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**ACEHR 2015 Annual Report**
**21 August Teleconference Meeting**

## Executive Summary

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) provides a biennial assessment of the National Earthquake Hazards Reduction Program (NEHRP) as required by the committee charter and Public Law 108–360. 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.

It has been more than 20 years since a major damaging earthquake struck in the United States. ACEHR is concerned that interest and support for NEHRP has waned as other natural disasters and national priorities have necessitated attention and competition for limited resources. We fear that federal policymakers as well as the public believe our nation has largely solved its earthquake problem; however, nothing could be further from the truth. Almost half of the U.S. population—150 million people—reside in portions of 42 states at risk of experiencing a damaging earthquake within the next 50 years. Sixteen of those states, including California, Oregon, Washington, Alaska, Hawaii, Tennessee, and Missouri, are at very high risk and their metropolitan regions could face unprecedented life loss, building and infrastructure damage, and cascading social and economic consequences. Since 2004, some of the most fatal and disastrous earthquakes in modern history have occurred elsewhere in the world, some resulting in catastrophic tsunamis. It is just a matter of time before a catastrophic earthquake, potentially coupled with a devastating tsunami, strikes in the United States.

Much has been accomplished in the 40 years since NEHRP began in 1977. However, many seismic-prone states and localities still have concentrations of buildings and infrastructure that are highly vulnerable to earthquake shaking. Many of these areas do not have or do not enforce building codes with seismic provisions. They lack sufficient data to conduct seismic hazard assessments that could lead to the implementation of hazard-based, risk reduction land use policies, and are insufficiently prepared for a major earthquake.

With this report, ACEHR seeks to advise and educate National policymakers on the urgency and critical need for a renewed commitment to our national effort at earthquake hazards risk reduction through NEHRP and ensure that earthquake hazard reduction remains a federal priority. To accomplish this, 18 specific recommendations are directed to the Director of the National Institute of Standards and Technology (NIST) and the Interagency Coordinating Committee on Earthquake Hazards Reduction (ICC)[1], as well as the NEHRP 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).

### Critical Observations for Congress and Recommendations to the ICC

[1] Under Public Law 108-360, membership of the Interagency Coordinating Committee on Earthquake Hazards Reduction (ICC) includes the directors of FEMA, NIST, NSF, USGS, Office of Science and Technology Policy (OSTP), and Office of Management and Budget (OMB).

Four key observations and recommendations, directed to Congress and the ICC, are essential for revitalizing and sustaining earthquake hazard reduction efforts in the United States. Foremost, ACEHR believes Congressional reauthorization of NEHRP[2] is essential for the long-term viability of NEHRP. Such legislation should address sufficient funding for NEHRP to maintain its foundational emphasis on earthquake hazards and seismic design for the built environment. We also call for an expanded emphasis on infrastructure, social, and economic dimensions of community seismic resilience as defined in the 2011 report by the National Research Council (NRC), *National Earthquake Resilience: Research, Implementation and Outreach*.

Second, prior to or as part of reauthorization, ACEHR believes a fundamental assessment of the nation's earthquake risk reduction progress to date, and the extent to which states, localities, tribes, and the private sector are taking steps to address the seismic vulnerability of buildings and infrastructure and the potential social and economic impacts of these vulnerabilities, must be conducted in order to define the next steps needed to improve national earthquake resilience. ACEHR believes a comprehensive assessment of the nation's seismic resilience progress and the "implementation deficit" that is evidenced, is necessary to establish adequate funding levels and assign appropriate statutory responsibilities to reduce this deficit in the reauthorization of NEHRP. ACEHR seeks to collaborate with Congress, the NEHRP agencies and stakeholders in defining the scope and specifications for this assessment and ensuring its completion.

Third, 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. This will require renewed consideration by the leadership of the ICC about the future of NEHRP and how their agencies can assist in moving NEHRP forward, along with stronger articulation of how NEHRP activities relate to other priorities and agendas within respective agencies.

Fourth, ACEHR recommends that the NIST Director, as Chair of the ICC, conduct a review of the status of core operational elements authorized and funded under NEHRP with attention to those elements that have been dropped or cutback, and those that have been expanded or added. This recommendation stems from concerns that some statutorily-mandated elements, such as George E. Brown Network for Earthquake Engineering, have been discontinued and, while supportive of the growing national emphasis on multi-hazard resilience, we are concerned that this may be channeling both Program focus and funding away from the unique issues of earthquake hazards. This may be adversely impacting core operational activities funded or developed under NEHRP.

ACEHR's other specific recommendations for the NEHRP Office and the four NEHRP agencies are listed below and discussed further in the body of the report.

**NEHRP Office Recommendation**

Recommendation 1 - ACEHR recommends the NEHRP Office work with the four NEHRP agencies to promote the development of consensus standards for a market-based, private sector-led rating system for the seismic performance of buildings.



[2] The Earthquake Hazards Reduction Act was first passed in 1977. NEHRP's 2004 reauthorization expired in 2009.

**Federal Emergency Management Agency Recommendations**

Recommendation 1 - ACEHR recommends FEMA commit to support its earthquake mitigation mission which is essential for the accomplishment of NEHRP-related implementation and outreach activities.

Recommendation 2 - ACEHR recommends FEMA return to a directly-funded state-based program for earthquake hazard mitigation, planning, education and preparedness efforts and that it also ensure its full funding.

Recommendation 3 - ACEHR recommends FEMA restore and give priority to its seismic hazard mitigation and resilience initiative for critical infrastructure and lifeline systems.

Recommendation 4 - ACEHR recommends FEMA invest in maintaining Hazus® as a utilizable, publicly available earthquake hazard mitigation tool and ensure that the tsunami module is fully integrated and functioning within the Hazus® software platform.

**National Institute of Standards and Technology Recommendations**

Recommendation 1- ACEHR recommends NIST enhance and expand the dissemination of NEHRP-related information and products to the architectural and engineering professions.

Recommendation 2 - ACEHR recommends NIST emphasize future NEHRP-related research and development programs on infrastructure systems, geotechnical engineering, non-structural elements, and residential and industrial structures that have seismic vulnerabilities.

**National Science Foundation Recommendations**

Recommendation 1- ACEHR calls upon NSF to clarify current and future programmatic funding commitments in support of NEHRP.

Recommendation 2 - ACEHR recommends NSF develop a mechanism for documenting, reporting, and publicizing current NEHRP-related research and the findings from it.

Recommendation 3 - ACEHR recommends NSF report to ACEHR, as part of the next ACEHR review, the status of earthquake-related research and funding commitments for its part of the Natural Hazards Engineering Research Infrastructure (NHERI) initiative.

Recommendation 4 - ACEHR recommends NSF review lessons of multi-disciplinary hazard-related initiatives to assess the quality of cross-disciplinary, and especially social science, participation. At the same time, NSF should continue and enhance investment in social science research related to earthquake hazards and disasters.

**U.S. Geological Survey Recommendations**

Recommendation 1 - ACEHR recommends the USGS work to provide the data necessary to reduce uncertainty in ground motion scaling in the eastern and central United States.

Recommendation 2 - ACEHR recommends the USGS make Earthquake Early Warning (EEW) a funding priority and provide the U.S. public with a service that has proven to be highly effective in saving lives and property in Japan, Mexico, and elsewhere.

Recommendation 3 - ACEHR recommends the USGS enhance its efforts to understand, educate and communicate the risks posed by induced seismicity.

Recommendation 4 - ACEHR recommends the USGS expand earthquake scenario development in conjunction with stakeholder engagement in order to examine consequences of earthquakes in high-risk urban areas.

Recommendation 5 - ACEHR recommends the USGS work with operators of critical infrastructure and lifeline systems to define and integrate near real-time earthquake data and other seismic information into system monitoring so that operators can quickly assess system impacts from earthquake movements and take appropriate actions.

## 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 the legislatively mandated biennial assessment of NEHRP. It 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 (ICC)[3]. The recommendations of this report are also relevant for the leadership of the four NEHRP agencies and other members of the ICC. This report builds upon earlier reports submitted for FY 2012 as a full report and for FY 2013 as a less extensive update.

Since NEHRP was first authorized in 1977, the NEHRP agencies and their stakeholders have worked collaboratively, across multiple disciplines and through interagency partnerships to develop, disseminate, and promote knowledge, tools and practices to achieve the NEHRP vision of *a nation that is earthquake resilient in public safety, economic strength, and national security* (NEHRP 2008). However, interest and support for NEHRP has waned in recent years as evidenced by the delayed reauthorization of the Earthquake Hazards Reduction Act and continued under-investment in NEHRP.

This report seeks to reinvigorate the federal investment and interest in NEHRP and ensure that earthquake hazard reduction remains a federal priority. The report is structured to first offer a synopsis of important contributions and developments since NEHRP's enactment and then to assess the effectiveness and needs of NEHRP. Our assessment considers future directions of NEHRP, the overall management, coordination, implementation, and activities of NEHRP through the NEHRP Office and the ICC, and NEHRP agency-specific assessments provided in alphabetical order. The Committee's assessment of new trends and developments in the science and engineering of earthquake hazards reduction is provided as an Appendix to this report.

## Important Contributions and Developments since NEHRP's Enactment

Over nearly 40 years since the 1977 passage of the Earthquake Hazards Reduction Act, federal funding for 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 both buildings and infrastructure, and raising earthquake awareness and preparedness across the United States and the world. More recently, there is a positive shift toward addressing earthquake hazards as part of community-scale and multi-hazard resilience.

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[3] Under Public Law 108-360, membership of the Interagency Coordinating Committee on Earthquake Hazards Reduction (ICC) shall be composed of the directors of the Federal Emergency Management Agency (FEMA); the United States Geological Survey (USGS); the National Science Foundation (NSF); the Office of Science and Technology Policy (OSTP); and the Office of Management and Budget (OMB).

The updated National Seismic Hazard Maps released in 2014 by the U.S. Geological Survey (USGS) reflects our improved understanding of the nation's earthquake risk (USGS 2014). This work finds that portions of 42 states could experience strong ground shaking in the typical life of a building; 16 of those states, including California, Oregon, Washington, Alaska, Hawaii, Tennessee, and Missouri, are at very high risk (see Figure 1). This characterization of seismic hazards, coupled with population growth and increasing urbanization, especially along the West Coast, means that 150 million people—almost half of the U.S. population—could experience a damaging earthquake within the next 50 years.  More work is still needed however, especially to better understand the low-probability, high-consequence seismic hazards in the central and eastern United States.

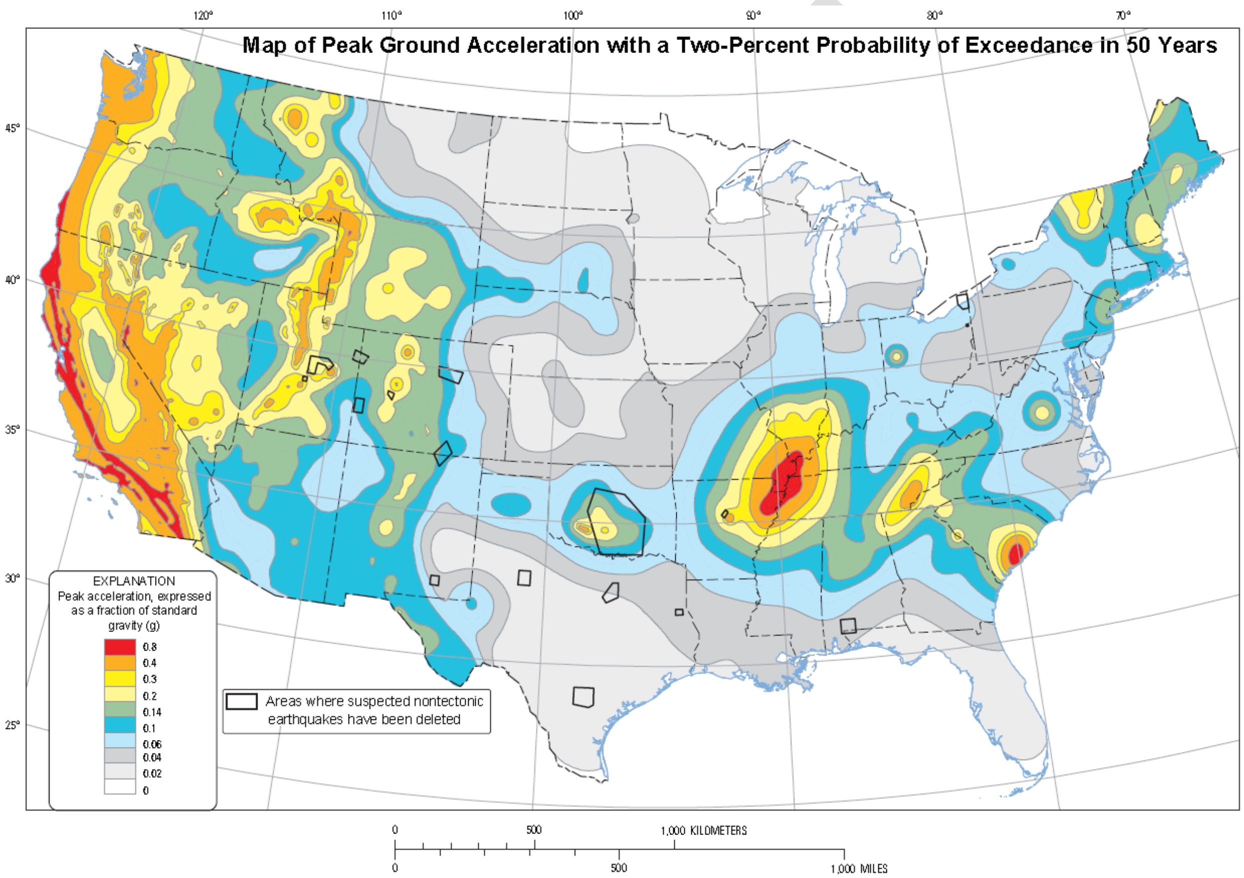


*Figure 1. Map of conterminous United States showing earthquake ground motions that may be met or exceeded in the next 50 years (USGS 2014).*

A newer phenomenon is the increased number of earthquakes associated with oil and gas production, particularly in the central and eastern United States.  This, as noted in the 2013 ACEHR report, has raised concerns about triggered or "induced" seismicity caused by the injection of waste water generated by this and other industrial activity (Walsh and Zoback 2015; Weingarten et al. 2015). While seismicity has increased throughout the region, the most dramatic increase has been in Oklahoma (Figure 2) where, in the last decade, there has been significant oil production activity as well as large volumes of production-related saltwater disposed in injection wells (Murray 2014).  Induced seismicity is causing damage to buildings and infrastructure and the implications of these operations on even more substantially damaging earthquakes are not fully understood.

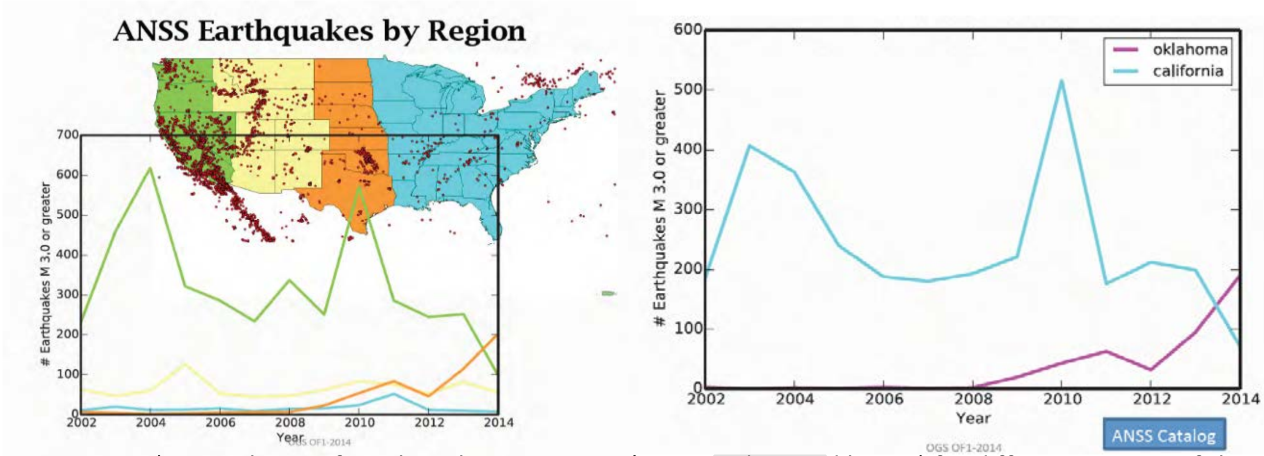


*Figure 2. a) Annual rate of earthquake occurrence (magnitude 3 and larger) for different regions of the United States (indicated by colors). b) A comparison of the annual rate of earthquake occurrence (magnitude 3 and larger) in California (light blue) and Oklahoma (purple). Most of the increase in seismicity in the central United States is occurring in Oklahoma. (Murray 2014)*

Many notable advances in earthquake engineering have occurred because of NEHRP funding. These advances have improved the seismic design of new buildings and have provided a basis for better seismic retrofits of existing and renovated buildings. These advances have also been incorporated into the seismic provisions of building codes and into the development of seismic-related guidelines for infrastructure systems. While substantial progress has been made, notable gaps still exist in earthquake engineering of critical infrastructure and lifeline[4] systems and the seismic rehabilitation of many older building types.

Two additional observations are important to underscore. One is that the 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. Some states and local jurisdictions have adopted building codes but have made amendments or exclusions relating to the seismic provisions. The second point is that seismic standards are based largely on a goal of preventing loss of life through collapse prevention. Many earthquake-damaged buildings may be uninhabitable until repaired or may be uneconomic to repair making it necessary to demolish and reconstruct them after experiencing one moderately sized earthquake.

For larger earthquakes, especially those striking major cities, great numbers of residents and businesses could be displaced from damaged buildings and infrastructure. A single, major earthquake in California, the Pacific Northwest, the western and central United States, as well as in parts of the Atlantic seaboard could cause damages in excess of $100 to $150 billion (CREW 2013; Elnashai et al. 2008; Jones et al. 2008; Kircher et al. 2006; RMS 2008). These losses could be much larger than those caused by Hurricane Sandy and even Hurricane Katrina and the economies of impacted regions could be drastically altered for years, even decades. Each could also have massive economic, political and social consequences with ripple effects across the country and the world.

[4] Lifelines 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 power, water, sanitation, telecommunications, and fuel.

The earthquake risk reduction needs have also evolved significantly since the 1977 passage of the Earthquake Hazards Reduction Act and its subsequent reauthorization. One key development has been the increasing attention being given by NEHRP agencies and the research community toward "multi-hazards" which include seismic, extreme wind, flooding and other natural hazards, and can also include man-made hazards, such as blast and chemical releases. This multi-hazards emphasis has been driven by what those at the front lines of risk reduction must generally consider—a variety of hazards rather than a single hazard—and by some in the research community who see parallels in engineering approaches to reducing the risks posed by multiple hazards (e.g. earthquake, wind, and blast).

The concept of disaster 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. A critical element of community disaster resilience is the implementation of risk reduction actions, and which is a fundamental purpose of NEHRP. As noted in ACEHR's 2012 report, the concept of disaster resilience has been discussed by earthquake professionals for years and multiple definitions, approaches, and frameworks have been proposed. Goal C in the 2008 NEHRP strategic plan focuses on improving the earthquake resilience of communities nationwide (NEHRP 2008). The 2011 NRC report, "*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. As discussed later in this report, a number of steps have been taken by NEHRP agencies to move in these directions. However, it is clear that in order to achieve earthquake resiliency and its numerous collateral benefits, so much more needs to be done.

NEHRP agencies along with the greater seismic community have much to offer to the multi-hazard and community-based resilience efforts, including decades of engineering and social science research, well developed analysis and design tools, and practical experience in the development of consensus-based standards and codes and the integration of seismic design into larger projects. With decades of post-earthquake investigations and studies from around the world, there is considerable information on both the built environment and societal impacts associated with disasters to help develop state-of-the-art resilience-based standards for communities. However, in addition to the commonalities between hazards, there are remain some very earthquake-specific issues that require focused attention, including earthquake source and ground shaking characterization, the seismic shaking and ground deformation effects on buildings and infrastructure systems, development of cost-effective seismic rehabilitation solutions for buildings and infrastructure systems, and the public policy and financial mechanisms to support large-scale seismic retrofit and post-earthquake repair programs.

## Program Effectiveness and Needs

### Future Directions for NEHRP

It has been more than 20 years since the last major damaging earthquake in the United States. Interest and support for earthquake risk reduction has given way to other natural disasters, like Hurricanes Sandy and Katrina, and other national priorities necessitating attention and competing for limited resources. In that same timeframe, extremely disastrous urban earthquakes have occurred elsewhere across the globe, some of which also resulted in catastrophic tsunamis and severely damaged built environments very similar to that of the U.S. Furthermore, as a nation, we are burdened with aging and deteriorating infrastructure, the condition of which (even without an earthquake) the American Society of Civil Engineers (ASCE) has given an overall grade of D+ (ASCE 2013).

Achieving national seismic resilience requires ongoing and sustained investments in seismic monitoring and engineering research, public education and awareness about earthquake hazards, seismic code adoption and implementation for new and existing buildings and infrastructure systems, and leadership at the federal level to ensure that there is a continuum of seismic expertise for generations to come. We fear that federal policymakers, both within Congress and the Executive branch, as well as the public believe that our nation has largely solved its earthquake problem. Nothing could be further from the truth.

**Critical Observation 1**

**ACEHR believes Congressional reauthorization of the National Earthquake Hazards Reduction Program is essential for the long-term viability of NEHRP. Such legislation should address sufficient funding levels for NEHRP to maintain its foundational emphasis on earthquake hazards and seismic design for the built environment, and provide an expanded emphasis on infrastructure, social, and economic dimensions of community seismic resilience.**

ACEHR remains convinced that for NEHRP to be effective and achieve the Act's vision of an earthquake resilient nation, considerably higher funding levels are required. Since the 2004 reauthorization expired in 2009, NEHRP activities have continued through individual agency appropriations processes. Most NEHRP agencies are working very hard to do more with less, while the Program continues to lack sufficient resources as well as, in some instances, crucial internal agency support to achieve the NEHRP legislative goals. For more than a decade, federal funding levels for NEHRP have hovered around $120 to $125 million annually and, as this Committee has noted in prior reports, the budget for some critical areas of earthquake hazards reduction—most notably implementation activities assigned to the Federal Emergency Management Agency (FEMA)—have decreased significantly over that timeframe.

One path for addressing the implementation deficit is what has been endorsed in the prior ACEHR reports – full funding of the NEHRP Strategic Plan (NEHRP 2008) and the 2011 NRC report, *National Earthquake Resilience: Research, Implementation, and Outreach* (NRC 2011). The NRC report estimates that the cost to carry out the 18-task program would total about $307 million a year during the first five years of implementation which is far beyond NEHRP's current funding levels. The NRC report provides a starting point for future reauthorization language and the funding levels necessary for achieving national earthquake resilience.

ACEHR believes a reauthorization of NEHRP needs 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 infrastructure standards, and a recasting of the earthquake hazard reduction effort as one of improving the nation's resilience to earthquake 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, namely the USGS Advanced National Seismic Research and Monitoring 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.

Finally, ACEHR notes that the National Windstorm Impact Reduction Program (NWIRP) is moving closer to reauthorization, which is a very positive development. In the past, NEHRP and NWIRP reauthorizations have been considered simultaneously, indicating the national value of continuing both programs.

**Critical Observation 2**

**ACEHR believes a fundamental assessment of the nation's earthquake risk reduction progress to date, and the extent to which states, localities, tribes, and the private sector are taking steps to address the seismic vulnerability of buildings and infrastructure, is essential for mapping the next steps that are needed to improve national earthquake resilience. This assessment should be performed either prior to or as part of a new NEHRP authorization. Put simply, we cannot plan our future footsteps wisely if we do not understand where we are now.**

ACEHR believes that the direction for NEHRP needs to be re-established first with a fundamental assessment of the nation's earthquake risk reduction progress to date. The emphasis should be on a detailed national and regional snapshot of seismic resilience of the nation and relevant states, cities, and other entities in various regions**.** ACEHR offers to be involved in helping to define the scope and specifications for this assessment.

Much evidence suggests that there is a sizeable "implementation deficit" when it comes to achieving earthquake resilience in the nation. As advances in earth sciences have identified larger portions of the nation with significant seismic hazards, we are faced with a number of seismic-prone states and localities that either do not have or do not enforce building codes with seismic provisions. Relatively few jurisdictions in areas with moderate to high seismic hazards have programs for addressing existing seismically vulnerable construction such as unreinforced masonry, pre-1980 non-ductile concrete buildings, and other vulnerable building types—many of which are used as hospitals, schools, offices, and apartments. Data for conducting local level seismic hazard assessments and implementing appropriate hazard-based land use policy are inconsistent or non-existent in many parts of the United States. Additionally, while substantial progress has been made in some parts of the country, elsewhere seismic vulnerability is given less attention by public and private entities that own and manage infrastructure systems.

Outreach programs supported by the NEHRP agencies are the means of disseminating practical information and training that is crucial to inform and empower our at-risk communities. Tools such as the Hazus® scenario loss estimation software developed by FEMA have been powerful aids in helping communities prepare for and mitigate earthquake risks. Given funding limitations, however, tools like Hazus® are not being maintained and updated and the NEHRP agencies are falling short in reaching the diverse constituencies across the country. This implementation deficit is the "Achilles heel" of earthquake risk reduction and needs to be recognized as such.

**Management, Coordination and Implementation of NEHRP**

<u>NEHRP Office</u>

Since ACEHR's last reports in 2012 and 2013, the NEHRP Office housed in NIST has continued to work collaboratively with the other NEHRP agencies to implement the *Strategic Plan for the National Earthquake Hazards Reduction Program: Fiscal Years 2009-2013* (NEHRP 2008) as well as elements of the NRC (2011) roadmap, *National Earthquake Resilience: Research, Implementation, and Outreach*. Also during this timeframe, the NEHRP Office and NIST funded a study to update the federal post-earthquake investigation strategy (NEHRP Consultants Joint Venture 2013), and the development of research and implementation roadmaps for earthquake risk reduction in buildings (NIBS 2013) and achieving earthquake resilient lifelines (NEHRP Consultants Joint Venture 2014)—a specific task called for in the 2011 NRC report. We applaud and encourage the focus on infrastructure systems and the proposed renewed emphasis on existing buildings.

There has also been strong coordination among program directors of NIST and FEMA on developing seismic standards for buildings and infrastructure and conducting earthquake mitigation-related work, and between the USGS and the National Science Foundation (NSF) on seismic instrumentation. These efforts are discussed in later sections of the report.

ACEHR recognizes that without the strong commitment and financial support from NIST, the NEHRP Office would have been far less effective in its leadership role. However, the Committee remains extremely concerned about the limited resources allocated for the NEHRP Office. NIST has been carrying out NEHRP lead-agency responsibilities for nearly a decade without increased funding. To be effective as an advisory body to the Program, ACEHR would also like to see its budget restored to allow for two in-person meetings per year.

The Committee is concerned about the repositioning of the NEHRP Office within the NIST Engineering Laboratory over the past two years. The NEHRP legislation calls for the directors of the four member agencies to serve on the ICC. With recent reorganizations, the NEHRP Program Director is now much farther removed from the NIST Director, and even more so than other NEHRP program officers at other member agencies. This places the NEHRP Program Director and NEHRP Office at a serious disadvantage in coordinating and engaging with other agencies on program-related matters and in advocating for program-related budget and needs within NIST.

The 2013 ACEHR report recommended that a building performance rating system be developed and implemented. To accomplish this, ACEHR called upon NIST to make the development of required tools and standards a priority and for FEMA to make implementation of the system a priority. FEMA representatives provided a detailed response to ACEHR's recommendation identifying a number of initiatives and series of governmental publications that may contribute to establishing a rating system, however noting that "implementing such a system is outside the authority of the federal government and must be done at the local government or private sector level" (Mahoney 2014). ACEHR continues to believe the 2013 recommendation has many merits and warrants further attention by relevant agencies.

**Recommendation 1**

**ACEHR recommends that the NEHRP Office work with the four NEHRP agencies to facilitate the development of consensus standards for a market-based, private sector-led rating system for the seismic performance of buildings**.

ACEHR wants to emphasize that this recommendation is for the NEHRP Office and the four NEHRP agencies to serve in a facilitation capacity, helping to foster development of consensus standards for a market-based, private sector-led building grading system. 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 consistency, which is essential for such a system to be successful. It can also 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. This has been the case with the General Services Administration (GSA) review of the "green" building rating systems, as required by the Energy and Independence and Security Act of 2007, and its formal recommendation that federal agencies use the Leadership in Energy and Environment Design (LEED) rating system. Voluntary and market-driven benchmarking and certification programs, like the LEED green building certification program and the ENERGY STAR® voluntary energy efficiency rating system, have been very effective in improving sustainability and efficiency within the built environment (van der Heijden 2014).

ACEHR also encourages the NEHRP Office and four NEHRP agencies to take a leadership role with standard development organizations, the U.S. Resiliency Council (USRC)[5] and other organizations engaged in the development of building rating systems to promote development of consensus within the engineering community on standards to be used in grading the seismic performance of buildings. At present, that consensus is still lacking and must be addressed for such a system to be effective.

There may also be a nexus between NEHRP and the NIST Community Disaster Resilience program that merits further exploration. The NIST Community Disaster Resilience program may be able to also help facilitate the consensus standard development which could also take an all-hazards resilience approach, rather than focusing solely on the seismic performance of buildings. NEHRP could help lead in the development of a nationwide stakeholder group, involving private industry and governmental entities, such as the cities of Los Angeles and San Francisco which are local leaders in the seismic evaluation of existing buildings. This may be accomplished under the auspices of the American National Standards Institute (ANSI), with the goal of developing a rating system standard to be referenced within the building code for new and existing structures.

[5] 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 grading has the goal of stimulating market forces to promote the upgrading of seismically deficient structures.

Interagency Coordinating Committee on Earthquake Hazards Reduction (ICC)

The ICC is the body that is intended to provide the senior political level of leadership to higher management within their respective agencies. The NEHRP legislation requires that the ICC meet three times a year. However, the ICC has apparently not met for more than two years. ACEHR is concerned that, as a result of this, much of NEHRP'S senior agency management as well as Congress and the White House Office of Science, Technology and Policy (OSTP), may not understand the challenges that the Program faces, particularly the financial problems brought about by sequestration and other budgetary cuts.

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 NEHRP agencies to work internally to secure 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) roadmap, *National Earthquake Resilience: Research, Implementation, and Outreach*. As this and prior ACEHR reports make clear, the needs are extensive in order for substantial progress to be made in reaching the goals of the NEHRP (2008) Strategic Plan and the NRC (2011) report. Also, should circumstances change, as would happen when a catastrophic earthquake occurs in this country, there may be more interest in funding this blueprint for improving the nation's earthquake resilience.

**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. This will require renewed consideration by the leadership of the ICC about the future of NEHRP and how their agencies can assist in moving the Program ahead, along with stronger articulation of how NEHRP activities relate to other priorities and agendas within the respective agencies.**

In prior decades, the ICC members had significant roles in advancing commitments of NEHRP agencies and working collectively on budget issues and policy decisions about future directions. This provided a mechanism for addressing the interdependencies of the NEHRP agencies and was a basis for desired additional funding for each of the agencies in the aftermaths of 1989 Loma Prieta and 1994 Northridge earthquakes. Should we experience a major U.S. earthquake today, ACEHR is concerned that the ICC will not be prepared to guide the new level of attention inevitably demanded of NEHRP in ways that build upon the many developments and directions noted in this report.

To make up for this void in higher-level coordination, the program officers at each NEHRP agency have formed a mid-level coordinating group, which has met on an ad hoc basis with a variety of levels of personnel participating. While this is an admirable undertaking, such a working group cannot replace the ICC and cannot deliver the overall vision and direction that the ICC provides.

Implementation of the recommendations included in this report requires close collaboration and action on the part of all four NEHRP agencies. Some may require a mutual commitment of resources and may result in significant changes in the current direction of NEHRP. The Committee hopes this report will be a stimulus for reengaging the ICC membership to bring them together for a substantive discussion of the report and its recommendations. This initial meeting could be followed by a series of meetings focused on topics such as how prepared, as a nation, we are for a large damaging earthquake, status and interdependencies of various NEHRP activities and initiatives, impacts of new and emerging issues and related initiatives, such as resilience and, of course, budgets.

ACEHR also asks the ICC to consider how NEHRP can develop more synergistic collaboration and funding opportunities to fulfill the NEHRP mission and work plans defined in the NEHRP (2008) Strategic Plan and the NRC (2011) report, as part of the broader multi-hazard community resilience momentum. A complementary path for addressing the implementation deficit rests on leveraging earthquake-related resilience efforts with other efforts to improve the nation's resilience for a range of natural and man-made risks that include catastrophic natural disasters. But, such leveraging may require a re-orientation of some existing NEHRP efforts to involve more than coordination with other resilience programs.

Earthquake resilience should be a notable component of programs like the National Infrastructure Protection Program led by the Department of Homeland Security (DHS) and the NIST Community Disaster Resilience program. At the same time, the Committee is concerned about maintaining an earthquake hazards reduction focus at NSF given its decision to move to a new multi-hazard engineering research program, NIST given the integration of the NEHRP Office into the NIST Community Disaster Resilience program, and at FEMA with the Earthquake Program's staff multi-hazard responsibilities within the FEMA Mitigation Directorate.

**Recommendation 2**

**ACEHR recommends the NIST Director, as Chair of the ICC, conduct a review of the status of core operational elements authorized and funded under NEHRP with attention to those elements that have been dropped or cutback, and those that have been expanded or added.**

This recommendation stems from two concerns. One is that some statutorily-mandated elements of the Program, discussed below, have been dropped. Secondly, the growing emphasis on multi-hazard resilience may be channeling both NEHRP focus and funding away from earthquake hazards and that this may be adversely impacting core operational activities funded or developed under NEHRP.

For example, in 2013, NSF decided not to make another five-year award for the George E. Brown Network for Earthquake Engineering Simulation Operations for FY2015-FY2019 (known as NEES2 Operations). Instead, it launched a new Natural Hazard Engineering Research Initiative (NHERI) in early 2014 and is distributing its support for the former NEES operations into a series of up to 10 separate awards for a network coordination office, experimental facilities, cyberinfrastructure, and computational modeling and simulation tools for both earthquake and wind engineering research. This decision is contradictory to ACEHR's 2013 urging for continued support of the NEES infrastructure, collaboratory, and associated research at current or increased levels. It is contrary to activities specified in the NEHRP authorizing legislation (section 7704a2D) to develop, operate and maintain the George E. Brown Network for Earthquake Engineering Simulation Operations. Much to this Committee's dismay, the NSF has been unable to provide sufficient information on how NSF will ensure that funding levels and investments in earthquake hazards reduction specifically requested by Congress will be maintained under this new approach.

**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 practices, supporting implementation activities at the State and local level, education and outreach and promotion of earthquake preparedness. ACEHR finds that FEMA continues to make noteworthy contributions to NEHRP with the small number of FEMA staff assigned to these tasks working diligently to fulfill their responsibilities. FEMA takes an active role in supporting and contributing to national building codes and standards (e.g. ASCE 7, ASCE 31, and ASCE 41), produces a prodigious amount of publications and related products for both technical and non-technical audiences, including consensus-based guidance on seismic design (i.e. NEHRP provisions) and delivers a broad scope of training opportunities to states, local governments and the public. For a recent example, following the 2014 M6.0 South Napa Earthquake, FEMA funded studies on the performance of buildings and non-structural components (FEMA P-1024) (FEMA 2015a) and also developed recovery advisories for properly repairing earthquake damaged masonry fireplace chimneys (FEMA DR-4193-RA1) (FEMA 2015b) and for earthquake strengthening of cripple walls in wood-frame buildings FEMA DR-4193-RA2) (under development by the Applied Technology Council).

FEMA is leveraging an array of public-private partnerships, such as with the International Code Council, standard development organizations, earthquake engineering membership organizations and state earthquake management to further its implementation reach. We recognize FEMA's commitment to the annual Shakeout preparedness drills (which have taken on a national flavor and thus increased earthquake awareness throughout the Nation) and to the development of QuakeSmart, a program for earthquake preparedness for businesses. FEMA has also demonstrated strong partnerships with NIST and the USGS, for example helping to assure the USGS information on current earthquakes is utilized and integrated into the mitigation, planning and preparedness efforts that it helps to fund.

However, FEMA's critical role in implementation and funding of risk reduction activities at the state and local levels, and translation of technical information into applicable tools for earthquake risk reduction has been seriously diminished by a variety of factors. The single most important issue is the continued reduction of the budget for the FEMA Earthquake Program and the lack of sufficient staffing, which we address further below.

The Committee supports the all-hazard approach that FEMA has embraced. However, as is the case for flood and hurricane risks, there are unique aspects of the earthquake hazard that must be addressed and incorporated for effective state and local hazards planning and risk reduction. To date, earthquake-funded research has led to a number of advances in technical knowledge that, in turn, have led to hazard mitigation applications that benefit multiple hazards, including wind and landslides. This is the role FEMA plays in translating research into practical applications by state and local governments, professional practitioners, private sector and the public. Therefore, FEMA's ability to adequately execute its role in translating research into successful implementation strategies for earthquake hazards reduction is critical to reducing the impacts of all disasters.

**Recommendation 1**

**ACEHR recommends FEMA commit to support for its earthquake mitigation mission and NEHRP-related implementation and outreach activities.**

ACEHR recognizes the constraints of the current budget environment. However, the Committee urges FEMA management to request funding levels that will allow the agency to fully fulfill its implementation role as part of a broader initiative to reinvigorate the implementation component of NEHRP. The substantial decline in FEMA's NEHRP-related funding is not due to budget cuts imposed by Congress, but by FEMA's own failure to request adequate funding to meet its NEHRP-related mandate.

Since 2001, FEMA's Earthquake Program budget has been reduced by over 60% and FEMA's requested Fiscal Year 2016 budget is 12% less than the Fiscal Year 2015 budget. FEMA headquarters currently has three full-time employee positions supporting NEHRP, down from approximately 12 positions—including the loss of two senior positions in the last year. Also, until very recently many of the Earthquake Program positions in FEMA regions have been either unfilled, or only staffed part-time. ACEHR believes that these reductions have led to a serious erosion of FEMA's capability, and the subsequent impacts that they have had in developing and delivering technical advice and tools to state and local partners and other critical earthquake constituents.

The mitigation mission of NEHRP is dramatically under-funded and FEMA's Earthquake Program is significantly under-supported relative to the scale of the problem, the increasing severity and frequency of natural disasters, and the potential for a major U.S. earthquake in the near future. We are very concerned that a major earthquake occurrence will expose the erosion of state and local capability to recover, in part, because of the erosion of funding from FEMA programs. ACEHR further recommends filling the many vacant Earthquake Program manager positions within the FEMA regions by active recruitment, restoring cuts in salary and benefits for these positions, and fully funding all Earthquake Program positions.

**Recommendation 2**

**ACEHR recommends FEMA return to a directly-funded state-based program for earthquake hazard mitigation, planning, education and preparedness efforts and ensure its full funding.**

ACEHR supports FEMA's re-evaluation of the current process of delivering its program of grants and assistance to states for earthquake related mitigation, planning, education, and preparedness through multi-state consortia. At the May 2013 National Earthquake Program Managers Meeting in Denver, state representatives called for a return to direct funding of the states rather than through the consortia, greater transparency in administration of the grants program, expansion of eligible projects for funding, and a long-term strategy for the grant program rather than an annual "needs list."

ACEHR believes it is important to recognize that, in some cases, the consortia are poorly equipped to serve as funding agencies and their service areas have little correspondence with FEMA's regional boundaries. Also, we encourage FEMA to reconsider the current state grant matching formula and whether it should be altered to realistically represent states abilities, and to increase the overall level of funding for the state earthquake programs that has declined steadily over the past decade.

**Recommendation 3**

**ACEHR recommends FEMA restore and give priority to its seismic hazard mitigation and resilience initiative for critical infrastructure and lifeline systems.**

In parallel with the reduction in NEHRP-related funding, FEMA has scaled back its investment in the development of codes and standards for critical infrastructure and lifeline systems as well as other related resiliency and preparedness efforts. FEMA is encouraged to initiate lifeline-related work consistent with the *Earthquake-Resilient Lifelines NEHRP Research, Development, and Implementation Roadmap (NIST GCR 14-917-33)* (NEHRP Consultants Joint Venture 2014).

**Recommendation 4**

**ACEHR recommends FEMA invest in maintaining Hazus® as a utilizable, publicly available earthquake hazard mitigation tool and ensure that the tsunami module is fully integrated and functioning within the Hazus® software platform**.

Hazus® is uniquely valuable as one of the only multi-hazard publicly-available scenario loss estimation software systems. It has been a crucial tool for state and local governments in hazard mitigation planning, developing and exercising disaster response scenarios, and for public education and preparedness. Unfortunately, there have not been any major updates or improvements to the Hazus® earthquake module in many years and the earthquake damage curves are outdated and require improvement. A tsunami module was initiated but never completed and it is critical that emergency management and mitigation planning for earthquakes and tsunamis be integrated and linked, especially in the coastal regions of California, Oregon, Washington, Alaska and Hawaii, where the threat of large near-shore, earthquake-generated tsunamis, like those experienced in Indonesia (2004) and Japan (2011), is very high. Additional modules will only serve to enhance the use of Hazus® as an all hazard scenario planning tool.



**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 and infrastructure 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.

We commend NIST for “leaning forward” on important and urgent topics to earthquake professionals. NIST, often in partnership with FEMA, has multiple ongoing projects related to performance-based structural design as well as programs related to the validation of specific lateral force-resisting structural systems and elements. Also, in the past several years, NIST has made significant strides in identifying future research needed to meet its core mission with the development of the research and development roadmaps for earthquake-resilient buildings (NIST GCR 13-917-23) (NIBS 2013) and lifelines (NIST GCR 14-917-33)(NEHRP Consultants Joint Venture 2014). These roadmaps provide specific recommendations for improving design requirements and practices for structures and infrastructure systems. Further, NIST is selecting high-priority topics identified in these roadmaps for funding and implementation, demonstrating good overall management of its research program and its charge to provide meaningful technology transfer to the practicing engineering community and further cooperation and coordination among the NEHRP agencies. The majority of the work has been published and project-related publications to date have been well-received by the practicing engineering and academic communities. However, they are not as effectively reaching the practicing design professionals who also could benefit from the information.

The NIST Engineering Laboratory is also leading a national Community Disaster Resilience program that aims to help to make buildings, infrastructure systems, and communities safer and more resilient to natural and human-made hazards. We appreciate the growing synergies between the Community Disaster Resilience program and the NIST NEHRP-related work, and encourage NIST to continue to identify and leverage opportunities for collaboration. At the same time, the Committee is concerned about ensuring that a focus on earthquake hazards reduction is maintained because the nation’s earthquake risk is immense and there are essential earthquake-specific issues related to both new and existing structures and infrastructure systems that require sustained investment and attention.

**Recommendation 1**

**ACEHR recommends NIST improve the dissemination of NEHRP-related information and products to the architectural and engineering professions.**

The NIST TechBrief report series, which consists of individual report volumes on a specific earthquake engineering topic, are typically concise with well-illustrated discussions that address practical problems faced by engineering design and construction practitioners. By FY2015, eleven Technical Briefs will have been written and made available. ACEHR encourages NIST to work on improving their outreach efforts with the “average” design engineers and others in the architectural and engineering communities. We also suggest that NIST investigate who is using their products and whether they are reaching the target audiences.

**Recommendation 2**

**ACEHR recommends NIST emphasize future NEHRP-related research and development programs on infrastructure systems, geotechnical engineering, non-structural elements, and residential and industrial structures that have seismic vulnerabilities.**

ACEHR encourages NIST to continue to place an emphasis on key areas that have been historically underrepresented in the NIST research program. This includes funding of research programs that complement the recently funded "*Scoping Study: Seismic Analysis and Design of Nonstructural Components and Systems*" and "*Critical Assessment of Lifeline System Performance and Recovery Timeframes.*" ACEHR also encourages NIST to identify building research that has the widest possible impact on seismic resiliency. Some of the most common elements of the nation's building stock are low-rise, residential and industrial structures, many of which have seismic vulnerabilities that have not been addressed at the same level of detail as other types of structures (i.e. high-rise and mid-rise commercial and residential structures and industrial and infrastructure-related facilities). Giving priorities to these topics may necessitate temporary reductions in other research areas. If necessary, ACEHR would recommend reductions in research focusing on steel beam-column members, thin concrete walls, and seismic collapse simulation analyses.

The current NIST team consists of internal researchers augmented by external research efforts which they manage. Together, there is the technical capability and experience to cover a wide range of important structural-related research areas, including steel and concrete systems, performance-based seismic design, nonlinear analysis methods and performance evaluation of existing buildings. ACEHR encourages NIST to increase in-house and external research capabilities in the lifelines and geotechnical areas, to help develop basic tools, guidelines and standards to improve the seismic performance of lifelines and geotechnical structures.

**National Science Foundation (NSF)**

The NEHRP statutory responsibilities and strategic plan tasks assigned to NSF mainly relate to the agency's Engineering and Geosciences Directorates. Social, behavioral, and economic science research related to NEHRP has been funded both through the Engineering Directorate and the Social, Behavioral, and Economic Sciences Directorate (specifically the Division of Social and Economic Sciences). The research funded by NSF represents a combination of coordinated research programs and unsolicited proposals.

ACEHR commends the NSF for maintaining a strong external research program that continues to build fundamental knowledge on earthquake hazards reduction along with supporting a strong community of earthquake researchers, educators, and practitioners. The multi-disciplinary and cross-disciplinary research programs, including those supported through the earthquake science and engineering research centers, and other NSF programs such as the Interdisciplinary Research in Hazards and Disasters (Hazard SEES) and Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) programs, facilitate inter-disciplinary collaboration. This collaboration, in turn, helps to strengthen scientific capacity to tackle multi-disciplinary problems such as assessing and planning for earthquake resilience. Furthermore, NSF's efforts to create shared research facilities, data repositories, and common simulation platforms, for example through the George E. Brown Network for Earthquake Engineering Simulation (NEES) program, have expanded access to research and accelerated learning.

ACEHR is concerned, however, about the dissipation of focus within NSF on earthquake hazards. This is due, in part, to the increased focus on the development of multi-hazard program solicitations and the end of a number of earthquake engineering specific programs and emphases. At present, earthquake-related social science and policy research emphases often appear as an appendage to multi-disciplinary research projects. Also, large infrastructure programs such as the Seismological Facilities for the Advancement of Geosciences & EarthScope (SAGE), Geodesy for the Advancement of Geoscience &

EarthScope (GAGE), and NEES need better plans and mechanisms for sustained support following initial funding phases.

**Recommendation 1**

**ACEHR calls upon NSF to clarify current and future programmatic funding commitments in support of NEHRP. This information should be integral to NEHRP coordination efforts by the ICC and the NEHRP Office.**

NSF program officers have reported to ACEHR that it does not fund programs that are dedicated solely to NEHRP. Research projects are identified as being NEHRP relevant when funded under a variety of NEHRP-related programmatic initiatives or as unsolicited projects. This allows flexibility in directing funds to investigator-initiated, high quality research in support of NEHRP. However, these practices obscure agency commitments to NEHRP, may diminish funding potential for earthquake-related research, and hamper the abilities of other NEHRP agencies to coordinate with NSF as required by the NEHRP legislation.

ACEHR believes the effectiveness of NSF's NEHRP contributions would be improved by more proactively reporting current and likely future funding commitments in different NEHRP programmatic areas. The designated areas should correspond to the categories identified in the NEHRP strategic plan (NEHRP 2008) with sufficient detail to allow the ICC and NEHRP Office, and the ACEHR, to understand how NSF commitments relate to other NEHRP activities.

Greater effort should be made to distinguish NSF funded research that is specific to NEHRP from that which is NEHRP-related. For example, it is unclear how much research focus NSF is putting on lifeline earthquake engineering. NSF program officials report to ACEHR that the Resilient Infrastructure Processes and Systems Science (RIPS) program has many projects, but it is unclear how much of this funding is for lifeline earthquake engineering research. Clarification of the NSF funding of lifeline earthquake engineering research that is consistent with the needs identified in the *Earthquake-Resilient Lifelines NEHRP Research, Development, and Implementation Roadmap (NIST GCR 14-917-33)* (NEHRP Consultants Joint Venture 2014) is an example of the recommended NSF NEHRP programmatic reporting.

**Recommendation 2**

**ACEHR recommends NSF develop a mechanism for documenting, reporting, and publicizing current NEHRP-related research and the findings from it.**

The merit-based funding mechanism of NSF is consistent with its goal to support high-quality scientific research. The funded research naturally covers a broad range of disciplines and topics. However, it is challenging for the other NEHRP agencies and those in the broader research community to know the range and specific details of the various funded projects. This, in turn, inhibits coordination among the NEHRP agencies. More can and should be done to document, disseminate, and publicize past and current research activities. Searches of NSF awards through the NSF website are insufficient for this purpose. In particular, with the end of the NEES program, there needs to be a coordinated mechanism by which to assemble and communicate the various NEHRP-funded projects for the purpose of learning about their activities. Some new mechanism, such as an annual NSF NEHRP funding awards workshop, needs to be created.

**Recommendation 3**

**ACEHR recommends NSF report to ACEHR, as part of the next ACEHR review, the status of earthquake-related research and funding commitments for its part of the Natural Hazards Engineering Research Infrastructure (NHERI) initiative.**

Over the past two decades, one of the major engineering-focused activities of NSF was the development, operations and research of the George E. Brown Network for Earthquake Engineering Simulation (NEES). Both the operations and the supported research programs under NEES are now in transition. NSF's new solicitation for proposals to establish the NHERI for 2015-2019 is intended to support a network coordination office, experimental facilities, cyberinfrastructure, and computational modeling and simulation tools for earthquake engineering and wind engineering research. ACEHR appreciates that the added emphasis on wind engineering will lead to improvements in the nation's resilience to natural disasters. However, NSF must ensure that earthquake-related research in support of NEHRP is not diminished by this new initiative.

**Recommendation 4**

**ACEHR recommends NSF review lessons of multi-disciplinary hazard-related initiatives to assess the quality of cross-disciplinary, and especially social science, participation. At the same time, NSF should continue and enhance investment in social science research related to earthquake hazards and disasters.**

Recent NSF initiatives have emphasized social science contributions as part of multi-disciplinary, hazard-related undertakings such as the Interdisciplinary Research in Hazards and Disasters (Hazards SEES) and Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) solicitations. Social science contributions to such initiatives are essential for implementing advances in earthquake engineering. Yet, too often the social science contributions continue to appear as appendages to such projects. There is now enough experience with such initiatives to draw lessons and consider best practices.

At the same time, continued investment in social science funding under the NSF Infrastructure Management and Extreme Events and the Civil Infrastructure Systems programs is important for advancing progress on important socio-demographic changes and societal issues relating to seismic resilience for the built environment and infrastructure systems. NSF remains the primary agency responsible for social science research to guide the design of implementation strategies for earthquake hazards reduction. ACEHR strongly recommends NSF demonstrate that it is supporting, and will continue to support, NEHRP-related social science research as a priority.

**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 finds that the USGS continues to maintain a holistic program that encompasses real-time seismic monitoring and reporting, millimeter-scale laboratory research, large-scale tectonic deformation modeling, to basic theoretical research on the earthquake process. It is also continually utilizing the data and knowledge resulting from these efforts to improve and upgrade the national- and local-scale understanding of earthquake likelihood, assessments of seismic hazards and many other products the public depends upon. The USGS Earthquake Hazards Program provides a strong mix of fundamental and applied science as well as a healthy public communication and outreach component. The USGS has also worked well with NSF on several NEHRP-related efforts, which are noted below.

Some of the notable accomplishments by the USGS Earthquake Hazards Program in addressing NEHRP goals are:

- Substantial expansion of seismic monitoring in the central and eastern United States through the adoption and upgrading of 160 EarthScope (N4) seismic stations. The conversion to permanent status of these previously "temporary array" stations was jointly funded by the USGS and NSF, and represents an excellent example of NEHRP collaboration between agencies.
- Commitment to ongoing improvements in the National Seismic Hazard Maps which are created using an open, collaborative process. Maps are updated on a 6-year cycle designed to correspond to the updating of seismic criteria in the International Building Code. The latest map update was released in 2014. Input parameters for the maps were solicited in open regional workshops and draft versions of the updated maps were posted online for public comment. This process has helped ensure that input to the nation’s seismic hazard model reflects state-of-art knowledge and is defensible.
- Demonstratively-responsive national earthquake monitoring, such as quick installation of additional seismic stations in Oklahoma which has been essential to evaluating the significance of recent and dramatic increases in seismicity in the state. These new stations were quickly integrated into the USGS national real-time seismic network. However, a lack of resources did not allow the USGS to investigate a recent increase of seismicity in Nevada.
- 24-hour operation of the USGS global earthquake reporting center—the National Earthquake Information Center (NEIC) in Golden, Colorado— which is supplemented by the USGS’ continued development of near real-time products such as ShakeMap and PAGER. Together, they keep government and the public informed within minutes about an earthquakes occurrence, its shaking intensity and the likely impacts of major earthquakes both within the United States and globally.
- Initial implementation of a public earthquake early warning (EEW) system in California.
- Maintaining a successful External Research program (representing 25% of the USGS Earthquake Hazards Program dollars) that is well focused and complements and fills gaps in the internal program. This represents a great leveraging of program dollars.
- Development of the Uniform California Earthquake Rupture Forecast (UCERF) in collaboration with the Southern California Earthquake Center which is used in setting residential earthquake insurance rates and policy coverages in the state as well as many other earthquake hazards mitigation and preparedness planning efforts.

Despite this strong record of accomplishments, the USGS' Earthquake Hazards Program faces a number of challenges:

- Maintenance of seismic and other monitoring networks along with the required telemetry and analysis for real-time data delivery represents a significant capital cost that grows annually. Adding new stations, while expanding recording and detection capabilities, further increases these capital costs. To ensure a healthy, holistic program, the USGS must be mindful of the balance between monitoring and its research and assessment programmatic elements.

- Determining how much effort to invest in geodetic monitoring with the primary constraint that the effort makes an impact on hazard assessment.
- Addressing the "implementation gap" with respect to the use of the National Seismic Hazard Maps by practicing engineers. The USGS' approach to updating the seismic hazard input parameters to reflect the most current and best available science has sometimes resulted in significant fluctuations in the seismic hazard estimates. The presentation of seismic ground shaking data in very precise terms also suggests a greater level of certainty than may be appropriate. ACEHR commends the USGS for creating a new industry council to help address these and other issues, and encourages the engagement of practicing engineers who are the primary users of these products on this council.
- Paying attention to an aging workforce.

**Recommendation 1**

**ACEHR recommends the USGS work to provide the data necessary to reduce uncertainty in ground motion scaling in the eastern and central United States. This may require assessing the merits of different strategies that include upgrading new stations obtained from NSF with strong motion sensors as well as placing more focus on rapidly instrumenting aftershock sequences and other targets of opportunity.**

In assessing seismic hazard in the central and eastern United States, the largest source of uncertainty is the lack of knowledge about how seismic shaking decays (attenuates) with distance from the earthquake source. Ground motion attenuation relations are key inputs into seismic hazard assessments and are obtained by direct measurement of strong ground shaking in earthquakes through special sensors.

The OMB and OSTP recently approved a joint USGS-NSF plan to convert 160 NSF-funded portable seismic stations in the central and eastern United States to permanent recording stations operated by the USGS. NSF is to fund the costs of inventory replacement, station upgrades, and operations and maintenance (O&M) costs through 2017. The USGS is also currently contributing to the O&M costs, and is seeking funding to operate the network beginning in 2018.

This newly expanded seismic network will have dense and nearly uniform station coverage across the central and eastern United States which provides an unprecedented opportunity to both greatly increase USGS' ability to monitor small earthquakes in the region, and to capture strong ground motion from moderate earthquakes. Currently the USGS plans to only put strong motion sensors on 60 of the 160 new stations (those in highest hazard regions). Since earthquakes occur randomly throughout this region (e.g., the 2011 Mineral, Virginia earthquake) and seismicity is increasing throughout the region due to oil and gas production, there is a great opportunity to get the required strong motion data which would be valuable for improving design codes, and for seismic safety analysis of the approximately 70 nuclear power plant sites in the central and eastern United States.

**Recommendation 2**

**ACEHR recommends the USGS make Earthquake Early Warning (EEW) a funding priority and provide the U.S. public with a service that has proven to be highly effective in saving lives and property in Japan, Mexico, and elsewhere. Additional federal funding will be required in order to develop, implement, and operate an EEW with priority given to the most seismically active regions in the United States.**

EEW systems can provide several seconds of advance warning before strong ground shaking begins. Such warnings can be used, for example, to slow trains to prevent derailment or pause delicate and life-threatening surgeries and industrial processes. EEW was one of the capabilities described in the 1999 USGS plan, *Requirement for an Advanced National Seismic System*, (USGS Circular 1188) (USGS 1999); but significant shortfalls in funding for this plan delayed its implementation. However, the USGS is now fully committed to this emerging technology and has appointed a national coordinator for the development and implementation of an EEW system for the West Coast of the U.S., with the long-term goal of extending the system to all seismically active regions in the country. While the technology to provide warning of impending ground shaking from an earthquake is reasonably mature (a nationwide EEW system was implemented in Japan in 2007), funding for expanding and upgrading the seismic networks in Washington, Oregon and California (prerequisite for a reliable, robust and timely EEW system), and operating such a system, is not assured.

Thus far, the USGS and participating universities and state government partners have obtained grants from a private foundation and limited federal funding, but no assurance of sufficient support for the needed seismic network upgrade, nor operating funds to run an EEW system along the West Coast.

In 2013, California passed legislation mandating the development and implementation of an EEW system for the state, but included a provision indicating that funding for the system could not come from the State's General Fund. Currently, there are five State-appointed committees—including one dedicated to the identification of funding strategies—working on an implementation plan for EEW in California. The estimated operating cost for a California and the Pacific Northwest system alone is $17 million per year, in addition to the current monitoring budget. The current annual budget for the entire USGS Earthquake Hazards Program is about $55 million per year, with about $26 million per year dedicated to earthquake monitoring. Thus, an operational EEW cannot come from the base budget of the USGS Earthquake Hazards Program.

ACEHR believes that EEW requires separate, long-term funding that does not degrade the USGS' overall mission to understand and mitigate earthquake hazards. One model being considered for EEW system funding is a subscription service in which users would pay a fee for access. ACEHR cautions, however, that geologic hazard warnings are a public good and should be available to all regardless of the ability to pay.

**Recommendation 3**

**ACEHR recommends the USGS enhance its efforts to understand, educate and communicate the risks posed by induced seismicity.**

A recent upswing in oil and gas production, particularly in the central and eastern United States, has raised concerns about triggered or "induced" seismicity related to injection of waste water generated by this (and other industrial) activity (Walsh and Zoback 2015; Weingarten et al. 2015). Work is also beginning on pilot projects throughout the central and eastern United State to investigate large-scale underground injection and permanent storage (sequestration) of $CO_2$. In support of the Obama Administration's "all of the above energy strategy," the USGS received $1.8 million in FY14 to expand its study of induced seismicity. In FY15, Congress increased funding to $2.5 million in support of research to better understand factors controlling induced seismicity and how to best assess the related seismic hazards.

ACEHR has identified three significant opportunities and challenges for NEHRP related to seismicity induced by subsurface injection of waste water/fluids, including $CO_2$:

- Quantify the seismic risks to neighboring communities posed by injection-induced seismicity (from oil and gas activities, $CO_2$ sequestration, or enhanced geothermal production).
- Determine how induced seismicity impacts the "tectonic based" USGS National Seismic Hazard maps and how the effects might be incorporated in some time-dependent assessment of seismic hazard.
- Take advantage of selected injection sites as opportunities to better understand the relationship between seismicity and injection pressures, and collect new ground motion data to better constrain seismic attenuation in the central and eastern United States; the largest uncertainty in producing seismic hazard maps for these regions.

In response to the 2013 ACEHR recommendation calling for more research to evaluate the impact of induced seismicity on seismicity rate models and how the hazard can best be represented, the USGS convened a National Seismic Hazard and Risk Steering Committee and their findings are provided in the USGS Open File Report 2015-1070, *Incorporating Induced Seismicity in the 2014 United States National Seismic Hazard Model —Results of 2014 Workshop and Sensitivity Studies* (Petersen et al. 2015). ACEHR concurs with the recommendations of the USGS's National Seismic Hazard and Risk Steering Committee that the USGS should develop short-term hazard products for induced seismic activity, which might be updated annually. We also recommend that an advisory group of state and local stakeholders be part of the product development.

**Recommendation 4**

**ACEHR recommends the USGS expand earthquake scenario development in conjunction with stakeholder engagement in order to examine consequences of earthquakes in high-risk urban areas.**

The development of earthquake scenarios in conjunction with key stakeholders (including local government, utility operators, emergency responders, etc.) has helped to stimulate mitigation action in major metropolitan regions of California, the Pacific

Northwest and the central United States. For example, the 2008 ShakeOut scenario (Jones et al. 2008) for a major earthquake on the southern San Andreas fault has led to the "Resilience by Design" seismic program announced by Los Angeles' mayor office in December 2014 (Mayoral Seismic Task Force 2014).

**Recommendation 5**

**ACEHR recommends the USGS work with operators of critical infrastructure and lifeline systems to define and integrate near real-time earthquake data and other seismic information into system monitoring so that operators can quickly assess system impacts from earthquake movements and take appropriate actions. This development should be linked with the EEW program.**

ACEHR encourages the USGS to explore joint funding models and cooperation with critical infrastructure and lifeline operators to purchase and maintain seismic instrumentation that can also be tied into both the strong motion networks of operators and the USGS. There is substantial value added by combining strong motion data in real-time with the USGS's existing network. ACEHR also recommends that the USGS work closely with the owners and operators of critical infrastructure and lifeline systems to develop and implement EEW systems—a priority topic identified in the NIST consistent with priorities research identified in the *Earthquake-Resilient Lifelines NEHRP Research, Development, and Implementation Roadmap (NIST GCR 14-917-33)* (NEHRP Consultants Joint Venture 2014).

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## Appendix – 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 the key disciplines that form the earthquake professions. Included are both suggested refinements to tasks in the FY2009–2013 NEHRP strategic plan (NEHRP 2008)and new tasks that should be considered for future plans.

### Social Sciences

The diversity of social science research—drawing from economics, land use planning, political science, public administration, public health, public policy and sociology—has provided a rich understanding of a range of topics concerning emergency response, disaster impacts and recovery, hazard adaptation and mitigation, and the vulnerability of different populations to extreme events. These are important research topics that warrant continued funding. Historically, much of this research has been funded by NSF. Three trends stand out in recent social science funding and research.

#### *The Diversification of Funding within NSF*

This diversification is evident in the launch of a number of larger-scale, interdisciplinary hazard-related initiatives that include social science contributions. These include current funding under the Interdisciplinary Research in Hazards and Disasters (Hazard SEES) and Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) programs, prior funding under the Human Systems Dynamics (HSD) Program and the Earthquake Engineering Research Centers, and NSF collaborative efforts with the Department of Agriculture and the National Oceanic and Atmospheric Administration. This trend is positive in injecting new funds and bolder undertakings that place social science contributions on stronger footing. Yet, issues remain concerning integration of the social sciences so that the contributions are not merely appendages to such projects.

#### *A Shift in Research Emphasizing Community and Societal Resilience*

A second trend is a shift in research emphasizing community and societal resilience. In recent years, social science researchers have developed frameworks for measuring community resilience, expanded assessments of vulnerability, considered factors that foster and limit community resilience, and examined the economic aspects of interdependencies in decision making for protective actions. Each of these topics deserves further attention with a continued need for a more comprehensive resiliency and vulnerability observatory network as called for in the NRC's 2011 National Earthquake Resilience report (NRC 2011). Gaps remain in the understanding of mechanisms for gaining private and public sector commitment for resilient infrastructure, the coordination of public and private actions at different levels of government in advancing community and societal resilience, and the prevention of, and response to, cascading disruptions across interdependent infrastructures.

#### *Continued Investment by NSF in Advancing Human Capital for Social Science Research*

A third trend is the continued investment by NSF in advancing human capital for social science research contributions. Two initiatives have been undertaken that go beyond support for graduate students and post-doctoral researchers as part of NSF-funded projects. One was the funding of graduate dissertation research scholarships for hazard-related research. A second is funding for a fourth round of the Enabling Program for the Next Generation of Hazards Researchers. This is aimed at recruitment, mentoring and training of emerging social science scholars as a means expanding and diversifying the pool of researchers. This has been an important program for confronting a generational change in the talent pool and for responding to new trends in research issues.

**Earth Sciences**

This section addresses aspects of earthquake seismology, strong-motion seismology, and developments in associated programs relevant to NEHRP. The knowledge, tools, and practices in this arena overlap science and engineering—especially relating to design ground motions, where scientists and engineers work closely together. They also overlap science and emergency management.

***Analyzing Induced Seismicity***

In the two years since ACEHR's last report, the pattern of earthquakes affecting the population has changed significantly with the large number of felt and minor damaging earthquakes in Oklahoma, Kansas and Texas. While these earthquakes may be associated with industrial activity, the precise mechanism for their occurrence is not well known. The determination of the location, size and type of faulting of these earthquakes has improved because of collaboration among universities, state and federal agencies in the operation of seismic stations in proximity of the earthquakes. By 2017, 160 stations of the NSF EarthScope Transportable Array will be transferred to the USGS. These stations located in the central and eastern United States will improve the ability of the USGS to locate and assign magnitudes to these earthquakes. The magnitudes, rates of occurrence and locations are used for hazard mapping by federal and state regulatory agencies.

***Seismic Monitoring and Archiving Seismic Data***

The issues of seismic monitoring and associated data preservation must be addressed. Under current funding guidelines, the USGS recently approved five-year cooperative agreements for regional seismic networks in Alaska and the western United States, but only three-year agreements for the networks in the eastern United States because of funding uncertainty. Stable monitoring is required to maintain and improve a system fundamental to emergency response and long-term research.

While the quality of seismic data meets standards imposed by the network operators, there is a fundamental requirement that the data be curated, archived and made accessible in perpetuity. NSF must continue to support the archiving infrastructure so that the data can be used to improve the understanding of nation's earthquake hazards and methods for mitigating their effects.

***Development of an Earthquake Early Warning (EEW) System***

EEW is a primary product resulting from a fully developed Advanced National Seismic System (ANSS). The infrastructure for an EEW system is being developed in California and the Pacific Northwest. The requirements for the infrastructure in other regions of the United States have yet to be developed. When implemented, an EEW system can provide critical warning time prior to severe shaking. In addition, significant progress has been made in creating a national earthquake monitoring system that serves the purposes of immediate notification as well as long-term hazard assessment. The challenge is to maintain and improve such a system so that the effects of earthquakes anywhere in the United States and its territories can be better anticipated and managed in real-time.

***Application of Digital Imaging Technologies for Fault Mapping***

Recent developments in airborne and terrestrial digital imaging methods such as Light Detection and Ranging (LiDAR) technology have enabled rapid and remote identification of subtle fault scarps and faulted materials at scales varying from a few meters to regional. These methods have led to more accurate and more extensive mapping of active fault traces in urban and non-urban areas.

**Geotechnical Earthquake Engineering**

Geotechnical earthquake engineering covers the design and construction of geotechnical structures under earthquake or impact loads and it closely interfaces with the disciplines of earth science, structural engineering, and lifeline engineering, and in general, affects all earthquake engineering-related disciplines. Advances in community seismic resilience can be achieved only if design, construction, and infrastructure operations account for the geotechnical effects of earthquakes, including surface fault rupture, seismic site effects, liquefaction, seismic instability, and soil-foundation-structure interactions. As the importance of a multidisciplinary approach to addressing earthquake hazards (as well as other hazards) is recognized, geotechnical engineering as a natural linkage between disciplines can provide a critical path forward in improving seismic resilience.

***Liquefaction in Recent Earthquakes***

Recent earthquakes, including the 2011 Tohoku, Japan earthquake and the 2010-2011 earthquake sequence effecting Christchurch, New Zealand, have shown the dramatic effects of earthquake-induced liquefaction with important lessons for buildings (especially residential structures) and infrastructure (including water and wastewater distribution systems, underground electric power cables, and highway bridges). For example, in the Tohoku earthquake stiff mat or grade beam foundations effectively protected residential structures from the effects of liquefaction. In the Christchurch earthquakes, highly ductile (high- or medium-density polyethylene) infrastructure pipelines accommodated large ground deformations with lateral displacements of three to five feet. As well, in the Tohoku earthquake, resistant ductile iron pipes in use for over 40 years accommodated large ground movements exceeding 9 feet without damage.

***Integration of Geotechnical Engineering and Earth Science***

NEHRP agencies need to support enhanced interconnections and interdisciplinary collaboration between earthquake science and engineering and geotechnical engineering must be an integral part of multidisciplinary seismic research. Although NIST's establishment of an extramural applied-research program fills a critical gap between NSF-funded basic research and the implementation of earthquake risk-reduction measures, the NIST program also need to emphasize geotechnical engineering knowledge transfer.

***Multihazard Considerations in Geotechnical Engineering***

Geotechnical earthquake engineering addresses numerous multihazard aspects of earthquakes, such as liquefaction induced ground deformations and impacts on other engineered facilities and increases in flood risk following an earthquake. Earthquake ground motions can damage common water retaining geotechnical structures, such as dams and levees, which protect communities from flooding. Areas of Wenchuan China, Tohoku Japan, and Christchurch, NZ all have on-going flood problems as a direct result of earthquake-related ground deformation and damage to levees and flood protection systems in the 2008, 2011, and 2010-2011 earthquakes, respectively. A holistic approach to community resilience requires a multi-hazard perspective for levee and flood protection system reliability, including design and construction as well as land use planning in advance of development.

***Predicting Liquefaction***

There have been significant improvements in the methods for predicting liquefaction potential and estimating the potential ground settlement and lateral ground movement resulting from liquefaction. Yet, it has been well over a decade since the geotechnical community last review of consensus guidelines for evaluating liquefaction potential and its consequences. Several major earthquakes have occurred and been investigated since that time and offer substantial new data on liquefaction behavior.

These new data on liquefaction and its effects on buildings and infrastructure must be reviewed, and integrated into the next generation of consensus guidelines for predicting and accounting for liquefaction and its consequences.

***Hazard Maps for Ground Failure***

Improved maps for ground failure hazards and methods for characterizing the magnitude and distribution of ground movements triggered by earthquakes are needed at scales meaningful for land use planning and policymaking as well as the proper siting, design, and rehabilitation of buildings and infrastructure.

***New Computational Tools and Data Archiving***

High-end computing coupled with enhanced visualization software is transforming how building and infrastructure seismic performance is evaluated. Practicing engineers require critical assessments of these sophisticated computational tools to ensure that reliable results are produced. Realistic modeling of soils, interfaces, and discontinuities remains an important need. Field and laboratory experiments are required to advance earthquake science and engineering through innovative site and material characterization technologies. The geotechnical information collected following earthquakes should be archived as well and made available to researchers, engineers, planners, and emergency managers. Incorporation of advanced technologies and imaging techniques, such as Light Detection and Ranging (LiDAR), in post-earthquake reconnaissance can strengthen the lessons that the profession can glean from future earthquakes.

***Tools for Performance-Based Design***

Performance-based earthquake engineering requires consensus methods for selecting and scaling ground motions to represent the seismic hazard at a project site. It also requires quantitative data that translates calculated engineering responses into damage as well as estimations of life loss, property damage, and business downtime. To accomplish this, full implementation of the ANSS is needed in order to refine the spatial variability of ground shaking due to local geology. Geotechnical structures, including downhole arrays, also should be better instrumented. Improved models of ground shaking near faults and in the eastern and central United States are also needed. The seismic response of IBC 2006 Site F soils also requires better characterization. In addition to advance building codes, NEHRP also should help advance tools that move the profession toward true performance-based design. Owners also need to better understand the special nature and needs of their project and engage engineers to design for the desired level of performance according to a site-specific hazard assessment.

**Structural Earthquake Engineering**

New trends and developments in structural earthquake engineering take multiple forms including advanced research, development of new codes and standards, and related activities in the structural earthquake engineering design community.  Current earthquake engineering research is wide ranging and covers a myriad of structural and non-structural topics. NEHRP agencies, primarily FEMA, NIST and NSF, are typically major supporters of this research in the United States. While it would be a major endeavor to cover all current research trends, it should be noted that significant research is being conducted related to structural and non-structural issues that is intended to provide options for improving the resilience of facilities after a major seismic event.

***New Building Codes and Standards***

In the structural engineering community at large, new trends and developments are typically disseminated through the issuance and implementation of new codes and standards. ASCE 7, which is the primary structural reference in the International Building Code (IBC), is the most widely utilized standard in the structural engineering community. It relies on the NEHRP Recommended Seismic Provisions for its technical underpinnings. Significant changes in the seismic provisions are first encountered by most structural engineers through ASCE-7. The USGS' 2014 issuance of revised ground motion maps will soon be affecting the building codes and standards for portions of 42 states where nearly half of the U.S. population resides.

***Guidance for Seismic Evaluation of New and Existing Buildings***

A recent milestone in the structural earthquake engineering community was the issuance of the revised ASCE 41 Standard, *Seismic, Evaluation and Retrofit of Existing Buildings* (ASCE 2014). This standard is a widely-referenced document for the seismic evaluation and retrofit of existing buildings, and its detailed information is also utilized in Performance-Based Seismic Design (PBSD) of new buildings. There are many other initiatives underway which examine specific issues and elements affecting seismic performance. A recent example is NIST GCR 12-917-20 *Tentative Framework for Development of Advanced Seismic Design Criteria for New Buildings* (NEHRP Consultants Joint Venture 2012), which was prepared under NEHRP. This document examines seismic performance factors with the objective of updating these factors for inclusion in future versions of seismic design codes.

***Knowledge Transfer through Local Associations***

As noted above, the majority of practicing structural engineers typically react to the new or updated seismic analysis and design requirements in the current codes and standards. However, it should be noted that many structural engineers who are not directly involved with research and/or the codes and standards process are active in their local associations or organizations that focus on structural and earthquake engineering. It is through these organizations and associations that many structural engineers advocate for stronger seismic codes, more advanced licensure requirements and better implementation of seismic design requirements as projects move through construction.

***Code Adoption, Quality Assurance and Enforcement***

The primary means of achieving resiliency in communities that are subject to earthquake risk is through the adoption and enforcement of modern building codes, but there are barriers to successful implementation of these codes. Truly effective seismic design of structures rests on three interdependent factors. The first is the use of modern, up-to-date codes and standards. Many communities do not adopt the latest edition of the code and may keep the same edition of the code in force for decades. The seismic provisions of the earlier editions of the building code may be unconservative - in some cases significantly unconservative. The second and third factors relate to enforcement of the codes. Even if current codes are adopted, they are ineffective unless properly enforced. Enforcement begins with an examination of the plans for the structural design by qualified individuals. Review of the plans during the permitting process can reduce the likelihood that design errors will impact the performance of the structure. Finally, the best of designs is of little value if the structure is not built in accordance with plans. Quality assurance programs during construction are critical to good seismic performance. Quality assurance programs often do not include anchorage and bracing of nonstructural components, items that account for the vast majority of damage and losses in past earthquakes.

Many communities lack the resources or the political will to enforce the codes they have, especially the seismic provisions in areas that have not experienced a strong earthquake in recent years. Education and outreach are needed to train and inform the code enforcement community on the proper interpretation and application of the seismic design provisions. Design professionals and contractors also need to be kept up to date on seismic requirements; especially in regions where earthquake resistant design has not been practiced in the past.

**Lifelines Earthquake Engineering**

Lifelines provide the networks for delivering resources and services necessary for the economic well-being and security of modern communities. Historically they have been grouped into six principal system types: electric power, gas and liquid fuels, telecommunications, transportation, wastewater and water supply. In the past decade there have been a number of events identifying the need to pay more attention to inundation protection systems as lifelines. The most notable of these events include 2005 Hurricane Katrina, 2011 Tohoku Japan Earthquake and the 2010-2011 Canterbury, New Zealand earthquake sequence. Inundation protection systems include the regional systems of levees, floodwalls, sea walls and other systems to protect infrastructure from flooding. These and other events also highlight the need to include solid waste management as a lifeline. Taken individually, or in aggregate, lifeline systems are essential for emergency response and restoration after an earthquake, and are indispensable for community resilience.

***Learning from Recent Earthquakes***

Superstorm Sandy and concerns about the future impacts from climate change have drawn significant attention to the need for more resilient communities for all types of hazards in the United States. Major global earthquakes, including the 2011 Tohoku Japan Earthquake and the 2010-2011 Canterbury, New Zealand earthquake sequence, remind us how devastating earthquakes can be to our communities. Japan and New Zealand are struggling with issues on how to make their cities more resilient while rebuilding after the devastation, all the while managing the serious economic impacts from the earthquake and cascading multi-hazard strikes (including tsunami and liquefaction). In all cases, lifeline performance was directly linked to community resilience.

***Lifeline Related Security Measures***

Since 2001, lifelines have received increasing national security attention. The Department of Homeland Security's National Infrastructure Protection Plan (DHS 2013) includes 18 different sectors of critical infrastructure that include or are directly related to the lifeline systems traditionally studied under NEHRP. These initial efforts were enhanced by Presidential Policy Directive 21 (PPD21) *Critical Infrastructure Security and Resilience* (White House 2013) in an attempt to improve resilient lifeline performance when severe hazards strike. Emphasis has been placed on the development of high-performance computational models that simulate the regional response of complex networks and their interdependencies. Communications and electric power have been identified as especially critical due to reliance of other systems on their functioning.  Following PPD21, NSF has funded research on Resilient Infrastructure Processes and Systems (RIPS).  NSF has other research programs in which lifeline systems may be integrated, including geotechnical and lifelines research for the New Zealand and Japan earthquakes.

***Community Disaster Resilience Planning Program***

NIST is undertaking a Community Disaster Resilience Planning Program, within which they will convene a panel on disaster-resilience standards to develop comprehensive, community-based resilience planning guidelines for buildings and infrastructure – products that can inform the development of private-sector standards and codes. This approach was included in the President’s Climate Action Plan (Executive Office of the President 2013). NIST has also prepared a roadmap for a research, development and implementation program for NEHRP activities to improve lifeline earthquake resilience (NIST GCR 14-917-33) (NEHRP Consultants Joint Venture 2014). A project was recently initiated for NIST as a direct result of recommendations in NIST GCR 14-917-33 to address lifeline system performance criteria needed to support community resilience.

#### ***Scenarios Including Lifeline Impacts***

The USGS has emphasized the complex interactions of lifeline systems and impacts on community resilience through scenario disaster events. For example, the Great Southern California ShakeOut of 2008, which at that time was the largest earthquake preparedness drill in U.S. history, examined the consequences of a magnitude 7.8 earthquake on the southern San Andreas Fault through a variety of computational models and included all regional lifeline systems (Jones et al. 2008). This scenario identified a number of critical lifelines-related issues needing to be addressed to improve Southern California’s seismic resilience. As an outcome of this work, Dr. Lucy Jones of the USGS became a science advisor for the mayor of Los Angeles for the 2014 calendar year, and led an effort to develop the *Resilience By Design* report (Mayoral Seismic Task Force 2014), which has many significant resilience recommendations for buildings, water, power and communication systems, and with a special emphasis on addressing fire-following-earthquake hazards.

These developments, driven by NEHRP agencies, aim to enhance the earthquake resilience of lifeline systems. There are also common trends revealed related to multi-hazards, dependency relationships and how lifelines are critical to supporting community resilience. Similar and related industry trends are exemplified by the ASCE’s creation of the Infrastructure Resilience Division with a mission to advance civil infrastructure and lifeline systems for local, regional and national resilience against all hazards.

#### ***Performance Standards for Lifelines***

Unfortunately, even with continued progress in lifeline earthquake engineering, there is an absence of unified or even loosely-coupled performance standards for lifelines. Clear expectations for emergency services and plans for the coordinated response of different lifeline systems are generally absent. Levels of infrastructure vulnerability are unnecessarily high and the ability to quickly restore system function following extreme events is much less effective than most communities recognize. Many significant needs in this area are identified in the NIST GCR 14-917-33 document.

### Disaster Warning, Response, and Recovery

The ultimate test of advances in earth science, engineering and social science is in their application and implementation in communities with significant seismic risk. Emergency managers are key functionaries in this process and significantly shape the manner in which new technologies and research findings are applied in warning the public of hazards, responding to significant events and implementing recovery programs that increase resilience to future hazards. Knowledge transfer, outreach and education are key components in this process.

#### ***Teaching the Public to Use Early Warnings for Earthquakes***

By far, the most promising new technology in disaster warning is earthquake early warning (EEW), now in a beta testing phase in California. The ability to provide a few seconds to a few tens of seconds of warning to people prior to the arrival of potentially damaging ground motion has enormous potential in saving lives and reducing damaging effects on buildings and infrastructure. The most significant challenge is not intrinsic to the technology which is quite mature, but in securing funding to support enhancement of the seismic network to facilitate warnings, for ongoing maintenance and operation of an EEW system, and to educate and train users to take full advantage of early warnings.

***Reenergizing FEMA's Role in Implementation***

FEMA is the primary federal agency charged with responding to natural and man-made disasters and they have successfully responded to numerous floods, hurricanes, tornados, wildfires and a variety of other disasters in recent years. However, their ability to successfully respond to a major earthquake has not been tested in over a decade. During this period, as is documented in other sections of this report, both financial and technical support to state and local partners steadily decreased. With some exceptions, this decrease in support, logically translates into a decrease in capabilities to respond to a major earthquake. While response functions for most disasters are interchangeable, an earthquake response requires some unique capabilities. For example, the determinations of the safety, habitability and use of buildings and infrastructure impacted by an earthquake require significant engineering and architectural capabilities. ACEHR is concerned that these capabilities have eroded or are not being developed because of a lack of funding and leadership.

***Response to Large Earthquakes***

FEMA, in cooperation with the states of Washington, Oregon and California and the Canadian Province of British Columbia completed a Cascadia Catastrophic Earthquake and Tsunami Response Plan in 2013 which will guide response to a large and possibly tsunamigenic earthquake in the Pacific Northwest along the Cascadia Subduction Zone (CREW 2013). This plan and the scenario-driven exercises based on the plan address a significant vulnerability in the region. This plan is the third such plan developed with FEMA support. The others are response plans for a large southern California earthquake on the San Andreas Fault and a similar earthquake in the San Francisco Bay Area.

***Considering the Complexity and Costs Associated with Recovery and Rebuilding following a Major Urban Earthquake***

In 2011, FEMA released the National Disaster Recovery Framework providing a first-time, federal articulation of policy and direction on long-term recovery and reconstruction (FEMA 2011). The impetus for its development emerged in the aftermath of Hurricane Katrina in which the federal government invested over $100 million in recovery and rebuilding, and which included the largest publicly-financed housing repair programs in U.S. history in Louisiana and Mississippi. A large damaging urban earthquake in California, the Pacific Northwest, or the central and eastern United States could cause far greater life loss, economic disruption and rebuilding challenges and costs than were experienced in 2005 Hurricane Katrina or 2012 Hurricane Sandy. In particular, today, less than 10% of California homeowners have earthquake insurance and post-earthquake housing needs, both interim and long-term, will be immense especially in tight and expensive housing markets in the Los Angeles and San Francisco regions for example.

There will be significant demands for federal funding for rebuilding and for NEHRP agency involvement in recovery, funding research and investigations into hazard and damage assessments and developing appropriate and effective mitigation and rebuilding solutions. It has been more than 20 years since a major urban earthquake occurred in the United States, and ACEHR is concerned that the ICC, NEHRP program officers and staff, as well as key federal agencies lack the hands-on expertise and real-life understanding of the complex nature of earthquakes and their consequences as well as the essential role that the federal government has provided in past earthquakes, such as funding large-scale ground deformation and steel-frame building damage investigations and mitigation efforts.