September 30, 2023

The Honorable Laurie E. Locascio, Ph.D.
National Institute of Standards and Technology
100 Bureau Drive
Gaithersburg, MD 20899-1000

Dear Dr. Locascio,

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) is authorized by Section 103 of the National Earthquake Hazards Reduction Program (NEHRP) Reauthorization Act of 2004 (Public Law 108-360), 42 U.S.C. § 7704(a)(5), and was established pursuant to the Federal Advisory Committee Act, as amended, 5 U.S.C. App. ACEHR members are non-Federal employees serving three-year terms from research and academic institutions, earthquake-related professions, and state and local governments. We are charged with assessing (1) trends and developments in the science and engineering of earthquake hazards reduction; (2) the effectiveness of NEHRP; (3) any need to revise NEHRP; and (4) the management, coordination, implementation, and activities of NEHRP.

The enclosed biennial report is submitted to you, as the Director of the National Institute of Standards and Technology (NIST) and as chair of the Interagency Coordinating Committee on Earthquake Hazards Reduction (referred to in this report as the "Interagency Coordinating Committee" or ICC). Our nine recommendations are also directed to the NIST NEHRP Office and the four NEHRP agencies—the Federal Emergency Management Agency (FEMA), NIST, National Science Foundation (NSF), and U.S. Geological Survey (USGS).

ACEHR is impressed by the activities undertaken over the past two years by the NEHRP agencies and the hardworking people who comprise these agencies. Noteworthy is the development and approval of the *FY22-29 Strategic Plan for the National Earthquake Hazards Reduction Program* (also referred to as the *FY22-29 NEHRP Strategic Plan*). The *FY22-29 NEHRP Strategic Plan* is ambitious, engages the complementary expertise of the NEHRP agencies, and reflects the input of subject matter experts. Related to this, ACEHR strongly supports and looks forward to engaging with the Program Coordination Working Group (PCWG) as it develops a complementary *Management Plan*. We anticipate it will enable the NEHRP agencies to collaborate even more effectively, benchmark their progress, and communicate their effectiveness using comprehensible performance metrics. We also expect it will respond aptly to the GAO (2022) recommendations, which refer to the use of leading practices to "develop performance measures linked to priority research outcomes " (Recommendation 5) and "identify and leverage the program's resources needed to achieve research priority outcomes'' (Recommendation 6). ICC input, feedback, and support will be critical to the timely development and implementation of the *Management Plan*.

Reporting by the Acting NEHRP Director and agency representatives at the ACEHR meetings for the past two years has been vital to the development of this report. Updates on activities as they pertain to the *FY22-29 NEHRP Strategic Plan* have enabled greater

understanding of both individual agency activities as well as NEHRP's collaborative efforts. In addition, the Acting NEHRP Director has responded generously to ACEHR's previous request for updates on its biennial report recommendations. We are grateful for the time and effort needed to develop and deliver these updates.

ACEHR happily notes that all members of the ICC have been officially appointed to their roles. Timely leadership transitions reduce stakeholder uncertainty and increase confidence in the decisions made. We imagine these appointments will facilitate an even greater level of collaboration, deliberation, and commitment as is appropriate for a high-level body such as the ICC. Finalizing appointments, including that of the current Acting NEHRP Director, sends a message to key stakeholders of a program's relative permanence and importance to those in high-level leadership positions.

Respectfully submitted on behalf of ACEHR, whose members endorse these comments.

Dr. Lucy A. Arendt, Chair of ACEHR (Donald J. Schneider School of Business & Economics, St. Norbert College, De Pere, WI)

Members, Advisory Committee on Earthquake Hazards Reduction (ACEHR)

- Dr. Ann Bostrom (Daniel J. Evans School of Public Policy & Governance, University of Washington, Seattle, WA)
- Mr. Jeff Briggs (Missouri State Emergency Management Agency, Jefferson City, MO)
- Mr. Robert Carey (Utah Division of Emergency Management, Salt Lake City, UT)
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- Dr. Michael W. Hamburger, *ex-officio*, Chair of SESAC (Earth and Atmospheric Sciences, Indiana University, Bloomington, IN)
- Mr. Thomas F. Heausler (Consulting Structural Engineer, Bay Saint Louis, MS)
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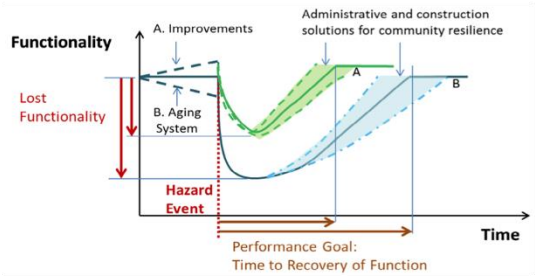
- Ms. Danielle H. Mieler (City of Alameda, CA)
- Dr. Ellen M. Rathje (Department of Civil, Architectural, and Environmental Engineering, University of Texas, Austin, TX)
- Dr. Jonathan P. Stewart (Civil and Environmental Engineering, University of California, Los Angeles, CA)
- Dr. Douglas Wiens (Dept of Earth, Environmental & Planetary Sciences, Washington University, St. Louis, MO)

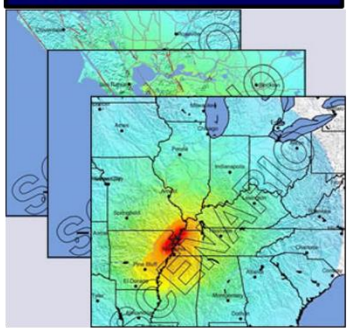
Enclosure

Research-to-Practice Pipeline

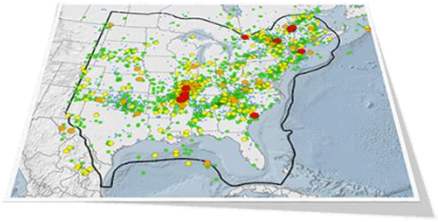
Functional Recovery

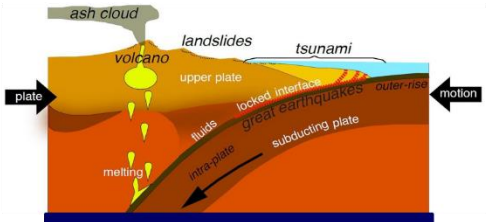


Earthquake Scenarios



Central & Eastern U.S. Research





Subduction Zone Research

Earthquake Insurance

Learning from International Earthquakes

A Report from the

Advisory Committee on Earthquake Hazards Reduction on NEHRP Effectiveness for FY22-23

September 30, 2023

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ACKNOWLEDGEMENTS

The members of ACEHR are fortunate to work closely with several exceptional individuals. We appreciate their passionate commitment to NEHRP and their tireless efforts to educate the members of ACEHR about NEHRP and the work of their agencies.

- Tina M. Faecke, Designated Federal Officer (ACEHR), NIST
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- Gavin P. Hayes, USGS
- Bill R. Blanton, FEMA
- Jonathan Foster, FEMA
- Andrew Herseth, FEMA
- Michael G. Mahoney (retired), FEMA

ON THE COVER

- Research-to-Practice Pipeline. Depiction of the four coordinating agencies' roles in the National Earthquake Hazards Reduction Program (NEHRP); Credit: fema.gov
- Functional Recovery. McAllister, T. (2016). Research needs for developing a risk-informed methodology for community resilience. *Journal of Structural Engineering*, 142(8), C4015008
- Earthquake Scenarios. https://earthquake.usgs.gov/scenarios/
- Central & Eastern U.S. Research. http://www.ceus-ssc.com
- Subduction Zone Research. https://www.usgs.gov/special-topics/subduction-zone-science/science/introduction-subduction-zones-amazing-events
- Earthquake Insurance: Courtesy of ACEHR member Thomas F. Heausler
- Learning from International Earthquakes: Courtesy of NIST

EXECUTIVE SUMMARY

"It was September 2010, and I was participating in my first post-earthquake reconnaissance trip to Christchurch, New Zealand. I was part of a multidisciplinary team of folks with backgrounds in engineering, architecture, seismology, and the social sciences. While on one of our walk-abouts, a local approached us, and asked with both worry and urgency, **"What caused this? Could this happen again? Was this it for us?"** Members of our team shared what we knew—and what was still unknown. While certainty was the local's hoped-for response, uncertainty in the form of probabilities and contingencies was the best we could offer. None of us knew that another earthquake would strike the same general area a mere five months later, leading to 185 deaths, nearly 7,000 injuries, and the eventual rebuilding of more than 10,000 homes and demolition of another 3,500 buildings—including much of Christchurch's historic central business district. It was devastating."

Lucy Arendt, Ph.D.
Professor of Management, St. Norbert College
Current ACEHR Chair

Earthquakes are complex phenomena. There are diverse types—shallow fault earthquakes, subduction zone earthquakes, and deep earthquakes—with magnitudes ranging from 2 or less to 8.0 or greater. They interact with the environment, natural and built, and can lead to injuries and deaths, psychological and emotional trauma, interruption of services, economic costs, and overall community disruption. Unlike other natural hazards, such as hurricanes and floods, earthquakes typically happen with only the briefest of warnings. Vulnerable populations tend to suffer disproportionately, both during and in the aftermath of earthquake events. Since the United States is one of the 10 most earthquake-prone countries in the world, it is critical that we study the antecedents and consequences of these complex phenomena using multiple perspectives—architecture, engineering (civil, geotechnical, structural), seismology, geology, risk management, public policy, sociology, and more—so that we might effectively and efficiently design the built environment and enhance the resilience of our communities and the people who comprise them. There remains much to be learned from the earthquakes affecting the U.S. directly and those affecting other parts of the world, such as in Morocco, Türkiye, México, Nepal, Haiti, Japan, Chile, Italy, Indonesia, China, and New Zealand.

Earthquakes continue to pose a substantial threat to the United States, despite the considerable progress toward earthquake risk reduction since the National Earthquake Hazards Reduction Program (NEHRP) was originally enacted in 1977. The approved and adopted *FY22-29 NEHRP Strategic Plan* required by the NEHRP Reauthorization Act of 2018 charges the NEHRP agencies (FEMA, NIST, NSF, and USGS) with pursuing specific and

measurable goals that will advance efforts to address earthquake risks and enable community resilience throughout the nation.

A distinguishing characteristic of NEHRP is its focus on evidence-based action. This bias for action necessitates the development of a *Management Plan* to ensure implementation of the *FY22-29 NEHRP Strategic Plan*. To this end, the Advisory Committee on Earthquake Hazards Reduction (ACEHR) calls upon the NEHRP Interagency Coordinating Committee (ICC) to provide the resources and support for timely development and approval of the *Management Plan*, thereby enabling full implementation and assessment of the *FY22-29 NEHRP Strategic Plan*. This support includes prioritizing the appropriations, allocations, and budgetary mechanisms needed to fulfill the Strategic Plan, recognizing there are myriad demands upon the agencies and their resources. Current allocations to the NEHRP agencies are simply inadequate to the responsibilities assigned to each agency in their charges and in the Strategic Plan. As creative, dedicated, and collaborative as the NEHRP agency members may be, it is essential that they have sufficient resources to execute the plans that have been approved. Appropriate funding for and timely implementation of the Strategic Plan are needed to move the nation to greater understanding of earthquake science and mitigation-led community resilience.

ACEHR provides a biennial assessment of NEHRP as required by the committee charter and PL 108-360 as amended in 2018. This document, ACEHR's FY22-23 Biennial Report, focuses on the noteworthy progress made by the NEHRP agencies on the goals, objectives, and focus areas described in the *FY22-29 NEHRP Strategic Plan*. Our assessment includes summaries of NEHRP's achievements along with **six** programmatic recommendations and **three** procedural recommendations.

Recommendations Summary

What follows is a "shorthand" list of the recommendations from in this report. The rationale for each recommendation is presented in the **ACEHR Recommendations** section, with recommendations numbered as follows and appearing in **bold** in that section.

Programmatic Recommendations

1. **Understand and Communicate the Research-to-Practice Pipeline**

    a. Clarify the research-to-practice pipeline for state, local, territorial, and tribal governments, and other stakeholders (aligns with GAO-22-105016 Recommendation 7).

    b. Develop a communication strategy as part of NEHRP's upcoming *Management Plan*, which may include for example, plans for enhanced and inclusive communication and public outreach regarding: (1) seismic hazards;

(2) expected seismic performance of the built environment; and (3) the opportunities and challenges associated with earthquake early warning systems.

c. Act to ensure that earthquake hazard mitigation programs are effectively designed to serve the whole community, including members of vulnerable populations.

d. Prioritize research regarding social vulnerability to earthquakes and related hazards.

e. Prioritize research comparing and contrasting the social equity aspects of safety-based and recovery-based earthquake performance of the built environment (in particular assessing buildings and lifeline infrastructure).

2. Build on Functional Recovery Efforts Toward Community Resilience

a. Existing buildings

i. Prioritize research on methods for retrofitting existing buildings to enable functional recovery.
ii. Prioritize research on methods for achieving functional recovery of existing buildings with benefit-cost ratios persuasive to those who own and manage existing buildings.
iii. Prioritize communication and guidance for implementing seismic retrofit projects designed to achieve functional recovery.

b. Lifelines

i. Restore NEHRP's commitment to and collaboration with appropriate partners to re-energize the American Lifelines Alliance.
ii. Support stakeholder meetings and prioritize research to inform the development of lifeline design and retrofit standards that promote functional recovery of lifelines.

3. Promote and Expand the Use of Earthquake Scenarios

a. Promote and expand the use of earthquake scenarios to:

i. Understand earthquake impacts, including on vulnerable communities.
ii. Enhance earthquake education and community engagement, emergency drills, and exercises to promote effective earthquake awareness.

iii. Improve risk assessments, and mitigation, response, and recovery planning.

4. Prioritize Essential Research and Problem-Focused Studies

a. Central and Eastern United States (CEUS) Research

i. Prioritize research on the needs of CEUS earthquake risk reduction, including basic research to improve source characterization, ground motion modeling, building code provisions, and lifeline infrastructure vulnerabilities.

b. Research Subduction Zone (SZ) Earthquakes and Hazards

i. Prioritize essential research on SZ earthquakes and their impacts on the built environment.
ii. Prioritize development and implementation of offshore sensors and datasets to facilitate research advances.
iii. Identify opportunities for more collaboration between the agencies and the academic community around SZ earthquake hazards, such as the use of offshore sensors for both research and earthquake early warning.

5. Review International Earthquake Response and Lessons Learned

a. Review and report to ACEHR lessons learned from the 2023 Kahramanmaraş, Türkiye Earthquake Sequence, including an after-action review of how the draft revision of USGS Circular 1242 was used, with attention to coordination across agencies and sectors and the speed of response.

6. Prioritize Research on Earthquake Insurance to Make It More Affordable and Attainable

a. Prioritize research on innovative approaches to making earthquake insurance more affordable and attainable, working with public agencies and private companies.

Procedural Recommendations

7. Update the NSF Synthesis Report

a. Update the 2017 "NSF Synthesis Report" every other year to coincide with the ACEHR biennial report cycle. The report should be similar to that generated in 2017 and highlight NEHRP-specific funded research.

8. **Finalize and Disseminate the NEHRP Biennial Report**

    a. Finalize and disseminate the latest draft of NEHRP's Biennial Report so that it may be considered by ACEHR as it prepares its own biennial report.
    b. Provide ACEHR members with the annual or biennial budget numbers that typically appear in the NEHRP Biennial Reports (e.g., distribution by agency and strategic goal).

9. **Update the NEHRP Website**

    a. Modernize the NEHRP website informed by user-centered design. Process-wise, this should include working with key stakeholders (e.g., state, local, tribal, and territorial governments) and principal users (e.g., ACEHR members), to assess their NEHRP-related information needs and uses.

We also highlight two emerging topics with the potential to benefit earthquake risk-reduction efforts and improve community resilience: **earthquake sequence research**, and **new technologies**. The Committee hopes its assessment and these recommendations add positively to the important work undertaken by the NEHRP agencies to address the significant risks posed by earthquakes to our nation's citizens.

INTRODUCTION

"An investment today could avoid future loss of life and structures"

The NEHRP Reauthorization Act of 2018 (PL 115-307 or the Act) was an important milestone for the nation. Since NEHRP was originally enacted in 1977, there has been significant progress by each of the NEHRP agencies (FEMA, NIST, NSF, and USGS) toward advancing the objectives of the Program. As a result, the earthquake community has made considerable strides in understanding earthquakes and reducing earthquake risk through basic and applied research on earthquake processes and earthquake engineering, hazard mapping, improved design and construction practices, stronger building codes and standards, public education, and community-based emergency response programs, among other activities (NRC, 2011; Leith, 2017).

The benefits derived from the federal investment in earthquake hazard mitigation far exceed the costs. A 2019 study by the National Institute of Building Sciences (Multi-Hazard Mitigation Council, 2019) found that federally funded earthquake hazard mitigation grants between 1993 and 2016 saved society $5.73 billion at a cost of only $2.2 billion—a benefit-cost ratio of approximately 3 to 1. The savings are due to reductions in loss of service (34%), reduced damage to property (26%), casualties (19%), and direct and indirect

business interruption (21%). This 23-year period was characterized by moderate seismic activity in the United States; the benefits to be realized in future, large earthquakes are therefore likely much greater. Furthermore, trillions of dollars of investments in buildings and infrastructure by state, local, territorial, and tribal governments and private organizations using developments from NEHRP will continue to increase these benefits.

Earthquake science and hazard mitigation can improve immeasurably and save the lives and livelihoods of men, women, and children—whether asleep in their homes, at work, in school, or wherever they find themselves during an earthquake. Video and still photos from recent earthquakes, such as those in Türkiye and Morocco this year, make clear the devastation and overwhelming sorrow that accompany the collapse of buildings and the lack of basic intended function that impedes continued use of buildings, sending people into temporary shelters that provide little in the way of the security offered by their own homes, workplaces, schools, and more. This perspective highlights a **moral imperative** to study and learn from earthquakes, and to develop and share tools that empower people to mitigate their risks from earthquakes. Earthquakes in the U.S. affect all citizens, directly or indirectly. Knowing we can reduce the costs associated with earthquakes means we must do everything in our power to achieve this end. We are fortunate to have NEHRP bridging the gap between knowledge and action.

Mitigation matters. While it may be challenging for those living in lower seismicity regions to imagine a highly damaging earthquake, we know from decades of social science research that the costs associated with mitigation are outweighed significantly by the costs associated with a high number of deaths and other casualties, and the downtime experienced by business owners, multi-family housing units, schools, and more as community members wait to find out if their buildings will be "red-tagged" and then whether their insurance—if they have it—will help them rebuild their lives and livelihoods. Far better to minimize the damage and heartache in advance than to address it in the aftermath of an earthquake.

Despite the progress made in the U.S., earthquakes still pose a substantial threat. All 50 states and five inhabited U.S. territories are vulnerable to earthquakes, and nearly half the U.S. population lives in areas with moderate or major seismic risk. A large earthquake in a major urban center could cause thousands of casualties, widespread population displacement and social disruption, and billions of dollars in economic losses (Jaiswal, et al., 2023). Leadership at the national level, and continuing collaboration among the NEHRP agencies, is needed to facilitate empowered action at the state, local, territorial, and tribal levels. The transfer of innovative earthquake science knowledge to those who can best apply it to their contexts and situations is critical to the nation's security and our citizens' ability to pursue their unalienable rights: the enjoyment of life, liberty and the pursuit of happiness, and the acquiring and possessing of property. People should further be reasonably certain in the aftermath of an earthquake that they will continue to have access to and be able to occupy and use their buildings in accord with their basic intended

function. This assumes that the earthquake is not a maximum considered earthquake (MCE) as these typically yield a level of destruction that even the best mitigation plans may struggle to prevent.

What can we learn from the February 2023 earthquakes in Türkiye?

After the earthquakes, Dr. Lucy Jones shared her opinion about the state of existing buildings in California, noting that a substantial number would likely be non-functional and might need demolishing should an earthquake occur similar to those in Türkiye in early 2023 (Jones, 2023; KCAL-News Staff, 2023).

In fact, we can learn a great deal from Türkiye.

- The Türkiye/Syria earthquake sequence provides examples of triggered earthquakes (e.g., the M7.8 started as a relatively "small" event on a fault that links to the east Anatolian Fault, which then triggered the rest of the mainshock) and an example of where this did not happen (e.g., the rupture ended at a step over to the Dead Sea Fault). Similar fault systems are present in California and the lessons learned from Türkiye should be examined for their compatibility with source models and the current generation of "earthquake rupture forecast" models used for the U.S. National Seismic Hazard Model.
- Agencies that maintain ground motion networks in Türkiye had many instruments located along the fault. The data collected will be very impactful, despite the fact that not all data were available in near-real time.[1] Major plate boundary faults in the U.S. (e.g., San Andreas) lack the same quantity of dense, on-fault instrumentation of this type. We should learn from the Türkiye experience and improve the instrumentation of these critical regions.
- The data from Türkiye has produced a wealth of information on building performance that could inform practice in the U.S. While many of the structures had deficiencies, others were constructed to similar codes as used in the U.S., though perhaps with lower construction standards and less oversight. NIST might consider reaching out to and working with AFAD (https://en.afad.gov.tr/about-us) to develop and disseminate a building inventory for the region (Cetin et al. 2023). FEMA might also consider using the information gathered on hospitals to update *FEMA P-767, Earthquake Mitigation for Hospitals*, as those structures tended to perform well.

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) provides a biennial assessment of NEHRP. ACEHR assesses (1) the effectiveness of NEHRP in performing its

[1] Gaining access to the data required an array of informal contacts and ad hoc agreements.

statutory activities; (2) its management, coordination, implementation, and activities; and (3) developments in the science and engineering of earthquake hazards reduction. This report presents an assessment of NEHRP achievements during fiscal years 2022-23; programmatic and procedural recommendations from ACEHR; and emerging topics. ACEHR's overarching goal is to ensure that NEHRP continues to help the nation understand and mitigate earthquake risk.

One critical observation remains to be made: **The funding available at the national level to support NEHRP and its activities is insufficient to the tasks for which it is responsible.** While a major earthquake may not have occurred in the U.S. since 1994, it is a matter of when, not whether. It is also a matter of where. We are not as prepared as we need to be. A review of the allocation to NEHRP reveals stagnant or declining funding. This in a time of inflation and increasing costs for human and other resources necessarily suggests that we are falling behind in our efforts. Mitigation matters to community resilience; communities that are resilient require fewer resources from governments when disasters happen. Resilient communities also suffer fewer lives and livelihoods lost, not to mention reduced psychological and emotional trauma for citizens of all ages.

We can and must do better.

NEHRP ACHIEVEMENTS (FY22-23)

> "The four NEHRP agencies work in close coordination to improve the Nation's understanding of earthquake hazards and to mitigate their effects. The missions of the four agencies are complementary, and the agencies work together to improve our understanding, characterization, and assessment of hazards and vulnerabilities; improve model building codes and land use practices; reduce risks through post-earthquake investigations and education; improve design and construction techniques; improve the capacity of government at all levels and the private sector to reduce and manage earthquake risk; and accelerate the application of research results" (https://nehrp.gov/about/agencies.htm).

Collaboration between and among the four NEHRP agencies is their *modus operandi*. While all four agencies can boast plenty of accomplishments for the past two years, the overarching focus on understanding and mitigating the effects of earthquake hazards is their collective *raison d'etre*. This formal collaboration allows for resource sharing and optimization, both important to the development and implementation of innovative solutions with positive benefit-cost ratios. Continuing efforts to collaborate and learn from each other are expected to best serve the nation as the NEHRP agencies tackle complex

problems, all of which require multi-faceted solutions developed by multidisciplinary teams of subject matter experts.

> "Because NEHRP has long supported multi-disciplinary research focused on learning about the physical properties of earthquakes as well as their impacts on people and the built environment, the program has helped to catalyze **deep integration** across the physical sciences, social sciences, and engineering. Earthquake reconnaissance teams have involved researchers from multiple disciplines for decades—a practice that teams focused on hurricanes, floods, wildfires, and other hazards are only now beginning to adopt on a wider scale. This is just one of many examples of how **NEHRP has served as a sort of force function**, bringing researchers together across disciplines. This matters because the challenges we face are so complex, they cannot be understood—let alone solved—when looking through only one disciplinary lens."
>
> *Lori Peek, Ph.D.*
> *Professor, Department of Sociology, University of Colorado Boulder*
> *Director, Natural Hazards Center and CONVERGE*

While events of the last several years have challenged the NEHRP agencies to retain their collaborative ethos and continue producing their best work, they have certainly done so. The Covid-19 global pandemic along with increased prevalence and impacts of other hazards (e.g., tornados, wildfires) have shifted the national gaze away from earthquake hazards. This shift is at least partially due to the fact that it has been nearly three decades since the 1994 Northridge earthquake, the last one in the United States with a high number of casualties. Competition for scarce human and other resources has also challenged the NEHRP agencies. In response, they have exercised their considerable creativity, found even more ways to collaborate effectively, and made difficult allocation decisions. One mechanism for maintaining and enhancing the agencies' collaborative focus is the *FY22-29 NEHRP Strategic Plan* (NEHRP, 2023). This plan, in development for several years, has guided both the agencies' activities and their report-outs to ACEHR. Through September 2023, the agencies have already made progress on all four goals and objectives 1-16 of 18.

While there are numerous examples of outstanding collaboration between the NEHRP agencies, this report calls out three of these. The first is the joint FEMA-USGS study providing an **Annualized Earthquake Loss** (AEL) update (Jaiswal et al., 2023, FEMA P-366 Update). According to the update, AEL increased to $14.7 billion per year (up from $6.1 billion in 2017). The increase is ascribed to increased building value, updated hazard information, and improved building inventory. The ratio of building loss to building value decreased in the western U.S., a result of progress made in reducing vulnerability of new buildings. Cost-effective retrofits of existing vulnerable structures remain an issue.

A second example of an essential collaboration is the joint NSF-NIST program that solicits and awards Disaster Resilience Research Grants (**DRRG**).[2] These grants support research to advance fundamental understanding of disaster resilience in support of improved, science-based planning, policy, decisions, design, codes, and standards. Twenty projects were funded in 2022 totaling $7.6 million USD.

Finally, another example of collaboration is the **functional recovery** work supported by both FEMA and NIST. The two agencies were specifically tasked in the 2018 NEHRP reauthorization language with jointly convening a Committee of Experts to develop the "Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time"[3] (FEMA P-2090/NIST SP-1254, 2021) report to Congress. A Project Technical Panel, supported by FEMA and led by the Applied Technology Council, was charged with developing the report, and a Project Review Panel, supported by NIST and led by the Science and Technology Policy Institute (STPI), was charged with providing review and feedback on the report.

FEMA has continued to support this critical topic, including through its leadership in the PUC Functional Recovery Task Committee and Subcommittees. FEMA's work on functional recovery, particularly its involvement in the provisions and code development process, is essential to community resilience throughout the nation. Life safety is no longer sufficient; citizens expect better performance from their buildings, especially new ones. Despite the importance of FEMA's continued involvement in functional recovery, a reduction in its budget allocation led to the difficult decision to end the work on functional recovery of lifelines (ATC 150, *Improving the Nation's Lifelines Infrastructure to Achieve Seismic Resilience*). This is **unconscionable**, as functioning lifelines are imperative to functional recovery of structures and community resilience.

NIST has also continued to support the work on functional recovery, both through its engagement in the PUC Functional Recovery Task Committee and Subcommittees and more. Along with ATC, NIST conducted a workshop that identified key issues affecting the effective implementation of earthquake resistant design in the Central and Eastern United States (CEUS) (Applied Technology Council, 2023). This effort identified both research and outreach needs for those working with buildings and lifeline infrastructure. What was particularly effective about this workshop was its atypical focus on the CEUS (most workshops emphasize areas of high seismic activity, such as the western United States), and its strong emphasis on pragmatic issues affecting practicing engineers and regulators.

[2] https://new.nsf.gov/funding/opportunities/disaster-resilience-research-grants-drrg
[3] https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1254.pdf

What follows are highlights from each of the NEHRP agencies, beginning with the NEHRP Program Leadership, housed in NIST.

NEHRP Program Leadership

> "Designated as the lead NEHRP agency, NIST has the primary responsibility for NEHRP planning and coordination" (https://nehrp.gov/about/agencies.htm).

In its capacity as the lead NEHRP agency, NIST has overseen the development of the *FY22-29 NEHRP Strategic Plan* and will do the same for the *Management Plan* for the National Earthquake Hazards Reduction Program. The latter is expected to articulate how the goals, objectives, and focus areas of the strategic plan will be operationalized, its outcomes assessed, and those outcomes communicated to stakeholders. Besides providing updates on the development and approval of both the strategic and *Management Plan*, the Acting NEHRP Director also shares with ACEHR the schedule and outcomes associated with meetings of the ICC (Interagency Coordinating Committee). As established by PL 108-360, the ICC includes the directors of the four primary program agencies, the White House Office of Science and Technology Policy (OSTP), and the Office of Management and Budget (OMB).[4] The NIST Director chairs the ICC. The ICC oversees NEHRP planning, management, and coordination—including the development of NEHRP's Strategic and *Management Plans*. The ICC also develops and submits a coordinated interagency NEHRP budget and an annual report to Congress that ensures appropriate balance among NEHRP activities.[5]

In addition, the Acting NEHRP Director has assumed responsibility for updating ACEHR on two assessment reports developed by the GAO (U.S. Government Accountability Office), including "Earthquakes: Progress Made to Implement Early Warning System, but Actions Needed to Improve Program Management"[6] (GAO-21-129, 2021) and "Earthquakes: Opportunities Exist to Further Assess Risk, Build Resilience, and Communicate Research"[7] (GAO-22-105016, 2022). These reports were required by The National Earthquake Hazards Reduction Program Reauthorization Act of 2018.

For the first report, the GAO "evaluated agency guidance and other planning documents, such as USGS's ShakeAlert implementation plans; assessed its ShakeAlert cost estimate; conducted site visits to selected cities; and interviewed federal and state officials, among others" (GAO-21-129, 2021). The GAO had nine recommendations for USGS (7), and 1 each for the Department of Commerce (DOC) and the Department of the Interior (DOI). Agency

[4] https://www.nehrp.gov/about/history.htm
[5] https://www.nehrp.gov/about/history.htm
[6] https://www.gao.gov/products/gao-21-129
[7] https://www.gao.gov/products/gao-22-105016

responses were included in Appendix III of the first report. For the second report, the GAO "reviewed NEHRP's strategic plans, agency guidance, and external communications; compared procedures to leading practices for interagency collaboration; and interviewed federal and state officials, among others" (GAO-22-105016, 2022). The GAO had seven recommendations for NIST (5), NSF (1), and FEMA (1). Agency responses were provided in Appendix III, IV, and V of the second report. Progress on these recommendations is available at https://www.gao.gov/products/gao-21-129 and https://www.gao.gov/products/gao-22-105016.

Finally, the Acting NEHRP Director has taken the lead on sharing with ACEHR the progress made on recommendations from ACEHR's most recent biennial report.

ACEHR commends the Acting Director's willingness to field questions from and provide responses to ACEHR's members on these and other topics relevant to ACEHR's work. ACEHR looks forward to continuing to receive updates on the Strategic and *Management Plans*, ICC meetings, the GAO assessment reports, and the agencies' responses to ACEHR's recommendations.

ACEHR is impressed with the overall responsiveness and thoroughness of the Acting Director, members of the PCWG (Program Coordination Working Group), agency representatives, and all agency members who help the agencies' representatives to prepare for and attend the ACEHR meetings. ACEHR appreciates the professionalism, time, and effort that go into maintaining a positive working relationship between itself and the NEHRP agencies. One consistent theme communicated during the updates provided to ACEHR, whether from the Acting NEHRP Director or the agency representatives, is the value associated with the agencies' commitment to collaborating with each other to achieve the overarching aims of NEHRP and serve the nation in doing so. Besides the vast number of collaborations yielding tangible outputs, the degree of willing cooperation and creativity in joint problem-solving is evident from the visibly positive interactions of the agency representatives during ACEHR's meetings.

The *FY22-29 NEHRP Strategic Plan*

Members of ACEHR, both current and past, contributed to the development of the *FY22-29 NEHRP Strategic Plan* (NEHRP, 2023) as subject matter experts who shared their input and feedback on drafts of the plan. ACEHR fully supports the *FY22-29 NEHRP Strategic Plan* and recognizes its importance in guiding the efforts of all its agencies going forward. To ensure the strategic plan's continued importance, and to measure its success, ACEHR encourages agencies to continue tying project activities and milestones to specific plan components in their updates to ACEHR. One benefit of this approach is the ability for ACEHR to observe directly how the mission, roles, and operations of the individual NEHRP agencies complement each other to achieve NEHRP's overarching goals, objectives, and focus areas. It is self-evident from the updates to ACEHR that working under the umbrella of NEHRP

enables the four agencies to achieve synergistic outcomes; continuing to coordinate and act collectively as much as possible benefits all NEHRP stakeholders.

ACEHR believes that developing an actionable *Management Plan* in support of the strategic plan is a critical step toward enabling the NEHRP agencies to achieve their overarching goals while also responding to GAO Recommendations 5 and 6 (GAO-22-105016, 2022) as well as those from ACEHR. ACEHR looks forward to project and activity updates that include performance measures and metrics, thereby demonstrating clearly both the progress made and the value of investing in NEHRP. To the degree possible, ACEHR perceives that tying budget allocations to the strategic plan will facilitate the measurement of both effectiveness and efficiency, while also providing the data needed to enhance budgeting and allocation requests. This would also enhance ACEHR's ability to advise on the balance of resources allocated to the strategic plan's goals, objectives, and focus areas.

Meetings of the ICC

ACEHR notes that the ICC did not meet in either 2021 or 2022, due to COVID, administration changeovers, and other priorities. Several of the agencies' top leaders served in an acting capacity during this period, with some leaders not sworn in until later in 2022. ACEHR looks forward to the resumption of ICC meetings and the support it provides to both the PCWG and the NEHRP agencies overall. Having a group of top leaders who support NEHRP's overarching goals, objectives, and focus areas is critical to NEHRP's long-term success and ability to serve the nation. Ensuring that the NEHRP agencies have the resources needed to achieve their missions in the context of the *FY22-29 NEHRP Strategic Plan* is a task the ICC is perhaps best positioned to achieve.

"For decades, NEHRP has advanced research and improved national/state/local capabilities to implement research knowledge and address earthquake risk. Since earthquakes can affect large regions at a time, happen without warning, and lead to substantial financial and economic losses that impact the entire nation, they need the sustained preparedness and mitigation focus that this nationally coordinated program provides. NEHRP's coordinated approach between four critical agencies leverages resources, **amplifies the impact** of each agency's work, and influences a broad community of external agencies, organizations, and individuals that also contribute to NEHRP objectives through their aligned work."

Heidi Tremayne
Executive Director, Earthquake Engineering Research Institute (EERI)

The NEHRP agencies have responsibilities for both (1) conducting **research** intended to increase the understanding of earthquake hazards and the means to mitigate their effects, and (2) making possible research-to-practice efforts, i.e., **implementation** of what is learned through research. While the NEHRP agencies have been both productive and responsive to their stakeholders, the 2022 GAO report (GAO-22-105016) noted that the agencies should (1) "assess and determine if additional actions are needed to obtain input from state, local, territorial, and tribal governments and stakeholders on **research priorities** that align with community and stakeholder needs" (Recommendation 3); and (2) "document and implement a comprehensive plan to better ensure that all state, local, territorial, and tribal governments and stakeholders are aware of the mechanisms and practices used by NSF and NIST for **disseminating research**" (Recommendation 7).

Each NEHRP agency has accomplished a great deal since the 2021 ACEHR report, despite the global disaster Covid-19 and while operating with limited human and funding resources. ACEHR applauds these accomplishments and recognizes the hardworking leaders and agency members throughout the nation who have made them possible.

Research

NSF

> "Supports fundamental research at the frontiers of science and engineering to advance the nation's health, welfare, and safety. NSF supports research in seismology, fault physics, and rock and mineral physics; structural and geotechnical earthquake engineering; and social, behavioral, and economic sciences pertinent to preparation for, mitigation of, responses to, and recovery from earthquakes and related events such as tsunamis and landslides. NSF also supports research to improve the safety and performance of geomaterials, buildings, structures, and infrastructure systems" (https://nehrp.gov/about/agencies.htm).

While NSF "works closely with the research community to shape (its) funding opportunities," what researchers study remains driven by their scholarly agendas. Once researchers submit their proposals, NSF uses "a rigorous system of merit review to ensure the proposals it receives are evaluated in a fair, competitive, transparent and in-depth manner." The process is characterized by mutual support between NSF and researchers, all committed to "keeping the U.S. at the leading edge of discovery in science and engineering, to the benefit of all, without barriers to participation."[8]

[8] https://new.nsf.gov/about#how-we-work-58d

ACEHR notes that the 2022 GAO report (GAO-22-105016) in its Recommendation 4 calls for NSF to develop strategies to better communicate NEHRP research priorities and results to research entities. ACEHR understands that research results often require development by other agencies (e.g., NIST) before adoption by stakeholders, and that researchers typically share their results themselves through peer-reviewed articles and presentations. NSF has embraced the GAO recommendation and has suggested strategies such as (1) adding information about research priorities to solicitations; (2) adding information about priorities to NSF web pages; and (3) discussing the priorities during outreach events attended by relevant research entities.

What follows are some notable NSF activities and awards addressing *FY22-29 NEHRP Strategic Plan* goals (NEHRP, 2023), organized by goal and objective. The activities and awards were reported to ACEHR at its 2022 and 2023 meetings.

Goal 1: *Advance the understanding of earthquake processes and their consequences*.

At least 140 new awards relevant to Goal 1 made since the 2021 ACEHR report.

NSF has supported numerous planning activities for Subduction Zones in 4 Dimensions (**SZ4D**) research. Components include research focusing on understanding subduction megathrust earthquakes as well as shallow subsidiary faults in the overriding plate. Data collection and synthesis activities focus on the Alaska, Cascadia, and Chile subduction zones. NSF also funded the Cascadia Region Earthquake Science Center (**CRESCENT**), research and community-building activities focused on Cascadia earthquake hazards.

Objective 1. Acquisition and deployment of seafloor geodetic equipment for a near-trench experiment to explore whether elastic strain is accumulating near the shallow subduction zone (trench) in Alaska and Cascadia, where land-based GNSS observations provide no constraints. Results will help estimate the likelihood of megathrust rupture extending to the trench and producing increased tsunami runup as with the Tōhoku, Japan earthquake.

Objective 2. **EPSCoR** award for development of a novel fault sliding detection system using neutron diffraction and nanoindentation techniques to study injection-induced seismicity associated with geothermal energy production in Alaska.

Objective 3. CISE: Distributed Acoustic Sensing Data Analysis Ecosystem (**DASDAE**), code development for efficient analysis of DAS data.

Objective 4. Engineering: **CAREER** project to incorporate multiscale assessment of soil responses to ground shaking and effects on critical water infrastructure.

Objective 5. Engineering: New project on consumer expectations of lifelines in disasters and how these affect preparedness and response.

Goal 2: *Enhance existing and develop new information, tools, and practices for protecting the nation from earthquake consequences*.

At least 35 new awards relevant to Goal 2 made since the 2021 ACEHR report.

Objective 8. Technology, Innovation and Partnerships: **I-Corps** award for software to enable end-to-end structural health monitoring and damage detection in infrastructure.

Objective 9. Renewed **NHERI's** RAPID Center and SimCenter, 5 years each.

Goal 3: *Promote the dissemination of knowledge and implementation of tools, practices, and policies that enhance strategies to withstand, respond to, and recover from earthquakes*.

At least five new awards relevant to Goal 3 made since the 2021 ACEHR report.

Coastlines and People (CoPe) program funds interdisciplinary research on coastal seismic hazards (e.g., subduction zones, crustal faults, other coastal hazards).

Objective 10. Renewed NHERI's Coordination Office – which coordinates outreach, education, partnerships, and planning across all NHERI facilities – for 5 years.

Objective 13. Investigators funded to participate in a consortium to address the growing need for assessment and reduction of disaster risk in urban settings.

Objective 14. Award for experiments and qualitative inquiries examining willingness-to-pay for retrofit of buildings and infrastructure to achieve functional recovery.

Goal 4: *Learn from post-earthquake investigations to enhance the effectiveness of available information, tools, practices, and policies to improve earthquake resilience*.

StEER briefings, a StEER Virtual Reconnaissance Report supported, and **RAPID** research projects supported.[9]

Focus areas. NSF provided funding for more than 80 new awards across all seven focus areas, especially for **subduction zone research** (34 awards) and **earthquake sequence research** (20 awards).

[9] ACEHR notes that mechanisms for even faster provision of RAPID funding, as well as the availability of RAPID funding for other NEHRP agencies, would both enhance and extend RAPID funding in the future.

USGS

> "Provides the Nation with earthquake monitoring and notification, delivers regional and national seismic hazard assessments, conducts targeted geoscience research, and coordinates post-earthquake investigations. The USGS Advanced National Seismic System (ANSS)[10] includes regional and national seismic networks and the National Earthquake Information Center (NEIC),[11] which provides rapid reporting of global earthquake information. NSF and USGS jointly support the GSN, which provides high-quality seismic data to support earthquake and tsunami disaster response, hazards assessments, national security (through nuclear test treaty monitoring), and fundamental research into earthquake processes and the structure of the Earth" (https://nehrp.gov/about/agencies.htm).

USGS fulfills its responsibility to coordinate post-earthquake investigations using the guidelines established in USGS **Circular 1242**, "The Plan to Coordinate NEHRP Post-Earthquake Investigations" (Holzer et al., 2003), which was developed by the NEHRP agencies and other partners. The *Circular* describes the coordination and responsibilities associated with earthquake disaster reconnaissance as discharged by multiple government, professional, and research organizations. *Circular 1242* has been revised recently, with the update nearing publication. The draft version facilitated a real-time tabletop exercise to coordinate the response to the 2023 Türkiye earthquakes, including activating the NEIC.

USGS has made great strides with the ShakeAlert **Earthquake Early Warning (EEW) system**. The system is 86% complete, with completion estimated by 2025. Recent improvements include magnitude weighting and better station cluster logic, and use of ground motion lookup tables. While some concerns about the system were raised previously by Scientific Earthquake Studies Advisory Committee,[12] this year's SESAC report compliments the USGS EHP on progress on the ShakeAlert system.

USGS is completing a major update to the **National Seismic Hazard Model (NSHM)** in 2023 (Petersen et al. 2023). For the first time, the NSHM has been updated for all 50 states. The 2023 NSHM significantly improves seismic hazard estimates for subduction zone areas as a result of implementing the NGA-Subduction ground motion models. Another major advancement is the introduction of local information sources like basin geometries to customize the hazard analyses to local conditions.

[10] http://earthquake.usgs.gov/monitoring/anss/
[11] http://earthquake.usgs.gov/contactus/golden/neic.php
[12] The committee that advises the USGS Earthquake Hazards Program (EHP). https://www.usgs.gov/programs/earthquake-hazards/scientific-earthquake-studies-advisory-committee-sesac

"The National Seismic Hazard Model (NSHM) provides seismic hazard curves from which ground motion levels for use in seismic design and other applications are derived. While the program is administered by the USGS, which assembles the models and performs the calculations, it contains major elements contributed by individuals and organizations outside of the USGS. These elements include data and models used for seismic source characterization and ground motion modeling, both of which are required for hazard calculations. As a result, the broader NSHM effort draws upon the **collective expertise of leading experts** across the U.S. Moreover, the model development process engages the broader community through a steering committee that reports to the NSHM leadership in each update cycle, and through a series of workshops that any member of the public is free to attend and where input on modeling decisions can be provided."

Jonathan P. Stewart, Ph.D., P.E.
Professor, UCLA Samueli School of Engineering

USGS provides **external grants**[13] to support research enabling the Earthquake Hazards Program (EHP). Since 2009, more than 3,000 proposals have been reviewed by panels, with just over 1,000 of those funded. Another 800 proposals were recommended for support, but there were insufficient funds. Slightly more than 1,200 were not recommended for support. Since 2021, 170 proposals were funded, with another 162 recommended for support that were not funded due to insufficient funds. These numbers suggest that while interest is high, funding is **inadequate** to support all of the meritorious research proposals.

What follows are some notable USGS accomplishments, linked to the *FY22-29 NEHRP Strategic Plan* (NEHRP, 2023). These were reported to ACEHR at its 2022 and 2023 meetings.

Goal 1: *Advance the understanding of earthquake processes and their consequences*.

Published the Cascadia subduction zone database (also Focus Area 1).[14]

Objective 1. USGS surveyed seafloor GPS monuments using an autonomous wave glider in the Alaska subduction zone.

Objective 2. The National Earthquake Information Center (**NEIC**) operationally deployed machine learning algorithms in real-time earthquake identification and analysis.

Objective 3. Progress on primary sensor upgrades for the Global Seismographic Network (**GSN**): Over the past several years, 33 of 83 needed replacements have been completed and the planned performance by end of 2026 is 55/83.

[13] https://www.usgs.gov/programs/earthquake-hazards/science/external-grants-overview
[14] https://www.usgs.gov/tools/cascadia-subduction-zone-database

Objective 4. Held a **subduction zone science** workshop in 2023 on: (1) new models of subduction zone processes, (2) the quantification of natural hazards and risk, and (3) forecasting and situational awareness of subduction zone hazards.

Goal 2: *Enhance existing and develop new information, tools, and practices for protecting the nation from earthquake consequences*.

Objective 6. **ARES** (Amateur Radio Emergency Service) LAX Northeast and other Southern California groups held a mock earthquake exercise in June 2022 to familiarize amateur radio operators with *USGS Did You Feel It?*

Objective 7. Rollout of public alerting for **ShakeAlert** in Washington in 2021, completing public alerting rollout for the West Coast system (CA in 2019 and OR in 2021).

Objective 8. Code-based seismic design criteria developed for ASCE Minimum Design Loads and Associated Criteria for Buildings and Other Structures update. Introduced the new concept of Multi-Period Response Spectra.

Goal 3: *Promote the dissemination of knowledge and implementation of tools, practices, and policies that enhance strategies to withstand, respond to, and recover from earthquakes*.

Objective 11. Updated the **NSHM** and earthquake hazard maps for Hawai'i, replacing and improving upon a 2003 model. The model was published in December 2021.

Objective 13. Piloted the use of **ArcGIS StoryMaps** as a tool for communicating recent earthquake sequences and seismotectonics, one describing the 2019 Ridgecrest earthquake sequence[15] and one for the 2020-21 Alaska subduction zone earthquakes.[16]

Objective 14. ShakeAlert licensed operator, Metrolink (Southern California Regional Rail Authority)/Rail Pros deployed a new version of the Commuter Railway Seismic Interface that integrates ShakeAlert with Metrolink's Positive Train Control (PTC) system.

Goal 4. *Learn from post-earthquake investigations to enhance the effectiveness of available information, tools, practices, and policies to improve earthquake resilience*.

Objective 15. Updated **USGS Circular 1242** through a contract with ATC.

[15] https://earthquake.usgs.gov/storymap/index-ridgecrest.html
[16] 2020-21 Alaska subduction zone earthquakes

Implementation | Practice

FEMA

> "Under NEHRP, FEMA is responsible for translating research results into design guidance products in addition to supporting: model building codes and national consensus standards; program implementation and outreach; multi-state Consortia and partnerships; State earthquake programs; disaster events (Subject Matter Expertise (SME), technical assistance, earthquake information clearinghouses and post-event studies); and standards for critical lifelines infrastructure" (https://nehrp.gov/about/agencies.htm).

FEMA serves as a critical bridge between the research-generating elements of NEHRP and the communities that need practical and implementable information and assistance. In this capacity, FEMA's contributions to the NEHRP partnership have been many over the past two years. Continued and enhanced support of FEMA's efforts, including their training and grant programs (including those not part of NEHRP, e.g., BRIC, HMGP), structural inventories, model retrofit ordinances, and more—will yield major benefits downstream for communities recovering from earthquakes.

> FEMA products, reports, advisories, and guidelines for both design and recovery, along with the NEHRP provisions for the building code, are essential to determining and addressing critical issues needed to advance performance of buildings to earthquakes. … Without this focus, the nation would be less prepared and able to withstand earthquakes. Despite this important effort by FEMA, earthquake-prone states with great mitigation ideas are often stymied by lack of funding and FEMA's resources in NEHRP remain limited. FEMA's current NEHRP budget and authorization limit also constrains their ability to **focus on lifelines** with the dedication they apply to buildings, and greatly diminishes the types and scale of mitigation and demonstration projects possible at the state and regional level. Increased national investment in earthquake mitigation activities, especially via NEHRP, could get states closer to their resilience goals and positively impact seismic safety nationwide."
>
> *Heidi Tremayne*
> *Executive Director, EERI*

What follows are some notable FEMA activities, linked to the *FY22-29 NEHRP Strategic Plan* (NEHRP, 2023). The activities listed were reported to ACEHR at its 2022 and 2023 meetings.

Goal 3: *Promote the dissemination of knowledge and implementation of tools, practices, and policies that enhance strategies to withstand, respond to, and recover from earthquakes*.

Objective 12.

FEMA Functional Recovery Workshop and Presentations. FEMA sponsored a Functional Recovery Planning Workshop to better coordinate functional recovery. Presentations included an update of the *FEMA P-58 Performance Based Seismic Design Guidelines*.

Seismic Resistant Design Guidance Publications. See Appendix B**.** FEMA continues to develop seismic design guideline products under contract with ATC.

FEMA/ATC Seismic Code Support Committee (SCSC). A FEMA Earthquake Program staff member and a member of the FEMA/ATC SCSC attended the ICC Group A Public Comment Hearings in 2021. The FEMA/ATC also testified at the ICC Group B Committee Action Hearings, held to develop the 2024 editions of the International Building Code (IBC), the International Existing Buildings Code (IEBC), and the International Residential Code (IRC).

Objective 13. Between the National Earthquake Technical Assistance Program (NETAP) and the Technical Team's support contract with ATC, the FEMA Earthquake Program conducted 39 training sessions in 2021 reaching over 9,000 participants. The FEMA Earthquake Program also conducted 39 training sessions in 2022 reaching over 5,500 participants.

Objective 14.

FEMA NEHRP State Assistance Grant Program Updates

- Individual State Earthquake Assistance (**ISEA**) funding. Awards in 2022 to 22 states and territories totaling $2.1 million USD. Awards expected in 2023 to 23 states and territories totaling approximately $2.145 million USD.
- Multi-State and National Earthquake Assistance (**MSNEA**) funding. 2022: Awards to six nonprofit organizations and institutions of higher education totaling $1.389 million USD. 2023: Awards to nonprofit organizations and institutions of higher education totaling approximately $1.2 million USD.
- **Earthquake Insurance Forum and National Earthquake Program Manager (NEPM) 2022 meeting** (Memphis, TN). Attended by nearly 100 state emergency managers and insurance professionals from around the country. Presentations focused on: NEHRP State of the Union, a FEMA NEHRP update, and a Logic Model and Performance Measures Workshop. Participants explored earthquake insurance as a resilience tool while examining equity and other concerns.

- **National Earthquake Program Manager (NEPM) 2023 Meeting** (Portland, OR). Attended by nearly 100 participants. Presentations focused on: Building inventories, grant/funding opportunities, a training session on FEMA GO, and more.
- **Transition to FEMA GO**. All new grant awards and funding opportunities under NEHRP will be managed in FEMA GO, instead of ND Grants ("Non-Disaster Grants Management System"). This new grant management platform is part of the FEMA Grants Management Modernization effort underway to improve the grants management experience for award recipients and applicants.

Goal 4: *Learn from post-earthquake investigations to enhance the effectiveness of available information, tools, practices, and policies to improve earthquake resilience*.

FEMA completed its review of the draft revision of USGS's Circular 1242 and approved use of the FEMA logo on the cover. FEMA was included in the development of this publication.

Focus areas. The ATC-138 project is using Performance Based Seismic Design to **Estimate Functional Recovery Time**. To be published as a new Volume 8 of the *FEMA P-58 Performance Based Seismic Design* series. Includes a new downtime estimation module based on NIST-funded research at the University of Colorado. This represents continuing development of performance-based seismic design guidelines initiated in 2001 and completed in 2018 with the publication of the *FEMA P-58 Seismic Performance Assessment of Buildings Methodology and Implementation* Volumes 1-7.

Although not part of NEHRP, FEMA's **BRIC** program has funded many resiliency improvements throughout the nation. BRIC provides equal funding to state, local, tribal, and territorial (SLTT) governments for Capability- and Capacity-building (C&CB) activities with remaining funds distributed through a national competition. State, tribal, and territorial governments are BRIC applicants, while local governments are subapplicants that must apply through their state or territory for mitigation projects (ICCo, 2022). ACEHR applauds the intent and overall success of this critical program, now in its third year. At the same time, ACEHR notes that the weight attached to a statewide building code in the competitive process means that states without such a code may not be able to compete as effectively as those with one, potentially leading to the negative unintended consequence of seismically vulnerable states—without a statewide code—being less seismically resilient than they otherwise could be.

> "All competitive grants are reviewed on technical criteria. Out of 115 total available points, applicants earn 20 points if they require the 2018 or 2021 IBC and IRC (or 10 points for the 2015 IBC and IRC) and an additional 20

> points if the subapplicant has a Building Code Effectiveness Grading Schedule (BCEGS) rating of 1 to 5" (ICCo, 2022, p. 1).

FEMA recently selected 124 competitive projects from a pool of 803 subapplications for further consideration in the FY22 BRIC Total Grant Cycle. The projects represent 115 communities, including one tribe, in 38 states and territories, and the District of Columbia, across all 10 FEMA regions. Of the 38 states and territories selected for an FY22 BRIC competitive grant, 23 states or 60% of all states are first-time recipients for competitive BRIC funding. Relative to building codes, 100 of the 124 FY22 National Competition selections are from states that have mandatory building code adoption—meaning that 24 of the selections are from states *without* mandatory building code adoption. This suggests an awareness of the potential unintended negative consequence and a willingness to address the issue. FEMA has stated it will continue to, "prioritize the adoption and enforcement of modern building codes in the BRIC program and encourage the submission of capability- and capacity-building activities related to building codes to assist states and local communities in being more competitive in accessing funding" (FEMA, 2023). Resilient communities depend on structures that follow the latest codes, something recognized by the Department of Homeland Security in the FEMA in its *Notice of Funding Opportunity (NOFO) for FY22 for Building Resilient Infrastructure and Communities (BRIC),*[17]

> "Hazard mitigation projects must, at a minimum, be in conformance with the latest published editions of relevant consensus-based codes, specifications, and standards that incorporate the latest hazard-resistant designs" (p.11).

Actions associated with this statement should contribute to increasing resiliency nationwide, as should the priorities identified in the FY22 NOFO for BRIC,[18]

> "For FY 2022, the priorities for the program are to incentivize natural hazard risk reduction activities that mitigate risk to public infrastructure and disadvantaged communities as referenced in EO 14008; incorporate nature-based solutions including those designed to reduce carbon emissions; enhance climate resilience and adaptation; and *increase funding to applicants that facilitate the adoption and enforcement of the latest published editions of building codes.* BRIC encourages hazard mitigation projects that meet multiple program priorities" (p. 7) (*emphasis added*).

Continuing to evaluate the potential for negative unintended consequences is important for any program, including BRIC, with the overarching goal to promote increased resilience among the most vulnerable.

[17] https://www.fema.gov/sites/default/files/documents/fema_fy22-bric-nofo_08052022.pdf
[18] Ibid., 7

NIST

> "NIST conducts applied earthquake engineering research to provide the technical basis for building codes, standards, and practices, and is responsible for working with FEMA and others to implement improved earthquake-resistant design guidance for building codes and standards for new and existing buildings, structures, and lifelines" (https://nehrp.gov/about/agencies.htm).

As is the case with FEMA, NIST connects the primarily research-generating elements of NEHRP (i.e., NSF, USGS) and the communities that need practical and implementable information and assistance. In addition, "PL 108–360 assigns NIST significant new research and development (R&D) responsibilities to close the research-to-implementation gap and accelerate the use of new earthquake risk mitigation technologies based on the earth sciences and engineering knowledge developed through NEHRP efforts."[19] In this capacity, NIST's contributions to the NEHRP partnership have been many over the past two years. What follows are some notable activities, linked to the *FY22-29 NEHRP Strategic Plan* (NEHRP, 2023). The activities were reported to ACEHR at its 2022 and 2023 meetings.

Goal 2: *Enhance existing and develop new information, tools, and practices for protecting the nation from earthquake consequences*.

Objective 6. Initiated development of an online tool to estimate seismic retrofit costs for buildings [also supports Focus Areas 6 and 8].

Objective 8.

- Published report (NIST SP-1269) focused on feedback received from the five stakeholder workshops held on functional recovery to support the development of the FEMA-NIST joint report [also supports Focus Area 2].
- Initiated an exploratory project to evaluate the benefits of low-damage rocking structural systems for mitigating the socio-economic risks associated with earthquake damage and subsequent downtime for buildings following an earthquake.
- Formed a task group to develop a pre-standard for the seismic design of fiber reinforced polymer retrofits for existing reinforced concrete buildings.
- Initiated a project to develop a **Framework for Functional Recovery Design of Lifelines**. The project is focused on water, wastewater, and power systems and is being completed through a contract to ATC [also supports Focus Area 2].

[19] https://nehrp.gov/about/agencies.htm

- Hosted a mini workshop at **12NCEE** on developing recovery categories and target recovery times for a functional recovery framework [also supports Focus Area 2].
- Hosted a Special Session at 12NCEE on rocking technologies as a practical approach to achieving functional recovery [also supports Focus Area 2].
- Hosted a workshop on the functional recovery of transportation systems. The workshop focused on ongoing efforts in developing functional recovery goals and decision tools for transportation systems, challenges to developing functional recovery performance objectives for transportation systems, and issues relevant to transportation systems to advance development and implementation of a functional recovery framework [also supports Focus Area 2].
- Hosted a workshop on seismic practice needs for buildings and lifeline infrastructure located in the **Central and Eastern United States** (CEUS). Workshop findings published in, "Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States (Applied Technology Council, 2023) [also supports Focus Area 2].
- Completed a research plan for the Study of Pre-Northridge Earthquake PJP-welded Column Splices and Weak Panel Zones.

Objective 9. Initiated a project to enhance resilience and functional recovery of urban rail transit networks [also supports Focus Area 2].

Goal 3: *Promote the dissemination of knowledge and implementation of tools, practices, and policies that enhance strategies to withstand, respond to, and recover from earthquakes*.

Objective 12.

- Held public review period for Standards of Seismic Safety for Existing Federally Owned and Leased Buildings, ICSSC Recommended Practice 10 (RP 10-22). This is an update to RP 8 as required by EO 13717 [also supports Focus Area 8].
- Published ICSSC RP 10-22, the latest edition of Standards of Seismic Safety for Existing Federally Owned and Leased Buildings [also supports Focus Area 8].
- Hosted 2022 **NIST-NSF Disaster Resilience Symposium**. The symposium consisted of 55 researchers and 617 registrants from across the country. The resulting database includes over 140 specimens from publicly available resources detailing experimental studies on FRP-retrofitted walls. The database will be published to DesignSafe CI Data Depot for public access.
- Committee Leadership positions held in a variety of committees and subcommittees (e.g., PUC Functional Recovery Hazard Subcommittee; ACI 374-A: Functional Recovery; ACI 133: Disaster Reconnaissance; ASCE 41: Seismic Evaluation and Retrofit of Existing Buildings; ASCE 7: Minimum Design Loads and Associated Criteria for Buildings and Other Structures).
- Active participation in a variety of committees (e.g., ACI 369: Seismic Repair and

Rehabilitation; ACI 440: Fiber Reinforced Polymer Reinforcement, ACI 318-H: Seismic Provisions; AISI Lateral Force Committee).

Objective 14. Also Focus Area 8.

- Published NIST Technical Note 2136-1, ICSSC Biennial Progress Report for 2018, Report on Progress Towards Implementation of Executive Order 13717: Establishing a Federal Earthquake Risk Management Standard Reporting Period: February 2, 2016, to February 1, 2018.
- Initiated work on NIST Technical Note 2136-2, ICSSC Biennial Progress Report for 2020, Report on Progress Towards Implementation of Executive Order 13717: Establishing a Federal Earthquake Risk Management Standard Reporting Period: February 2, 2018, to February 1, 2020.
- Developed updated reporting template for agencies to submit EO 13717 compliance data for February 2, 2020, to February 1, 2022 (for NIST Technical Note 2136-3, ICSSC Biennial Progress Report for 2022).

Goal 4: *Learn from post-earthquake investigations to enhance the effectiveness of available information, tools, practices, and policies to improve earthquake resilience*.

Objective 15.

- NIST participated in the update to the draft revision of **USGS's Circular 1242**.
- NIST EEG and NEHRP Office members are actively completing training and credentialing to be ready and approved for deployment for post-earthquake investigation.

ACEHR RECOMMENDATIONS TO NEHRP

ACEHR offers nine recommendations based on its review of NEHRP's accomplishments since the 2021 ACEHR biennial report. The recommendations fall into two categories, programmatic and procedural. Programmatic recommendations address opportunities for the agencies to enhance their current task efforts. Procedural recommendations suggest ways to enhance their communication with ACEHR and other stakeholders.

Programmatic Recommendations

1. Understand and Communicate the Research-to-Practice Pipeline

Translating research findings into practice is vital to NEHRP agency success as well as societal perceptions of NEHRP's value, as delineated in the GAO report, "Earthquakes: Opportunities Exist to Further Assess Risk, Build Resilience, and Communicate Research'' (GAO-22-105016, 2022). ACEHR understands that the translation from research through

development and ultimately to implementation is complex and rarely direct. The Committee applauds and encourages NEHRP agencies to continue pursuing increasingly effective means to move their research contributions forward to practice.

Agency budgets suggest that further enabling the dissemination of actionable research by FEMA and NIST to those implementing these practices (e.g., state, local, tribal, territorial governments) would come at the cost of current hazards research efforts, unless additional support were provided from new sources outside NEHRP. The primarily research-oriented agencies (i.e., NSF, USGS) need the resources they have and more to effectively advance our understanding of earthquake hazards in service to the nation and meet NEHRP objectives.

ACEHR recommends continued and expanded efforts to disseminate information to key stakeholders knowing this is essential for maintaining the research-implementation cycle. This also aligns with GAO's Recommendation 7 (GAO-22-105016, 2022). In addition, ACEHR perceives social science-based research as a key conduit for advancing earthquake hazard mitigation and believes this is well positioned for strengthening implementation in practice as it takes into account the human factors influencing mitigation and response. Thus, **ACEHR recommends that NEHRP**:

- **Clarify the research-to-practice pipeline for state, local, territorial, and tribal governments, and other stakeholders (aligns with GAO-22-105016 Recommendation 7).**

- **Develop a communication strategy as part of NEHRP's upcoming *Management Plan*, which may include for example, plans for enhanced and inclusive communication and public outreach regarding: (1) seismic hazards; (2) expected seismic performance of the built environment; and (3) the opportunities and challenges associated with earthquake early warning systems.**

- **Act to ensure that earthquake hazard mitigation programs are effectively designed to serve the whole community, including members of vulnerable populations.**

- **Prioritize research regarding social vulnerability to earthquakes and related hazards.**

- **Prioritize research comparing and contrasting the social equity aspects of safety-based and recovery-based earthquake performance of the built environment (in particular assessing buildings and lifeline infrastructure).**

2. Build on Functional Recovery Efforts Toward Community Resilience

Goal 2, Objective 8 of the *FY22-29 NEHRP Strategic Plan* states, "Enhance and develop cost-effective tools and practices, including up-to-date building codes and national consensus

standards, that improve the seismic performance of new and existing buildings and lifeline infrastructure" (NEHRP, 2023, p. 16). The *FY22-29 NEHRP Strategic Plan* further identifies eight focus areas to support NEHRP; the second area is "develop enhanced performance-based seismic design procedures and metrics for the functional recovery of new and existing buildings and lifeline infrastructure." In addition to collaborating on the report required by Congress in the 2018 reauthorization (FEMA P-2090/NIST SP-1254, 2021), both FEMA and NIST have found ways to contribute toward advancing functional recovery under their current NEHRP responsibilities, despite the lack of additional funding. An area of current focus is the functional recovery of new buildings, expected to be addressed in the *2026 NEHRP Recommended Seismic Provisions* (*2026 NEHRP Provisions*). **ACEHR supports continued work on functional recovery for new buildings.**

The development of the *2026 NEHRP Provisions* is a FEMA project through a contract with the Building Seismic Safety Council (BSSC) within the National Institute of Building Sciences (NIBS). The *NEHRP Provisions* serve as a source document for the seismic provisions contained within the ASCE 7 standard, which is adopted by reference by the International Building Code. NIBS and the BSSC Provisions Update Committee (PUC) recently published a report (NIBS-BSSC, 2023) from the Functional Recovery Planning committee, the precursor to the PUC Task Committee now seeking to address the recommendations of the planning committee. The report documents efforts to consider post-earthquake functional recovery as part of the *2026 NEHRP Provisions*. The current goal is for the *2026 NEHRP Provisions* to include a chapter on "Seismic Functional Recovery for New Buildings." Those involved in this effort are working to develop "first generation" functional recovery design criteria and other requirements. Whether to include language that mandates these provisions for all or some buildings, or that leaves the provisions voluntary is not yet decided. Regardless, this is expected to be a major step forward that can be used to design new buildings to meet post-earthquake functional recovery objectives and therefore, community resilience goals.

With much of the NEHRP focus on functional recovery for new buildings, ACEHR recommends extending these efforts to existing buildings and lifelines. While newly constructed buildings designed to achieve functional recovery will have a positive impact on community recovery, attention to evaluation and retrofit of existing buildings will have an even more significant impact on community resilience due to their greater numbers in a community. Lifelines underpin the function of a community, and their delayed recovery will significantly delay the recovery of the overall community, even if the buildings have recovered. These efforts should engage state, local, tribal, and territorial government agencies, and professional organizations to foster consensus. Consideration should be given to the needs of vulnerable populations and to including representatives of affected populations in the design of any functional recovery guidance. Data gathered in the aftermath of the 2023 Türkiye earthquakes (e.g., Elgendy, 2023) supports the critical need for increased focus on functional recovery for existing buildings and lifelines.

"NEHRP has played a unique and critical role in developing resources to advance seismic design provisions in current building codes and other structural engineering standards, but more work needs to be done within NEHRP and more progress needs to be made beyond NEHRP. Since the NEHRP agencies cannot control the eventual language adopted into codes and standards, it is important for NEHRP and/or Congress to consider ways to encourage and incentivize, if not require (when allowed), the full adoption of NEHRP-based information into applicable codes and standards. Furthermore, it is equally important, if not maybe more important, for NEHRP agencies to contribute to the development of other resources and policies separate from research and technical development. For example, NEHRP could play a greater role in **establishing best practices for mitigation programs** and policies, particularly regarding the identification and prioritization of vulnerable existing buildings that are in need of retrofit or other risk mitigation due to being built to outdated codes that resulted in construction now considered deficient compared to current codes."

Ryan Kersting, SE, F.SEAOC
Principal, BUEHLER

Existing Buildings

Communities throughout the seismically active regions of the nation remain at risk of significant economic and social disruption and prolonged recovery times due to collapse of older buildings. Communities still have thousands of buildings that are at risk of collapse during significant shaking, including emergency facilities, schools, and buildings that provide affordable housing. With this in mind, ACEHR believes that performance objectives for the design of new, as well as evaluation and retrofitting of existing buildings, should consider functional recovery to improve community resilience. This will require prioritization of research efforts to guide design, construction, and retrofit as well as the means to communicate the why and the how of functional recovery. Thus, research efforts should be multidisciplinary, drawing on both engineering science and social science. Increasing awareness of the effectiveness of mandatory retrofitting laws and providing guidance for available funding are two additional tasks that may be undertaken. History has shown that mandatory programs are significantly more effective at reducing risk than voluntary retrofit programs. A possible first step is to provide guidance and support for communities to develop inventories of their vulnerable buildings. There should also be greater priority placed on implementing seismic retrofit projects, perhaps through FEMA's BRIC and other grant programs, and also through waivers of the individual cost benefit requirement for other proven seismic retrofitting techniques (e.g., residential seismic retrofitting techniques in FEMA P-1100, soft story seismic retrofits using FEMA P-807).

Aging, poorly engineered buildings, especially non-ductile concrete and unreinforced masonry buildings, are one of the leading drivers of increasing damage and losses from

earthquakes in the United States. The annualized loss from earthquakes nationwide is estimated to be $14.7 billion per year, with California, Washington, and Oregon accounting for $11.6 billion in estimated annualized earthquake losses, or 78% of the U.S. total (Jaiswal et al., 2023). The remaining 22% of estimated annualized losses are distributed across the central United States ($1.10 billion), the northeastern states ($180 million), the Rocky Mountain/Great Basin region ($870 million), the Great Plains ($90 million), and the Southeast ($350 million). The states of Hawaii and Alaska have a combined annualized loss of $250 million, whereas the Caribbean has an annualized loss of $340 million.

Thus, **ACEHR recommends that NEHRP**:

- **Prioritize research on methods for retrofitting existing buildings to enable functional recovery.**

- **Prioritize research on methods for achieving functional recovery of existing buildings with benefit-cost ratios persuasive to those who own and manage existing buildings.**

- **Prioritize communication and guidance for implementing seismic retrofit projects designed to achieve functional recovery.**

Lifelines

Lifelines include critical utility and transportation infrastructure which underpin the functioning of modern societies. The HayWired Scenario, developed for the San Francisco Bay Area in 2019, found that lifeline related damage from a plausible Magnitude 7.0 earthquake and resulting aftershocks on the Hayward Fault would result in restoration of service that, "takes at least 10 days for fuel, weeks for electric power, months for gas, water, and highway bridges, and years for some Bay Area Rapid Transit (BART) stations in the east bay" (Wein et al., 2021). Earthquakes threaten key United States economic drivers, including oil refining and energy production. The estimated Gross Regional Product (GRP) losses from a Hayward Fault earthquake total $44.2 billion in the six-month post-earthquake period with lifeline service disruptions increasing the losses by an estimated $1.4 billion (Wing, et al., 2022). National loss estimates due to lifeline disruption in earthquakes are currently not known.

Unlike buildings, lifeline design is not governed by national or state codes, however ensuring these systems are designed to withstand natural hazards is critical to a community's resilience. Some lifelines, such as electrical transmission towers, are sufficiently redundant in number and strength to provide adequate performance, while other lifelines, such as water supply, utilize older materials that are subject to frequent failure in earthquake ground motions, severely impacting their resiliency. Seismic design guidance for lifelines needs to be tailored to the individual lifeline. Established in 1998

through a cooperative agreement between FEMA and the American Society of Civil Engineers (ASCE), the American Lifelines Association (ALA) facilitated the "creation, adoption and implementation of design and retrofit guidelines and other national consensus documents that, when implemented by lifeline owners and operators, will systematically improve the performance of utility and transportation systems to acceptable levels in natural hazard events, including earthquakes." In 2002, the ALA was brought under the Multihazard Mitigation Council of FEMA through a partnership with the National Institute of Building Sciences. In 2006, FEMA determined that it did not have the funds to continue to support the ALA program. To date, sufficient funding has not been identified to continue this critical program.

Thus, **ACEHR recommends that NEHRP**:

- **Restore NEHRP's commitment to and collaboration with appropriate partners to re-energize the American Lifelines Alliance.**
- **Support stakeholder meetings and prioritize research to inform the development of lifeline design and retrofit standards that promote functional recovery of lifelines.**

3. Promote and Expand the Use of Earthquake Scenarios

Earthquake scenarios[20] are a tool that can be employed to help stakeholders understand the effects earthquakes may have on their communities. Historically, community leaders have sometimes struggled to understand the hazard and risk of earthquakes in their jurisdictions. Finding resources to assist in this nuanced understanding can be challenging. With scenarios, the goal "is to catalyze public and private actions that will increase pre-disaster resiliency through earthquake preparedness—being prepared to withstand, to respond, and to recover" (Earthquake Engineering Research Institute, Utah Chapter, 2015). Besides enabling public communication and education, scenario earthquakes are an important research tool to investigate the impacts of specific design earthquakes on critical infrastructure or individual communities. They are a key tool in deterministic seismic hazard analysis. Scenarios may be comprehensive in nature, like the HayWired Earthquake Scenario (Detweiler & Wein, 2017), or with a lesser scope, like the Wasatch Fault Earthquake Scenario (EERI, Utah Chapter, 2015). In some cases, scenarios may be used as an earthquake preparedness exercise, whereas in others they represent a detailed forward model of earthquake shaking and anticipated secondary effects and their potential impacts.

Vulnerability assessments or loss estimation studies can provide valuable information and insight into the impacts and consequences of earthquakes on an area's resources. Most

[20] Earthquake scenarios are understood to include single mainshock events with aftershocks and earthquake sequences.

scenarios use HAZUS as part of their impact assessment, but there are other tools, like the Regional Resilience Assessment Program (RRAP/CISA), that can provide an in-depth study of various infrastructures, such as water, wastewater, and more.

The *FY22-29 NEHRP Strategic Plan* supports the focus on and use of earthquake scenarios in its Goal 2, Objective 6 (NEHRP, 2023, p. 14). These scenarios can be used "to support and enhance earthquake education, emergency drills, and exercises to promote effective earthquake awareness as well as mitigation, response, and recovery planning," Goal 3, Objective 13 (NEHRP, 2023, p. 25). Additionally, scenarios can "promote the implementation of earthquake preparedness, safety, response, and recovery strategies, which account for social, behavioral, and economic factors, including equity," Goal 3, Objective 14 (NEHRP, 2023, p. 26). Estimates from earthquake scenarios have been used in the development of preparedness activities, response planning and exercises, identifying mitigation strategies and post-earthquake recovery, for example the Wasatch Range Earthquake Response Plan Rehearsal of Concepts Exercise, a joint FEMA Region 8/State of Utah activity. Earthquake scenarios and other tabletop exercises are important to better understand weaknesses and gaps.

Moderate to high hazard earthquake states should have, at minimum, performed some level of assessment on their vulnerability to earthquakes. NEHRP has a program, the Earthquake Hazards Assistance Program, which provides funding opportunities for state and local governments along with some private contracting that clearly would support NEHRP Strategic Plan goals in supporting scenario development and other related activities (Code of Federal Regulations, Part 361, National Earthquake Hazards Reduction Assistance to State and Local Governments). [21]

There is a need to develop more scenarios for more regions, perhaps for the Eastern United States, New Madrid region, I95 corridor—places where earthquake awareness may be particularly low—and provide products that can be used at local jurisdictional level. Using the Supplemental State funding grant may be an avenue to develop these scenarios for high and moderate risk states. Consideration should be given to the needs of vulnerable populations and to including representatives of affected populations in the design of any scenarios. Publicity generated by the publication of a scenario can lead to additional recommendations for needed mitigation, recovery, and response activities (e.g., Accelerated Building Reoccupancy programs). Based on past developed scenarios, best practices can be provided: to define the desired outcomes, format, the proper balance of investment and time required, and the desired level of detail needed to take action. Finally, scenarios can help to inform FEMA Local Hazard Mitigation Plans and local tabletop exercises.

Earthquake scenarios provide an opportunity to compare the effectiveness of community retrofit laws and facilitate the shift to functional recovery performance objectives.

[21] https://www.ecfr.gov/current/title-44/chapter-I/subchapter-F/part-361

Complementary to probabilistic analyses, scenarios can be utilized to compare data between pre-retrofit and post-retrofit of specific structural types. For example, how will retrofit of thousands of non-ductile concrete structures in southern California change the results related to costs and casualties? In addition, scenarios can be used to evaluate other resiliency aspects such as risk assessment, mitigation planning, community education, and engagement. Designed appropriately, scenario research can also advance our understanding of how communicating different scenarios can influence community earthquake attitudes, engagement, and protective actions.

Thus, **ACEHR recommends that NEHRP**:

- **Promote and expand the use of earthquake scenarios to:**
  - **Understand earthquake impacts, including on vulnerable communities.**
  - **Enhance earthquake education and community engagement, emergency drills, and exercises to promote effective earthquake awareness.**
  - **Improve risk assessments, and mitigation, response, and recovery planning.**

4. Prioritize Essential Research and Problem-Focused Studies

ACEHR recognizes two additional research areas that will benefit from being prioritized: (1) Central and Eastern United States (CEUS) research; and (2) subduction zone (SZ) research.

CEUS Research

The hazard and risk from natural earthquakes in the central and eastern United States (CEUS) is generally lower than in the western U.S. but is still significant. Four of the top ten U.S. states in annualized earthquake losses are in the CEUS—and half of the top 20 are CEUS states (Jaiswal et al., 2023). However, there are substantial deficits at many levels in our ability to accurately characterize this hazard and risk, and therefore to effectively address it in engineering and mitigation practice. ACEHR recommends addressing several critical research needs, in line with what the *FY22-29 NEHRP Strategic Plan* describes as part of the challenge facing NEHRP,

> "Historically, large earthquakes have occurred in areas such as the Pacific Northwest, Atlantic Coast and Central United States, but *there is no firsthand experience in those areas with severe ground shaking and its impact on the modern built environment.* In order to devise loss reduction strategies in regions that have not experienced large earthquakes in recent times, results from smaller earthquakes, and large earthquakes in other areas, must be extrapolated to estimate the risks. This leads to large uncertainties in

damage and impact assessments, as well as in the public awareness of risk" (NEHRP, 2023, p. 4) (*emphasis added*).

First, fundamental research is needed to identify the locations and recurrence rates of earthquake sources, characteristics of sources of induced earthquakes, crustal wave propagation characteristics and their regional variations, and site conditions. Resources with which to characterize these essential factors affecting CEUS seismic hazard lags well behind the western United States. Related to this, it will be important to identify regions of the CEUS vulnerable to liquefaction and other ground failure hazards, and to facilitate the development of public policy options that consider such hazards in seismic design.

Next, there is a need to develop inventories of building types in active regions of the CEUS and perform fundamental research to understand the seismic performance of these structures. This relates also to the need to identify through research effective mitigation strategies for vulnerable structural typologies.

Finally, it is critical to address through outreach and education the perceptions that ASCE 7 (ASCE, 2022) and ASCE 41 (ASCE, 2017) are too complicated for the CEUS and potentially not applicable. One approach to this, building on ACEHR's Recommendation 3 in this report, is to promote earthquake scenario exercises for the CEUS to focus attention on critical problems affecting seismic hazard estimates, seismic risk estimates, emergency response, and public perception of earthquakes. These scenario exercises could be jointly coordinated by NEHRP along with local authorities and stakeholders.

More information on research needs in the CEUS, which are consistent with recommendations provided here, are provided in the report, "Seismic Practice Needs for Buildings and Lifeline Infrastructure Located in the Central and Eastern United States (CEUS)" (ATC, 2023).

ACEHR recommends that NEHRP:

- **Prioritize research on the needs of CEUS earthquake risk reduction, including basic research to improve source characterization, ground motion modeling, building code provisions, and lifeline infrastructure vulnerabilities.**

Subduction Zone (SZ) Earthquakes and Hazards Research

ACEHR fully supports Focus Area 1 of the *FY22-29 NEHRP Strategic Plan*, "Advance earthquake science for subduction zone regions" (NEHRP, 2023, p. 33). Subduction zone hazards have generally received less attention in the NEHRP program compared to strike-slip fault environments. However, subduction zone earthquakes pose significant earthquake and tsunami hazards in the Pacific northwest, Alaska, Puerto Rico, and the Mariana Islands. Many aspects of subduction zone earthquakes are poorly understood,

particularly because the megathrust fault occurs largely beneath the seafloor. For example, basic questions like the relationship between slow slip events and the initiation of mainshock rupture, as well as occasionally observed precursory activity are not well understood. There are also major questions about the controlling factors of large tsunami excitation, and the extent to which megathrust earthquakes may trigger slip along adjacent subduction zone segments. Research is also needed to better understand subsidiary forearc faults in the upper crust, which pose significant hazards due to shallow locations beneath populated areas. In addition to the source aspects of subduction zones, research is also needed to better understand the impacts of these earthquakes on the built environment. The unique ground motion characteristics from subduction events, including the potential for very long duration shaking, has the potential to influence damage patterns, the types of structures damaged, and the occurrence of earthquake-induced liquefaction and landslides.

Recent technological advances, such as seafloor geodesy, make significant SZ research progress likely in the next few years, if prioritized with sufficient resources. Research results can address important hazard questions, such as whether seismic strain is accumulating near the trench, increasing megathrust earthquake and tsunami hazards. This will directly contribute to achieving Goals 1 and 2 of the NEHRP strategic plan. Offshore real-time instrumentation is also important for improving earthquake early warning. Such instrumentation will thus facilitate the achievement of both the research and operational goals of NEHRP. ACEHR is encouraged by the ongoing planning of subduction research programs by both the USGS and NSF. Enhanced coordination between the subduction research programs of these two agencies will further NEHRP objectives.

Thus, **ACEHR recommends that NEHRP**:

- **Prioritize essential research on SZ earthquakes and their impacts on the built environment.**
- **Prioritize development and implementation of offshore sensors and datasets to facilitate research advances.**
- **Identify opportunities for more collaboration between the agencies and the academic community around SZ earthquake hazards, such as the use of offshore sensors for both research and earthquake early warning.**

5. Review International Earthquake Response and Lessons Learned

The United States can learn a great deal from earthquakes occurring abroad, for example, the recent Kahramanmaraş, Türkiye Earthquake Sequence (6 February 2023) and Al Haouz, Morocco Earthquake (8 September 2023). Learning from these earthquakes aligns

with Goal 4 of the *FY22-29 NEHRP Strategic Plan*, "Learn from post-earthquake investigations to enhance the effectiveness of available information, tools, practices, and policies to improve earthquake resilience" (NEHRP, 2023, p. 27) and reflects NEHRP's increasing international cooperation (NEHRP, 2023, pp. 52-53). While each country may have its own approach to building code adoption and enforcement, as well as construction practices, there are always lessons to be learned from earthquakes wherever they occur and the response of the affected area's soil, buildings, infrastructure, and people.

"USGS Earthquake Hazards Program products (i.e., National Seismic Hazard Model, Advanced National Seismic System, Earthquake Scenarios) have transformed our knowledge about the seismic hazard. Many of these products (i.e., ShakeMap,[22] PAGER,[23] Aftershock Forecasts[24]) also provide **essential, real-time information** used by agencies, nongovernmental organizations, companies, and individuals across the nation and globe to inform and influence their response and recovery activities when earthquakes occur. USGS products, tools and collaboration have been essential to situational awareness at state/regional Emergency Operation Centers and at Earthquake Clearinghouses that are formed in many states after major earthquakes to coordinate earthquake field investigations and share observations and knowledge among emergency responders, engineers, and scientists. Continued USGS leadership and emphasis on conducting NEHRP Post-Earthquake Investigations for earthquakes **around the globe** can further advance resilience to and recovery from future U.S. earthquakes, especially if the findings are proactively used to influence strategy, improve alignment, and enhance activities in NEHRP programs of the four agencies."

Heidi Tremayne
Executive Director, Earthquake Engineering Research Institute (EERI)

The draft revision to *Circular 1242*, "The Plan to Coordinate NEHRP Post-Earthquake Investigations" (Holzer, et al., 2003) was used to provide guidance during the Türkiye earthquake sequence as a tabletop "test" of sorts. The execution of the draft revision to *Circular 1242* (in publication) brought together federal and non-federal partners to discuss available information in the days and weeks following the 6 February 2023 earthquake. Ultimately, the United States' in-person response was mainly coordinated by GEER and EERI. The response was resource-constrained and did not include federal partners in the immediate reconnaissance (i.e., performed within approximately 1-6 weeks following the event). Participation from federally funded experts would have benefitted the reconnaissance teams. ACEHR believes it important to continue to engage with non-federal partners (e.g., EERI) during post-earthquake reconnaissance (rapid response environment), in the spirit of *Circular 1242* and its draft revision, as well as at a

[22] https://earthquake.usgs.gov/data/shakemap/
[23] https://earthquake.usgs.gov/data/pager/
[24] https://earthquake.usgs.gov/data/oaf/

programmatic level (long-term). An after-action/process review of how the draft revision of *Circular 1242* was used, including the field component of the response, would be useful to ensure that mechanisms for USGS and NIST participation in responses to future events are facilitated.

Thus, **ACEHR recommends that NEHRP**:

- **Review and report to ACEHR lessons learned from the 2023 Kahramanmaraş, Türkiye Earthquake Sequence, including an after-action review of how the draft revision of *USGS Circular 1242* was used, with attention to coordination across agencies and sectors and the speed of response.**

6. Prioritize Research on Earthquake Insurance to Make It More Affordable and Attainable

Earthquake insurance is a fundamental part of the recovery process; property owners must be able to rebuild, and insurance is how most will be able to afford it. But this insurance is increasingly unaffordable throughout the nation's high-risk seismic zones, and some companies no longer write policies. As a result, many building owners will be unable to rebuild after a large earthquake, and community recovery will be at risk.

As earthquake insurance premiums and deductibles have risen in recent years, fewer and fewer property owners are able to buy it. As documented by the Missouri Department of Commerce & Insurance (2023), over the past 20 years, the percentage of homeowners with earthquake insurance has shrunk from 60 percent to less than 11 percent in the highest risk areas of southeast Missouri. The West Coast has the same problem. A report prepared by the California Department of Insurance (2023) shows that less than 13 percent of that state's homeowners have earthquake insurance. While the California Earthquake Authority[25] is making a positive difference in that state, the uptake rate would likely be even lower without its assistance.

Consistent with Goal 1, Objective 5 of the *FY22-29 NEHRP Strategic Plan* (NEHRP, 2023, p. 13), ACEHR believes that the NEHRP agencies may be able to assist with this issue, perhaps through convening subject matter experts and tasking them to identify the full range of issues and possible solutions. As stated in the *FY22-29 NEHRP Strategic Plan*,

> "Research that integrates engineering with social, behavioral, public policy, and economic sciences in an equitable manner is thus of critical importance. This includes studies focused on risk perceptions and tradeoffs, mitigation incentives for households and communities, risk communication, and roles

[25] https://www.earthquakeauthority.com/

that private and public sectors could play to help reduce earthquake losses, including issues related to federal, state, and local financial mechanisms, such as disaster relief policies and the *availability and affordability of earthquake insurance*" (NEHRP, 2023, p. 13) (*emphasis added*).

It seems most likely that innovative approaches will be needed to address this insurance crisis; traditional coverage is no longer working. Research and actions that prioritize collaboration with a variety of stakeholders, including those in the private sector, is encouraged. Possibilities might include all-hazards models, pooled funds, parametric coverage, or other newer models. Parametric insurance is generally affordable, but payouts may be smaller than what people expect or need. The Florida Hurricane Catastrophe Trust Fund,[26] part of that state's Hurricane Loss Mitigation Program,[27] is an innovative reinsurance-type approach to covering a disaster when traditional insurance is not sufficient. A question to be explored is whether it is adaptable to earthquakes.

Thus, **ACEHR recommends that NEHRP**:

- **Prioritize research on innovative approaches to making earthquake insurance more affordable and attainable, working with public agencies and private companies.**

Procedural Recommendations

7. Update the NSF Synthesis Report

The myriad of research activities supported by the NSF can be challenging to report and understand on ACEHR's twice-annual schedule which may or may not coincide with the agency's fiscal year. One approach to addressing this task is to update the "NSF Synthesis Report," first created in 2017 to respond to requests from ACEHR. The report is available at: https://tinyurl.com/jnwy6rf7 (starting on page 6).

Receiving an update to the 2017 "NSF Synthesis Report" every two years, beginning in 2025, for the first ACEHR meeting of the calendar year, would greatly enhance ACEHR's understanding of NSF's responsibilities vis-à-vis NEHRP. The reporting period for the update should be the preceding two fiscal years. Thus, for the update prepared for the first ACEHR meeting of 2025, the reporting period would be October 2022-September 2024. The update's overarching purpose would be to keep ACEHR members informed about the means by which NSF provides funding to individuals and entities consistent with the goals, objectives, and focus areas of the *FY22-29 NEHRP Strategic Plan*. In addition, the report should include a brief explanation of the role of NSF in NEHRP along with highlights from

[26] https://fhcf.sbafla.com/
[27] https://www.floridadisaster.org/dem/mitigation/hurricane-loss-mitigation-program/

different NSF-funded programs. Budget details as available will also aid ACEHR in achieving its assessment goals. The timing of the update to the NSF Synthesis Report is intended to match the cycle for the preparation of ACEHR's biennial report, thereby facilitating the report's development.

Thus, **ACEHR recommends that NEHRP**:

- **Update the 2017 "NSF Synthesis Report" every other year to coincide with the ACEHR biennial report cycle. The report should be similar to that generated in 2017 and highlight NEHRP-specific funded research.**

8. Finalize and Disseminate the *NEHRP Biennial Report*

Similar to the previous recommendation, ACEHR requests more timely completion and dissemination of the *NEHRP Biennial Report* than has been the case in the recent past. For example, the last *NEHRP Biennial Report* published on the NEHRP website was for fiscal years 2018 and 2019; it was published in August 2021. The information in these reports, along with the updates from the Acting Director of NEHRP and the NEHRP agency representatives at ACEHR meetings, are essential to ACEHR's ability to assess:

- Trends and developments in the science and engineering of earthquake hazards reduction.
- The effectiveness of NEHRP in performing its statutory activities (improved design and construction methods and practices; land use controls and redevelopment; prediction techniques and early-warning systems; coordinated emergency preparedness plans; and public education and involvement programs).
- Any need to revise NEHRP.
- The management, coordination, implementation, and activities of NEHRP (https://nehrp.gov/committees/about.htm).

Without this information, it can be difficult for ACEHR members to understand how the NEHRP agencies prioritize and evaluate tasks for both effectiveness and efficiency. Some of the background for such assessments will likely be found in the *Management Plan* that will accompany the *FY22-29 NEHRP Strategic Plan*. Without these plans and reports, ACEHR risks making recommendations without a full understanding of the context and challenges facing the NEHRP agencies.

When deliberating what should appear in an ACEHR biennial report, it is useful to have available any reports, presentations, or other documents that would allow the ACEHR Committee a more complete view of what the NEHRP agencies have accomplished and planned for the future. Ideally, the *NEHRP Biennial Report* would be available—perhaps even as a draft—before the ACEHR Biennial Report is finalized every other September. One

item particularly useful to ACEHR's discussions will be program budgets as they are parsed across the *FY22-29 NEHRP Strategic Plan* Goals 1-4.

Thus, recognizing that some "catching up" is needed, **ACEHR recommends that NEHRP**:

- **Finalize and disseminate the latest draft of NEHRP's Biennial Report so that it may be considered by ACEHR as it prepares its own biennial report.**
- **Provide ACEHR members with the annual or biennial budget numbers that typically appear in the NEHRP Biennial Reports (e.g., distribution by agency and strategic goal).**

9. Update the NEHRP Website

The NEHRP website, while containing a significant amount of relevant and timely information, is densely populated and not particularly user-friendly for those not having a pre-existing understanding of NEHRP, its agencies, and their activities vis-à-vis NEHRP's mission. One result of this is that the NEHRP website is unlikely to be a "go to" for stakeholders needing information, for example, on the means for translating research findings into practical applications. A more user-centered website redesign is needed to enhance two-way communication with key stakeholders and principal users. The more traffic that drives to the NEHRP website, the greater the awareness of NEHRP and the value associated with it.

Thus, **ACEHR recommends that NEHRP**:

- **Modernize the NEHRP website informed by user-centered design. Process-wise, this should include working with key stakeholders (e.g., state, local, tribal, and territorial governments) and principal users (e.g., ACEHR members), to assess their NEHRP-related information needs and uses.**

ON THE HORIZON—EMERGING TOPICS

"... The NEHRP programs have been and continue to be effective at regularly improving seismic design practice and reducing seismic risk. Importantly, they do so in a way that engages the **world-leading earthquake engineering and seismology expertise** within the US academic and practitioner communities. This makes the U.S. National Seismic Hazard Model (NSHM) and building codes among the best world-wide."

Jonathan P. Stewart, Ph.D., P.E.
Professor, UCLA Samueli School of Engineering

Earthquake Sequence Research

Several recent earthquakes have occurred in sequences in which a damaging earthquake is followed by additional events of sufficient magnitude to cause additional damage. For example, an earthquake of modest size, perhaps on a relatively short fault, may be followed by a larger magnitude event on a longer fault (e.g., 2023 Türkiye). The *FY22-29 NEHRP Strategic Plan* notes the need to "advance the science of earthquake sequence characterization," mainly in connection with public outreach (NEHRP, 2023, Focus Area 7, p. 35). ACEHR encourages a broader prioritization of work in this area. These sequences challenge certain aspects of how earthquake hazard and risk are computed and communicated to the public, and research to address these issues—and more—is needed.

First, it is important that we understand how an earthquake on one fault can trigger (or not) continuation on neighboring faults. This includes identifying the aspects of the fault slip and geometries (e.g., step over dimensions) required to estimate trigger probabilities. ACEHR recognizes that USGS's Aftershock Forecast (e.g., using the M 5.1 - 7 km SE of Ojai, CA earthquake[28]), which aims to link foreshock and aftershock earthquakes to a main shock, may provide at least a basic start for addressing these research needs.

Next, researchers are interested in discovering how these sequences of ground motions affect building response. Not clear is the extent to which the fragility of a structure in a subsequent event is changed by the shaking in a prior event. Nor is it clear how the structure is affected by damage from the initial event.

Shifting into research concerns rooted in the social sciences, we need to understand how best to communicate the possibility of subsequent damaging events to emergency responders and the public. This aligns with the vignette shared in this report's Executive Summary, in which Lucy Arendt recalled the following about her reconnaissance trip to New Zealand in September 2010,

> "While on one of our walk-abouts, a local approached us, and asked with both worry and urgency, **"What caused this? Could this happen again? Was this it for us?"** Members of our team shared what we knew—and what was still unknown."

The simple fact is, researchers do not yet know enough about what might happen in the aftermath of an earthquake, or when. With this in mind, and with an awareness of the importance of timely and appropriate communication to effective response and recovery, researchers need to also address whether ShakeAlert messaging related to an earthquake should be formulated to consider the possibility of a subsequent larger, triggered event or

[28] https://earthquake.usgs.gov/earthquakes/eventpage/ci39645386/oaf/commentary

link to forecasting of subsequent events. Experiences from Christchurch and Puerto Rico offer a starting point for this research (e.g., van der Elst et al., 2022).

New Technologies

New data sources and sensing technologies, machine learning, and data-driven models are changing the landscape of earthquake science. For example, new or recently expanded sensing technologies, such as LiDAR, InSAR, nodal seismic sensors, and distributed acoustic sensing (DAS) generate exciting new datasets, but data volumes are much greater than previously imagined. These technologies have the potential to transform fundamental earthquake research as well as hazard estimation and response planning. New technologies and strategies must be implemented to collect, store, access, and preserve these massive datasets. Data-intensive computing approaches incorporating machine learning and artificial intelligence (AI) must also be developed to take advantage of these opportunities.

Some advances in this field have already been made. Examples of these efforts include the many-fold expansion of existing earthquake catalogs using advanced data mining techniques and the use of machine learning to routinely extract and monitor ground deformation from InSAR and GNSS. AI approaches can also be applied to fast evaluation of real-time data following a major earthquake, thus providing vital earthquake information to responders in the moments following an earthquake without the delays associated with traditional analysis. Finally, open-science principles, including open-source codes and open data, will allow greater impact and promote participation by early career and international investigators.

CONCLUDING THOUGHTS

The research and implementation activities undertaken individually and collectively by the NEHRP agencies are central to community resilience and our nation's security. Continued and increasing support for these efforts is essential to NEHRP's efforts. ACEHR's assessment of the NEHRP programs is this: Much has been done to move the nation forward with respect to earthquake risk and much more remains to be done. We cannot fail those who rely upon the research expertise of our federal agencies and myriad academic and other collaborators along with the knowledge, skills, and ability to make the research understandable and actionable by those at the state, local, tribal, and territorial levels.

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APPENDICES

APPENDIX A: ACEHR MEMBERS AND AFFILIATIONS

- Dr. Lucy A. Arendt, Chair of ACEHR (Donald J. Schneider School of Business & Economics, St. Norbert College, De Pere, WI)
- Dr. Ann Bostrom (Daniel J. Evans School of Public Policy & Governance, University of Washington, Seattle, WA)
- Mr. Jeff Briggs (Missouri State Emergency Management Agency, Jefferson City, MO)
- Mr. Robert Carey (Utah Division of Emergency Management, Salt Lake City, UT)
- Mr. David W. Cocke (Structural Focus, Gardena, CA)
- Dr. Michael W. Hamburger, *ex-officio*, Chair of SESAC (Earth and Atmospheric Sciences, Indiana University, Bloomington, IN)
- Mr. Thomas F. Heausler (Consulting Structural Engineer, Bay Saint Louis, MS)
- Dr. Tara Hutchinson (Department of Structural Engineering, University of California, San Diego, CA)
- Dr. Anne Metzler (Lehigh University, Bethlehem, PA)
- Ms. Danielle H. Mieler (City of Alameda, CA)
- Dr. Ellen M. Rathje (Department of Civil, Architectural, and Environmental Engineering, University of Texas, Austin, TX)
- Dr. Jonathan P. Stewart (Civil and Environmental Engineering, University of California, Los Angeles, CA)
- Dr. Douglas Wiens (Dept of Earth, Environmental & Planetary Sciences, Washington University, St. Louis, MO)

APPENDIX B: GUIDING PRINCIPLES & ASSUMPTIONS

1. The NEHRP agencies are committed to aligning their decisions and actions with the expectations outlined in the Earthquake Hazards Reduction Act of 1977 as reauthorized and amended by Public Law 115-307 (December 2018).

2. The NEHRP agencies will pursue the goals, objectives, and focus areas in the *FY22-29 NEHRP Strategic Plan* and will update as needed in accordance with future NEHRP Reauthorization.

3. The resources needed to implement the goals, objectives, and focus areas in the Strategic Plan are authorized and appropriated by Congress. The NEHRP agencies cannot by themselves increase the resources associated with NEHRP.

4. ACEHR is committed to aligning its recommendations and observations with the expectations outlined in the Earthquake Hazards Reduction Act of 1977 as reauthorized and amended by Public Law 115-307 (December 2018) as well as the *FY22-29 NEHRP Strategic Plan*.

5. ACEHR relies upon information shared by the NEHRP agencies as well as other subject matter experts in discharging its responsibilities.

6. Transparency in communication is valued by the members of ACEHR in their interactions with the NEHRP agencies.

7. ACEHR's overarching goal in preparing its biennial reports and other documents is to facilitate the effectiveness of the NEHRP agencies as they work to meet the expectations outlined in the Earthquake Hazards Reduction Act of 1977 as reauthorized and amended by Public Law 115-307 (December 2018).

8. ACEHR recognizes that each of the NEHRP agencies plays a unique role in contributing to the implementation of the *FY22-29 NEHRP Strategic Plan*.

9. ACEHR builds upon prior reports and documents in developing its recommendations.

10. ACEHR recognizes that the recommendations in any one of its biennial reports will most typically require more than two years to fully implement and evaluate.

APPENDIX C: REPRESENTATIVE PUBLICATIONS, PAPERS, & PRESENTATIONS

USGS

Goal 1. *Objective 2*.

- gCent article: The Geodetic Centroid (gCent) Catalog: Global earthquake monitoring with imaging geodesy. Published in the *Bulletin of the Seismological Society of America*.

Objective 3.

- Ringler et al. *The Seismic Record*, "Improved resolution across the Global Seismographic Network: A new era in low-frequency seismology."
- Goldberg et al. "Beyond the Teleseism: Introducing Regional Seismic and Geodetic Data into Routine USGS Finite-Fault Modeling"

Objective 4.

- In February 2022, the USGS released a study of the Ground Failure effects associated with the August 2021 Nippes, Haiti, Mw7.2 earthquake, published in *Seismological Research Letters*.

Objective 5.

- Jenkins et al. "Considerations for creating equitable and inclusive communication campaigns associated with ShakeAlert, the earthquake early warning system for the West Coast of the USA."
- McBride et al. "Evidence-based guidelines for protective actions and earthquake early warning systems."

Goal 2. *Objective 6*.

- Noh et al. "An efficient Bayesian framework for updating PAGER loss estimates," *Earthquake Spectra*. https://doi.org/10.1177/8755293020944177.

Objective 7.

- Cochran et al. "Alert Optimization of the PLUM Earthquake Early Warning Algorithm for the Western United States."
- Ghahari et al. "Earthquake Early Warning for Estimating Floor Shaking Levels in Tall Buildings."
- Goltz et al. *Earthquake Spectra "*Development of a companion questionnaire for "Did You Feel It?": Assessing response in earthquakes where an earthquake early

warning may have been received" (https://doi.org/10.1177/87552930221116133).

Goal 3. *Objective 13*.

- McBride & Ball "#TheSmoreYouKnow and #emergencycute: A conceptual model on the use of humor by science agencies during crisis to create connection, empathy, and compassion." *Science for Everyone*.

FEMA

Goal 3. *Objective 12*.

- *The Role of the NEHRP Recommended Provisions in the Development of Nationwide Seismic Building Code Regulations: A Thirty-Five Year Retrospective* (FEMA P-2156) (2021).
- *The 2020 NEHRP Provisions: Design Examples, Training Materials and Design Flow Charts* (FEMA P-2192) (2021).
- *Seismic Design for Rigid Wall-Flexible Diaphragm Buildings – An Alternative Procedure, 2e* (FEMA P-1026) (2021).
- *Earthquake-Resistant Design Concepts: An Introduction to Seismic Provisions for New Buildings*, 2e (FEMA P-749) (2022).
- *FEMA Guidance for Accelerated Building Reoccupancy Programs* (FEMA P-2055-1) (ABR) (2023).
- *FEMA Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings with Weak First Stories* SUPPLEMENT: *Best Practices and Retrofit Guidance for Soft, Weak, or Open-Front Buildings* (SWOF) (FEMA P-807-1) (2023).
- ATC-58-7 *Report, Proceedings of FEMA-Sponsored Workshop on Functional Recovery* (ATC, 2022).
- *FEMA Homebuilders Guide to Earthquake Resistant Design and Construction* (FEMA P-232) (2023), which will include provisions of the 2024 IRC.
- Next (2026) edition of the *FEMA NEHRP Recommended Seismic Provisions for New Buildings and Other Structures* in development. FEMA and the Building Seismic Safety Council (BSSC)[29] started the cycle of 2026 NEHRP Recommended Provisions in 2021. The 2026 Provisions Update Committee (PUC) was formed in 2022.

[29] Under contract with the Federal Emergency Management Agency (FEMA), the BSSC develops and maintains a key resource — the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures. The Provisions are used as the primary resource for the professional design standard ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures (https://www.nibs.org/bssc). ACEHR supports the efforts of the Building Seismic Safety Council (BSSC) in conjunction with FEMA.

- *ATC 154*, very high seismic design guidance, is in development. This project is intended to address the issue that buildings in very high seismic regions still face much higher risk of collapse despite the building strength being increased per code for very high earthquake ground motions.
- Updated *FEMA P-366 HAZUS Estimated Annualized Earthquake Losses for the United States*. Together, FEMA and USGS updated the annualized earthquake losses by using the 2020 census data and latest seismic hazard information.
- *New Seismic Design Category Maps* for 2024 International Building Codes (IBC) and International Residential Code (IRC). FEMA worked with the Seismic Code Support Committee and USGS to produce new sets of seismic design category maps for the 2024 IBC and IRC.
- Developing next cycle of *FEMA NEHRP Recommended Revisions to ASCE/SEI 41 Seismic Evaluation and Retrofit of Existing Buildings*. This FEMA/ATC project (ATC-140) updates and improves FEMA 306, 307, & 308 guidance for post-earthquake assessment, repair, and retrofit procedures.

NIST

Goal 2.

Objective 2.

- [*Earthquake Spectra*] The Total Costs of Seismic Retrofits: State of the Art (Fung, et al.)
- [*Journal of Earthquake Engineering*] Review of Seismic Risk Mitigation Policies in Earthquake-Prone Countries: Lessons for Earthquake Resilience in the United States (Zhang, et al.)

Objective 6.

- [*Earthquake Spectra*] Motivators and impediments to seismic retrofit implementation for wood-frame soft-story buildings: A case study in California (June 2022) (Zhang, et al.)
- [NIST Technical Note] A Framework to Evaluate the Cost Effectiveness of Recovery-Based Design (May 2022) (Fung, et al.)

Objective 8.

- [NIST TN 2169] Seismic Behavior and Design of Deep, Slender, Wide Flange Structural Steel Beam-Columns (Chanusk, et al.)

- [*Earthquake Spectra*] Implementing the performance-based seismic design for new reinforced concrete structures: Comparison among ASCE/SEI 41, TBI, and LATBSDC (Sattar, et al.)
- [*ACI Structural Journal*] Quantifying Material Uncertainty in Seismic Evaluations of RC Structures [Segura, et al.]
- [17WCEE] Uncertainty in the Seismic Response of Reinforced Concrete Structures Due to Material Variability (Segura, Sattar)
- [17WCEE] Quantifying the Uncertainty in Modeling of RC Walls (Arteta, et al.)
- [ASCE *Journal of Structural Engineering*] Development of Enhanced Seismic Compactness Requirements for Webs in Wide-Flange Steel Columns (Ozkula, et al.)
- [12NCEE] Preliminary Recovery Categories and Times for a Functional Recovery Framework (Sattar et al.)
- [12NCEE] Using Seismic Energy to Assess Structural Performance (Wong, Speicher)
- [12NCEE] Challenges in Determining Nonlinear Modeling Parameters of FRP-Retrofitted Shear Walls (Dukes, Sattar)
- [12NCEE] Scenario-Based Performance Assessment of Dams using Stochastic Ground Motion Simulations (Rezaeian, Hariri-Ardebili)
- [12NCEE] Uncertainty Quantification of Structural Systems with Subset of Data (Hariri-Ardebili, et al.)
- [12NCEE] The Effect of Increased Strength and Stiffness Requirements on the Functional Recovery Performance of Reinforced Concrete Special Moment Frames (Cook, Sattar)
- [12NCEE] Economic considerations for recovery-based design (Fung, et al.)
- [12NCEE] No Longer Just a Research Idea - Rocking Technologies as a Practical Approach to Achieving Functional Recovery (Segura, Speicher)
- [12NCEE] Assessing the Effect of Design Variations on Seismic Stability of Steel Special Concentrically Braced Frames (Shitao, et al.)
- [12NCEE] Impact of Detailing on the Lateral Performance of Cold-Formed Steel Framed Walls (Zhang, et al.)
- [12NCEE] Quantification of Modeling Uncertainty in an RC Bridge (Hariri-Ardebili, et al.)
- [12NCEE] Probabilistic Moment Curvature Analysis using Random Forest-Based Ensemble Regression (Hariri-Ardebili, et al.)
- [ACI Special Publication] An Overview of Research Needs Concerning the Performance of Fiber Reinforced (FR) Composite Retrofit Systems for Buildings and Infrastructure (Dukes, et al.)
- [STESSA] A Case for Rethinking ASCE 41 Performance-Based Assessment Criteria for Cold-Formed Steel (Speicher, et al.)
- [*Journal of Earthquake Engineering*] Review of seismic risk mitigation policies in earthquake-prone countries: lessons for earthquake resilience in the United States (Zhang, et al.)

- [8th International Conference on Advanced Composite Materials in Bridges and Structures] Framework for Developing Modeling Parameters of FRP—Retrofitted Reinforced Concrete Shear Walls (Dukes, Sattar)
- [CFSRC Colloquium] Effects of Modeling Decisions on the Lateral Performance of Cold-Formed Steel Framed Walls (Zhang, et al.)
- [*Journal of Earthquake Engineering*] Quantification of Equivalent Strut Modeling Uncertainty and Its Effects on the Seismic Performance of Masonry Infilled Reinforced Concrete Frames (Haindl, et al.)
- [3rd International Conference on Natural Hazards & Infrastructure] Regional Risk Assessment of Bridge Inventories In California Using Machine Learning Techniques (Dukes, Mangalathu)
- [NIST GCR 22-917-51] Research Plan for the Study of Pre-Northridge Earthquake PJP-welded Column Splices and Weak Panel Zones.

Goal 3. *Objective 12*.

- Published a series of magazine articles in *Structure* about first-generation Performance-Based Seismic Design used for design and assessment of steel buildings (Oct 2021, Nov. 2021, and Jan. 2022) [also supports Focus Area 2 and 3].

Goal 4. *Objective 16*.

- [*Earthquake Spectra*] Performance of externally bonded fiber-reinforced polymer retrofits in the 2018 Cook Inlet Earthquake in Anchorage, Alaska (Tatar, et al.)
- [17WCEE] Lessons on Recovery of Function from Anchorage, Alaska After the 2018 Cook Inlet Earthquake (Johnson, et al.)
- [International Conference on FRP Composites in Civil Engineering] Seismic and Durability Assessment of Externally Bonded FRP Retrofits in Reinforced Concrete Structures After 2018 Anchorage, AK Earthquake (Milev, et al.)
- [*Construction and Building Materials*] Materials characterization of FRP composite seismic retrofits after long-term service in a 5 subarctic Alaskan environment (Milev, et al.)

APPENDIX D. ABBREVIATIONS AND ACRONYMS

12NCEE	12th National Conference on Earthquake Engineering
ABR	Accelerated Building Reoccupancy
ACEHR	Advisory Committee on Earthquake Hazards Reduction
AFAD	Disaster and Emergency Management Authority (Türkiye)
AI	Artificial Intelligence
ALA	American Lifelines Association
ANSS	Advanced National Seismic System
ARES	Amateur Radio Emergency Service
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
BCEGS	Building Code Effectiveness Grading Schedule
BRIC	Building Resilient Infrastructure and Communities
BSSC	Building Seismic Safety Council
CEUS	Central and Eastern United States
DAS	Distributed Acoustic Sensing
DRRG	Disaster Resilience Research Grants
EERI	Earthquake Engineering Research Institute
EHRA	Earthquake Hazards Reduction Act
EEW	Earthquake Early Warning
EO	Executive Order
FEMA	Federal Emergency Management Agency
FY	Fiscal Year
GAO	U.S. Government Accountability Office
GEER	Geotechnical Extreme Events Reconnaissance
GNSS	Global Navigation Satellite System
GSN	Global Seismographic Network
HAZUS-MH	Hazards U.S. Multi-Hazard (FEMA's Loss Estimation Methodology)
HMGP	Hazard Mitigation Grant Program
IBC	International Building Code
ICC	Interagency Coordinating Committee
ICCo	International Code Council
ICSSC	Interagency Committee on Seismic Safety in Construction
IEBC	International Existing Buildings Code
InSAR	Interferometric Synthetic Aperture Radar
IRC	International Residential Code
IRIS	Incorporated Research Institutions for Seismology
ISEA	Individual State Earthquake Assistance
LiDAR	Light Detection and Ranging

M	Magnitude
MCE	Maximum Considered Earthquake
MSNEA	Multi-State and National Earthquake Assistance
NEHRP	National Earthquake Hazards Reduction Program
NEIC	USGS National Earthquake Information Center
NEPM	National Earthquake Program Manager
NETAP	National Earthquake Technical Assistance Program
NHERI	Natural Hazards Engineering Research Infrastructure
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NIST EEG	NIST Earthquake Engineering Group
NOFO	Notice of Funding Opportunity
NRC	National Research Council
NRF	National Response Framework
NSF	National Science Foundation
NSHM	National Seismic Hazard Model
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PAGER	Prompt Assessment of Global Earthquakes for Response
PBSD	Performance-based Seismic Design
PCWG	Program Coordination Working Group
PL	Public Law
PUC	Provisions Update Committee
RAPID	Rapid Response Research
SAGE	Seismological Facilities for the Advancement of Geoscience
SCSC	Seismic Code Support Committee
SDR	Subcommittee on Disaster Reduction
SESAC	Scientific Earthquake Studies Advisory Committee
SLTT	State, Local, Tribal, and Territorial
SRST	Subcommittee for Resilience Science and Technology
StEER	Structural Extreme Events Reconnaissance
STPI	Science and Technology Policy Institute
SZ	Subduction Zone
USC	United States Code
USGS	U.S. Geological Survey

APPENDIX E. FULL TESTIMONIALS

Ryan Kersting, SE, F.SEAOC, Principal, BUEHLER

NEHRP has played an extremely valuable role to expand technical knowledge, as well as develop critical products and resources, to support advancements in the science, engineering, and public policies related to earthquake hazards reduction. NEHRP also plays a vital role as it provides factual information that is developed in partnership with leading researchers, practitioners, and other key stakeholders that represents the newest thinking in combination with proven best practices. This contribution is critical and unique in that it yields unbiased resources not subject to the pressures and influences that may affect other consensus-based processes.

NEHRP has played a unique and critical role in developing resources to advance seismic design provisions in current building codes and other structural engineering standards, but more work needs to be done within NEHRP and more progress needs to be made beyond NEHRP. Since the NEHRP agencies cannot control the eventual language adopted into codes and standards (which are developed by private entities even if considered "consensus" or "model" codes and standards), it is important for NEHRP and/or Congress to consider ways to encourage and incentivize, if not require (when allowed), the full adoption of NEHRP-based information into applicable codes and standards. Furthermore, it is equally important, if not maybe more important, for NEHRP agencies to contribute to the development of other resources and policies separate from research and technical development. For example, NEHRP could play a greater role in establishing best practices for mitigation programs and policies, particularly regarding the identification and prioritization of vulnerable existing buildings that are in need of retrofit or other risk mitigation due to being built to outdated codes that resulted in construction now considered deficient compared to current codes.

Prior studies (e.g., National Research Council, 2011) have noted that additional funding is needed in order for the NEHRP agencies to be able to complete their current responsibilities as well as address topics known to need attention yet cannot be covered under current funding (let alone begin to study emerging topics in need of consideration). While the 2018 NEHRP Reauthorization was a significant step to re-validate the current mission as well as expand to scope with a new focus on community resilience, Congress still needs to appropriate the necessary funding or the NEHRP agencies will not be able to address the stated goals of the Program, particularly regarding functional recovery design provisions in support of improved community resilience, until additional funding is provided.

Lori Peek, Ph.D., Professor, Department of Sociology, University of Colorado Boulder and Director, Natural Hazards Center and CONVERGE

It is hard to know just how or where to begin when reflecting on the 40+ year impact of NEHRP on research and its applications. In looking across the landscape, it is clear that the impact has been profound in terms of shaping not just what we know, but also what we do with what we have learned.

Because NEHRP has long supported multi-disciplinary research focused on learning about the physical properties of earthquakes as well as their impacts on people and the built environment, the program has helped to catalyze deep integration across the physical sciences, social sciences, and engineering. Earthquake reconnaissance teams have involved researchers from multiple disciplines for decades—a practice that teams focused on hurricanes, floods, wildfires, and other hazards are only now beginning to adopt on a wider scale. This is just one of many examples of how NEHRP has served as a sort of force function, bringing researchers together across disciplines. This matters because the challenges we face are so complex, they cannot be understood—let alone solved—when looking through only one disciplinary lens.

The research that has been supported through the NEHRP program is also unapologetically applied. Our nation is better prepared in terms of how we monitor earthquake hazards, understand seismic vulnerability of the built environment, and generate loss estimates for communities and entire regions of the country. The knowledge that has been produced has helped motivate mitigation efforts for homes, businesses, schools, and other infrastructure that is vital for the health and safety of the people of this nation.

I am so proud to have served two terms on the ACEHR. Each meeting felt like we were gathered there for a common purpose: to reduce the loss of life and harm and suffering caused by earthquakes. It has been heartening to see other programs established, such as those focused on wind and landslides, to ensure that we work together to keep natural hazards from becoming human disasters.

Jonathan P. Stewart, Ph.D., P.E., Professor, UCLA Samueli School of Engineering

I offer my first-hand perspective of how NEHRP programs operate to advance the broad aims of reducing seismic risk by establishing and applying frameworks for regular improvement of seismic hazard assessments and seismic design procedures for the nation's infrastructure. This happens in two coordinated and inter-dependent programs.

The first program, referred to as the National Seismic Hazard Model (NSHM), provides seismic hazard curves from which ground motion levels for use in seismic design and other applications are derived. While the program is administered by the USGS, which assembles the models and performs the calculations, it contains major elements contributed by individuals and organizations outside of the USGS. These elements include data and models used for seismic source characterization and ground motion modeling, both of which are

required for hazard calculations. As a result, the broader NSHM effort draws upon the collective expertise of leading experts across the US. Moreover, the model development process engages the broader community through a steering committee that reports to the NSHM leadership in each update cycle, and through a series of workshops that any member of the public is free to attend and where input on modeling decisions can be provided.

The second program produces the NEHRP Provisions and Commentary, which is a "pre-code" document that is adapted by other agencies (mainly ASCE) to update building codes used across the US. The NEHRP Provisions and Commentary are updated on a regular schedule (approximately 5-year intervals) by the Provisions Update Committee (PUC) to reflect advancements in knowledge and best practices. The PUC's activities are facilitated by the Building Seismic Safety Council, which operates under contract with FEMA, and as a result this program is part of NEHRP. The PUC is community-based, being populated mainly by leading earthquake professionals with experience in different subject areas relevant to building code provisions (e.g., different structural materials). Moreover, when major changes are being considered, the PUC forms issue teams to study the problem and develop proposals for document revisions. The issue teams are constituted to provide subject matter expertise and are typically diverse, often including younger professionals than the PUC membership. This diversity of engaged professionals strengthens the process and provides a "bench" of talent to move up to the PUC level at later stages of their careers.

Typically, the issues that need to be addressed to improve the NSHM or the NEHRP Provisions and Commentary are substantive, requiring sustained support of applied research to advance knowledge and produce improved models and procedures. A mechanism for support of such research exists for the NSHM via the USGS External Research Program. Such mechanisms are less well developed for engineering procedures such as those used in the NEHRP Provisions; applied research is not the priority for NSF, FEMA lacks a research grant program, and NIST research on building systems and lifelines is not as closely linked with the priorities of the PUC as might be preferred.

While there are opportunities for improvement going forward, my overall message is that the NEHRP programs have been and continue to be effective at regularly improving seismic design practice and reducing seismic risk. Importantly, they do so in a way that engages the world-leading earthquake engineering and seismology expertise within the US academic and practitioner communities. This makes the US NSHM and building codes among the best world-wide.

Heidi Tremayne, Executive Director, Earthquake Engineering Research Institute (EERI)

For decades, NEHRP has advanced research and improved national/state/local capabilities to implement research knowledge and address earthquake risk. Since earthquakes can affect large regions at a time, happen without warning, and lead to substantial financial and economic losses that impact the entire nation, they need the sustained preparedness and

mitigation focus that this nationally coordinated program provides. NEHRP's coordinated approach between four critical agencies leverages resources, amplifies the impact of each agency's work, and influences a broad community of external agencies, organizations, and individuals that also contribute to NEHRP objectives through their aligned work

FEMA's work within this four-agency program supports two critical components necessary for U.S. earthquake resilience: (1) improving seismic resistant design guidance in codes and standards for buildings, and (2) implementing earthquake mitigation activities. FEMA projects take lessons and findings from NIST, NSF, and USGS then put them into action. FEMA products, reports, advisories, and guidelines for both design and recovery, along with the NEHRP provisions for the building code, are essential to determining and addressing critical issues needed to advance performance of buildings to earthquakes. FEMA is also the sole agency tasked to address mitigation and preparedness, while serving as a critical coordinator between states. Without this focus, the nation would be less prepared and able to withstand earthquakes. Despite this important effort by FEMA, earthquake-prone states with great mitigation ideas are often stymied by lack of funding and FEMA's resources in NEHRP remain limited. FEMA's current NEHRP budget and authorization limit also constrains their ability to focus on lifelines with the dedication they apply to buildings, and greatly diminishes the types and scale of mitigation and demonstration projects possible at the state and regional level. Increased national investment in earthquake mitigation activities, especially via NEHRP, could get states closer to their resilience goals and positively impact seismic safety nationwide.

USGS's work in support of NEHRP has significantly advanced our knowledge of earthquakes and our ability to quickly respond to them over the decades. USGS Earthquake Hazards Program products (i.e., National Seismic Hazard Model, Advanced National Seismic System, Earthquake Scenarios) have transformed our knowledge about the seismic hazard. Many of these products (e.g., ShakeMap, PAGER, Aftershock Forecasts) also provide essential, real-time information used by agencies, nongovernmental organizations, companies, and individuals across the nation and globe to inform and influence their response and recovery activities when earthquakes occur. USGS products, tools and collaboration have been essential to situational awareness at state/regional Emergency Operation Centers and at Earthquake Clearinghouses that are formed after major earthquakes to coordinate earthquake field investigations and share observations and knowledge among emergency responders, engineers, and scientists. Continued USGS leadership and emphasis on conducting NEHRP Post-Earthquake Investigations for earthquakes around the globe can further advance resilience to and recovery from future U.S. earthquakes, especially if the findings are proactively used to influence strategy, improve alignment, and enhance activities in NEHRP programs of the four agencies.