Gottlieb
Jim Harris	Thomas Heausler
Rob Jackson	Sanaz Razaein
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Lawrence Novak	Cristian Vimer
Nancy Varney	

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CEUS Buildings Breakout Session #3
Existing Buildings

Facilitators:
Karl Rubenacker, P.E., S.E., CWI, F.SEI
Nathan Gould, D.Sc., P.E., S.E.

Note Takers:
Julie Furr, P.E.
Emily Guglielmo, S.E., P.E., F.SEI

1

Goals of Breakout Session

1. Identify CEUS Seismic Building Issue/Problem
2. Identify Potential Project Capable of Solving it
   1. Research, Applied Research, Education/Training, Survey?
   2. Description of Project & Steps/Tasks
   3. Stakeholders/Partners
   4. Duration, Difficulty Level
   5. Challenges
   6. Relative Priority

2

Potential Issue Categories

1. Survey Issues
2. Technical Issues
3. Regulatory Issues
4. Education Issues
5. Ethical Issues

3

Potential Survey Issue Topics

- What are significant CEUS typologies, due to fragility or ubiquity?
- How many of what type/vintage?
- Is metric # bldgs., # of occupants?
- How many being altered/upgraded?
- Individual & collective building life span?

4

Potential Technical Issue Topics

- Are fragility curves appropriate for various typologies.
- What is CEUS bldgs expected performance/how vulnerable?
- How can they be reliably retrofitted/altered/upgraded?
- Material issues – material types/properties, deterioration
- Structural subsystem issues – diaphragms, connections, walls
- System Issues – adjacencies, multi-lot bldgs. ie w/party walls

5

Potential Regulatory Issue Topics

- What code is in effect for alterations in each CEUS jurisdiction?
- Are the bldgs being seismically improved during alterations?
- Systems in place to facilitate, quality assurance inspections?
- Should alterations achieve similar seismic reliability as new bldgs?
- Which public policies improve, or trend against improvement?

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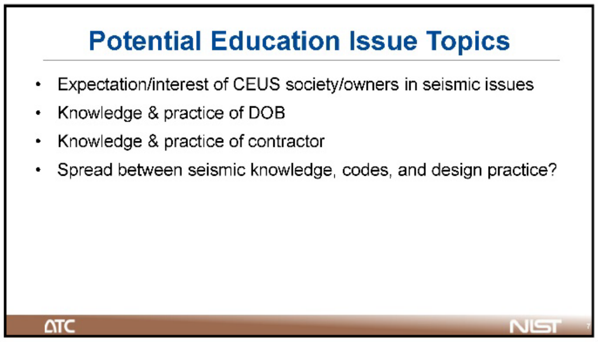

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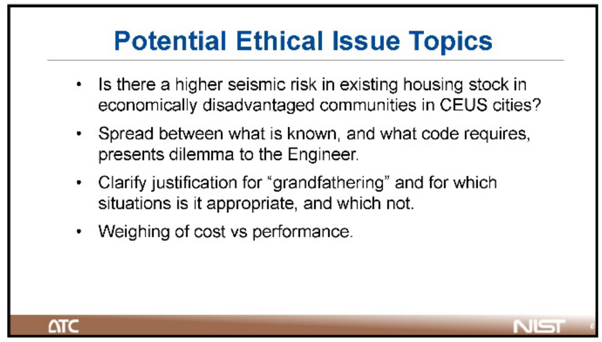

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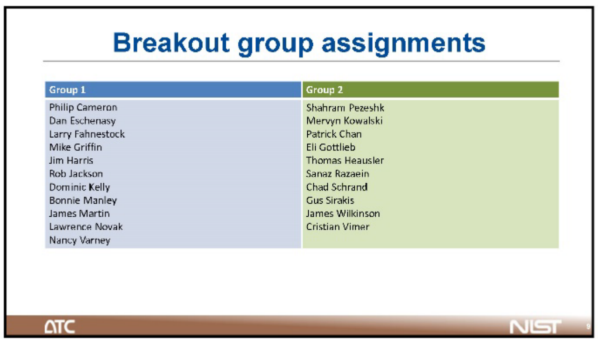

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Lifeline Infrastructure Systems Breakout #1: Societal Expectation of Lifeline System Performance and Recovery

Louise Comfort, PhD, F. NAPA
Craig Davis, PhD, PE, GE
Kent Yu, PhD, PE, SE
October 18, 2022

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1

Outline for Societal Expectation of Lifeline System Performance and Recovery Discussion

- Recovery of Lifeline Systems from Non-Seismic Event
- Societal Expectation for Seismic Event

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Community Member Needs

Adapted from Maslow 1943

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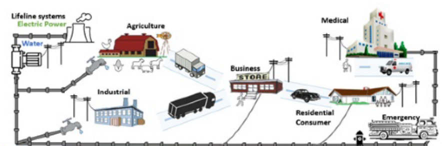
Lifeline Services

- The systems provide services for customers to use
  - Customers include other lifeline infrastructure systems
- Lifeline system service combinations are used to provide other societal services



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Social/Economic Needs

- Social/economic needs of community after a disaster drive infrastructure performance requirements

Source: NIST, 2016

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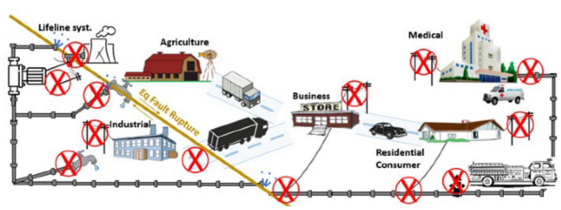
Lifeline System Earthquake Damage



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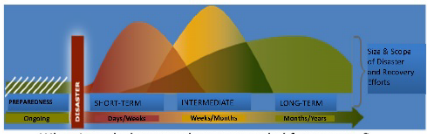
Recovery of Built Environment

Organize around restoring functionality over time



When is each cluster and system needed for recovery?

Survival
Safety and Security
Belonging
Growth and Achievement

Source: National Disaster Recovery Framework

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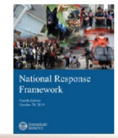
Functionality Needs For Recovery

- **Short-Term:** Secure, Rescue, Stabilize, Clear Routes
  - Clusters: Critical Facilities, Emergency Housing
    Related Infrastructure Systems
- **Intermediate:** Restore Neighborhoods, meet social needs
  - Clusters: Housing, healthcare, main street, schools, Churches
    Related Infrastructure Systems
- **Long-Term:** Community Social and Economic Recovery
  - Clusters: Commercial and Industrial Businesses
    Related Infrastructure Systems



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Previous Societal Expectation Topics Identified

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Lifelines Track - Breakout Session #1

Topic	NIST Lifelines Roadmap - Element I. Establish national lifeline system performance and restoration goals	Priority Ranking
1	Develop an overarching framework for national lifeline performance and restoration goals	
2	Assess current societal expectations of acceptable lifeline performance levels and restoration times informed by the phases of response and recovery	
5	Develop tools to quantify and rank the societal benefits and costs of different lifeline system performance levels and restoration times, as well as prioritize lifeline upgrades and investments	
13	Develop guidelines for post-earthquake lifeline assessment, response, and recovery	
23	Develop tools, guidance, incentives, and funding mechanisms for voluntary adoption and implementation of lifeline seismic resilience programs and earthquake-resilient design and construction standards	
24	Develop strategies and techniques for the public and key customers to engage lifeline system providers to define acceptable performance levels and restoration timeframes	
25	Assess the direct and indirect socioeconomic consequences and financial implications of different lifeline performance levels and restoration timeframes	

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Lifelines Track - Breakout Session #1

Rec.	NIST Societal Needs - A. Lifeline Codes, Standards, and Guidelines	Priority Ranking
A5	Develop lifeline system performance requirements that relate to community resilience and better reflect societal considerations.	

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Lifelines Track - Breakout Session #1

Rec.	NIST Societal Needs - B. Research	Priority Ranking
B1	Gather information on and systematically study the relationships between service disruptions, and societal impacts and expectations to better understand lifeline system performance.	
B2	Develop and conduct a targeted research program to assess societal expectations associated with lifeline system performance.	
B3	Systematically study and compare the array of design approaches and methods for addressing societally-based performance requirements within current codes, standards and guidelines for lifeline systems.	
B4	Investigate the differential vulnerability among social groups to lifeline system outages.	
B5	Systematically collect and review various "proxies" and secondary evidence for societal expectations of lifeline performance and restoration timeframes.	
B7	Conduct research on needed service restoration times, including how system operability as a performance metric supports community resilience.	

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Lifelines Track - Breakout Session #1

Rec.	NIST Societal Needs - C. Modeling	Priority Ranking
C1	Aggregate the existing suite of infrastructure modeling tools and create a user-friendly interface so communities can properly assess their lifeline-related system performance and restoration risks, including uncertainty.	

Rec.	NIST Societal Needs - D. Lifeline System Operations	Priority Ranking
D2	Develop guidance for lifeline service providers on how to engage and collaborate with communities, including emergency management agencies and other key community institutions, in developing resilience strategies and preparing system restoration and contingency plans.	
D3	Develop guidance for local planning (e.g., for fuel delivery to emergency responders and critical infrastructure).	

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13

Societal Expectation

1. Societal Expectation of Lifeline Performance and Recovery for Non-Seismic Events
   - Hurricane
   - Winter Storm
   - Flood
   - Tornado
   - Other Hazards

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Societal Expectation

2. Societal Expectation of Lifeline Performance and Recovery for Seismic Events
   - Transportation
   - Water
   - Electric Power
   - Liquid Fuel and Natural Gas
   - Communications
   - Wastewater
3. When designing lifeline infrastructure systems, should we define their restoration goals first?

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15

Lifelines Track - Breakout Session #1

Topic	NIST Lifelines Roadmap - Element I. Establish national lifeline system performance and restoration goals	Priority Ranking
1	Develop an overarching framework for national lifeline performance and restoration goals	3 (16/0/0)
2	Assess current societal expectations of acceptable lifeline performance levels and restoration times informed by the phases of response and recovery	3 (9/4/2)
5	Develop tools to quantify and rank the societal benefits and costs of different lifeline system performance levels and restoration times, as well as prioritize lifeline upgrades and investments	2 (5/10/0)
13	Develop guidelines for post-earthquake lifeline assessment, response, and recovery	1.5 (1/6/9)
23	Develop tools, guidance, incentives, and funding mechanisms for voluntary adoption and implementation of lifeline seismic resilience programs and earthquake-resilient design and construction standards	2.5 (9/2/4)
24	Develop strategies and techniques for the public and key customers to engage lifeline system providers to define acceptable performance levels and restoration timeframes	1.5 (2/6/7)
25	Assess the direct and indirect socioeconomic consequences and financial implications of different lifeline performance levels and restoration timeframes	3 (15/0/0)

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Lifelines Track - Breakout Session #1

Rec.	NIST Societal Needs - A. Lifeline Codes, Standards, and Guidelines	Priority Ranking
A5	Develop lifeline system performance requirements that relate to community resilience and better reflect societal considerations.	3 (15/0/0)

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Lifelines Track - Breakout Session #1

Rec.	NIST Societal Needs - B. Research	Priority Ranking
B1	Gather information on and systematically study the relationships between service disruptions, and societal impacts and expectations to better understand lifeline system performance.	3 (9/4/2)
B2	Develop and conduct a targeted research program to assess societal expectations associated with lifeline system performance.	2.5 (7/4/4)
B3	Systematically study and compare the array of design approaches and methods for addressing societally-based performance requirements within current codes, standards and guidelines for lifeline systems.	1 (0/0/15)
B4	Investigate the differential vulnerability among social groups to lifeline system outages.	3 (12/1/2)
B5	Systematically collect and review various "proxies" and secondary evidence for societal expectations of lifeline performance and restoration timeframes.	2 (2/8/5)
B7	Conduct research on needed service restoration times, including how system operability as a performance metric supports community resilience.	3 (10/4/1)

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Lifelines Track - Breakout Session #1

Rec.	NIST Societal Needs - C. Modeling	Priority Ranking
C1	Aggregate the existing suite of infrastructure modeling tools and create a user-friendly interface so communities can properly assess their lifeline-related system performance and restoration risks, including uncertainty.	3(12/1/2)

Rec.	NIST Societal Needs - D. Lifeline System Operations	Priority Ranking
D2	Develop guidance for lifeline service providers on how to engage and collaborate with communities, including emergency management agencies and other key community institutions, in developing resilience strategies and preparing system restoration and contingency plans.	2.5 (7/6/2)
D3	Develop guidance for local planning (e.g., for fuel delivery to emergency responders and critical infrastructure).	2.5 (7/6/2)

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Multihazards
Lifeline Infrastructure Systems

Craig A Davis
October 18, 2022

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1

Multihazards

- Context for Multihazards
  1. Design infrastructure for several different hazards
     - Earthquake
     - Wind
     - Flood
  2. Multiple cascading hazards within a primary hazard
     - Earthquake = shaking, surface fault rupture, liquefaction, landslide, tsunami, fire following, hazmat release etc.
     - Hurricane = wind, rain, surge, flood, tornado, fire following
  3. An independent hazard strike preceding or following an initial
     - An annual rain, storm, or hurricane following an earthquake
     - An existing drought before an earthquake

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2

Barriers for Addressing Earthquake Hazard

- Identify multihazard barriers that inhibit how the CUES can address the earthquake hazard.

Examples:

- Earthquake is uncommon, not recognized
- Other hazards are more frequent and top of mind
- Address current common threat vs. not addressing the rare but highly dangerous threat
- Earthquake is properly addressed, there is no barrier

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3

Miltihazards – Previous Identified Topics

Topic	NIST Lifelines Roadmap - Element I. Establish national lifeline system performance and restoration goals	Priority Ranking
3	Establish procedures to quantify hazards over spatially distributed lifeline systems	
12	Develop guidelines for mitigating damage to lifelines from tsunamis and other flood-related hazards	
14	Develop geohazard guidelines for owners and contractors for engineering, procurement, and construction of pipelines	
17	Develop methods for analysis and mitigation of damage from fire following earthquakes and hazardous material releases	
18	Improve and extend methods for mitigating the effects of earthquake-induced ground displacement on underground pipelines, conduits, and cables	
26	Implement post-earthquake information and response services for lifeline systems	

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4

Miltihazards – Previous Identified Topics

Rec.	NIST Societal Needs - B. Research	Priority Ranking
B12	Establish procedures to quantify hazards for spatially distributed systems.	
B14	Perform studies on changes in water demand considering an array of hazards as well as seasonal and longer-term climate variability, like drought.	
B15	Improve knowledge, databases and modeling for the impact of drought, widespread flooding and storm damage on regional fuel supplies.	

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Multihazards

1. Design infrastructure for several different hazards
   – How can CEUS gain synergy when designing for more common hazards and improving earthquake performance?

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Multihazards

2. Multiple cascading hazards within a primary hazard
   – Are there earthquake hazards needing special attention in the CEUS?

7

Multihazards

3. An independent storm, or other natural hazard following an earthquake
   – Are any aspects from this context where we can gain seismic improvements for the CEUS?

8

Multihazard Barriers

- How can we address multihazard-related barriers?

9

Miltihazards – Previous Identified Topics

Topic	NIST Lifelines Roadmap - Element I. Establish national lifeline system performance and restoration goals	Priority Ranking
3	Establish procedures to quantify hazards over spatially distributed lifeline systems	3 (13/3/1)
12	Develop guidelines for mitigating damage to lifelines from tsunamis, seiche, and other flood-related hazards	1 (0/3/14)
14	Develop geohazard guidelines for owners and contractors for engineering, procurement, and construction of pipelines	1.5 (3/6/8)
17	Develop methods for analysis and mitigation of damage from fire following earthquakes and hazardous material releases	2 (6/9/2)
18	Improve and extend methods for mitigating the effects of earthquake-induced ground displacement on underground pipelines, conduits, and cables	3 (11/4/2)
26	Implement post-earthquake information and response services for lifeline systems	2.5 (10/4/3)

10

Miltihazards – Previous Identified Topics

Rec.	NIST Societal Needs - B. Research	Priority Ranking
B12	Establish procedures to quantify hazards for spatially distributed systems.	repeat
B14	Perform studies on changes in water demand considering an array of hazards as well as seasonal and longer-term climate variability, like drought.	1 (0/5/12)
B15	Improve knowledge, databases and modeling for the impact of (EQ-induced) widespread flooding and storm damage on regional fuel supplies.	1 (4/6/7)

11

Lifeline Infrastructure System
Analysis, Design, Codes, Standards

12

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Analysis, Design, Codes, Standards

- These are topics associated with how a lifeline infrastructure system can achieve the provision of services to meet societal needs/expectations

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13

Previous Identified Topics

Topic	NIST Lifelines Roadmap - Element II. Develop Lifeline System Specific Performance Manuals, Guidelines, Standards, and Codes	Priority Ranking
15	Develop seismic qualification standards for lifeline components and systems	3 (13/1/2)

Rec.	NIST Societal Needs - A. Lifeline Codes, Standards, and Guidelines	Priority Ranking
A1	Identify or establish an organization and process for advocating, harmonizing and unifying the consensus procedures for lifeline guidelines and standards development.	3 (10/5/1)
A2	Develop more consistent terminology for lifeline standards.	2 (5/5/6)
A4	Develop a methodology to combine component-based design criteria into system level performance targets.	2 (5/8/3)
A6	Develop consensus-based guidelines and standards for the design of new lifelines and the retrofit of existing lifelines that reflect community resilience performance requirements and societal considerations.	3 (14/1/1)
A8	Reduce inconsistencies in the compendium of codes and standards that guide design, construction and resilience of the built environment, such as fire codes, building codes, and lifelines codes, standards, and guidelines.	2 (5/8/3)

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14

Previous Identified Topics

Rec.	NIST Societal Needs - B. Research	Priority Ranking
B13	Enhance the understanding of lifeline system supply sources and end-point facilities and their role in system performance, restoration, and community and regional recovery with the goal of improving databases and modeling of such sources and facilities.	2.5 (9/5/2)

Task	FEMA/NIST Functional Recovery – Recommendation 1. Develop a Framework for Post-EQ Re-occupancy and Functional Recovery Objectives	Priority Ranking
1.2	Develop Design Criteria for Achieving Recovery-Based Objectives.	2.5 (9/3/4)
1.3	Determine Appropriate Hazard Levels for Recovery-Based Objectives.	2.5 (9/6/1)

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15

Analysis, Design, Codes, Standards

- Are there any CEUS specific/additional items we should address?

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16

Previous Identified Topics

Topic	NIST Lifelines Roadmap - Element II. Develop Lifeline System Specific Performance Manuals, Guidelines, Standards, and Codes	Priority Ranking
15	Develop seismic qualification standards for lifeline components and systems	

Rec.	NIST Societal Needs - A. Lifeline Codes, Standards, and Guidelines	Priority Ranking
A1	Identify or establish an organization and process for advocating, harmonizing and unifying the consensus procedures for lifeline guidelines and standards development.	
A2	Develop more consistent terminology for lifeline standards.	
A4	Develop a methodology to combine component-based design criteria into system level performance targets.	
A6	Develop consensus-based guidelines and standards for the design of new lifelines and the retrofit of existing lifelines that reflect community resilience performance requirements and societal considerations.	
A8	Reduce inconsistencies in the compendium of codes and standards that guide design, construction and resilience of the built environment, such as fire codes, building codes, and lifelines codes, standards, and guidelines.	

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17

Previous Identified Topics

Rec.	NIST Societal Needs - B. Research	Priority Ranking
B13	Enhance the understanding of lifeline system supply sources and end-point facilities and their role in system performance, restoration, and community and regional recovery with the goal of improving databases and modeling of such sources and facilities.	

Task	FEMA/NIST Functional Recovery – Recommendation 1. Develop a Framework for Post-EQ Re-occupancy and Functional Recovery Objectives	Priority Ranking
1.2	Develop Design Criteria for Achieving Recovery-Based Objectives.	
1.3	Determine Appropriate Hazard Levels for Recovery-Based Objectives.	

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Lifeline Infrastructure Systems Breakout #3: Dependencies and Potential Impact on Response and Recovery

Kent Yu, PhD, PE, SE
October 18, 2022

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1

Outline for Dependencies Discussion

- Commonalities between Earthquake and Other Hazards
- Status of Coordination among Sectors
- Issues and Barriers for Identifying and Mitigation Dependencies

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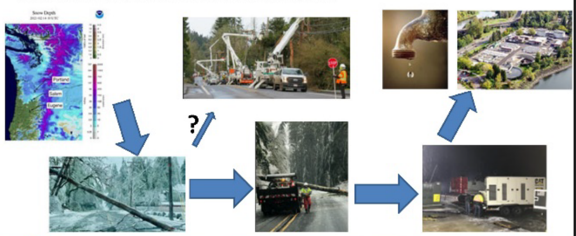
2

Infrastructure System Dependencies

The 2021 Winter Storm (Oregon) exposed several dependency issues



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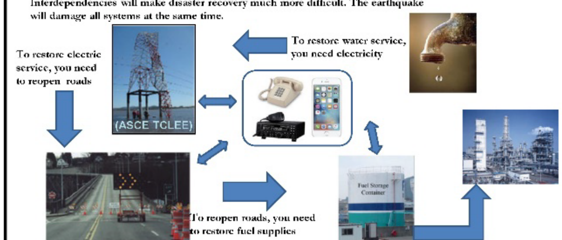
3

Infrastructure System Dependencies

Interdependencies will make disaster recovery much more difficult. The earthquake will damage all systems at the same time.



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4

Previous Dependencies Topics Identified

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5

Lifelines Track - Breakout Session #3

Topic	NIST Lifelines Roadmap - Element I. Establish national lifeline system performance and restoration goals	Priority Ranking
4	Develop modeling tools to support design approaches, planning, and restoration for interdependent lifeline systems	
16	Evaluate the feasibility of new interdependent lifeline system configurations	

Rec.	NIST Societal Needs - A. Lifeline Codes, Standards, and Guidelines	Priority Ranking
A7	Develop guidelines to inform the design, interoperability, and upkeep of lifeline system dependencies. Establish procedures to quantify hazards over spatially distributed lifeline systems	

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Lifelines Track - Breakout Session #3

Rec.	NIST Societal Needs - B. Research	Priority Ranking
B9	Enhance the understanding of infrastructure-related failures and cascading effects resulting from low-probability/high-consequence events.	
B10	Develop post-disaster data collection protocols to assess lifeline system recovery and restoration timeframes and improve the understanding of restoration processes across individual and interdependent lifeline systems.	
B11	Develop tools to identify interdependent infrastructure systems and services along with their restoration criteria.	

Rec.	NIST Societal Needs - C. Modeling	Priority Ranking
C2	Develop first-generation models and practical tools to analyze community resilience that account for lifeline system dependencies and interdependencies.	

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Lifelines Track - Breakout Session #3

Rec.	NIST Societal Needs - D. Lifeline System Operations	Priority Ranking
D3	Develop guidance for local planning (e.g., for fuel delivery to emergency responders and critical infrastructure).	
D4	Develop guidance for lifeline service providers to evaluate the effects of system component failures, both in isolation and in combination, and considering upstream and downstream dependencies.	

Task	FEMA/NIST Functional Recovery – Recommendation 4. Design, Upgrade, and Maintain Lifeline Infrastructure Systems to Meet Recovery-Based Objectives	Priority Ranking
4.4	Create Regional Lifelines Councils	

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8

Dependencies

1. Commonalities between Earthquake and Other Common Hazards
   - In the CUES, what are common dependencies identified for response and recovery of non-seismic events
     - Hurricane
     - Winter Storm
     - Flood
     - Tornado
     - Other hazards?
   - Are these dependencies applicable to earthquake hazards?

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9

Dependencies

2. Status of Coordination among Lifeline Sectors
   - In the CUES, how dependencies are being addressed in planning, design, mitigation, response and recovery for non-seismic hazards?
     - Hurricane
     - Winter Storm
     - Flood
     - Tornado
     - Other Hazards
   - Are the coordination efforts adequate?

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Dependencies

3. Issues and Barriers for Identifying and Mitigating Dependencies
   - What has the CEUS done well for identifying and managing dependencies?
   - What are issues/barriers for identifying and managing dependencies?
   - How can the CUES leverage response and recovery experience for other common hazards for rapid recovery for earthquake hazards?

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Lifelines Track - Breakout Session #3

Topic	NIST Lifelines Roadmap - Element I. Establish national lifeline system performance and restoration goals	Priority Ranking
4	Develop modeling tools to support design approaches, planning, and restoration for interdependent lifeline systems	3 (11/3/3)
16	Evaluate the feasibility of new interdependent lifeline system configurations	2 (0/11/6)

Rec.	NIST Societal Needs - A. Lifeline Codes, Standards, and Guidelines	Priority Ranking
A7	Develop guidelines to inform the design, interoperability, and upkeep of lifeline system dependencies.	2 (7/8/2)

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Lifelines Track - Breakout Session #3

Rec.	NIST Societal Needs - B. Research	Priority Ranking
B9	Enhance the understanding of infrastructure-related failures and cascading effects resulting from low-probability/high-consequence events.	3 (12/4/1)
B10	Develop post-disaster data collection protocols to assess lifeline system recovery and restoration timeframes and improve the understanding of restoration processes across individual and interdependent lifeline systems.	3 (8/3/6)
B11	Develop tools to identify interdependent infrastructure systems and services along with their restoration criteria.	2.5 (7/8/2)

Rec.	NIST Societal Needs - C. Modeling	Priority Ranking
C2	Develop first-generation models and practical tools to analyze community resilience that account for lifeline system dependencies and interdependencies.	3 (12/2/3)

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Lifelines Track - Breakout Session #3

Rec.	NIST Societal Needs - D. Lifeline System Operations	Priority Ranking
D4	Develop guidance for lifeline service providers to evaluate the effects of system component failures, both in isolation and in combination, and considering upstream and downstream dependencies.	2 (3/8/6)

Task	FEMA/NIST Functional Recovery – Recommendation 4. Design, Upgrade, and Maintain Lifeline Infrastructure Systems to Meet Recovery-Based Objectives	Priority Ranking
4.4	Create Regional Lifelines Councils	3 (17/0/0)

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Acronyms

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AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AHJ	Authority Having Jurisdiction
AISC	American Institute of Steel Construction
ALA	American Lifelines Association
AREMA	American Railway Engineering and Maintenance-of-Way Association
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
BOCA	Building Officials and Codes Administrators
BSSC	Building Seismic Safety Council
CEUS	Central and Eastern United States
CMU	concrete masonry unit
EOR	Engineer of Record
EPRI	Electric Power Research Institute
FEMA	Federal Emergency Management Agency
FR	functional recovery
GC	General Contractor
GMM	ground motion model
HVSR	horizontal-to-vertical spectral ratio
IBC	International Building Code
ICC	International Code Council
IEBC	International Existing Building Code
IRC	International Residential Code

M	magnitude
MCE_R	risk-targeted maximum considered earthquake
MPRS	multi-period response spectrum
NCEER	National Center for Earthquake Engineering Research
NCSEA	National Council of Structural Engineers Association
NEHRP	National Earthquake Hazards Reduction Program
NFPA	National Fire Protection Association
NGA-East	Next Generation Attenuation Relationships for Central & Eastern North-America
NGL	Next Generation Liquefaction
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NRC	Nuclear Regulatory Commission
NRI	National Risk Index
NSHM	National Seismic Hazard Map
PE	Professional Engineer
PEER	Pacific Earthquake Engineering Research center
PGA	peak ground acceleration
PSHA	probabilistic seismic hazard analysis
RDP	Registered Design Professional
SBC	Standard Building Code
SDC	seismic design category
SEI	Structural Engineering Institute
SPUR	San Francisco Bay Area Planning and Urban Research Association
SSHAC	Senior Seismic Hazard Analysis Committee
TCLEE	Technical Council on Lifeline Earthquake Engineering
UBC	Uniform Building Code

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UHS	uniform hazard spectrum
URM	unreinforced masonry
USGS	United States Geological Survey
WUS	Western United States

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