ACEHR BIENNIAL REPORT FY21-23

COVER PAGE

(This draft document will be discussed during the August 2-3, 2023 ACEHR meeting. Nothing from this document should be quoted or considered final.)

EXECUTIVE SUMMARY

Despite the significant progress toward earthquake risk reduction since the National Earthquake Hazards Reduction Program (NEHRP or Program) was originally enacted in 1977, earthquakes continue to pose a substantial threat to the United States. The NEHRP Reauthorization Act of 2018 (Act) is an important opportunity to build on NEHRP's 40-year record of achievement. The approved and adopted FY22-29 Strategic Plan as required by the Act is an important opportunity for the Program agencies (FEMA, NIST, NSF, and USGS) to pursue specific and measurable goals that will advance efforts to address earthquake risks and enable community resilience throughout the nation. The focus now shifts to ensuring the Plan is implemented. 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 that will enable full implementation and assessment of the Strategic Plan. This support includes prioritizing the appropriations and budgetary mechanisms needed to fulfill the Strategic Plan at agency and sub-agency levels.

ACEHR provides a biennial assessment of the National Earthquake Hazards Reduction Program as required by the committee charter and Public Law 108-360 as amended in 2018. ACEHR is charged with assessing (1) the effectiveness of NEHRP in performing its statutory activities and any needed revisions; (2) the management, coordination, implementation, and activities of NEHRP; and (3) trends and developments in the science and engineering of earthquake hazards reduction.

ACEHR's FY21-23 biennial assessment focuses on the significant progress made by the NEHRP agencies on specific initiatives related to earthquake hazard, mitigation, response, and recovery, as well as via collaborative efforts such as the FY22-29 Strategic Plan. Our assessment includes summaries of agency progress, additional needs related to functional recovery and community resilience, early earthquake warning research, and the basic earth science, engineering, and social science research needed to support NEHRP's mission. We also highlight three emerging topics and issues—earthquake sequencing research, earthquake insurance, and data-driven models and new sensing technology—that have significant potential to yield lessons that could benefit earthquake risk-reduction efforts and improve community resilience.

Finally, ACEHR offers ___ observations and ___ recommendations related to the items listed above for consideration by the NEHRP agencies. The Committee believes these observations and recommendations will help address the significant risks posed by earthquakes to our nation and its citizens.

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

Build to the annual Office of Management and Budget (OMB) and Office of Science and Technology Policy's (OSTP) Research and Development (R&D) Priorities Memo. If the

report captures the interest of those offices, it might help shape that memo. See link within White House announcement for FY 2024

INTRODUCTION

The NEHRP Reauthorization Act of 2018 (PL 115-307 or the Act) is an important milestone for the nation. Since NEHRP was originally enacted in 1977, there has been significant progress by each of the NEHRP agencies (NIST, FEMA, 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 recent study by the National Institute of Building Sciences found that federally funded earthquake hazard mitigation grants between 1993 and 2016 saved society $5.7 billion at a cost of only $2.2 billion—a benefit-cost ratio of approximately 2.6 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 (U.S.); the benefits to be realized in future, large earthquakes are likely many times greater. Furthermore, trillions of dollars of investments in buildings and infrastructure by state, local, and private organizations using developments from NEHRP have increased these benefits manyfold and will continue to do so.

Despite this progress, earthquakes still pose a substantial threat for the nation. 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.

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) provides a biennial assessment of NEHRP as required by the committee charter and Public Law 108-360 as amended. ACEHR is charged with assessing (1) the effectiveness of NEHRP in performing its statutory activities and any needed revisions; (2) the management, coordination, implementation, and activities of NEHRP; and (3) trends and developments in the science and engineering of earthquake hazards reduction. This report provides ACEHR's FY21-23 assessment and is organized to present an assessment of progress by the NEHRP agencies during fiscal years 2021-23; key initiatives where additional effort and investment are needed to continue building on progress to date; a summary of the important role of basic research to support NEHRP; and topics and issues for which lessons learned have significant potential to affect earthquake mitigation, preparedness, response, and recovery. This report also presents ACEHR's observations and recommendations for consideration by the NEHRP

agencies to ensure that NEHRP remains a vital element of the nation's efforts to mitigate earthquake risk.

Elements potentially for inclusion in the Introduction

- Turkey EQ (lessons from around the globe, see below)

- research to implementation — collaboration among agency partners

- The importance of federal leadership with state and local engagement and implementation

- resilience matters to our nation's future

- mitigation matters

- EQs affect everyone in the country, directly or indirectly

- moral imperative to act on the knowledge we have

- costs from FEMA/USGS report

- support needed to execute the strategic plan, the promise of the 2011 NRC report, and to achieve the level of resilience that American citizens expect and deserve

Lessons from Turkey

1. The Turkey/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 Turkey should be examined for their compatibility with source models.
2. Agencies that maintain ground motion networks in Turkey had many instruments located along the fault. The data collected will be very impactful. Major plate boundary faults in the U.S. (e.g., San Andreas) lack dense, on-fault instrumentation of this type. We should learn from the Turkey experience and improve the instrumentation of these critical regions.
3. The data from Turkey has produced a wealth of information on building performance that could inform US practice. While many of the structures had deficiencies, many others were constructed to similar codes as used in the US. NIST should work with AFAD to develop and disseminate a building inventory for

the region to provide more value to the field performance data that has been collected (Cetin et al. 2023).

4. https://www.geerassociation.org/index.php/component/geer_reports/?view=geerreports&layout=build&id=109

OBSERVATIONS AND RECOMMENDATIONS SUMMARY

This section summarizes the observations and recommendations from the FY21-23 ACEHR biennial report in a concise format for ease of reference. The rationale for these observations and recommendations is presented in subsequent sections of this report, with observations *italicized* and recommendations in **bold**.

Observations

1. ACEHR agenda time needed to address the GAO Report and planned actions/responses.
2. Supports the PCWG in its efforts to develop a Management Plan to accompany the FY22-29 Strategic Plan within the coming biennium.
3. Continue presentations at ACEHR meetings on NEHRP agency contributions/role. Consider developing a common format across agencies for reporting to ACEHR on goals, gaps, and performance measures. Connect reporting to specific recommendations in Strategic Plan and previous ACEHR reports.
4. Observes that finalizing the leadership of NEHRP is important for its continued effectiveness. Specifically, shift from having an Acting Director.
5. Notes that there appears to be an imbalance in research vs. implementation. Cite GAO report. Note budget allocations. Request more for FEMA and NIST without taking away from NSF or USGS. Getting information to key stakeholders is essential for maintaining the research-implementation cycle.

Recommendations

Programmatic

1. National Risk Assessment - supports an update to the 2011 Report
2. Community Resilience & Functional Recovery
3. Existing Buildings
4. Lifelines
5. Scenarios
6. Essential Research
    a. CEUS
    b. SDZ and more

Procedural

7. Update 2017 NSF Synthesis Report every two years, for the first ACEHR meeting of the calendar year, through the preceding two fiscal years.

8. Requests that the NEHRP agency biennial report be finalized as soon as possible, preferably before this ACEHR report is submitted to the NIST Director. Asks that future biennial reports be made available, at least in draft form, to ACEHR members before they are tasked with finalizing their biennial report.
9. Update the NEHRP website to enable better and more effective communication with stakeholders.
10. Provide onboarding of ACEHR members in conjunction with ACEHR Chair.

TO DO's

Observations

GAO Report. ACEHR requests space on its agenda to address the GAO Report with NEHRP Leadership and members of the PCWG.

> Acknowledgement of and reaction to the GAO report -- alignment between NEHRP agency actions and GAO observations
>
> How the NEHRP agencies comply with the GAO recommendations in spirit, given the nature of each organization
>
> Consider how the GAO recs might be used to develop/implement the Management Plan
>
> Utilize GAO Guide Leading Practices in Collaboration Across Governments, Nonprofits, and the Private Sector

Management Plan. ACEHR supports the PCWG in its efforts to develop a Management Plan to accompany the FY22-29 Strategic Plan within the coming biennium. ICC support and resources. Having an approved Management Plan will enable the agencies to make presentations at ACEHR meetings that include:

- Information from each agency provided to ACEHR members in advance to study.
- NEHRP Leadership presents an update on progress toward fulfilling Strategic Plan goals/objectives and elements of the Management Plan.
- Performance indicators that could potentially be similar for each agency. Updates from NEHRP Leadership might include:
    - Funding updates
    - Major projects funded in last two years
    - List of goals and progress
    - Others?

ACEHR Meetings. The ACEHR meeting approach generally works, assuming ACEHR members are onboarded well (see recommendation __). Continue presentations at ACEHR meetings on NEHRP agency contributions/role. Consider developing a common format across agencies for reporting to ACEHR on goals, gaps, and performance measures. Connect reporting to specific recommendations in Strategic Plan and previous ACEHR reports. We recognize that the expanse of the NEHRP Strategic Plan makes it difficult to succinctly address.

Leadership and Management of NEHRP. Observes that finalizing the leadership of NEHRP is important for its continued effectiveness. Specifically, shift from having an Acting Director.

Greater Focus on Implementation Needed. Notes that there appears to be an imbalance in research vs. implementation. Cite GAO report. Note budget allocations. Request more for FEMA and NIST without taking away from NSF or USGS. Getting information to key stakeholders is essential for maintaining the research-implementation cycle.

Social science-based research and implementation on earthquake hazard mitigation

- Communication and public outreach about seismic hazards
- Research on social vulnerability to earthquake and related hazards
- Social equity aspects of safety-based and (or versus) recovery-based earthquake performance of the built environment (buildings and lifeline infrastructure) - need for assessment and research
- Need for coordination among agencies, levels of government?
- Need for social science-based research to inform communication (NSF funding for social, behavioral, and interdisciplinary research) - (how to ensure cross-agency social science research relevant to earthquakes?)
- Communicating to the public about expected seismic performance of the built environment (link with FR, why don't we design to MCE? Communicate the tradeoffs) Building code is minimum standard and owners can design to higher standard for additional cost (maybe 2% of structural cost, not including nonstructural); should it be required in more cases?
- Examples from existing programs
    - Joint committee on communication/outreach JCCEO (ShakeAlert) Social Science Working Group (SSWG) as a model for coordinating research

Programmatic Recommendations

National risk assessment. Supports an update to the 2011 Report.

- Joint funding opportunities
- Multidisciplinary opportunities
- coordination needs
- Need to identify gaps in existing funding mechanisms
- Relation to USGS-NEHRP funding
- Importance of research centers (e.g., SCEC, proposed Cascadia center)
- Could involve other agencies (NOAA, EPA, etc.). Largest earthquake risk in Pacific Northwest, Alaska may be tsunamis, which involve coordination with NOAA.
- Are there “heroes” within NSF to help carry the torch?
- Emphasize distinct missions/roles of different agencies to achieve the overall goal
- Need to align science questions with agency interests
- Importance of continuity in large-scale programs

Community Resilience & Functional Recovery. Add text here.

*** codes, enforcement, support

Existing Buildings. Looking at the role of public policy beyond codes and standards ... tackling the existing building conundrum with effective public policy that achieves community resilience needs and meets sustainable design/construction goals

- Focus on existing buildings inventory, evaluate, retrofit- consider functional recovery standards for existing buildings? Performance objectives should consider functional recovery.
    - Existing deficient buildings that have not been retrofitted represent __% of the risk of our total building stock. Data shows…

    - Earthquakes cost the nation an estimated $14.7 billion annually in building damage and associated losses (USGS-FEMA HAZUS Study, 2023)
        - 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. 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

- Earthquake scenarios provide an opportunity to compare the effectiveness of community retrofit laws. Use scenarios to compare data between pre-retrofit and post-retrofit of specific structural types. For example, how will retrofit of thousands of NDC structures in southern Cal change the results related to dollars, deaths and downtime?
- Communities remain at risk due to collapse of older buildings, significant economic and social disruption and prolonged recovery times. Communities still have thousands of buildings that are at risk of collapse during significant shaking, many of which provide affordable housing.
- Existing buildings at risk should be inventoried and retrofitted. History has shown that mandatory programs are significantly more effective at reducing risk than voluntary retrofit programs.
- NEHRP should promote mandatory retrofitting laws and provide guidance for available funding.
- Call out examples in Utah and Washington for URMs and schools

Lifelines. Making the case for the importance of lifelines systems research and implementation projects, including problem focused studies and demonstration projects.

Review for gaps. Make the case in the report for the value of investment in this area. [Note that this can affect economy as well - e.g., losing oil refining capabilities as well]. Request reintroduction of and support for a new ALA.

Scenarios. Importance of conducting earthquake scenarios and (tabletop) exercises to understand weaknesses and gaps (examples from Haywired, Utah - Wasatch front, Cascadia Rising, DR2 CSZ scenario workshop)

- Need to develop more scenarios for more regions 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.
- Can lead to recommendations for needed mitigation, recovery, and response activities (e.g., ABR (formerly BORP))
- Work with local agencies and municipalities to validate information and provide results that are of interest and use to them. Performing Regional Resiliency Assessments (RRAP) to better understand the vulnerabilities of the different lifelines.
- Best practices for scenarios - what are the desired outcomes? What format? (pertains to # 6 below) Balance of investment and time required and desired level of detail needed to take action; balance also default HAZUS runs with those that include research to improve scenarios.
- Can inform FEMA Local Hazard Mitigation Plans and local tabletop exercises
- Use scenarios to compare data between pre-retrofit and post-retrofit of specific structural types. For example, how will retrofit of thousands of NDC structures in southern Cal change the results related to dollars, deaths and downtime?

Essential Research. CEUS/CENA & SDZ

Action needed on CEUS needs – agency responses and RFPs to achieve aims from the workshop (NIST 2023) (not in strategic plan? Not clear what this is)

- Fundamental research 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.
- Develop publicly accessible information on site conditions, which is essential to advance ground motion modeling. Here are a few numbers: in, CA > 50% of the stations have site-specific information (Vs profiles) whereas in CENA this number

is 3%. This increases the uncertainties in CENA ground motion predictions. Future work should emphasize the importance of data sharing, where that data is being generated, and in programs to generate and archive this information.

- Identify regions of CENA vulnerable to liquefaction and other ground failure hazards. Public policy options to facilitate consideration of such hazards in seismic design.
- Develop inventories of building types in active regions of CENA, and as needed, perform fundamental research to understand the seismic performance of these structures.
- Identify through research effective mitigation strategies for vulnerable structural typologies.
- Address through outreach / education the perceptions that ASCE 7 and ASCE 41 are too complicated for CENA and potentially not applicable.
- Recommend an updated scenario, table top exercise, and report?
- Emphasize collaboration between USGS, NIST, FEMA?
- Recommend continued investment in earthquake hazards for CEUS - earthquake sources, recurrence, and building response remains poorly understood, vulnerability is higher than in more earthquake-prone Western US.

<u>Prioritize research into subduction zone (SDZ) earthquakes and hazards</u>.

- Subduction zone hazards have generally received less attention in the US compared to strike-slip fault environments.
- 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 and triggering of slip on shallow crustal faults after megathrust rupture are not well understood.
- Recent technological advances, such as seafloor geodesy, make significant monitoring and research progress likely in the next few years, if research is prioritized. This will directly contribute to achieving goals 1 and 2 of the NEHRP strategic plan.
- Monitoring and research results can address important hazard questions, such as whether seismic strain is accumulating near the trench, increasing megathrust earthquake and tsunami hazards.

- Research should also allow better understanding of subsidiary forearc faults in the upper crust, which can pose significant hazards due to shallow locations beneath populated areas.
- Offshore real-time instrumentation is important for improving earthquake early warning, particularly in the Pacific Northwest.
- ACEHR is encouraged by the ongoing planning of subduction research programs by both the USGS and NSF.

Fundamental earthquake research such as the relationship between slow slip and large earthquakes, earthquake precursory activity, controlling factors for large tsunami excitation, and triggering of upper crustal faults and/or rupture in adjacent subduction zone segments will improve seismic hazard analysis. There has been progress on investments in offshore measurement (NSF), but not enough. Next generation instrumentation is available to improve observations. Offshore real time instrumentation is required, both for fundamental research as well as EEW.

Procedural Recommendations

NSF Synthesis Report. Update 2017 NSF Synthesis Report every two years, for the first ACEHR meeting of the calendar year, through the preceding two fiscal years.

NEHRP Biennial Report. Requests that the NEHRP agency biennial report be finalized as soon as possible, preferably before this ACEHR report is submitted to the NIST Director. Asks that future biennial reports be made available, at least in draft form, to ACEHR members before they are tasked with finalizing their biennial report.

NEHRP Website. Update the NEHRP website to enable better and more effective communication with stakeholders.

ACEHR Onboarding. Provide onboarding of ACEHR members in conjunction with ACEHR Chair. Given that ACEHR meets infrequently and members serve a minimum of 3 year term, the first meeting for new members can be very overwhelming. More extensive onboarding would be valuable. Perhaps new members (any others interested) could attend a half-day before the first meeting of the term to learn about:

- Organizational structure including the four NEHRP agencies and their areas of responsibility
- Explanation of funding for NEHRP

- History of NEHRP and how it's evolved
- Mission of ACEHR
- Clarify roles of ACEHR members, and ACEHR's responsibilities to NEHRP process
- Schedule for ACEHR report to NIST (what will be accomplished at each meeting as progress towards the report? Should an agenda for each meeting be available at the start of the cycle?)
- Purpose and content of report to NIST (should the report be the same format as the last one?)
- List of relevant acronyms and their roles relative to NEHRP, graphic of how all the pieces fit together, org chart, acronyms, NEHRP/ACEHR 101) (acronym list: https://www.fema.gov/pdf/plan/prepare/faatlist07_09.pdf)
- Clarify roles of ACEHR members, responsibility to NEHRP process
- Also see all links in *New Member Background Material* provided by Tina

NEHRP AGENCY ACHIEVEMENTS (2021-23)

- Compile list from ACEHR meeting updates

- Identify impact of example programs (e.g., NSHM, NEHRP Provisions)

Discussion of what agencies have done to make progress and address implementation gaps

Highlight the complementary nature of the different agencies that are part of NEHRP as opposed to assessing individual agencies

How effective has the collaboration been in developing collaborative programs, for example, in assessing subduction zone science and its application to earthquake hazards? Could it be done in a more strategic way?

Cross-agency successes

NIST Program Leadership

- Strategic Plan

ACEHR fully supports the NEHRP FY22-29 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 tie project milestones to specific plan objectives. Quarterly, or at regular intervals, project progress should be reported in alignment with strategic plan objectives to ensure progress is in line with the overall plan.

Project progress reports should also include performance measures, to track progress and demonstrate investment value. Recommendation 5 of the GAO's recent report on NEHRP activities also reflects this guidance.

ACEHR also encourages budget allocations to be tied to strategic plan objectives. By connecting funding with outcomes in the plan, agencies can measure effectiveness in achieving its goals, as well as have concrete tools for future budgeting.

Description of the recently approved NEHRP Strategic Plan and the process used to engage ACEHR in ongoing review (e.g., gathering feedback and input during its development and adjusting actions as needed)

NEHRP strategic plan for FY22-29 is the roadmap for achieving NEHRP objectives

ACEHR reactions, takeaways -- how might we amplify what we're seeing in the plan?

Mission, roles and operations of individual agencies complement each other to achieve overarching NEHRP goal

How can implementation of the strategic plan go really well?

- Better coordination of agency activities that work together towards addressing the strategic plan. Part of PCWG activities?

Need for performance metrics in order to assess agency progress?

Observation that there are a lot of assessment reports that are hard to coordinate

Moving forward, how does the strategic plan guide our assessment of effectiveness?

Possible development of advisory structures for individual agencies' contributions to NEHRP

Linkage between budget priorities and NEHRP Strategic Plan priorities

Social Science research as exemplar of cross-agency needs (possible involvement of NSF social science directorate (and engineering))

It would be useful to see an overall assessment of budget allocations across the different parts of the Strategic Plan and across all of the agencies. Is there a balance? Is something being missed?

Implementation

FEMA

1. FEMA grant programs have been very helpful and should be continued. Discuss how enhanced investment in these grant programs can yield major benefits downstream. We discussed structural inventories as an example of impactful projects (can cite Turkey example here). Model retrofit ordinances

Description of DRRG program, the response to it, and ACEHR recommendations on enhancements and continuation of this program

FEMA's multi-billion dollar BRIC program has successfully funded many resiliency improvements throughout the country. But its competitive awards process has resulted in many of the neediest recipients being unable to qualify for funds. A statewide building code is heavily weighted in the competitive process, and the many states with no code are unable to compete. These states are among the most seismically vulnerable in the nation.

FEMA could remove this grading requirement, resulting in many additional applicants. And it could require successful applicants to build to the latest building code, thereby ensuring all new structures are earthquake resilient.

NIST

Functional recovery (FEMA also)

Focused attention on needs of CENA (ATC workshop)

Research

NSF

- Call out examples of successful calls for research, types of grants being funded and how they address NEHRP mission
- We note that the GAO report calls for NSF to develop better strategies to communicate NEHRP's priorities to research entities. NSF has a strong record of encouraging publication of research results in technical literature, but some more organized method of delivering important results to stakeholders should be considered, perhaps in collaboration with other NEHRP agencies.
- Joint calls - … NSF/NIST
- NSF has funded planning for an SZ4D "science of subduction zone hazards" program. Major components of this program would be research focusing on subduction zone megathrust earthquakes and also faults in the overriding plate.
- NSF has also funded seafloor geodetic equipment and a near-trench community experiment to explore whether elastic strain is accumulating near the 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.
- Emphasize opportunities for direct collaboration with partner agencies

USGS

Update to Circular 1242

Coordination on EQ disaster reconnaissance with multiple government, professional and research/university organizations, taking advantage of new technologies and protocols for data collection, archiving and sharing that have been developed for other hazards (e.g., hurricanes & floods - which occur more frequently and provide best practices)

> Given the new Guidelines coming for NEHRP Coordination in responding to events, do we need this as an emerging topic?? Maybe this should be addressed in the Assessment Part 1
>
> Application to international disasters (e.g., Turkey earthquakes)
>
> Linkage to tsunami hazards (collaboration with NOAA, other agencies)

EEW - The USGS has made great strides in EEW. ~86% complete, estimated completion by 2025. Recent system improvements include magnitude weighting and better station cluster logic, and use of ground motion lookup tables.

> note concerns raised in SESAC report :
>
> - instances of false and missed alarms
> - incorporation of GNSS data into alert algorithms
> - post event assessment of where strong shaking did (or didn't) occur

Progress in subduction zone science (importance of continued investment in other tectonic environments as well)

Advancements made in developing the 2023 NSHM (50-state update, improved utilization of local information sources like basin geometries) Updated models for AK and Hawaii for the first 50-state model. Seismic Hazard Models for PR, US VI, and other US Territories in process leading to National model (50-state and territories).

Joint USGS-FEMA study Annualized Earthquake Loss update (FEMA P-366 Update), AEL increased to $14.7 billion per year (up from $6.1 billion in 2017). Increase due to increased building value, updated hazard, and improved building inventory. Estimated ratio of building loss to building value decreased in western US - indicates progress in reducing vulnerability (of new buildings) - cost-effective retrofits of existing vulnerable structures remains an issue.

ON THE HORIZON -- EMERGING TOPICS & ISSUES

Earthquake Sequence Research

Several recent earthquakes have occurred in EQ 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., 2019 Ridgecrest, 2023 Turkey). These sequences challenge certain aspects of how earthquake hazard and risk are computed and communicated to the public,

1. It is important that we understand how an earthquake on one fault can trigger (or not) continuation on neighboring faults. What aspects of the fault slip and geometries (e.g., step over dimensions) are required to estimate trigger probabilities.
2. How do these sequences of ground motions affect building response? In particular, to what extent is the fragility of a structure in the subsequent (2nd) event changed by the shaking in the prior event?
3. Impact on previously damaged buildings
4. Social science research on multiple events How might the possibility of subsequent damaging events be communicated to emergency responders and the public?
5. Should Shake Alert messaging related to an earthquake be formulated to consider the possibility of a subsequent larger, triggered events or link to forecasting of subsequent events?
6. Note USGS is developing an Earthquake Sequence Product linking foreshock and aftershock earthquakes to a main shock providing enhanced information on earthquake sequences

Earthquake Insurance

Earthquake insurance is increasingly unaffordable throughout the nation's high-risk seismic zones; many insurance companies are no longer writing policies. As a result, many communities will be unable to rebuild after a large quake.

ACEHR suggests that agencies look for innovative approaches to address this insurance crisis. Possibilities could include all-hazards models, pooled funds, parametric coverage, or other newer models. Collaboration with the private sector is encouraged.

Insurance - increasing unaffordability (relate to what's happening with insurance for other hazards? Insights from a recent earthquake insurance conference in Missouri?) Suggest that agencies look for innovative approaches, different models of insurance (parametric approach), all hazards insurance to cover earthquakes, fires and floods,

New Technologies

New data sources and sensing technologies, machine learning, data-driven models (how is AI transforming earthquake research and hazard response).

- 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.
- Examples of these efforts include 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. (perhaps add more examples?)
- Data-intensive computing approaches incorporating machine learning and artificial intelligence (AI) must be developed to take advantage of these opportunities.
- New technologies and strategies must also be implemented to collect, store, access, and preserve these massive datasets.
- Open-science principles, including open-source codes and open data, will allow greater impact and promote participation by early career and international investigators.

ABBREVIATED BIBLIOGRAPHY

APPENDICES

Full testimonials

Call to Action document

EERI White Paper