Effectiveness of the
National Earthquake Hazards Reduction Program

A Report from the
Advisory Committee on Earthquake Hazards Reduction

First Draft, July 17, 2017

Contents

Executive Summary

(To be completed once the recommendations are confirmed.)

Introduction

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) was established in 2004 as part of the reauthorization of the National Earthquake Hazards Reduction Program (NEHRP) (Public Law 108-360). The ACEHR membership consists of non-Federal employees serving three-year terms and includes members from research and academic institutions, earthquake-related design professions, and state and local governments. ACEHR is charged with assessing trends and developments in the science and engineering of earthquake hazards reduction; the effectiveness of NEHRP in performing its statutory activities and any need to revise NEHRP; and the management, coordination, implementation, and activities of NEHRP.

This report is provided to the Director of the National Institute of Standards and Technology (NIST) who, under the NEHRP authorizing legislation, also serves as the Director of the Interagency Coordinating Committee on Earthquake Hazards Reduction (referred to in this report as the "ICC")[1]. The recommendations of this report are also directed to the NEHRP Program Office and the four NEHRP agencies—the Federal Emergency Management Agency (FEMA), NIST, the National Science Foundation (NSF), and the U.S. Geological Survey (USGS).

The report is structured to first offer a synopsis of important contributions and developments since NEHRP's enactment in 1977, and then to assess the effectiveness and needs of NEHRP. Our assessment considers the overall management, coordination, implementation, and activities of NEHRP through the ICC and the NEHRP Program Office, and the NEHRP agency-specific assessments provided in alphabetical order. This is followed by the Committee's assessment of new trends and developments in the science and engineering of earthquake hazards reduction.

[1] Under Public Law 108-360, the ICC shall be chaired by the NIST Director and membership shall be composed of the directors of the Federal Emergency Management Agency (FEMA); the National Science Foundation (NSF); the United States Geological Survey (USGS); the Office of Science and Technology Policy (OSTP), and the Office of Management and Budget (OMB).

Strategic Considerations

2017 marks the 40th anniversary of NEHRP's first authorization in 1977 (Public Law 95-124). It is with great pride that we reflect upon the knowledge, tools, and practices in earthquake hazards reduction that the federal investment in NEHRP has fostered, and the progress that has been made to achieving the NEHRP vision of *a nation that is earthquake resilient in public safety, economic strength, and national security* (NEHRP 2008). NEHRP activities has been essential to improving our understanding of the nation's earthquake-related hazards and risks, improving the seismic design and construction techniques for buildings, critical infrastructure and lifeline[2] systems, and raising earthquake awareness and preparedness across the United States and the world.

- Insert a table or cite key accomplishments succinctly including Executive order 13717 – Establishing a Federal Earthquake Risk Management Standard.

As discussed in ACEHR's 2015 biennial assessment, the challenges for bringing about earthquake hazards reduction have evolved considerably during the past 40 years. Earthquake prediction—a major scientific endeavor in 1977—has proven to be infeasible, and there has been wider acceptance of the risk that earthquake hazards pose across the country and the need for public investments to focus on averting earthquake damage and loss.

Earthquakes are not just a West Coast problem. Portions of 42 states and almost half of the U.S. population could experience a damaging earthquake within the next 50 years; 16 states, including California, Oregon, Washington, Alaska, Hawaii, Tennessee, and Missouri, are at very high risk (USGS 2014). The increased number of earthquakes caused by the injection of waste water generated by oil and gas production and other industrial activity—or "induced" seismicity—is causing added risk to buildings, critical infrastructure and lifeline systems, particularly in the central and eastern United States. In an increasingly interconnected global economy, earthquake disasters anywhere in the world not only stress local resources, but they can significantly impact the U.S. as well.

While substantial progress has been made in improving the seismic design of new buildings, implementation of modern seismic codes at state and local levels varies considerably across and within states, even in areas with high levels of seismic hazard.

[2] Lifeline is a term often used in the earthquake engineering field that refers more specifically to those infrastructure systems that are essential to societal functioning, such as electric power, water, wastewater, telecommunications, and gas and liquid fuels.

There is a greater recognition of the limitations of existing codes which focus on preventing loss of life caused by building collapse, but still may results in buildings being deemed uninhabitable or uneconomical to repair after an earthquake. Notable gaps also remain in the earthquake engineering of critical infrastructure and lifeline systems and the seismic rehabilitation of many older building types.

The concept of societal resilience has gained national and international prominence in recent years as communities strive to do more than just withstand the shocks caused by major disasters, and instead enhance their capacity to maintain important societal functioning and recover more quickly when major disasters occur. The NEHRP strategic plan envisions *a nation that is earthquake resilient in public safety, economic strength, and national security* (NEHRP 2008) and the 2011 report by the National Research Council (NRC), "*National Earthquake Resilience: Research, Implementation, and Outreach,*" commissioned by NEHRP outlines an 18-task, 20-year program to make the nation's communities more earthquake-resilient.

Despite notable accomplishments toward this goal, the NEHRP program is now at a crossroad. A confluence of forces has diminished the program's impact to the point that it is arguably more a program in name than actuality. Without new concerted efforts to renew and revive NEHRP, as discussed further in this report, the program will continue to struggle to bring about coordinated action in addressing earthquake risks. Legitimate questions can and should be asked regarding the desired future for NEHRP.

Four sets of forces have diminished the viability of the program:

1. The lack of reauthorization since 2004 (PL 108-360) and annual appropriations that fall far short of the original authorization levels and the $306.5 million annually recommended in the 2011 NRC Report as necessary to implement the 2008 NEHRP Strategic Plan and to materially improve national earthquake resilience. NEHRP is presently sustained on out-of-date annual appropriations that place it on auto-pilot.
2. The failure to achieve strong agency-level leadership for a coordinated program. The ICC mechanism established in the 2004 legislation has not fulfilled its purpose. The Committee has rarely met in recent years. Agency commitments to the program have also been variable as evidenced by the diminished emphasis within critical agencies such as FEMA and the inability to account for NEHRP efforts at NSF.
3. The limited ability to plan for and guide a national program. The 2008 – 2013 NEHRP Strategic Plan and Program management plans need updating and the efforts of core agencies tend to be in parallel more than intertwined. The notion of a national program is further hampered by the fact that only the USGS has direct NEHRP appropriations. Other agencies rely on internal agency budgeting processes for allocating program funds, which have proved problematic given varied agency commitments to NEHRP goals.

4. The dissipation of NEHRP research and implementation efforts as some of the core agencies have been replaced by new emphasis on broader risk-resilience and multi-hazards programs (e.g., NIST community resilience planning program) and research efforts (e.g. NSF Natural Hazards Engineering Research Infrastructure (NEHRI)). These, along with cutbacks in implementation efforts at FEMA (e.g., state and local funding), have led to a weakening of NEHRP as an identifiable set of efforts across key federal agencies.

Despite these basic concerns, ACEHR commends the hard work of the NEHRP Program Office in attempting to coordinate and lead NEHRP efforts as well as a number of important cross-agency and collaborative initiatives within and between some of the NEHRP agencies. The issues we raise are more fundamental.

Like any crossroad, there are choices that need to be made. For NEHRP, the basic one is between renewal and reemphasis as a separate program, folding earthquake risk reduction efforts into a broader national program around resilience, or muddling through as at present. ACEHR strongly endorses the first path as the most appropriate given the unique research needs for understanding seismic risks and their mitigation. Central to this is the reauthorization by Congress of a revitalized NEHRP.

These observations are more pointed than ACEHR reported in 2015. Since then, we have seen little progress in resolving key coordination and program management issues. There continues to be a lack of engagement of the ICC in fostering top level attention and emphasis on a strong program. The need for and value of strong NEHRP leadership and direction is as important now as it was in the ACEHR 2015 report.

Critical Observation 1

ACEHR urges Congressional reauthorization of the Earthquake Hazards Reduction Act.

NEHRP Reauthorization is essential for the long-term viability of NEHRP. Any reauthorization needs to address the shortfalls noted above and establish:

- Strong agency-level leadership for a coordinated program. A revitalized ICC that allows for delegated membership on the ICC of principal agencies and annual reports by the ICC to Congress. The chair of the ACEHR should have an observer role (or some other designated one) on the ICC.
- Appropriations and budgetary mechanisms that clearly identify NEHRP funds and activities at agency and sub-agency levels, and that hold agencies accountable for using those funds for such purposes.
- A stronger Program Office for planning and coordinating NEHRP efforts. This entails sufficient staff to guide development of periodic strategic and management plans, to fund and/or conduct special analyses relating to future program

directions, and authority to recommend changes in NEHRP annual budgets to meet pressing needs or fund innovative collaborative programs.
- Greater accountability of individual agencies for fulfilling their NEHRP program obligations.

Any reauthorization needs to recast the Program to reflect current needs to address seismic risks: renewed consideration of earthquake hazards in the central and eastern United States; greater attention to the vulnerability of existing buildings; renewed emphasis on the implementation and adoption of seismic provisions in building codes and standards for critical infrastructure and lifeline systems; and a recasting of the earthquake hazards reduction effort as one of improving the nation's resilience to earthquakes as well as other hazards. Core technological interests of NEHRP also need to be updated to consider advances in remote sensing, computing and data archiving, and social networking and to also consider the current status and future versions of NEHRP-mandated and developed technologies and operations. These include the USGS Advanced National Seismic System (ANSS), the formerly NSF-funded George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), and the joint USGS-NSF funded Global Seismographic Network. An enhanced emphasis on community resilience will also require expanded roles and emphases of the core NEHRP agencies.

Critical Observation 2

ACEHR calls for the conduct of an assessment to fully understand the nation's earthquake risk reduction progress to date in order to guide future direction and funding levels for improving national earthquake resilience.

This assessment should address the extent to which the federal government, states, localities, tribes, and the private sector are taking steps to address the seismic vulnerability of buildings, critical infrastructure and lifeline systems. It was recommended in the 2015 ACEHR report and reiterated in ACEHR's 2016 interim reports. It is envisioned as a formative undertaking that assesses progress in achieving seismic risk-reduction and identifies key gaps that remain with an emphasis on implementation of seismic risk-reduction measures. This is not intended as an evaluation of individual programs or agencies. The assessment should be national in scope, consider multi-sector roles (government, private sector, nonprofit sectors), and focus on risk reduction for the built environment including lifelines and infrastructure.

The main foci should be the implementation of seismic risk-reduction practices for reducing risks to the built environment. These practices include seismic building code adoption and enforcement; efforts to identify and address risks posed by hazardous existing buildings (e.g. unreinforced masonry, soft story, tilt up, non-ductile concrete frame); efforts to identify and address risks to lifelines and infrastructure; and use of planning practices to lessen exposure to seismic hazards including tsunami risks. The assessment should have sufficient detail to provide state and/or regional assessment of risk reduction practices among at least high and moderate seismic regions of the country.

Part of the assessment should include methodological development of measures (indices) of risk reduction efforts with data collection that can be replicated over time to track progress in risk reduction. Sufficient detail should be gathered to allow for targeting of future implementation efforts among critical sectors, regions, or practices. Such targeting should consider overall risk levels as indicated by hazard maps, HAZUS projections, or other means for calibrating need.

The envisioned assessment is more focused than what might be labeled a national assessment of seismic vulnerability, resilience capabilities, emergency preparedness, recovery planning, or seismic risk assessment. Each of these is potentially important for other purposes than that envisioned for the national assessment of seismic risk reduction progress and gaps.

Program Management, Coordination and Implementation

Interagency Coordinating Committee (ICC)

The ICC is the body that provides the senior leadership for NEHRP. The NEHRP legislation requires that the ICC meet three times a year. However, the ICC has met only once in at least the last three years. ACEHR is concerned that, as a result of this, much of NEHRP'S senior leadership may not understand the challenges that the Program faces, particularly the financial problems brought about by sequestration and other budgetary cuts.

ICC Recommendation 1
ACEHR calls upon the NIST Director, as Chair of the ICC, to revitalize the ICC as a mechanism for advancing NEHRP within the respective agencies.

In order for NEHRP to fulfill its mission, the leadership of the four agencies must have an understanding of and commitment to the basic tenet of NEHRP and be well-briefed on progress within their own agencies and links with partner agencies. Although we recognize the difficulty of scheduling meetings with the agency principals, it is critical that education of new agency leadership appointees be undertaken with the idea of their understanding of how critical this program is to the public safety and economic viability of the nation.

While agency priorities may vary, it is incumbent on senior management in the NEHRP agencies to ensure that Administration leadership is aware of the importance of the NEHRP mission and the potential implications of not performing or supporting their responsibilities, when an earthquake occurs. The leadership of all NEHRP agencies must be informed and able to participate in decisions that advance earthquake hazards reduction and reduces the impacts of future earthquakes. Budget increases and other

initiatives resulting from an earthquake, as has occurred in the past, require leadership and coordination among the NEHRP agencies and a champion within the Administration.

For example, when the next earthquake occurs:

- NEHRP will be under scrutiny by the Congress, the press and the public. Congressional hearings, press enquiries and many public events will all be events in which the NEHRP leadership will be required to participate.
- Agency and Administration leadership, or the lack there of, will be held accountable by Congress for their roles in supporting and enabling earthquake hazards reduction in the past.
- Although FEMA may lead response, other NEHRP agencies will be called on, and have a role to play, especially in recovery.

In the absence of a major earthquake, people become complacent. But, historically, it is shown that when an earthquake disaster occurs, even when small or localized, there is an economic effect, and communities demand answers.

ICC Recommendation 2

ACEHR calls upon the NIST Director, as Chair of the ICC, to work with the ICC to ensure appropriate and coordinated program budgets and an updated Strategic Plan and implementation strategy necessary for NEHRP to fulfill its mission.

Advancing implementation has always been a critical goal of NEHRP but has often been given a minimum of support. Lacking a base of agency leadership support, senior agency management plays a crucial role in program coordination but they are often limited in impact relative to budget decisions, staffing, etc.

Although enhanced funding may not be forthcoming from Congress, it is important to underscore the need for this funding to the ICC as a reminder of what needs to be accomplished. We fully endorse prior recommendations by ACEHR and ask the ICC to work with the four NEHRP agencies to carefully consider full funding at an estimated $307 million annually for the first five years of implementation of the 18-task, 20-year program for achieving national earthquake resilience outlined in the NRC (2011). In particular, FEMA has had significant reductions to its earthquake budget in recent years, yet it is the primary agency tasked with program implementation.

Aside from budgetary problems, an updated NEHRP Strategic Plan and implementation strategy are needed to translate and integrate the knowledge and advances of the four agencies into implementation at the Federal, State and local level. A critical step in developing this Plan is the nationwide implementation assessment that ACEHR has been calling for. Such a Plan must require certain commitments from partners at all levels of government as well as within the other nonprofit and private organizations. This “whole

community" approach could revolutionize how we achieve earthquake hazards reduction implementation in the future.

NEHRP Secretariat

ACEHR commends the NEHRP Secretariat, which is housed at NIST, for its collaborative leaderships in integrating and coordinating resources and initiatives with the senior management of the four agencies; however, their efforts to engage high–level leadership within the NEHRP agencies has not been as effective as would hope.

NEHRP Secretariat Recommendation 1

ACEHR recommends the NEHRP Secretariat work with the NIST leadership and ICC to engage the leadership of the other three agencies about the importance of the NEHRP mission and the critical nature of their roles and responsibilities when an earthquake occurs.

When the next earthquake occurs, each will want to be well-informed about the Program and for all the agencies to be individually prepared and mutually supportive.

The ICC should review the responsibilities of its agencies, personnel and programs to educate the public, the Congress, and other groups on issues and implications of issues such as the local and national impact of a major earthquake.

NEHRP Secretariat Recommendation 2

ACEHR recommends that the NEHRP Secretariat work with the other NEHRP agencies in a more organized information exchange between the NEHRP agencies and the NEHRP constituencies on how earthquake risk can impact their constituencies and their communities and what they can do to minimize the impacts of a future earthquake.

The existing NEHRP website would be one of the useful tools but we would like to see more outreach to local influential organizations such as U.S. Conference of Mayors, National League of Cities, professional societies, and risk groups such as the Association of State Flood Plain Managers.

NEHRP Secretariat Recommendation 3

ACEHR recommends the NEHRP Secretariat, with the four NEHRP agencies, take an active role in facilitating the process of establishing a risk-based rating system for the seismic performance of buildings in the United States.

The 2013 and 2015 ACEHR reports have recommended that a seismic building performance rating system be developed and implemented. ACEHR recognizes that no single NEHRP agency currently has the resources to develop and implement such a

system on its own, nor should it. However, the federal government can help ensure nationwide consensus standards for a market-based, private-sector-led building rating system, which is essential for such a system to be successful. This may be accomplished by empowering the American National Standards Institute (ANSI), through their consensus process, to work with the appropriate stakeholders to establish an adoptable standard. A further, and perhaps more desirable, consideration is to bring together the U.S. Resiliency Council (USRC)[3], International Standards Organization (ISO), the various engineering organizations and the International Code Council (ICC) to establish codes, standards and guidelines for new and existing buildings with specific deadlines and objectives. The federal government can help source funds for the development of consensus standards and for implementation of a rating system. The federal government can also be a powerful force in helping to "incentivize" the desired market take-up or use of a building rating system through financial or other incentives and become an early adopter of such a system.

The rating system must be both cost and time-effective for evaluating the existing building stock. The existing building stock continues to grow with no risk-based rating systems, and thus market transparency about risk and safety, in place. A study in 2012 indicated that the United States had 5.6 million commercial buildings, comprising 87.4 billion square feet of floor space, yet the average age of commercial buildings in the United States was 41.7 years. Recent studies indicate that the total value of the U.S. housing stock exceeds $23.9 trillion, but 80 percent of it is 15 years old or older. These aging structures represent an unquantified human safety and economic risk to cities, states and even the nation, and it must be addressed.

Program Effectiveness and Needs

This section of the report focuses on the activities of the four NEHRP agencies (in alphabetical order).

Federal Emergency Management Agency (FEMA)

FEMA is the primary agency within NEHRP for implementation of earthquake hazards reduction and mitigation programs and strategies. These activities include development of seismic provisions and the dissemination of guidelines about seismic building

[3] The USRC has undertaken the process of developing a universal building rating system by obtaining input from a variety of sources and stakeholders. Their proposed star rating has the goal of stimulating market forces to promote the upgrading of seismically deficient structures.

practices, supporting implementation activities at the state and local level, education and outreach, and promotion of earthquake preparedness.

FEMA Recommendation 1

Given the persistent underfunding of FEMA earthquake-related activities, ACEHR recommends that FEMA review their areas of responsibility, prioritize those efforts that have maximum impact on seismic resilience, and identify efforts that may no longer be needed or must be discontinued in order to prioritize critical efforts.

ACEHR finds that while FEMA continues to make noteworthy contributions to the NEHRP program, the agency's mitigation efforts continue on a persistent multi-year path of significant underfunding, characterized by the request for only 30 percent of their authorized budget for the current year. FEMA earthquake-related activities are dramatically underfunded compared of the seismic risk facing the nation. It is vital that FEMA explore different avenues for obtaining additional resources. This could include linking FEMA earthquake activities with the efforts of other FEMA branches, and within other multi-hazard, risk, and threat-oriented activities and initiatives.

Even with severely constrained resources, FEMA has made notable progress in the past two years. The long-anticipated addition of a tsunami module to Hazus was completed. The new recovery policy for Public Assistance following a disaster has shifted from treating Public Assistance as reimbursement of the costs to rebuild to the pre-existing code level, to one that requires use of the latest hazard-resistant provisions found in model building codes. FEMA continues to actively support the adoption of model building codes with strong seismic design provisions, and sponsors an array of earthquake-related projects that support implementation of research results; promote use of building practices that enhance seismic resilience, and improve earthquake education and awareness.

The lack of adequate resources means many opportunities to advance seismic resilience initiatives are being missed. The following are examples of critical areas lack adequate support:

- Land use planning, a key component in mitigating risk in areas subject to multiple hazards and presents opportunities to improve resiliency.
- Lifeline and infrastructure performance, critical to community resiliency following an earthquake. Little progress has been made over the last decade due to resource constraints.
- Hazus is the premier disaster assessment and planning in the United States. While the addition of the tsunami module to Hazus is a welcome and critical improvement, Hazus requires significant updates to incorporate the latest developments in seismic design.

FEMA Recommendation 2

ACEHR continues to recommend that FEMA return to a directly-funded state-based program for earthquake hazard mitigation, planning, education and preparedness efforts and to reconsider the current state grant matching formula.

The steady decline in overall funding to state earthquake programs must be reversed, if the nation is to be adequately prepared for a major seismic event.

National Institute of Standards and Technology (NIST)

NIST is responsible for carrying out research and development to improve building codes and standards and practices for structures, critical infrastructure and lifeline systems. This mission is of critical importance to NEHRP, since it is through these efforts that the NEHRP research activities are implemented in the built environment.

NIST activities include promoting the implementation and integration of NEHRP research into model codes and standards for buildings, cost-effective performance-based seismic engineering, and providing resources to practicing architects and engineers to enhance seismic design and construction. NIST also supports the efforts of national standard organizations in the development of seismic safety standards and best practices for critical infrastructure and lifeline systems. In addition, NIST works with NSF, FEMA, and USGS on planning for earthquake engineering research.

ACEHR commends NIST for continuing the move the NEHRP agenda forward in priority areas. The ACEHR 2015 biannual report made two recommendations to: (1) "improve the dissemination of NEHRP related information and products to the architectural and engineering professions", and (2) "continue and emphasize NEHRP-related research and development programs on critical infrastructure and lifeline systems, geotechnical engineering, non-structural elements, and residential and industrial structures that have seismic vulnerabilities." NIST worked toward accomplishing both of these recommendations in the past two years, among other things, through (a) enhancing the disseminating information using numerous methods, (b) publishing a document titled "Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery" (NIST GCR 16-917-39), and (c) obtaining approval to hire geotechnical engineers to work on NEHRP-related products, as well as planning other planned geotechnical-related projects, and (d) publishing a document titled "Seismic Analysis, Design, and Installation of Nonstructural Components and Systems—Background and Recommendations for Future Work" (NIST GCR 17-917-44).

ACEHR encourages NIST to continue with the above described efforts and to select priority topics outlined in prior developed roadmaps for earthquake-resilient buildings (NIST GCR 13-917-23) (NIBS 2013) and lifelines (NIST GCR 14-917-33)(NEHRP Consultants

Joint Venture 2014) and recommendations made in subsequent studies undertaken as a result of these roadmaps.

ACEHR is also pleased to see the approximately 25% increase in NIST funding levels from Congress in FY2016 for resilience. However, the above referenced roadmaps identify the need for about $10 million total per year for earthquake-related engineering aspects, and this gap still needs to be filled. ACEHR recognizes that this gap exists among all NEHRP agencies, but NIST plays a significant role in the development and implementation of many topics needing to be undertaken as outlined in the roadmaps. NIST has a unique role in NEHRP as an agency where the in-house technical staff can undertake significant technical projects that make broad contributions to applied seismic engineering. Staff is needed to support technical initiatives for critical applied research in lifelines and existing building areas as outlined in the roadmap.

NIST Recommendation 1

ACEHR recommends NIST initiate development of uniform seismic performance objectives, assessments, and design criteria for lifeline systems consistent with building systems.

Given the unique and critical role of lifelines in community resilience, building systems (clusters) and lifeline systems need a common basis for providing post-earthquake services consistent with community recovery needs. A critical effort is needed to establish procedures to develop a framework for national lifeline performance and restoration goals and to quantify hazards over spatially distributed lifeline systems as described in NIST GCR 14-917-33 (NEHRP Consultants Joint Venture 2014). There is synergy for creating the framework for performance and restoration goals with the NIST Community Resilience Planning Guide and the American Society of Civil Engineers Infrastructure Resilience Division (IRD). The IRD is developing a plan to develop resilience based standards which NIST should consider how to coordinate and leverage to achieve the first steps in developing lifeline system performance and restoration goals.

Performance goals, no matter the level at which they are established, cannot be realistically achieved until there are procedures established to quantify earthquake hazards in a uniform manner across all spatially distributed systems including building clusters and lifeline systems. There is a need to incorporate recently developed methods to quantify ground motions and permanent ground deformations which may occur during an earthquake (e.g., fault rupture, lateral spreading, landslides, settlement, etc.) in estimates of the uncertainly on how any performance objective can be met.

NIST Recommendation 2

ACEHR recommends that NIST assess the social and economic consequences and financial implications of different lifeline and building cluster performance levels and restoration timeframes

This task was recommended in the NIST report GCR 14-917-33 (NEHRP Consultants Joint Venture 2014). The building clusters should focus on the relationship between facilities with enhanced seismic design (Risk Categories III and IV structures) and whether the measures used to achieve the enhanced seismic performance also translates into enhanced performance (or not) for other hazards.

National Science Foundation (NSF)

NSF has NEHRP responsibilities that extend across three of the Foundation's Directorates in Engineering; Geosciences; and Social, Behavioral, and Economic Sciences. Supported activities include a broad spectrum of fundamental research of transformative intellectual merit with the potential for broader impacts, facility support, and data resources that are essential to the advancement of the goals of NEHRP.

Through Geosciences, NSF has supported basic research on the earthquake source that has fundamentally altered our understanding of how earthquakes nucleate and the strong ground motions that are produced, especially in subduction zones. In Engineering, NSF has supported research on the influence of earthquake ground shaking, ground deformations, tsunamis and other earthquake effects on the performance of buildings and civil infrastructure. This, combined with research to develop technologies for earthquake risk assessment and mitigation, has resulted in an evidence-based approach for advancements in earthquake engineering and risk assessment to inform policy development, reduce earthquake losses, and improve societal resilience to earthquakes. The Social, Behavioral, and Economic Sciences have supported social and behavioral science investigations that have transformed theoretical models of earthquake risk communication and have informed generations of work on public education, policy development, and early alert warnings.

Community-based collaborations through NSF-funded programs such as EarthScope, SAGE, GAGE, the Southern California Earthquake Center (SCEC), Network for Earthquake Engineering Simulation/Natural Hazards Engineering Research Infrastructure (NEES/NHERI), and the Natural Hazards Center, create shared instrumentation and open data management resources to support experimental and modeling programs. The programs also provide information resources to the broader hazards and disaster community. These programs have greatly enhanced observational data on the significance of Earth structure and strong ground motions and have enriched understanding regarding their effect on civil infrastructure. Moreover, these programs have led to the development of simulation and monitoring technologies to assess risks to diverse communities. The NEES/NHERI and other engineering programs have supported development of improved materials and innovative structural systems to improve seismic performance of civil infrastructure, with the end goal of reducing vulnerability of the built and social environments.

NSF's NEHRP partners have been instrumental in developing guidelines and model building codes, encouraging social scientific theory building, and facilitating other contributions that have led to technology transfer of fundamental NSF research into practical outcomes. This includes technical briefs, guidelines, and standards for performance-based earthquake engineering that have been developed by NIST, FEMA, and the USGS through contracts with the Applied Technology Council (ATC), the National Institute of Building Sciences (NIBS), the Earthquake Engineering Research Institute (EERI), and other professional organizations. Earthquake engineering and risk professionals have used this information to mitigate earthquake risk and promote more resilient communities.

With such as broad portfolio of research and successful outcomes, NSF has the opportunity to demonstrate the value of coordination between multidisciplinary earthquake hazard assessment and interdisciplinary rapid reconnaissance research that is essential to the success of NEHRP. However, ACEHR has been dissatisfied with NSF's response to repeated requests to (1) provide a strategic overview of its NEHRP activities and (2) build on inter-Divisional linkages and synergies with programs in other NEHRP agencies along with related programs in other federal, state and industry programs. Response to these requests from NSF leadership at the Director-level is vital to advancing NEHRP's mission.

ACEHR recognizes that NSF does not have a dedicated NEHRP category or line-item for funding. Rather, research accomplishments reflect decisions within various NSF programs and directorates to fund initiatives and unsolicited proposals that address NEHRP and other broadly related hazards activities. The amounts listed as NSF NEHRP funding in annual reports are an after-the-fact cataloging of the NSF funds spent on any activity associated with earthquake research. This has three serious consequences:

- This process makes it difficult for other NEHRP agencies to coordinate their research and mission-related activities with NSF.
- It blurs of the extent to which earthquake-specific research is being funded. This is reflected in the shift over time at NSF from funding earthquake-specific programs and facilities (for example, the three Engineering Research Centers, including the Pacific Earthquake Engineering Research (PEER) Center, the Multidisciplinary Center for Earthquake Engineering Research (MCEER), and the Mid-America Earthquake (MAE) Center) toward broader, all-hazards-related initiatives. The latter include major funding for PREVENTS – Prediction of and Resilience against Extreme Events and for NHERI – Natural Hazards Engineering Research Infrastructure.
- Other NEHRP agencies and the research community more generally have a hard time identifying the latest relevant findings from NSF funded research and activities once complete.

The 2015 ACEHR report included recommendations to NSF aimed at clarifying current and future programmatic funding commitments in general and specifically under NHERI, and recommended NSF develop mechanisms for documenting, reporting, and publicizing current NEHRP-related research and findings from it. The NSF response to these recommendations has been unsatisfactory. NSF personnel have repeatedly stated their funding approach prohibits specifying research contributions in advance, but by searching relevant, on-line, publicly available NSF databases one can identify earthquake related research funding and research accomplishments. This response, however, misses the opportunity for NSF to demonstrate the value of multi-disciplinary investigations and overlooks the challenges associated with not being able to coordinate research programs in advance or commit to earthquake-specific research in funding opportunities.

ACEHR makes the following recommendations in response to these challenges.

NSF Recommendation 1

ACEHR recommends that NSF prepare a synthesis report that identifies how current major NEHRP-related initiatives (e.g., PREVENTS, NHERI, SCEC, EarthScope, NGEO, Natural Hazards Center) contribute to NEHRP strategic goals and plan.

This report should be guided and prepared at a high enough level within the Foundation to acknowledge and merge NSF's contributions across Directorates. The report should identify how in thematic terms each initiative advances earthquake-specific research needs and gaps with attention to the key scientific issues and questions being addressed as well as the broader impacts of these initiatives. The emphasis should be concise higher-level explanations and not simply listings of projects.

NSF Recommendation 2

ACEHR recommends that NSF work with the NEHRP Program Office at NIST to devise a reporting and information sharing approach that provides a better basis for coordinating NSF NEHRP-related activities with other NEHRP agency activities.

This process should, on an annual basis, identify specific contributions to the NEHRP strategic plan, opportunities for collaboration, and research gaps. This should be designed to inform annual budget and programmatic planning for the NEHRP Program Office, rather than an after-the-fact summary of what was funded. In order to provide balanced reporting across NSF investments, representatives from the Engineering, Geosciences, and Social, Behavioral, and Economic Science Directorates should participate regularly in ACEHR meetings.

ACEHR recommended in 2015 that NSF review lessons from multidisciplinary hazard-related initiatives to assess the quality of cross-disciplinary participation.

The NSF response to the earlier recommendation was that "NSF continues to review the accomplishments and continuing challenges of cross-disciplinary and multidisciplinary research" with a listing of such multi-disciplinary initiatives. The response does not speak to lessons learned, identification of problems, or ways to enhance social science participation.

NSF Recommendation 3

ACEHR recommends that NSF fund a workshop or other forum on past and future opportunities for multidisciplinary initiatives to contribute to the success of NEHRP.

This workshop or forum should explicitly address contributions of social science components, with attention to the scientific contributions of such components, their degree of integration in funded projects, lessons learned about such activities, identification of problems, and ways to enhance social science participation. At the same time, NSF should continue and enhance investment in social science research related to earthquake hazards and disasters, and other NEHRP agencies should utilize social science to implement change to promote resilience.

Many of NSF's activities have been coordinated with national and international partners. Some of these collaborations have been initiated by community organizations (e.g., IRIS, UNAVCO, SCEC, EERI, ATC and others) and some have been facilitated by interagency agreements. In particular, ACEHR commends NSF collaborations with (1) USGS in achieving significant advances in the observational and data resources that jointly support the Advanced National Seismic System (ANSS), and (2) FEMA, NIST and USGS for efforts to disseminate knowledge and improve earthquake engineering practice through design guidelines, building codes and standards, and other technologies.

NSF Recommendation 4

ACEHR recommends that NSF work with the NEHRP partner agencies and external organizations to improve interactions with the earthquake engineering research and professional communities.

In addition to representation from the core NEHRP agencies, this process should include representatives from other federal and state agencies, professional organizations and the private sector. The purpose should be to (1) develop visionary research goals and challenges to advance the NEHRP mission in the long- and short-term, and (2) work with national and international partners (both academic and governmental) to leverage investments across NSF Directorates to support collaboration and coordination of both research program and long-term investments in facilities and data collection and management.

As one of the nation's scientific leaders, NSF has the potential to not only fund transformative research activities. It is also well situated to further encourage and support the collaborative activities and technology transfer mechanism that will result in even more wide-reaching broader impacts.

United States Geological Survey (USGS)

Under NEHRP, the USGS is responsible for conducting research and other activities necessary to characterize and identify earthquake hazards, assess earthquake risks, and monitoring seismic activity.

ACEHR's 2015 report highlighted five areas of emphasis for the USGS:

1. Proactive acquisition of seismic data to address the uncertainty in ground motion scaling relations for the central and eastern US
2. Implementation of Earthquake Early Warning (EEW) for the Nations' West Coast
3. Development and communication of the risks posed by induced seismicity
4. Continued development of earthquake scenarios for high-risk urban area
5. Improved interaction with operators of critical infrastructure and lifeline systems on the use of near real-time data products.

Significant implementation progress has been made in all these areas, but continued progress is hampered by uncertainty in funding that also affects the ability to be responsive to new needs.

USGS Recommendation 1

ACEHR recommends that the USGS continue to use advisory panels to target immediate and long-term strategies to meet its obligations under NEHRP.

Guidance for implementing the goals of NEHRP is essential to ensure that opportunities are not missed, priorities are set, and implementation is accomplished within program constraints. Currently the USGS is advised by the Scientific Earthquake Studies Advisory Committee on the NEHRP program, and by the Advanced National Seismic System (ANSS) National Steering Committee and the ANSS National Implementation Committee, among others. Ad hoc groups have been convened to provide critical review of topics as varied as updating of seismic hazard maps, the national strong motion program and the incorporation of geodetic data on rapid evaluation of earthquake consequences.

Some recently published reports and reports in progress are:

- Advanced National Seismic System – current status, development opportunities, and priorities for 2017-2027, U. S. Geological Survey Circular 1429, 2017. ISBN 9781411341364

- USGS National Strong-Motion Project Strategic Plan: 2017-2022 (draft)
- Leveraging Geodetic Data to Reduce Losses from Earthquakes, U. S. Geological Survey Open File Report (under review)

USGS Recommendation 2

ACEHR recommends that the USGS continue to develop products that address community needs for information about earthquakes.

The USGS provides many valuable services to include immediate earthquake notification to governmental entities, researchers and the public, ShakeMap, ShakeCast and Prompt Assessment of Global Earthquakes for Response. The questions that arise are: "How can these products be improved?" and "Are there unmet needs for information?" Given the distribution of seismic instruments in the nation, developments in digital communication, and implementation of data processing, current efforts at dissemination earthquake information can be improved to permit the public to see all information about earthquakes and to watch the development of earthquake sequences in near real-time.

USGS Recommendation 3

ACEHR supports continued implementation of the ANSS and EEW efforts as an integral component of meeting NEHRP goals.

Emerging Trends and New Developments

ACEHR's review of emerging trends and new developments in the science and engineering of earthquake hazards reduction is organized around six key disciplines that form the earthquake professions. They are: social sciences, earth sciences, geotechnical earthquake engineering, structural earthquake engineering, lifeline earthquake engineering, and disaster warning, response and recovery. Suggested refinements to tasks in the F2009–2013 NEHRP strategic plan (NEHRP 2008) and new tasks that should be considered for future plans are both addressed in each of the six following disciplinary-related discussions (A1-A6).

Social Sciences

The 2015 ACEHR report focused on three broad trends in terms of related social science work. Those included (1) a focus on the diversification of funding streams within NSF for social science research; (2) a shift in research emphasizing community and societal resilience; and (3) continued investment by NSF in advancing human capital—through doctoral dissertation funding and next generation mentoring programs—for social science research. Social science involvement in earthquake-related research continues to

reflect the trends discussed in the 2015 ACEHR report. Here we again emphasize a number of apparent trends, while highlighting positive outcomes as well as gaps.

Diversification of funding and broadening of research emphasis. The NEHRP agencies have invested in a number of key initiatives that incorporate social science research in studying hazards and community and social resilience. Illustrative examples include:

- The NIST Center for Risk-Based Community Resilience Planning. Headquartered at Colorado State University and led by two engineers, this major effort involves more than 12 institutions and over 100 investigators including faculty, postdoctoral scholars, and graduate students. NIST has committed $20 million over 5 years to establishing this Center, with the potential for continued funding. The grant supports an economics team and a social science team; both are integral to the overall modeling effort.
- NIST has also established a Community Resilience Fellows program. Funding for this initiative is dedicated to supporting fellows with expertise in engineering, transportation, and lifelines, as well as support for a social science fellow, a fellow with expertise in communications, and a private sector scholar working on social vulnerability issues.
- Two DHS Centers of Excellence relating to natural hazards – the Coastal Resilience Center headquartered at the University of North Carolina-Chapel Hill and the Critical Infrastructure Resilience Institute at the University of Illinois at Urbana-Champaign – include important social science components.
- NSF funding for Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) requires that project proposals incorporate social, behavioral, and economic sciences. However, very few of the CRISP funded projects involve large numbers of social scientists, and of the funded projects, an extremely small number are actually led by social scientists.
- NSF Natural Hazards Engineering Research Infrastructure (NHERI) represents a multi-million dollar investment for engineering, but entails an exceptionally limited amount of social science engagement. All of the major research facilities under NHERI are led by engineers.

Adequate engagement of social, behavioral, and economic sciences remains elusive. As the examples above suggest, there has obviously been progress in terms of major funding initiatives that require the engagement of social scientists. Yet, these and other related multi-disciplinary initiatives vary in their treatment of the social and behavioral sciences. Too often the "social sciences" are treated as a single discipline with one person from one discipline added to a team or with a project. This creates a veneer of multi-disciplinary involvement. The NSF section of this report emphasizes the need for a serious review of research engagement of the social, behavioral, and economic sciences.

Fundamental issues remain unaddressed. The attention to community and societal resilience and other multi-disciplinary initiatives have emphasized applied research. More

theoretically informed, fundamental social, behavioral, and economic research issues remain that require renewed commitments to investigator-driven research funding. These include research that improves understanding of:

- The social roots of risk with an emphasis on the social, cultural, political, and economic practices that facilitate risk creation.
- Barriers and facilitators for the diffusion of risk reduction practices among public and private entities that reduce vulnerability and enhance seismic resilience.
- Behavioral and economic considerations for public and private sector decisions about improving resilience.
- Decision-making and behaviors for the prevention of and response to cascading disruptions across interdependent lifeline and community systems.
- Factors that contribute to vulnerabilities and variation in them with changing population patterns, urban development, infrastructure and building aging, and transportation patterns.

Need for a more comprehensive resiliency and vulnerability observatory network. The National Research Council's National Earthquake Resilience report (2011) called for such an observatory network. There is still a pressing need for such a laboratory that would build the research infrastructure for social, behavioral, and economic research.

Continued investment in advancing human capital for social science research. This is recurring need that NSF has supported in the past. Involvement of all NEHRP agencies in furthering this goal would broaden such opportunities for women, racial and ethnic minorities, and other underrepresented groups and for members of various social science communities to be engaged in research activities that affect some of the most vulnerable and exposed communities in the nation.

Earth Sciences

There has been excellent synergy between the USGS and NSF in the acquisition of seismic data that can be used for research and for near real-time determination of earthquake properties. The Global Seismic Networks and the almost completed EarthScope efforts are examples of this interaction. There are areas for continued cooperation that meet the NEHRP goals of each agency. One concept might be the "Decade of the Seismogenic Crust" that focuses on the shallowest part of the Earth where the earthquakes occur that affect lives, infrastructure, and the economic well-being of the nation. Another is an international program on Subduction Zone Observatory and Processes. We recognize that such efforts require community involvement in evaluating the current knowledge base and the expected benefits of such an effort.

Earthquake Engineering – Geotechnical, Structural, and Lifelines

This section looks at the consideration of hazard/risk assessment of networks and systems), codes, and quality assurance. Some recent trends and new developments are:

- Liquefaction severity, induced permanent ground deformations and impacts on buildings and lifeline systems. Recent earthquakes in Christchurch and Japan have provided significant information to further the predictability of liquefactions severity and its impacts to the build environment.
- Ground failure hazard maps. There is a need for hazard maps related to permanent ground deformations to be developed and used consistently with seismic ground shaking maps.
- Resilience-based codes and standards for buildings and lifeline systems, which include scenario based assessments.
- "Smart" infrastructure increasing the dependencies of all other infrastructure on communications and electric power lifelines (this includes buildings and lifeline systems).
- Aging infrastructure continuing to increase earthquake vulnerabilities.
- Advanced numerical modeling for building and infrastructure systems. The need to assess community resilience against earthquakes demands the improvement of computer-based modeling to reliably include the performance of all systems supporting and making up a community and their interactions.

Disaster Warning, Response, and Recovery

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