DRAFT for ACEHR teleconference meeting June 1, 2012

Effectiveness of the National Earthquake Hazards Reduction Program

A Report from the
Advisory Committee on Earthquake Hazards Reduction

June 2012

Contents

Executive Summary

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) of the National Earthquake Hazards Reduction Program (NEHRP) is deeply concerned about inevitable catastrophic earthquakes in the United States and their potential to cause severe economic losses (e.g., topping $100 billion for each occurrence) and prolonged human suffering. Despite being a strong nation, we are not well prepared. Entire regions will be seriously damaged and permanently impaired, and will take decades to recover. Large gaps exist between current and desired levels of seismic risk because much infrastructure was built long before we understood the underlying earthquake hazards and our communities were not constructed to recover from earthquake damage.

The 2010 and 2011 earthquakes in Haiti, Chile, New Zealand, and Japan are stark reminders that damaging earthquakes are a constant threat and that there are gaps in our knowledge that need to be filled. The magnitude 9.0 Japan earthquake and tsunami, which swept 20,000 people to their deaths, reminds us of the similar seismological and topographic conditions in our Pacific Northwest. The magnitude 7.1 and 6.2 New Zealand earthquakes, which effectively destroyed the central district of Christchurch, remind us of the importance of seismically strengthening our older building stock. The magnitude 7.0 Haiti earthquake, in which more than 300,000 people died in poorly constructed buildings, and the magnitude 8.8 Chile earthquake, where fewer than 100 people died in modern buildings, remind us of the importance of modern building codes.

Where does the United States stand? Our seismic regions span 30 States, and contain populations who have developed varying degrees of earthquake preparedness. Many communities have only recently adopted or have not yet adopted seismic building codes. In those communities where seismic codes have been adopted, large inventories of older construction that predate these codes remain vulnerable. If an earthquake struck today, we would expect many casualties in communities that had not adequately prepared, where recovery would be slow due to low levels of resilience.

This remains true despite NEHRP's many significant accomplishments. Working in a collaborative and coordinated manner from 1977 to the present, the NEHRP agencies have carried out pioneering work in such areas as seismic monitoring, seismic mapping, building code development, risk mitigation, and emergency preparedness. NEHRP's activities in these and other areas can reduce earthquake casualties and shorten the time it takes for stricken communities to heal. The 2009–2013 NEHRP strategic plan and the companion road map developed in 2011 by the National Research Council (NRC), "National Earthquake Resilience: Research, Implementation, and Outreach," together provide a comprehensive statement of what needs to be done in the near term to build on NEHRP's foundation of achievement and move the Nation toward earthquake resilience. The NRC estimated that just over $300 million per year will be required over the next 5 years to begin this work. Currently, however, annual NEHRP funding is only about one-third of that amount.

Unfortunately, given the slow pace at which NEHRP is currently able to implement its strategic plan and focus on the NRC road map, the Nation's vulnerability to earthquake hazards is steadily increasing and our Nation continues to head toward certain disaster. Human suffering will be intense, mega-losses will occur, and recoveries will be prolonged unless a more aggressive rate of implementation is enabled.

ACEHR has developed a set of key recommendations derived from areas within the NEHRP strategic plan and the new NRC road map that are not being addressed, and from recommendations made in ACEHR's 2010 report that need further attention. While the committee fully endorses the NRC road map, we realize that funding for its full implementation is years off due to budget constraints. We have selected 5 of the 18 tasks specified in the NRC report for focused attention by NEHRP. These tasks, listed below under the numbers assigned by the NRC, go beyond current NEHRP activities and should be initiated, but not at the expense of ongoing program work. Accompanying the tasks, each of which is expected to require up to 20 years for full implementation, are the NRC's cost estimates for the first 5 years of work on the task (average cost per year) and for the entire 20-year NRC implementation period (total cost for task implementation).

10. Socioeconomic Research on Hazard Mitigation and Recovery: years 1–5, $3 million (M)/year; years 1–20, $60M total. (Potential economic cascade if losses become too great in any one community.)
11. Observatory Network on Community Resilience and Vulnerability: years 1–5, $2.9M/year; years 1–20, $57.3M total. (Reinvigorate community initiatives; similar to the Federal Emergency Management Agency's former Project Impact program.)
15. Guidelines for Earthquake Resilient Lifeline Systems: years 1–5, $5M/year; years 1–20, $100M total. (The gap between this task and current NEHRP activities may be larger than for any of the other tasks. One area of emphasis is on geographic distribution and network performance, as opposed to single components. This task may also require the largest budget increase for NEHRP, primarily because this area has been so underfunded.)
17. Knowledge, Tools, and Technology Transfer to/from the Private Sector: years 1–5, $8.4M/year; years 1–20, $168M total.
18. Earthquake Resilient Community and Regional Demonstration Projects: years 1–5, $15.6M/year; years 1–20, $1 billion total. (This is the single largest element in the road map, and the area that requires the most attention.)

ACEHR's recommendations are listed below, and are discussed in the body of the report.

Management, Coordination, and Implementation of NEHRP

- ***Recommendation 1***—The NEHRP Interagency Coordinating Committee (ICC) should work to ensure that the amount of funding requested for NEHRP in the President's budget each year is sufficient to permit full and timely implementation of the NEHRP strategic plan. At the present pace of plan implementation, the program will likely never meet its goals of providing the information and tools needed to achieve resilience nationwide.

- ***Recommendation 2***—A national road map is needed for developing the earthquake resilience of targeted lifelines that are critical to the Nation's security (e.g., in the energy, telecommunications, transportation, and water sectors) and community resilience. The NEHRP Office should focus on understanding and improving lifeline services during earthquakes to ensure delivery of critical resources and to support community resilience and restoration. This includes establishing performance objectives for lifelines under various seismic conditions, developing and promoting seismic guidelines for new and existing components and systems, and considering interdependencies and cascading effects.

Federal Emergency Management Agency

- ***Recommendation 1***—Support, encourage, and help facilitate the expanded involvement of the private sector, non-governmental organizations, and community stakeholders in earthquake and "All Hazards" disaster preparedness, mitigation, response, and recovery programs. Support efforts to provide the data and motivation needed to encourage non-governmental investment in community resilience.

- ***Recommendation 2***— Support and encourage State and local efforts to assess the seismic preparedness of public education facilities, and highlight schools and other essential community facilities as being among the highest priorities for mitigation.

- ***Recommendation 3***—Support the revitalization of State earthquake programs and provide strong support and leadership to State commissions to characterize and mitigate unacceptable risk in communities. Promote cost-effective risk management approaches to prepare and protect emergency facilities, critical infrastructure, and public buildings. Encourage the assessment of high-occupancy buildings with high community value using rapid screening techniques suitable for use on large building inventories.

- ***Recommendation 4***—Build on the lessons learned and on the observations and assessments made by researchers and earthquake professionals following recent seismic events. Recent earthquakes in Japan, Chile, New Zealand, and Haiti provided many important lessons and challenges.

National Institute of Standards and Technology

- ***Recommendation 1***—Continue to expand internal and external programs to effectively carry out the agency's roles in conducting applied research, in facilitating the implementation of cost-effective mitigation through codes and standards for the Nation's broad range of new and existing lifelines, buildings, and industrial structures, and in transferring technology for use in actual mitigation.
- ***Recommendation 2***—Continue to build multidisciplinary expertise within the agency and to foster relationships with other public agencies, private-sector entities, and consultants to accomplish and manage the applied research.

National Science Foundation

- ***Recommendation 1***—Commit to supporting, in close cooperation with the NEHRP Office, coordinated earthquake reconnaissance, technology transfer, and dedicated research programs to learn from significant earthquakes occurring throughout the world. Back this commitment to immediate reconnaissance with support for follow-up research enabling in-depth analysis of the tectonics, earthquake source, ground motion, engineering and socioeconomic consequences, emergency response, and long-term recovery.
- ***Recommendation 2***—Assess large-scale experimental facilities throughout the United States, including the equipment sites of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), to determine how best to ensure that sufficient state-of-the-art experimental capabilities for earthquake science and engineering are available. Continue support for the NEES laboratories, data repository, and remote participation and simulation capabilities, at least those elements that have demonstrated their effectiveness during the past 10 years of NSF support. Continue to support, at current or increased levels, research that uses these facilities.
- ***Recommendation 3***—Assess the effectiveness of current approaches to soliciting and coordinating research in comparison with past approaches, and develop a future approach that adopts best practices to achieve the NEHRP strategic plan. Coordinated research programs to efficiently achieve resilience objectives should be supported, including the Observatory Network.

U.S. Geological Survey

- ***Recommendation 1***—Develop earth science models and products needed to support the development of an approach for evaluating what changes should be made to the design ground motion used for the "International Building Code" to account for the medium-term (1–10 years) change in the seismic hazard in a region due to aftershocks following a major earthquake. Take the lead in establishing collaboration with the building code development community to address this issue. Pursue full implementation of the Advanced National Seismic System (ANSS), through use of both Federal and non-Federal funding, to ensure that the required data is available to implement the approach for characterizing the post-earthquake changes in seismic hazards (as well as hazard estimates used for many other essential purposes).

- ***Recommendation 2***—Work with public and private lifeline operators on the use of information available from early warning systems to help achieve earthquake resilience.

Call to Action

The NEHRP strategic plan and the newly developed NRC road map recognize that the traditional NEHRP goal of protecting lives and reducing damage needs to be expanded to improving earthquake resilience. Our problems will not be fixed overnight. Making progress will require long-term and dedicated efforts. However, the consequences will be less severe if we start applying meaningful and effective efforts toward fully implementing the NEHRP strategic plan now. If we don't, the consequences could be catastrophic and entire communities may never recover.

ACEHR recognizes that the Nation's ability to fund discretionary programs is severely challenged and that the expansion of such programs is often considered unacceptable. This reaction, however, appears to be inconsistent with the fiscal year 2013 Federal budget request now under consideration in Congress. It is a greatly expanded budget that reportedly addresses the priorities of the Nation while actually decreasing funding levels to NEHRP overall. Developing a disaster-resilient Nation should be among the program efforts that are worthy of expansion. The cost of doing otherwise is staggering.

ACEHR strongly urges the ICC to take steps toward arresting the growth of the Nation's vulnerability to seismic hazards by starting to implement the new NRC road map and to secure the resources needed for its ongoing implementation.

Call to Action (ALTERNATE version suggested by Yumei)

U.S. citizens face a catastrophic threat with tens of thousands of fatalities, over $100 billion of direct losses, and many years of socioeconomic disruption from impacted critical infrastructure at risk in a single large earthquake. Unless meaningful actions are taken by NEHRP on ACEHR's 2012 recommendations, the American public and our communities will continue to be exposed to greater and greater life-safety and lifestyle risk.

ACEHR agrees with the NEHRP strategic plan and the newly developed NRC road map that the traditional NEHRP goal of protecting lives and reducing damage needs to be expanded to meet an adequate level of earthquake resilience in the United States. We recognize that there are extraordinary challenges and these urgent problems will not be fixed overnight. Yet, NEHRP is accountable for making progress with tangible and transparent results for the American people. This will require added long-term and dedicated efforts by NEHRP.

ACEHR recognizes that the Federal Government's ability to fund discretionary programs is severely challenged and that the expansion of such programs is often considered unacceptable. To this end, the cost of inaction on ACEHR's 2012 recommendations would be even more detrimental.

ACEHR strongly urges the ICC to arrest the growth of the Nation's vulnerability to harmful earthquakes by embracing ACEHR's 2012 recommendations and securing the resources needed for their immediate implementation. It is imperative for NEHRP to start applying meaningful and effective efforts toward fully implementing the NEHRP strategic plan now. If we don't, the consequences will be staggering and entire communities in our Nation will never recover.

Introduction

The National Earthquake Hazards Reduction Program (NEHRP), first authorized in 1977, is embodied in Public Law 108–360. The program has grown to embrace an overarching vision of *a nation that is earthquake-resilient in public safety, economic strength, and national security,* and its mission *to develop, disseminate, and promote knowledge, tools, and practices for earthquake risk reduction—through coordinated, multidisciplinary, interagency partnerships among the NEHRP agencies and their stakeholders—that improve the Nation's earthquake resilience in public safety, economic strength, and national security*.

NEHRP is a highly successful program that for more than 30 years has uniquely contributed to improving earthquake awareness and preparedness in the United States and around the world. Through its four member agencies, it has significantly advanced our understanding of the earthquake process and related hazards and risks. This enhanced understanding has led to earthquake-safe design and construction techniques that when properly applied serve to secure communities against catastrophic failure. The earthquake community is beginning to understand how to best deal with seismic hazards and risks, and today, there is a growing understanding that we need to expand our goals from safety to resilience.

The differing impacts of the recent earthquakes in Haiti, Chile, New Zealand, and Japan starkly illustrate the importance of what NEHRP is trying to achieve in the United States and the benefits of understanding and preparedness. The differences in death tolls and in the speed of recoveries strongly validate a national commitment to earthquake risk reduction and the advantages of preparing for recovery.

Resilience—the Twenty-First-Century Goal for NEHRP

NEHRP has been committed since its inception to protecting lives through pre-event planning and mitigation of risks. Many program efforts, such as in seismic monitoring, seismic mapping, building code development, risk mitigation, and emergency preparedness have helped to provide a solid framework for community development and disaster planning. Yet serious gaps in these efforts do exist and these are reflected in the current NEHRP strategic plan for 2009–2013. For example, the vast majority of the existing physical infrastructure was constructed to inadequate seismic safety standards, well below current standards for new construction; even the new standards focus on life safety and are not sufficient to achieve earthquake resilience. Most buildings will suffer costly damage in a major earthquake, and critical lifelines (e.g., highways, ports, water supply systems, electricity grids, and telecommunications networks) will not provide their intended services for weeks or months after such an earthquake. The Nation lacks the information and tools needed to address these deficiencies and target the areas needing cost-effective and affordable rehabilitation.

There is growing recognition that communities need more than the capacity to be self-sufficient for 72 hours following an earthquake or other disaster. They need to be able to quickly recover, that is, to be disaster resilient. This concept has been discussed by earthquake professionals for years and multiple definitions, approaches, and frameworks have been proposed.

Goal C in the current NEHRP strategic plan, which was developed in 2008, focuses on improving the earthquake resilience of communities nationwide. In 2009, the NEHRP Advisory Committee on Earthquake Hazards Reduction (ACEHR) authored the report "Achieving National Disaster Resilience through Local, Regional, and National Activities." The following year, the National Institute of Standards and Technology (NIST) commissioned the National Research Council (NRC) to develop a road map for earthquake hazard and risk reduction that would lead to national earthquake resilience. The resulting NRC report, "National Earthquake Resilience: Research, Implementation, and Outreach," was published in 2011 and outlines a thoughtful and comprehensive road map that uses the following working definition for national earthquake resilience:

> A disaster-resilient nation is one in which its communities, through mitigation and pre-disaster preparation, develop the adaptive capacity to maintain important community functions and recover quickly when major disasters occur.

The NRC report endorsed the NEHRP strategic plan for 2009–2013 and identified 18 specific tasks that could be implemented over a 20-year period to achieve national earthquake resilience. These tasks are listed below along with the NRC's cost estimates for the first 5 years of work on each task (average cost per year) and for the entire 20-year implementation period (total cost for task implementation). During the first 5 years of implementation, the total annualized cost for all tasks would be just over $300 million per year.

1. Physics of Earthquake Processes: years 1–5, $27 million (M)/year; years 1–20, $585M total.
2. Advanced National Seismic System (ANSS): years 1–5, $66.8M/year; years 1–20, $1.3 billion total.
3. Earthquake Early Warning: years 1–5, $20.6M/year; years 1–20, $283M total.
4. National Seismic Hazard Model: years 1–5, $50.1M/year; years 1–20, $946.5M total. (This is the underpinning for U.S. building codes and a high point of NEHRP technology transfer.)
5. Operational Earthquake Forecasting: years 1–5, $5M/year; years 1–20, $85M total. (The community is working with tools to provide long-term (30-year-plus) models. Beyond 20 years, the costs are not known.)

6. Earthquake Scenarios: years 1–5, $10M/year; years 1–20, $200M total. (Scenarios are a valuable planning tool, and help make the earthquake risk real to communities.)
7. Earthquake Risk Assessments: years 1–5, $5M/year; years 1–20, $100M total.
8. Post-earthquake Social Science Response and Recovery Research: years 1–5, $2.3M/year. (No estimate for 20 years; will be reviewed after 5 years.)
9. Post-earthquake Information Management: years 1–5, $1M/year; years 1–20, $14.6M total. (May evolve into a true multi-hazard system.)
10. Socioeconomic Research on Hazard Mitigation and Recovery: years 1–5, $3M/year; years 1–20, $60M total. (Potential economic cascade if losses become too great in any one community.)
11. Observatory Network on Community Resilience and Vulnerability: years 1–5, $2.9M/year; years 1–20, $57.3M total. (Reinvigorate community initiatives; similar to the Federal Emergency Management Agency's former Project Impact program.)
12. Physics-based Simulations of Earthquake Damage and Loss: years 1–5, $6M/year; years 1–20, $120M total. (Integrate knowledge gained in tasks 1, 13, 14, and 16.)
13. Techniques for Evaluation and Retrofit of Existing Buildings: years 1–5, $22.9M/year; years 1–20, $543.6M total.
14. Performance-based Engineering (PBE) for Buildings: years 1–5, $46.7M/year; years 1–20, $891.5M total.
15. Guidelines for Earthquake Resilient Lifeline Systems: years 1–5, $5M/year; years 1–20, $100M total. (The gap between this task and current NEHRP activities may be larger than for any of the other tasks. One area of emphasis is on geographic distribution and network performance, as opposed to single components. This task may also require the largest budget increase for NEHRP, primarily because this area has been so underfunded.)
16. Next-Generation Sustainable Materials, Components, and Systems: years 1–5, $8.2M/year; years 1–20, $334.4M total.
17. Knowledge, Tools, and Technology Transfer to/from the Private Sector: years 1–5, $8.4M/year; years 1–20, $168M total.
18. Earthquake Resilient Community and Regional Demonstration Projects: years 1–5, $15.6M/year; years 1–20, $1 billion total. (This is the single largest element in the road map, and the area that requires the most attention.)

ACEHR unconditionally endorses the NRC road map and congratulates the NEHRP Interagency Coordinating Committee (ICC) and NIST for commissioning its development. We agree with the NRC recommendation that all 18 tasks be initiated immediately and be implemented in a manner that balances practical activities aimed at enhancing resilience with research aimed at strengthening the knowledge on which resilience measures are based. We are surprised that the strong and fully justified recommendations of the NRC report have not led to increased levels of funding for NEHRP. Unfortunately the opposite is true. The President's 2013 budget recommends lower funding levels overall for NEHRP despite overall increases in many other programs reported to be of national significance.

Preparation and Organization of This Report

ACEHR was established in the congressional reauthorization of NEHRP in 2004, and was charged to oversee the program in four specific areas—new trends and developments, effectiveness, needed revisions, and management. By statute, ACEHR was formed of non-Federal employees representing research and academic institutions, industry standards development organizations, State and local government, and financial communities across all related scientific, architectural, and engineering disciplines.

ACEHR was directed to report to the ICC within 1 year of its formation and at least once every 2 years thereafter, with due consideration given to the recommendations of the U.S. Geological Survey's (USGS) Scientific Earthquake Studies Advisory Committee (SESAC). ACEHR first met in May 2007 and has filed reports every year since 2008. The committee has prepared comprehensive reports every other year beginning in 2008 and correspondence-based updates in the alternate years. This 2012 report is a comprehensive update to the 2010 report and is based on the briefings we have received at our meetings, the NRC road map, and the professional activities and perceptions of the committee members. Since preparing its last report, ACEHR has met face to face for 2-day sessions in April and November 2011, and held conference calls in December 2011 and April and June 2012. Summaries of all of these meetings and materials representing all reports and presentations delivered to the committee are available at www.NEHRP.gov.

This report is a brief synthesis of the committee's observations, conclusions, and recommendations related to the current status of NEHRP. It does not attempt to repeat information received by ACEHR concerning NEHRP's activities to date. That information is adequately addressed in NEHRP's annual reports and strategic plans. This report also does not attempt to outline the process used to develop the recommendations it presents, as that is well noted in the meeting summaries. For the report, ACEHR has developed a set of key recommendations derived from areas within the NEHRP strategic plan and the new NRC road map that are not being addressed, and from recommendations made in ACEHR's 2010 report that need further attention.

While the committee fully endorses the NRC road map, we realize that funding for its full implementation is years off due to budget constraints. We have selected 5 of the 18 tasks specified in the NRC report for focused attention by NEHRP. These tasks go beyond current NEHRP activities and should be initiated, but not at the expense of ongoing program work. The tasks (NRC tasks 10, 11, 15, 17, and 18) concern technology transfer to the community, socioeconomic research, a network of observatories on community resilience and vulnerabilities, and specific attention to the Nation's lifeline systems. Each of these areas represents a critical choke point in the process of achieving national earthquake resilience.

This report is organized around the task areas assigned to ACEHR by NEHRP's authorizing legislation. The next section, "Program Effectiveness and Needs," is largely organized by NEHRP agency and focuses on past and current accomplishments, future plans, and modifications needed to address the goals of the 2009–2013 NEHRP strategic plan. The recommendations that are included for each agency relate to augmenting agency activities beyond current efforts. An additional subsection, entitled "Management, Coordination, and Implementation of NEHRP," provides complementary assessments of the NEHRP Office within NIST, the effectiveness of the Program Coordination Working Group (PCWG), and the intrinsic value of the ICC, which is composed of the directors of the NEHRP agencies and the directors of the White House's Office of Management and Budget and Office of Science and Technology Policy.

The appendix, "Trends and Developments in Science and Engineering," updates ACEHR's observations relating to eight disciplines that are highly relevant to NEHRP. These observations point to areas that are developing and trends that extend beyond the period addressed in NEHRP's current strategic plan. They are not exhaustive summaries of all work being undertaken in each discipline of the earthquake professions. Rather, they provide the NEHRP agencies with an overview of recent achievements that have been made and the issues and challenges facing the Nation, and include suggestions about where future strategic priorities should be focused.

ACEHR represents a uniquely qualified cross section of the earthquake professions, and the personal knowledge, experience, and vision of its members, combined with the information presented to the committee, form the basis for this report.

Program Effectiveness and Needs

Management, Coordination, and Implementation of NEHRP

Since 2005 NEHRP has benefited from the strong, focused, and collaborative leadership of the NEHRP Office, housed in NIST. The "Strategic Plan for the National Earthquake Hazards Reduction Program: Fiscal Years 2009–2013" has proven to be an important and lasting tool, setting direction and fostering collaboration among the PCWG and ICC. Since the last comprehensive ACEHR report to the ICC in 2010, additional progress has continued to be made to implement the goals set forth in the strategic plan. In 2011 ACEHR recognized the NEHRP Office for addressing several areas of concern: enhancing coordination between NEHRP and other Federal agencies, developing a road map for community resilience, hiring highly qualified and dedicated staff, and establishing an electronic library for post-earthquake information. The NEHRP Office is to be commended for accomplishing so much with such limited resources. 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.

Recommendation 1

> Once again, ACEHR calls on the ICC to work to ensure that the amount of funding requested for NEHRP in the President's budget each year is sufficient to permit full and timely implementation of the NEHRP strategic plan. At the present pace of plan implementation, the program will likely never meet its goals of providing the information and tools needed to achieve resilience nationwide.

In reviewing the recommendations that were included in our 2010 report, we are dismayed to note that once again, the President's budget does not include increased funding for NEHRP. While we appreciate the difficulties in the current economic and political climate, funding in the President's budget continues to be insufficient to permit full and timely implementation of the NEHRP strategic plan or the administration's goal of national preparedness. ACEHR registered its concern about current funding levels in 2010 and 2011 but unfortunately, the funding situation has gone from bad to worse. In 2010 we stated that NEHRP's ability to implement its 2009–2013 strategic plan fully was hampered by funding levels that were well below congressional authorizations.

The NEHRP reauthorizing legislation under consideration in the House of Representatives, H.R. 3479, was introduced in the fall of 2011 by Representative Biggert. Subcommittee hearings were held in December 2011, but the bill has not yet been brought to the House floor for a vote. Unfortunately, this legislation includes significant cuts to the NEHRP funding authorized for NIST and the Federal Emergency Management Agency (FEMA). This is of great concern to ACEHR. NIST has been carrying out NEHRP lead-agency responsibilities for over 7 years without additional funding. Instead of augmenting the NIST authorization to cover these significant lead-agency responsibilities, the proposed legislation sends a message that these activities are of little to no value. ACEHR believes that there is a limit to the effectiveness of the lead agency when its funding is continuously jeopardized, and that that limit has been reached.

S. 646, which reauthorizes NEHRP and other Federal natural hazards reduction programs, was introduced in the Senate on March 17, 2011, by Senators Boxer and Feinstein. This legislation does not include the significant cuts to NIST and FEMA contained in the House bill. The Senate bill also transfers responsibility for the leadership of post-earthquake investigations from USGS to NIST, a move that ACEHR has endorsed as appropriate given NIST's role as the NEHRP lead agency. We are, however, particularly concerned that this new responsibility is unfunded. Without dedicated funding, it is unlikely that NEHRP will be able to ensure a smooth and effective Federal response following future earthquakes, establish access protocols with communities at risk, develop pre-event collaboration and coordination with other organizations and agencies, utilize the most effective communication and data-gathering tools, and ensure multidisciplinary participation. The House bill retains USGS as the lead agency for post – earthquake investigations. Should these bills pass out of their respective chambers, they will be directed to a conference committee, where efforts will be made to resolve these numerous differences.

Regardless of which agency is given leadership of earthquake investigations, it will fall to NIST as the NEHRP lead agency to ensure broad dissemination of field observations, to identify areas where findings have building code implications, and to report on code-modification outcomes to Congress. ACEHR is looking forward to a post-earthquake investigations planning workshop that NIST plans to convene in 2012; it should provide more information about the range and scope of NIST's plans pertaining to future earthquake coordination.

Recommendation 2

> The NEHRP Office should focus on understanding and improving lifeline services during earthquakes to ensure delivery of critical resources and to support community resilience and restoration. This includes establishing performance objectives for lifelines under various seismic conditions, developing and promoting seismic guidelines for new and existing components and systems, and considering interdependencies and cascading effects.

President Obama has issued Presidential Policy Directive 8, which is aimed at strengthening the resilience of our Nation. There are many existing and proposed NEHRP projects and tasks that support the President's priorities and complement the U.S. Department of Homeland Security (DHS) National Preparedness Goal. As NEHRP's lead agency, NIST is in an opportune position to utilize its unique capabilities to enhance the mitigation knowledge base. Building on the NEHRP strategic plan and the NRC's 2011

report “National Earthquake Resilience: Research, Implementation, and Outreach,” there are clear directions for an all-nation approach to earthquake resilience.
The NRC report was the outcome of a study begun in 2009 at the request of NIST to build on the NEHRP strategic plan. The intent was to develop a road map for addressing national needs in research, knowledge transfer, implementation, and outreach that, if addressed, would provide the tools to make the United States more earthquake resilient. The NRC was also asked to update and validate information issued earlier by the Earthquake Engineering Research Institute in its 2003 report “Securing Society Against Catastrophic Earthquake Losses.” Produced with support from the National Science Foundation (NSF), this plan outlined and costed a 20-year program of research and outreach designed to prevent catastrophic earthquake losses and strengthen the disaster resilience of communities.

The 2011 NRC report identifies 18 tasks that must be undertaken to fully implement the NEHRP strategic plan and achieve national earthquake resilience over the next two decades. The study estimates that the cost to carry out these tasks would total about $307 million a year during the first 5 years of task implementation. Regrettably, at $122 million for fiscal year (FY) 2012, NEHRP’s current funding falls far below this level.

The 18 tasks identified in the NRC study are critical to full implementation of the NEHRP strategic plan and a more fully resilient Nation. Of the 18 tasks, ACEHR recommends 5, in particular, for focused attention by NEHRP. As indicated in table 1, NEHRP has a crucial role in coordinating each of these tasks. The NEHRP Office also has an important role to play, to support and encourage not only the NEHRP agencies, but also other organizations in the public and private sectors to adopt the tasks outlined in the NRC report and ensure that advances in knowledge and technologies are implemented throughout the country to improve earthquake mitigation, response, and recovery.

Table 1—NEHRP agency roles in the five NRC tasks emphasized by ACEHR

Tasks from NRC report		NEHRP agency involvement			
No.	**Title**	**NIST**	**USGS**	**NSF**	**FEMA**
10	Socioeconomic research on hazard mitigation and recovery	X		X	X
11	Observatory network on community resilience and vulnerability	X		X	X
15	Guidelines for earthquake-resilient lifeline systems	X	X		X
17	Knowledge, tools, and technology transfer to public and private practice	X	X	X	X
18	Earthquake-resilient communities and regional demonstration projects	X			X

NRC task 15 specifically highlights the need to focus on understanding and improving lifeline systems that are critical to the Nation's security, including those in the energy, telecommunications, transportation, and water sectors. ACEHR has been concerned for some years about the absence of a road map for developing the earthquake resilience of these crucial resources.

The NRC study notes the need to conduct collaborative research to better characterize infrastructure network vulnerability and resilience, and to provide a basis for reviewing and updating existing standards and guidelines. It also calls for demonstration projects to be put into place in the near future. We are pleased to see that the NEHRP Office plans to hold a lifelines research needs workshop in FY 2012 and look forward to learning how the workshop will guide future research and implementation that will ensure continued operation of critical lifelines, enabling speedy recovery of communities in the aftermath of future earthquakes.

Federal Emergency Management Agency

Recommendation 1

> Support, encourage, and help facilitate the expanded involvement of the private sector, non-governmental organizations (NGOs), and community stakeholders in earthquake and "All Hazards" disaster preparedness, mitigation, response, and recovery programs. Support efforts to provide the data and motivation needed to encourage non-governmental investment in community resilience.

In most disasters, the first response and initial relief comes from within the local community and is delivered by individuals, families, businesses, and community- and faith-based organizations. The private and non-governmental sectors have proven that they can and do play a fundamental role in building the resilience of society against the potential impacts of disasters. The non-governmental sector provides resources, expertise, and essential services supporting the economic base and critical infrastructure on which a community depends. Corporations can support successful, reasonably sized risk reduction projects in the communities where their workers, suppliers, or customers live. Natural hazard diplomacy also offers opportunities for socially responsible private companies to help their communities reduce risk from natural hazard events. The benefits and rationale used to encourage private-sector-stakeholder investment in resilience should be tied to individual and corporate values.

Businesses often utilize benchmark studies to support investment decisions. ACEHR encourages FEMA to consider funding or sponsoring a study on the benefits of private sector investment in pre-disaster mitigation based on the highly successful FEMA funded 2005 Multihazard Mitigation Council study on Federal Government investment in pre-disaster mitigation (4:1 benefit/cost ratio). ACEHR also encourages the ongoing development and promulgation of case studies covering community disaster preparedness structures that integrate a wide cross section of community stakeholder organizations and neighborhood interests. The collaborative efforts of these organizations produce innovative local disaster preparedness, mitigation, response, and recovery programs. These programs are focused and formatted to address the specific needs of local residents, encourage the sharing of information, and promote cooperation in the creation of innovative, repeatable, and sustainable community resilience projects.

Recommendation 2

> Support and encourage State and local efforts to assess the seismic preparedness of public education facilities, and highlight schools and other essential community facilities as being among the highest priorities for mitigation.

Schoolchildren have a right to learn in buildings that are safe from earthquakes. Protecting our schools and children from the impact of natural hazards is one of the cornerstones of socially responsible and resilient communities. A comprehensive approach to resilience requires that education—both facilities and course content—fulfill an essential community role. FEMA, through its support and ties to the earthquake consortia, State earthquake preparedness coordinators, and State earthquake policy commissions, should emphasize the critical importance of schools and other essential community facilities. FEMA should encourage the development of non-technical reports aimed at school administrators, and adoption of State and local policies and programs on achieving student safety in dangerous schools.

Public schools built prior to modern seismic building codes share seismic deficiencies common to other buildings of the same structural types and ages, but the community importance of schools brings considerations to bear that justify priority attention. School buildings tend to remain in use longer than comparable structures in private ownership and tend to receive less frequent and less predictable capital renewal investment to address maintenance issues that can jeopardize structural performance. Schools can also play a critical role in a community's recovery from a disaster, when they may be called upon to function as temporary shelters or service centers during relief operations. Encouraging the mitigation of collapse-prone schools will help to reassure local communities, reduce the impact of earthquakes on schools, and accelerate the resumption of school services following a disaster. Information on the causes and effects of earthquakes and other natural hazards and on corresponding preparedness measures should be a standard component of educational coursework. Such education provides the direct societal benefit of bringing the message on disaster preparedness into the home.

FEMA should support this recommendation through the provision of recommended standards and guidance for school-facility mitigation, updated guidelines for hazard-related curricula and teacher training, and FEMA technical assistance and financial support for state earthquake programs.

Recommendation 3

> Support the revitalization of State earthquake programs and provide strong support and leadership to State commissions to characterize and mitigate unacceptable risk in communities. Promote cost-effective risk management approaches to prepare and protect emergency facilities, critical infrastructure, and public buildings. Encourage the assessment of high-occupancy buildings with high community value using rapid screening techniques suitable for use on large building inventories.

Funding for State earthquake programs is vital to sustaining State and local earthquake preparedness and education functions. The involvement, commitment, and contribution of local and national community stakeholders are needed to support these funding requirements. Research, including case studies of socioeconomic policies for cost-effective mitigation, will help to guide the effective use of available funds at the community level and promote the adoption of cost-effective strategies and programs among stakeholders.

An important element of community resilience is the establishment of proactive disaster preparedness and mitigation programs by utility and critical infrastructure providers. These providers need encouragement, direction, and recognition to gain support from local and national community stakeholders for the implementation of new preparedness and resilience action plans.

Assessing and strengthening essential community facilities (emergency operations centers, fire and police stations, schools, shelter facilities, and hospitals) are also important elements of community resilience and a needed focus area for collaborative funding and pre-disaster mitigation grants. Essential facilities and critical infrastructure will also benefit from expanding the development and accessibility of seismic event consequence modeling (example: HAZUS) among building architects, engineers, developers, and owners, and among local government agencies and infrastructure providers.

Recommendation 4

> Build on the lessons learned and on the observations and assessments made by researchers and earthquake professionals following recent seismic events. Recent earthquakes in Japan, Chile, New Zealand, and Haiti provided many important lessons and challenges.

With our limited understanding of the recurrence of natural disasters (earthquakes, hurricanes, floods), we need to examine how we can better design and prepare for extreme impacts and moderate probable events and cascading failures during disasters. In communities with infrequent but recurrent disasters, we need to review practices that will help sustain community preparedness while educating community stakeholders (individuals, families, government officials).

Information gathered and assessments of recent earthquakes should be incorporated into a process of continuous improvement and dissemination, contributing toward more effective risk assessment, mitigation, and community resilience measures. The information gathered can be used for many purposes including the improvement of techniques used for the development of probabilistic hazard assessments that incorporate lower probability (outlier) events. Earthquake preparedness practices and potential-impact assessments should be reviewed and considered for updating along with lifeline standards. The information gathered from recent events could contribute toward identifying and supporting improved technology transfer inside and outside the United States. We should examine and assess the standards of performance for current and proposed alert and warning systems with respect to monitoring, analysis, dissemination (including pre-event public education), and message content.

There are many lessons related to the post-event management of social, economic, communication, health, sheltering, logistic, and educational issues that should also receive attention at local, State, and Federal levels. Post-disaster sheltering and housing remain significant challenges during widespread events. Guidance and case studies concerning these areas need to be updated. Research findings, standards, advocacy, and training developed as a result of the lessons learned from recent seismic events can be effectively utilized to increase the disaster resilience of government, NGOs, and the private sector.

By carrying out the four recommendations discussed above along with its existing work under NEHRP, FEMA can play the central role that it needs to play in helping to implement the NEHRP strategic plan and the NRC tasks. Table 2 shows how the recommendations contribute to the five NRC tasks emphasized by ACEHR.

Table 2—ACEHR's recommendations for FEMA mapped to the NRC tasks emphasized by ACEHR

Tasks from NRC report		ACEHR's recommendations for FEMA			
No.	**Title**	**#1**	**#2**	**#3**	**#4**
10	Socioeconomic research on hazard mitigation and recovery	X		X	X
11	Observatory network on community resilience and vulnerability	X		X	
15	Guidelines for earthquake-resilient lifeline systems		X	X	
17	Knowledge, tools, and technology transfer to public and private practice	X	X	X	X

Table 2—ACEHR's recommendations for FEMA mapped to the NRC tasks emphasized by ACEHR

Tasks from NRC report		ACEHR's recommendations for FEMA			
No.	**Title**	**#1**	**#2**	**#3**	**#4**
18	Earthquake-resilient communities and regional demonstration projects	X	X	X	X

National Institute of Standards and Technology

Recommendation 1

> Continue to expand internal and external programs to effectively carry out the agency's roles in conducting applied research, in facilitating the implementation of cost-effective mitigation through codes and standards for the Nation's broad range of new and existing lifelines, buildings, and industrial structures, and in transferring technology for use in actual mitigation.

In the years before the 2004 NEHRP reauthorization, NIST's research role within NEHRP was not fully realized because of a very low level of funding. Two increments in funding, in FY 2007 and FY 2009 (from the American Competitiveness Initiative), have brought a substantial change to the NEHRP research program at NIST. Both the internal and extramural research programs are off to a successful start. This has resulted in meaningful technology transfer in the area of guideline and code development, as well as in the area of technical information that is directly applicable to the practicing engineering community as envisioned by NRC task 17 ("Knowledge, tools, and technology transfer to public and private practice"). The new research program staff is successfully implementing external research projects and is showing great promise on its internal research initiatives. To help ensure that meaningful technology transfer will continue into the future, NIST is in the process of evaluating its research plan for new and existing buildings. The resulting plan will guide the expansion of internal and extramural work over the next 8 years.

NIST has responsibility under the NEHRP strategic plan for applied research and development in earthquake engineering focusing on improving standards and codes for new and existing buildings, infrastructure, lifelines, and construction practices, as well as on measurement and evaluation tools for testing new methods and technologies. The need for this work was documented in the report prepared by the Applied Technology Council entitled "The Missing Piece: Improving Seismic Design and Construction Practices." As NEHRP's lead agency, NIST is also responsible for coordinating the program's efforts to promote implementation of risk reduction measures, support the development of performance-based earthquake engineering, ensure the use of social science research on hazard mitigation and recovery (as envisioned under NRC task 10, "Socioeconomic research on hazard mitigation and recovery"), coordinate Federal post-earthquake investigations, and make and track recommendations for changes in codes and standards of practice. Some of the research activities associated with these lead-agency responsibilities will also be carried out at NIST through its internal and extramural programs.

External research projects began in the fall of 2008, and more than two dozen projects have been funded to date. These projects have all been directed at high-priority objectives identified in prior planning. The results of numerous projects have already been published, and have been well received; for example, the six completed technical briefs, which are prime examples of deliverables envisioned by NRC task 17, have garnered compliments from practicing engineers as well as university faculty. Completed, active, and planned projects supporting advancements in technical standards for structural design and for performance-based earthquake engineering, such as the projects listed below, demonstrate that NIST is managing its research program to provide meaningful technology transfer to public and private practice and to cooperate and coordinate with the other NEHRP agencies.

- ATC-82/Task Order 9: "Selection and Scaling of Earthquake Ground Motions"
- ATC-89/Task Order 16: "Cost-Benefit Analysis of Codes and Standards for Earthquake-Resistant Construction in Selected U.S. Regions—Phase I (Memphis Area)"
- ATC-92/Task Order 19: "Chilean-U.S. Seismic Provisions and Design Comparisons"
- Task Order 23: "Analysis, Modeling, and Simulation for Performance-Based Seismic Engineering"
- Task Order 24: "Technical Brief: Mat Foundations"

Recommendation 2

> Continue to build multidisciplinary expertise within the agency and to foster relationships with other public agencies, private-sector entities, and consultants to accomplish and manage the applied research.

The four professional researchers added to the NIST staff in recent years have expertise in the key areas of structural engineering. The staff has been effective in defining and procuring NIST's external NEHRP research, and internal research projects on compatible high-priority topics are well under way, but it is still too early to measure the effectiveness of the internal research at NIST. Examples of statutory responsibilities and strategic plan tasks that have not been met because of a lack of funding include working with national standards developers to improve seismic safety standards for existing buildings and for many types of new and existing lifelines (as outlined in NRC task 15, "Guidelines for earthquake-resilient lifeline systems").

In light of the substantial changes in the content and format of design standards and model building codes in recent years, the subject of how to most effectively regulate construction to achieve the goals of economical resilience is deserving of a series of coordinated projects, focused on questions such as the following:

- What manner of design and construction provisions are least or most likely to be correctly understood, implemented, or enforced?
- Will special-purpose standards (for example, scope limited to a set of smaller building types) be efficient and effective, or simply ignored in favor of general-purpose standards?
- Have current model codes and standards unduly encumbered innovation that could lead to more economical or better resilience?

Some of this work may well fit better within FEMA's NEHRP activities, but the overall effort is clearly within the purview of NEHRP as a whole, and the economics program at NIST could be a key resource, as indicated in NRC task 10, if financial support were made available.

In support of NRC task 11, "Observatory network on community resilience and vulnerability," NIST can play a role by helping to establish the measurement metrics and the standardized data collection instruments and protocols. NRC task 18 calls for earthquake-resilient communities and regional demonstration projects. NIST's role in support of this task encompasses (1) providing socioeconomic data for use in assessing a baseline for a community's resilience capacity, (2) assisting in the identification of existing examples of resilience capacity by estimating its cost and broader implications, and (3) measuring the cost and effectiveness of various resilient actions.

Assisting the implementation of cost-effective measures for mitigation of seismic risk involves many technical disciplines, such as structural, geotechnical, and lifeline engineering, and has to be informed by research on communicating risk information and on strategies for adopting mitigation policies, such as economic incentives, well-enforced regulations and standards, and insurance. NIST faces a challenge: it must continue to develop expertise to both conduct the internal and manage the external components of the research program. This broad competence is also necessary to carry out the mandate to promote cost-effective mitigation. The staff, in large part, is in place to meet this challenge and must continue to grow into their roles to successfully carry out the research program. Planning for the future, which is under way, must also take into account the recommendations from the reviews of national needs for earthquake resilience, including the suggestions recently issued in the 2011 NRC report.

National Science Foundation

The NEHRP statutory responsibilities and strategic plan tasks assigned to NSF are distributed within the agency's Engineering and Geosciences Directorates. Social behavior and economic science research related to NEHRP is currently housed within the Engineering Directorate. In both Engineering and Geosciences, the research funded by NSF represents a combination of coordinated research programs and unsolicited proposals.

Recommendation 1

> Commit to supporting, in close cooperation with the NEHRP Office, coordinated earthquake reconnaissance, technology transfer, and dedicated research programs to learn from significant earthquakes occurring throughout the world. Back this commitment to immediate reconnaissance with support for follow-up research enabling in-depth analysis of the tectonics, earthquake source, ground motion, engineering and socioeconomic consequences, emergency response, and long-term recovery.

NEHRP and the earthquake professional communities have relied on NSF's support of post-earthquake reconnaissance to provide feedback regarding earthquakes and their effects on the natural and built environment, as well as field data on the effectiveness of mitigation, preparedness, emergency response, and recovery efforts. In recent years, NSF has focused on funding its Rapid Response Research (RAPID) grants, which support individual researchers in conducting reconnaissance on specific topics reported to be of interest for a particular earthquake. Coordination is primarily in the form of research coordination workshops involving the funded researchers. Technology transfer efforts appear to have diminished. Although ACEHR finds that important results are being achieved through the RAPID grants and recommends their continuation, the committee is concerned that funding for coordinated earthquake reconnaissance, post-earthquake technology transfer, and post-earthquake research has diminished, and this, in turn, is diminishing our learning from earthquakes. Such efforts, especially if broadly based and coordinated, are the most direct way to learn about the factors that contribute to or limit earthquake resilience in our communities, and are an effective vehicle for transferring knowledge on good practices to the public and private sectors.

ACEHR believes that earthquake reconnaissance needs to be supported by all NEHRP agencies in a collaborative and complete manner. Each agency's support needs to mirror their contribution to NEHRP; in this regard, NSF has a significant role. ACEHR encourages NSF to identify and fund an appropriate mechanism for coordinating earthquake reconnaissance, including the coordination of RAPID grants; identify and fund mechanisms for technology transfer following earthquakes with important lessons; and aggressively pursue funding opportunities for transformative engineering, social science, and geosciences research opportunities exposed by earthquakes.

Recommendation 2

> Assess large-scale experimental facilities throughout the United States, including the equipment sites of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), to determine how best to ensure that sufficient state-of-the-art experimental capabilities for earthquake science and engineering are available. Continue support for the NEES laboratories, data repository, and remote participation and simulation capabilities, at least those elements that have demonstrated their effectiveness during the past 10 years of NSF support. Continue to support, at current or increased levels, research that uses these facilities.

Experimental facilities are essential to increasing the resilience of the United States by supporting the development of better seismic hazard estimates, by building knowledge about the vulnerability of the natural and built environments, and by developing standards and innovative construction technologies to increase the resilience of our communities. These facilities include those invested in the study of fault friction, roughness, and other physical factors that are related to earthquake ruptures, as well as those designed to study the performance of the natural and built environment subjected to earthquake effects. Networked facilities linked with a dedicated and focused cyberinfrastructure enhances efficiency and remote access, thereby increasing and accelerating learning.

ACEHR notes that NSF has made a significant contribution to NEHRP by supporting the development, operation, and use of the large-scale simulation facilities of NEES. NEES plays a critical role in NEHRP by providing a network of physical and virtual facilities for large-scale testing of both vulnerable and resilient components and systems. NEES also provides simulation tools integrated with a central data repository and a cyber-platform for collaboration, NEEShub, that are accelerating learning from laboratory-based research. A secondary, though important, role of NEES is providing a continuing mechanism for international collaboration.

NEES operations have greatly improved in recent years, providing improved oversight and access to data. As a result, NEES has enabled giant advances in understanding the vulnerability of older systems; in developing new, highly resistant systems; and in advancing simulation capabilities. These advances are reflected in standards widely used by engineers nationally. NEES is approaching the tenth year of the original ten-year program. NSF is in the process of reviewing the performance of NEES and deciding a future path, and is considering input from the community and expert panels. ACEHR urges that resources be identified for continuing support of key successful elements of the NEES collaborator and its research programs.

Recommendation 3

> Assess the effectiveness of current approaches to soliciting and coordinating research in comparison with past approaches, and develop a future approach that adopts best practices to achieve the NEHRP strategic plan. Coordinated research programs to efficiently achieve resilience objectives should be supported, including the Observatory Network.

NSF has contributed substantially to NEHRP by providing mechanisms for collaboration among researchers in the social sciences, geosciences, and earthquake engineering. Major investments have been made, for example, in the Southern California Earthquake Center (SCEC) and the earthquake engineering research centers (EERCs), leading to transformative research on a grand scale. In the geosciences, SCEC has pooled the intellectual resources of multiple institutions to conduct fundamental research leading to time-dependent hazard assessments for the State of California, which if propagated to other regions will set the stage for a resilient Nation. In engineering and the social sciences, the EERCs also pooled resources of multiple institutions to develop and advance performance-based earthquake engineering and seismic resilience methodologies that will be key to advancing national resilience.

NSF also has supported smaller coordinated research programs, such as efforts aimed at the mitigation of existing hazardous construction, the development of innovative precast construction, and maximizing learning from specific earthquakes. Since the sun-setting of the EERC program, multidisciplinary research in earthquake engineering has decreased markedly. Funding for coordinated programs on directed topics, including research following earthquakes, also has diminished.

ACEHR believes that the foundations for many of the most important achievements in the earth sciences, seismic hazard mitigation, performance-based earthquake engineering, lifeline engineering, and the social sciences can be traced directly to NSF-funded centers and other coordinated research programs. Coordinated research will play an important role in efficiently exploring the multi-disciplinary components of community seismic resilience. In particular, the observatory network recently recommended in the NRC 2011 report on national earthquake resilience (see task 11) would be an excellent mechanism for achieving increased collaboration. Additionally, centers and coordinated activities also provide opportunities to engage broad stakeholder communities in NEHRP's efforts. ACEHR encourages NSF to continue support for coordinated research activities and to find avenues for increasing such activities.

Community seismic resilience depends on the vulnerability of complex systems, as well as preparedness measures taken to respond and recover. The role of coordinated research programs in efficiently achieving resilience objectives should be considered. In particular, the observatory network recently recommended in the NRC's 2011 report on national earthquake resilience (see task 11) would be an excellent mechanism for achieving this increased level of collaboration.

U.S. Geological Survey

Recommendation 1

> Develop earth science models and products needed to support the development of an approach for evaluating what changes should be made to the design ground motion used for the "International Building Code" to account for the medium-term (1–10 years) change in the seismic hazard in a region due to aftershocks following a major earthquake. Take the lead in establishing collaboration with the building code development community to address this issue. Pursue full implementation of the Advanced National Seismic System (ANSS), through use of both Federal and non-Federal funding, to ensure that the required data is available to implement the approach for characterizing the post-earthquake changes in seismic hazards (as well as hazard estimates used for many other essential purposes).

Earthquake resilience is defined by the ability to recover from large seismic events. Recent experiences following major earthquakes in New Zealand and Japan have highlighted a key issue for recovery: Are intermediate-term changes to building-code design ground motions needed to address the elevated seismic hazard that is present for 1 to 10 years after large earthquakes due to aftershocks and triggered events?

In Christchurch, New Zealand, the 2010 Darfield earthquake caused moderate damage, but the 2011 Christchurch earthquake that occurred 5 months later caused extensive damage, impacting pipelines and structures that had just been repaired. Over the next year, aftershocks from the Christchurch earthquake continued to cause additional damage. Deciding on the appropriate modifications to the building code to address this intermediate-term increase in the seismic hazard in Christchurch has added to the delay in the recovery.

Although USGS has been active in real-time earthquake hazard studies as a participant in the ongoing Uniform California Earthquake Rupture Forecast (UCERF-3) project, the earthquake engineering community has not yet become involved. Scientists need to work with earthquake engineers to consider the practical issues affecting reconstruction following a major earthquake that generates an energetic aftershock sequence. Should higher design ground motion values be required in the intermediate term? If so, should these higher values be reduced in the long term? Alternatively, should some reconstruction be delayed until the hazard has reduced to an acceptable level? Also, should the procedures used to inspect and tag buildings for safety and continued occupancy following large earthquakes be adjusted to reflect the expected performance of those buildings in an environment of elevated seismic hazard? These issues should be addressed now, using earthquake scenarios as examples, so that there is a method that can be implemented following a major earthquake without delaying the recovery.

A robust national seismic monitoring system is required to supply the data needed to accurately characterize the changes in seismic hazard that can follow large earthquakes.

Full implementation of ANSS is also urgently needed for a host of other reasons impacting the fields of emergency management, earthquake engineering, and earthquake science. For example, one of the main opportunities for improving seismic hazard estimates over the next 10 years concerns understanding and accounting for regional differences in ground motions in the Eastern United States. This type of regionalization requires a robust and dense network of seismic monitoring stations as envisioned in ANSS.

Only a small fraction of the authorized and required funding for ANSS has been appropriated by Congress. ACEHR continues to recommend full Federal funding of this critical earthquake infrastructure, but given the current budget pressures, other funding sources (non-Federal) should also be pursued as described in the "Earth Science" portion of the appendix.

Recommendation 2

> Work with public and private lifeline operators on the use of information available from early warning systems to help achieve earthquake resilience.

USGS has been developing a prototypical earthquake early warning (EEW) system and is working to test it in 2012. EEW technology has the potential to improve the earthquake resilience of lifelines (the focus of NRC task 15, "Guidelines for earthquake-resilient lifeline systems") if lifeline operators can be shown how the system can best work for them. There is a need for information exchange between USGS and lifeline operators with regard to how the different lifeline systems could use EEW information. While it is clear how some lifelines, such as railroads, could use this information, it is less clear for others, such as utilities.

ACEHR recommends that USGS continue to develop and test the EEW system and, as this work proceeds, conduct workshops with lifeline operators to discuss the practical uses and limitations of EEW information.

Finally, we note that ACEHR is instructed under its charter to consider the recommendations of the USGS SESAC in developing its own recommendations. We endorsed and included the latest available recommendations from SESAC to USGS in our 2008 report, and we look forward to receiving the recommendations that SESAC has been developing for its 2011 report.

Appendix
Trends and Developments in Science and Engineering

ACEHR is charged to report on new trends and developments related to NEHRP. Time constraints and the size of the committee do not permit this to be an exhaustive treatment of the topic, though the committee's unique composition does permit an expert-based overview. The presentation that follows is organized around the key disciplines that form the earthquake professions and should serve to provide a concise picture of the possible future. Included are both suggested refinements to tasks in the 2009–2013 NEHRP strategic plan and new tasks that should be considered for future plans.

Social Science

This section addresses applied research developments in sociology, psychology, political science, economics, organizational management, public administration, public health, and land use planning that are related to seismic risk reduction. The social scientists conducting this research are increasingly focusing on hazard vulnerability, disaster recovery, and hazard mitigation, but still greater attention is needed in these areas to achieve NEHRP strategic plan objectives 3 ("Advance understanding of the social, behavioral, and economic factors linked to implementing risk reduction and mitigation strategies in the public and private sectors"), 9 ("Improve the accuracy, timeliness, and content of earthquake information products"), and 13 ("Increase public awareness of earthquake hazards and risks").

Developments

NEHRP agencies have continued to support seismically relevant social science research during the past 2 years. This research has primarily been supported by NSF funding, especially the Infrastructure Management and Extreme Events Program in the Engineering Directorate and the Decision, Risk, and Management Sciences Program in the Social, Behavioral, and Economic Sciences Directorate. NSF RAPID grants awarded after the major earthquakes in Haiti and Chile in 2010 and in New Zealand and Japan in 2011 have focused on immediate (seconds to minutes) and short-term (hours to days) behavioral responses to these events. Other NSF grants have supported research directed toward long-term post-impact issues such as community recovery and hazard mitigation. In addition to projects that have focused specifically on the aftermath of earthquakes, NSF has funded studies of other hazards that will generate findings that can be applied to earthquake hazards. These include studies of the effects of risk communication and risk perception on a variety of hazard adjustments (pre-impact actions to reduce damage, casualties, and disruption) such as purchasing insurance.

This research has continued to develop the scientific understanding of individuals' and organizations' immediate and short-term responses to earthquake shaking. Recent research has shown that authorities' recommendations to "drop, cover, and hold on" are implemented by only a minority of those in the earthquake impact area. Consequently, more research is needed to better understand why community hazard awareness programs appear to have such limited effectiveness. In addition, NEHRP research has advanced social scientists' understanding of the processes by which communities adopt mitigation measures such as land use regulations and building codes, but more research is needed before this knowledge can produce practical results. Finally, social science research continues to examine the process of pre-impact disaster recovery planning, but here too, more research is needed to identify ways in which more communities can be induced to engage in this form of planning.

Needs

Recent reports have identified a number of priorities for social science research relevant to seismic risk reduction (CDRSS, 2006; CNER, 2011; EERI, 2005; SDR, 2005). Six especially important issues and challenges are (a) hazard/vulnerability analysis, (b) hazard awareness and public outreach, (c) hazard mitigation and emergency preparedness, (d) inducements for household and business adoption of hazard risk reduction measures, (e) earthquake early warning and aftershock warnings, and (f) disaster response and recovery. In addition, there are some broader issues regarding NEHRP agency collaboration.

Hazard/Vulnerability Analysis

Past reports have emphasized the need to better understand the factors that affect communities' vulnerability to earthquake impacts (CDRSS, 2006; EERI, 2005; SDR, 2005) and, conversely, their resilience to these seismic hazards. Recent research has shown that some population segments (low education/income, ethnic minorities, and female-headed households) and economic sectors (small businesses and those that are reliant on just-in-time processes) are affected more severely than others. Continued research is needed so that members of the most vulnerable population segments and economic sectors can be identified before disasters occur and so that compensatory programs can be developed that will reduce vulnerability, accelerate recovery, and increase long-term resilience.

Hazard Awareness and Public Outreach

Federal, State, and local agencies have conducted a number of hazard awareness and public outreach programs, but few of these programs have been subjected to systematic evaluation. FEMA's QuakeSmart (earthquake mitigation for businesses) initiative appears to be quite promising in terms of its effects on hazard mitigation, but its outcomes have not been systematically evaluated. This program is extremely relevant to social science research; FEMA program managers and social scientists would both benefit from collaboration on a systematic program evaluation. Similarly, ShakeOut earthquake drills have been conducted in California, the Central United States, and other locations, but systematic evaluation of their effects on people's behavior is extremely limited. Systematic formative and summative evaluations of these and other hazard awareness programs could provide valuable information about whether they need to be revised and, if so, what components need to be modified.

Hazard Mitigation and Emergency Preparedness

Recent research has made progress in explaining the adoption of household hazard adjustments by finding evidence that this process is influenced as much by people's perceptions of a hazard adjustment's attributes (e.g., effectiveness in protecting persons and property, utility for other purposes, and required time/effort, knowledge/skill, tools/equipment, and social cooperation) as by their risk perceptions. To date, there has been no evaluation of household emergency preparedness and hazard mitigation actions to assess their actual performance (as opposed to their perceived performance) with respect to these criteria. Such an assessment would allow emergency managers to promote the risk reduction measures that are most effective and also most likely to be adopted by households and businesses.

Inducements for Household, Business, and Local Government Adoption of Hazard Adjustments

Recent reports have emphasized the need to develop a better understanding of the role of economic incentives, standards, and regulations. Research in these areas is important because hazard adjustments generally require households, businesses, and local governments to make an immediate payment in exchange for an uncertain return. For example, the payoff for hazard insurance premiums is uncertain with respect to both time (When will an earthquake occur?) and amount (How much damage will it cause?).

As a result of these uncertainties, households, businesses, and local governments lack the imminent deadline that typically motivates action during emergency response. The ambiguous planning horizon makes people unwilling to make appropriate levels of investment in risk reduction. This underinvestment in risk reduction raises the question of what inducements governments at various levels could offer to supplement risk communication in generating more appropriate levels of investment. Specifically, how can local governments more effectively influence households and businesses, how can State governments more effectively influence local governments, and how can the Federal Government more effectively influence State governments? Research is needed to assess the effectiveness of regulations (building codes and land use plans) and incentive programs (Federal disaster reimbursement policies, such as increases in the Federal share of disaster response and recovery expenditures) at the point of actual implementation, not just jurisdictional adoption.

Earthquake Early Warning and Aftershock Warnings

Warning research has identified four critical topics that need to be addressed in constructing effective warnings—a description of the hazard, the geographic areas and population segments at risk, recommended protective actions, and sources to contact for further information and assistance. However, the types of disasters upon which this guidance is based are mostly ones for which there is significantly more forewarning than is likely for an earthquake. Thus, the provision of complete warning information in earthquake early warnings and aftershock warnings may prove infeasible. On the one hand, even partial information might be able to significantly increase the percentage of the risk area population who drop, cover, and hold on. On the other hand, forewarning might prompt people to take maladaptive actions such as attempting to evacuate buildings. Consequently, research will be needed to identify the elements of pre-impact hazard awareness programs and warning message content that will increase the levels of adaptive behavior and decrease the levels of maladaptive behavior.

Disaster Response and Recovery

The likelihood that a major urban earthquake could prevent government agencies from reaching needy households and businesses for more than 72 hours creates a need for research to assess the extent to which neighborhood organizations such as Community Emergency Response Teams have been established and are likely to be effective in responding during the immediate post-impact period. In addition, research is needed to assess the extent to which local jurisdictions have developed pre-impact disaster recovery plans and to use established procedures for plan quality evaluation to examine their effectiveness.

Broader Issues Regarding NEHRP Agency Collaboration

Almost all of the NEHRP social science research has been supported by NSF and, given current budget constraints, this pattern is likely to continue. Nonetheless, NEHRP could develop improved mechanisms for collaboration between NSF and the mission agencies (FEMA, NIST, and USGS) to link these mission agencies' social science research needs (especially program evaluations) with the social science research capabilities available through NSF. This would require only an extension of NSF's past efforts rather than a completely new activity because NSF has previously supported collaborative research with agencies such as the U.S. Department of Transportation and the National Oceanographic and Atmospheric Administration. The observatory network recently recommended in the NRC's 2011 report on national earthquake resilience (see task 11) would be an excellent mechanism for achieving this increased level of collaboration.

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Earth Science

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.

Seismologists currently emphasize three basic approaches to meeting societal needs for earthquake loss reduction: (1) monitoring, analysis, and mapping of seismic hazards; (2) predicting the severity of future ground shaking for design and scenario planning; and (3) rapid post-event alerting together with relevant information products. At the same time, there is vigorous research aimed at the following: integrating seismology, geology, geodesy, and fault mechanics to develop a comprehensive physics-based understanding of earthquake phenomena; achieving capabilities for earthquake *forecasting*, based on rigorous statistical studies of space-time patterns of earthquake occurrence; and developing reliable methods for providing *earthquake early warning* (real-time alerting once an earthquake is in progress and before energetic seismic waves arrive).

Developments

Achievements and developments in earth science relevant to NEHRP goals have recently been highlighted in several places, including in "New Research Opportunities in the Earth Sciences," a 2012 report developed by the NRC; in a November 2011 report delivered to U.S. Senator Barbara Boxer by Dr. William Leith of USGS; and in the NEHRP-agency updates presented to ACEHR at the committee's November 2011 meeting. Based on these materials and the observations of ACEHR members, the developments summarized below have been selected as particularly worthy of note.

Advanced National Seismic System

Comprehensive monitoring of earthquakes within the United States is the backbone of earthquake hazard reduction. The recordings and catalogs of earthquakes are essential to the products that provide for a safer environment. The magnitudes, locations, and number of earthquakes that occur provide essential information for developing the seismic hazard maps that are the linchpins for engineering design criteria. Recordings of actual strong ground motions are necessary to improve empirically derived ground-motion prediction equations used to determine expected ground motions at sites in the built environment. Seismic networks are the foundation for products such as ShakeMap, PAGER (Prompt Assessment of Global Earthquakes for Response), and the emerging EEW technology, that are used by emergency responders, government agencies, and the public and private sectors. The heart of the monitoring system in the United States is ANSS, which was first authorized by Congress in 2001. Funds provided under the American Recovery and Reinvestment Act of 2009 in the amount of $29.9 million were used to upgrade seismic and geodetic monitoring networks and data processing centers in the United States, and included $19.2 million for modernizing ANSS infrastructure. Yet, as of November 2011, ANSS is only 30 percent complete.

As noted by Dr. Leith in his report to Senator Boxer, "A 2005 cost-benefit study of ANSS by the National Research Council concluded that the economic benefits of the improved national system outweigh costs by approximately 10 to 1. The quantitative economic benefits in just one benefit area (performance-based seismic design) exceed the cost of deploying the entire system."

Recent Earthquakes in the Eastern United States

Several earthquakes have recently been recorded in the Eastern United States (EUS). USGS conducted post-earthquake investigations for the 2011 Virginia, Oklahoma, and Arkansas earthquakes.

The magnitude 5.8 Virginia earthquake was the largest event recorded in the eastern portion of North America since the 1988 Saguenay, Canada, earthquake. While this earthquake provided a large set of recordings at epicentral distances of 100–1,000 kilometers (km), there was only one recording station within 50 km of the epicenter. Data within 50 km are critical as this distance range controls the hazard for the short-period ground motions. The lack of close-distance recordings points to the need to expand the density of recording stations in the EUS. Because the earthquake was in a sparsely populated region, the damage was limited. However, had the earthquake been closer to a metropolitan area the damage could have been much more significant, vis-à-vis the magnitude 6.2 Christchurch, New Zealand, earthquake of February 22, 2011, which cost an estimated $20 billion. The 2011 Virginia earthquake has renewed USGS efforts to assess earthquake hazards in the EUS; this is evidenced in the 2013 call for proposals issued for the agency's external research program.

Multi-Hazards Demonstration Projects

In 2011, ShakeOut exercises were conducted in the Central United States and in California. The Central U.S. exercise involved 3 million participants in 11 States. The California exercise was expanded to include the entire State and involved 8.6 million participants. With the success of these events, a greater number of ShakeOut exercises have been planned for 2012; in addition to the drills in California and the Central States, they will include exercises in Idaho, Nevada, Oregon, Utah, and Washington.

Earthquake Early Warning

In recent years, significant progress has been made in the development of EEW systems designed to provide alerts ahead of the arrival of strong shaking in heavily populated areas. Such systems are currently operational in five countries (Italy, Japan, Mexico, Romania, and Turkey) and are under development in six others (Egypt, Greece, Iceland, Switzerland, Taiwan, and the United States). Early warnings create an immediate awareness that may allow for various responses. For example, during a school day, it could give students the time needed to "drop, cover, and hold on." Automated response systems could react instantly.

USGS has funded the initial development of EEW technology in the United States. Recently three universities have been awarded $2 million each by a private foundation (the Gordon and Betty Moore Foundation) to improve the technology and prepare it for a full analysis of its effectiveness. System development has started, aimed at demonstrating whether an operational system is feasible in California and Washington.

Japan has the most sophisticated EEW system in the world. In October 2007, after 7 years of development, Japan began providing public alerts of shaking. The 2011 Tohoku earthquake illustrated both positive and negative aspects of Japan's EEW system. Eight seconds after recording the first seismic waves the Japan Meteorological Agency issued an alert of strong shaking associated with a magnitude 7.2 earthquake; about 1.5 minutes later the magnitude had been revised to 8.1. The initial warning reached millions of people and provided a warning time of 5–40 seconds. However, the system never revised the magnitude to 8.1, thus leading to an incorrect assessment of the tsunami threat. The physical size of the fault was also not accounted for, leading to underestimation of the shaking intensity in Tokyo. During the immediate aftershock sequence, the system provided no alerts for the first 3 hours. As the EEW system in the United States continues to be developed, USGS will need to review case histories, such as Tohoku, in order to ensure that the system is robust at the time it is most needed.

The following paragraph is a shorter, alternative version of the preceding paragraph; both versions were provided by Ralph Archuleta

Japan has the most sophisticated EEW system in the world. In October 2007, after 7 years of development, Japan began providing public alerts of shaking. The 2011 Tohoku earthquake illustrated both positive and negative aspects of Japan's EEW system. While millions of people received a warning 5–40 seconds before the strongest shaking was expected, the system severely underestimated the magnitude, leading to incorrect assessments of the tsunami threat and the area of strong shaking. As the EEW system in the United States continues to be developed, USGS will need to review case histories, such as Tohoku, in order to ensure that the system is robust at the time it is most needed.

Source Characterization Model for the Eastern United States

In 2012, a major update of the source characterization for the EUS was completed. This study, funded by the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, and the Electric Power Research Institute, provides suites of alternative models for the areal source zones and for large-magnitude earthquakes in fixed regions. The models will be available to USGS for consideration in the next update of the national seismic hazard maps.

Trends and Challenges

Questioning of Seismic Hazard Methods

The magnitude 6.2, 2011 Christchurch earthquake occurred on a previously unidentified source. The 2011 Tohoku earthquake in Japan had a larger magnitude (9.0) than had been used in seismic hazard evaluations for that region. Because these two destructive earthquakes were not properly characterized in the seismic hazard studies completed prior to their occurrence, there has been a series of articles questioning the validity of seismic hazard analysis. This highlights the challenge of properly communicating the limitations and uncertainty in seismic hazard maps.

Induced Seismicity

The magnitude 5.6, 2011 Oklahoma earthquake occurred in an area of fluid injection and has caused renewed interest in induced seismicity. Was this a tectonic earthquake that was triggered by the injection or was it a direct result of the injection? Are the resulting ground motions relevant for tectonic earthquakes or is there some difference in their characteristics?

Ground Motion Prediction Equations

The Pacific Earthquake Engineering Research Center (PEER) is continuing its "Next Generation Attenuation for Eastern North America" (NGA-east) project to model ground motions from crustal earthquakes in the EUS. Funding delays will likely postpone the completion of this project until the end of 2015.

PEER is also updating the ground motion models for the Western United States through the NGA-west2 project, which will be completed in 2012. Key improvements are the scaling for small and moderate magnitudes (< 5.5), hanging wall effects, and regional differences in the site terms and inelastic attenuation terms. These new NGA-west2 models will be available for use in the next updates to the USGS national seismic hazard maps. PEER has also begun developing new ground motion models for subduction zone earthquakes; these models will be completed in 2015.

Ground Motion Simulation Methods

SCEC is conducting a major effort to evaluate finite-fault numerical simulation methods. Simulation methods are important as they provide a means to develop data sets of simulated ground motions from a large set of earthquakes that are not well captured in the empirical databases. While simulation methods have been available for years, there has not been a systematic and rigorous validation of these methods. The SCEC study will test a simulation method that uses recordings from about 20 past large-magnitude earthquakes, and will test the methods for generating source parameters for future earthquakes. This work is scheduled to be completed in 2013. Once it is complete, it is expected that there will be much greater reliance on finite-fault simulated ground motions for hazard studies.

Seismic Information for Nuclear Utilities

In the 1970s, many utilities funded the operation of seismic monitoring systems in the regions around their nuclear power plants to support the collection of data required for plant licensing. Once the license was issued, however, most utilities stopped supporting these local seismic networks. Since the 2011 Tohoku earthquake and 2011 Mineral earthquake, there has been an increased focus on seismic safety at nuclear power plants. Nuclear utilities operators are now understanding the value and importance of seismic data from seismic monitoring systems. These data are now also needed for required 10-year updated assessments of seismic safety at nuclear power plants.

In view of the nuclear utilities' need for improved and updated seismic information, there is an opportunity to seek long-term funding from these utilities to help redress the shortfall in Federal funding for the full implementation of ANSS. Broad industry groups, such as the Electric Power Research Institute, may be in a position to coordinate such funding.

Needs

Using the NEHRP strategic plan for 2009–2013 for guidance, ACEHR has identified at least two earth-science-related areas in which continued attention or increased emphasis by the NEHRP agencies is warranted. These areas are discussed below.

Full Funding of ANSS

Full funding of ANSS continues to be a compelling NEHRP need. The ability of USGS and its regional partners to provide real-time earthquake data and information products that enable rapid and efficient local, State, and Federal response is dependent on the completion of ANSS and on funding that can not only sustain operations, but also make the system resilient enough to withstand disruptive impacts. Progress in engineering seismology is being hindered by the sparseness of strong-motion recording systems throughout the Nation, and more strong-motion instrumentation in buildings and structures is needed for improved engineering evaluation and design. Given the current Federal budget constraints, long-term funding for ANSS from private operators of large-scale infrastructure (e.g., utilities) with critical seismic safety needs should be considered to supplement Federal funding.

Clear Communication of Important Earthquake Information to the Public

As operational earthquake forecasting is developed, there will be an even greater need to have procedures in place—with help from social scientists—for how important earthquake information should be communicated to the public so that it is easily and correctly understood. A lack of clear procedures was one cause of the poor communication that occurred prior to the 2009 L'Aquila, Italy, earthquake and the resulting indictments of the seismologists.

Geotechnical Earthquake Engineering

Geotechnical earthquake engineering is situated between the disciplines of earth science and structural engineering, where it affects all earthquake-related disciplines. Advancements in earthquake resilience can be achieved only if design, construction, and infrastructure operations account for the geotechnical effects of earthquakes, including surface fault ruptures, seismic site effects, liquefaction, seismic instability, and soil-foundation-structure interaction. As the criticality 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 increasing earthquake resilience.

Developments

The important effects of local ground conditions on earthquake ground motions are now widely appreciated and incorporated in the "International Building Code" (IBC). Liquefaction is also widely recognized as a critical hazard affecting safety and resilience, and liquefaction triggering procedures are fairly well established for many soils. Potential seismic slope-instability hazards are mapped by several State geologic surveys, and dam/waste regulatory agencies have established comprehensive evaluation procedures for such hazards. Geotechnical engineers have led the development of quantitative, GIS-based documentation of the effects of earthquakes.

Recent earthquakes, including the Tohoku earthquake in Japan and the Canterbury earthquake sequence in Christchurch, New Zealand, have shown the important effects of earthquake-induced liquefaction on buildings, especially residential structures, and on lifeline systems, including water and wastewater distribution systems, underground electric power cables, and highway bridges. Of particular importance is the experience gained from the Tohoku earthquake, which shows that the incorporation of stiff mat or grade beam foundations has been effective in protecting residential structures from the effects of liquefaction. Highly ductile lifelines in Christchurch, composed of high- or medium-density polyethylene pipelines, have been able to accommodate large ground deformations with lateral displacements of 3 to 5 feet.

Needs

Earthquake science and engineering should grow more interconnected and interdisciplinary. NEHRP should support this interaction. Geotechnical engineering needs to 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 should include the effective transfer of geotechnical engineering knowledge.

The broader goal of sustainability requires that earthquake resilience issues be addressed. For example, levee and flood protection system reliability, including their seismic performance, must be addressed and measures taken to strengthen critical flood protection systems. Resilience can be achieved through the use of innovative mitigation techniques, such as those for liquefaction.

Of particular importance is the improvement of methods that both predict the occurrence of liquefaction and provide estimates of the settlement and lateral ground movement resulting from liquefaction. It has been well over a decade since consensus guidelines for evaluating the potential for liquefaction and its consequences have been reviewed by the geotechnical community. Several major earthquakes have occurred and been investigated, resulting in substantial new data on liquefaction behavior. The new data on liquefaction and its effects on lifeline systems and buildings need to be reviewed, and the next generation of consensus procedures for predicting and accounting for the consequences of liquefaction need to be developed.

Improved hazard maps for ground failure and methods for characterizing the magnitude and distribution of ground movements triggered by earthquakes are needed. Better methods are needed for predicting liquefaction impact on geographically distributed systems. The triggering of liquefaction or ground softening in silty and clayey soils requires greater understanding, and engineers require improved tools for evaluating the consequences of liquefaction. Robust analytical procedures have been developed for predicting ground deformation and characterizing structural response to ground movements. Research facilities, such as NEES, can be employed to clarify ground movement and soil-structure interaction for practical purposes. In particular, the profession lacks clear guidance on the potential impact of soil-structure interaction on building performance and of soil-water-structure interaction on earth dam and levee performance.

High-end computing coupled with enhanced visualization software is transforming the manner in which we evaluate seismic performance. Practicing engineers require critical assessments of these sophisticated computational tools to ensure that reliable results are produced. Realistic modeling of earth particles, interfaces, and discontinuities remains an important need. Supporting efforts need to continue toward characterization of geo-material properties and the uncertainty inherent in any seismic problem. 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 responders. 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.

Performance-based earthquake engineering requires consensus methods for selecting and scaling ground motions to represent the seismic hazard at a project site and quantitative data that translates calculated engineering responses into damage and then deaths, dollars, and downtime. Without full implementation of ANSS, the spatial variability of ground shaking due to local geology cannot be refined or utilized optimally in post-earthquake emergency response. Geotechnical structures, including downhole arrays, should be better instrumented. Improved models of ground shaking near faults and in the Eastern and Central United States are required. The seismic response of IBC 2006 Site F soils requires better characterization. Owners should be motivated 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. While NEHRP should advance building codes, the program should also advance tools that move the profession toward true performance-based design.

Structural Earthquake Engineering

At the time of ACEHR's 2010 report, some of the most recent developments in structural engineering had been efforts to develop performance-based seismic engineering and methods to develop tools for health monitoring and rapid assessment of structural condition following earthquakes. Since then two major accomplishments have been achieved: (1) the publication of the American Society of Civil Engineers (ASCE) and Structural Engineering Institute (SEI) standard "Minimum Design Loads for Buildings and Other Structures" (ASCE/SEI 7-10), which introduces performance-based procedures including a risked-based approach; and (2) the U.S. Nuclear Regulatory Commission (USNRC) has published Generic Issue (GI) 199, which requires the development of performance-based seismic design methods (i.e., Regulatory Guide 1.208) for developing the ground motion response spectra for reevaluating all existing nuclear power plants that are located in the Central and Eastern United States. GI-199 is mentioned in the USNRC's responses to frequently asked questions related to the March 11, 2011, earthquake and tsunami in Japan (see www.nrc.gov/japan/faqs-related-to-japan.pdf).

The magnitude 5.8 earthquake in Virginia on August 23, 2011, reminded us of the post-event need to identify those buildings and structures that are safe for continued occupancy and for use as centers for recovery. Structures as far away as Washington, D.C. (80 miles from the epicenter) and New York suffered considerable architectural and some structural damage. These included the Washington Monument, The Castle (headquarters of the Smithsonian Institution), and the Washington National Cathedral. In addition, many downtown Washington buildings were evacuated, but fortunately with very few injuries. At the Smithsonian Pods, warehouses where exhibits are stored 6 miles southeast of The Castle, considerable structural damage occurred. The three-story steel frames inside the Pods experienced seismic forces that caused the lateral cross-bracing at each floor to fail and many anchor bolt failures. This further reinforces the need, expressed in the ACEHR 2010 report, for local and regional agencies to identify those buildings and structures that are safe for continued occupancy and for use as centers for recovery following a damaging earthquake. The Castle did not reopen its doors until after it was inspected by knowledgeable structural engineers, highlighting the need for trained personnel who can promptly perform such inspections.

Developments

As stated in ACEHR's 2010 report, "The ability to predict before an earthquake occurs how individual buildings and structures, as well as entire portfolios of buildings and structures, will behave is essential to any program intended to increase the Nation's earthquake resilience. Without this capability, it is impossible to understand the risks or to effectively allocate resources to mitigate these risks." One major improvement in the last 20 years is the availability of HAZUS, the loss estimation tool developed by FEMA.

Following the Virginia earthquake, HAZUS was run using the magnitude and location data recorded during the event. HAZUS predicted that two schools would experience moderate damage, and in fact, two schools in Louisa County suffered enough damage to cause their indefinite closure. In addition, HAZUS indicated that five homes would be extensively damaged, while volunteer code officials from the surrounding areas had found four homes with major damage. This exercise further demonstrates the potential use of HAZUS as a reasonable methodology for estimating future losses from earthquakes. However, as noted in ACEHR's 2010 report, HAZUS does not provide engineers with the ability to reliably predict the likely performance of an individual structure.

Work previously undertaken at several EERCs began to provide engineers with the tools needed to reliably predict the performance of individual buildings and structures in terms of the likely damage and, more importantly, the human, economic, and societal losses resulting from this damage. This work has been continued through the ongoing FEMA-sponsored ATC-58 project, "Development of Next-Generation Performance-Based Seismic Design Procedures for New and Existing Buildings." The 75-percent draft of the project report was published in May 2011 rather than in May 2010 as stated in the ACEHR 2010 report, 1 year behind schedule. The final draft of the report has been prepared; it is now being reviewed by the development teams and is currently scheduled to be released in 2012. This next-generation methodology and an accompanying calculation tool will be available for use by practicing professionals to assist in their design process and for use by academia for future research ideas and as a teaching tool.

In the ACEHR 2010 report it was stated that many important projects had been developed by NEHRP agencies in the preceding 5 years that were providing structural engineers with a better understanding of the likely seismic performance of buildings and structures or guidance on the proper seismic design of building systems or components. Readers are referred to the 2010 report for a list of those activities. The following are new additions to that list:

- FEMA worked with the Building Seismic Safety Council's Code Resource Support Committee to plan for and monitor the model-building-code development process conducted by the International Code Council for the 2012 edition of the International Codes. FEMA representatives attended and provided testimony at hearings on several proposed changes to the IBC, the "International Existing Building Code," and the "International Residential Code" (IRC). FEMA has performed this important role for each successive edition of the codes since their first issuance in 2000.

- NIST has continued to publish its NEHRP TechBriefs, produced through the NEHRP Consultants Joint Venture, by adding "Seismic Design of Composite Steel Deck and Concrete-filled Diaphragms: A Guide for Practicing Engineers" and "Seismic Design of Cast-in-Place Concrete Special Structural Walls and Coupling Beams: A Guide for Practicing Engineers."
- NSF has continued its support for the operations of NEES as well as for research projects utilizing the network's experimental facilities and cyber infrastructure.
- USGS led development of the paper "Risk-Targeted versus Current Seismic Design Maps for the Conterminous United States." The subsequent incorporation of this content into the 2009 edition of the "NEHRP Recommended Seismic Provisions for New Buildings and Other Structures" (NEHRP Recommended Provisions, FEMA P-750), into the ASCE/SEI 7-10 standard, and into the 2012 IBC represents a major milestone.

Once earthquake risks to society have been identified, it is essential that engineers have cost-effective construction technologies capable of limiting damage to acceptable levels if these risks are to be effectively controlled. As noted in the ACEHR 2010 report, 20 years ago, seismic isolation and passive energy dissipation technologies were known and available, but proved to be prohibitively expensive for many structures. Structural engineering researchers have focused much attention in recent years on the development of alternative damage-resistant structural systems that are more economical. Some noteworthy success has been achieved, including the development and adoption into building codes of buckling-restrained braced steel frames and precast-hybrid concrete frames, both damage-resistant systems. In addition, new methods of constructing traditional structural systems and components are becoming available, providing the capability to design and construct a more damage-resistant, resilient community. Perhaps equally important, researchers are also developing methods to reduce risk associated with a variety of nonstructural components and systems, including storage racks, ceiling systems, interior partitions, and electrical distribution and piping systems. This is particularly important because most of the economic losses associated with recent U.S. earthquakes have resulted from nonstructural rather than structural damage.

Trends and Challenges

As mentioned above, through ASCE/SEI 7-10 and USNRC GI-199 the use of performance-based seismic engineering in the design of new structures and the rehabilitation of existing structures has become more commonplace, especially for high-profile projects. Typically, however, project performance goals continue to be based on the code-specified, life-safety level. Also, as discussed in the ACEHR 2010 report, the deterministic approach to performance has continued to be the norm. Unlike in the 2010 report, however, which included the words "has not been able to take advantage of the probabilistic approaches," ACEHR now finds considerable evidence that the probabilistic approach to performance is gaining significant ground. As a result, ACEHR feels that the use of performance-based seismic design procedures for new and existing buildings has started to become a reality in some major areas.

The 2010 report also noted that the use of performance-based seismic designs for new buildings has led to the adoption of "prescriptive" performance-based design requirements in jurisdictions such as San Francisco and Los Angeles, requirements that are intended to produce buildings that will respond, at a minimum, in a life-safe manner given design earthquake ground motions occurring at the site. In November 2010, the Tall Buildings Initiative, sponsored by PEER with funding from the Pankow Foundation and California's Alfred E. Alquist Seismic Safety Commission, published "Guidelines for Performance-Based Seismic Design of Tall Buildings."

The standards "Seismic Evaluation of Existing Buildings" (ASCE/SEI 31-03) and "Seismic Rehabilitation of Existing Buildings" (ASCE/SEI 41-06) are used in the seismic evaluation and rehabilitation of existing structures. These documents utilize discrete, deterministic performance goals for a variety of earthquake hazard levels. In general, these performance goals are similar to those associated with the design of new buildings. ASCE is in the third year of a project to update and combine these standards; the new combined standard, ASCE/SEI 41-13, will be completed in 2012.

ACEHR now feels that, given the advancement of probabilistic, performance-based seismic assessment and design procedures, the metrics for designing new buildings and rehabilitating existing buildings for earthquake resistance *have* changed rather than *will* change, and that performance-based seismic design and evaluation is now providing, rather than will allow for, a reliable means of predicting the probable behavior of buildings and structures in terms of repair costs, repair times, and casualties. With this new performance-based trend, goals for resilient structures, specified in terms of these metrics, will now be able to be reliably formulated.

National Earthquake Resilience

In 2009 NIST asked the NRC to conduct a study, building on the NEHRP strategic plan for 2009–2013, of the research, knowledge transfer, implementation, and outreach needed to provide the tools to make the United States more earthquake resilient. As noted earlier in this report, the resulting NRC report endorsed the NEHRP strategic plan and identified 18 specific task elements required to implement that plan and materially improve national earthquake resilience.

The NEHRP strategic plan identified three goals and 14 associated objectives for the program. Five of the objectives can be considered directly related to the improvement of structural earthquake engineering (SEE) and another five can be considered indirectly related, as shown in table 3.

Table 3—Objectives from NEHRP strategic plan (numbered as in the plan) related to structural earthquake engineering (SEE)

Objectives from NEHRP strategic plan	
Directly related to SEE	**Indirectly related to SEE**
(4) Improve post-earthquake information acquisition and management	(1) Advance understanding of earthquake phenomena and generation process
(6) Develop advanced loss estimation and risk assessment tools	(2) Advance understanding of earthquake effects on the built environment
(7) Develop tools that improve the seismic performance of buildings and other structures	(5) Assess earthquake hazards for research and practical application
(8) Develop tools that improve the seismic performance of critical infrastructure	(10) Develop comprehensive earthquake risk scenarios and risk assessment
(11) Support development of seismic standards and building codes and advocate their adoption and enforcement	(12) Promote the implementation of earthquake-resilient measures in professional practice and in private and public policies

The 18 tasks identified in the NRC report generally cut across the above objectives because, as explained in the report, the tasks "are formulated as coherent activities that span from knowledge building to implementation." These crosscutting relationships are shown in tables 4–7 below. Table 4 shows which NRC tasks relate to each of the five NEHRP objectives that are directly related to SEE. Table 5 does the same, but also identifies the NEHRP strategic goals to which these tasks and objectives relate. Tables 6 and 7 are identical to tables 4 and 5, except that the NEHRP objectives are those indirectly related to SEE.

Table 4—NRC tasks related to those NEHRP objectives that are directly related to structural earthquake engineering (SEE)

NRC task number	NEHRP objectives directly related to SEE (from table 3)					Totals
	4	6	7	8	11	
1	X					1
2	X					1
3	X					1
4		X				1
5	X					1
6					X	1
7		X			X	2
8	X			X	X	3
9	X	X	X	X	X	5
10	X	X			X	3
11	X					1
12		X	X	X		3
13			X			1
14		X			X	2
15	X	X	X	X		4
16				X		1
17						0
18					X	1
Totals	9	7	4	5	7	

Table 5—NRC tasks related to those NEHRP goals and objectives that are directly related to structural earthquake engineering (SEE)

NEHRP objectives directly related to SEE*	NEHRP goals		
	Improve understanding of earthquake processes and impacts	Develop cost-effective measures to reduce impacts	Improve community resilience
4	Tasks 1, 2, 3, 5, 8, 9, 10, 11, 15		
6		Tasks 4, 7, 9, 10, 12, 14, 15	
7		Tasks 9, 12, 13, 15	
8		Tasks 8, 9, 12, 15, 16	
11			Tasks 6, 7, 8, 9, 10, 14, 18

* These objectives are identified in table 3.

Table 6—NRC tasks related to those NEHRP objectives that are indirectly related to structural earthquake engineering (SEE)

NRC task number	NEHRP objectives indirectly related to SEE (from table 3)					Totals
	1	2	5	10	12	
1	X	X	X	X		4
2	X	X	X			3
3	X	X		X	X	4
4			X	X		2
5	X		X			2
6				X	X	2
7				X	X	2
8			X			1
9		X		X		2
10		X	X	X	X	4
11		X				1
12	X	X	X	X		4
13		X		X		2
14	X	X		X		3
15		X		X	X	3
16						0
17						0
18		X	X	X	X	4
Totals	6	11	8	12	6	

Table 7—NRC tasks related to those NEHRP goals and objectives that are indirectly related to structural earthquake engineering (SEE)

NEHRP objectives indirectly related to SEE*	NEHRP goals		
	Improve understanding of EQ processes and impacts	Develop cost-effective measures to reduce impacts	Improve community resilience
1	Tasks 1, 2, 3, 5, 12, 14		
2	Tasks 1, 2, 3, 9, 10, 11, 12, 13, 14, 15, 18		
5		Tasks 1, 2, 4, 5, 8, 10, 12, 18	
10			Tasks 1, 3, 4, 6, 7, 9, 10, 12, 13, 14, 15, 18
12			Tasks 3, 6, 7, 10, 15, 17, 18

* These objectives are identified in table 3.

The tables above show how progress in accomplishing the goals and objectives identified in the NEHRP strategic plan and in achieving national earthquake resilience will depend heavily on continued advancements in SEE. Following are summary observations drawn from tables 3–7:

- All three goals and 10 of the 14 objectives in the NEHRP strategic plan are directly or indirectly related to improvements in SEE.
- Except for task 17, every one of the NRC tasks is linked to at least one of the NEHRP objectives related to SEE. Fifteen of the 18 NRC tasks are each linked to at least three of these objectives. Nearly half of the tasks are each linked to at least five, and as many as seven, of the objectives.
- To achieve any one of the five NEHRP objectives that are directly related to SEE, at least 4 and as many as 9 of the NRC tasks must be completed. Of special note is task 9 ("Post-earthquake Information Management"), which is involved in the achievement of all of these objectives. Achieving one of the objectives that are indirectly related to SEE will require the completion of at least 6 and as many as 12 of the NRC tasks.

Needs

ACEHR's 2010 report presented 10 significant needs, which continue to merit attention and are paraphrased below. The reader is referred to that report for more detailed descriptions of these needs.

1. Fragility and consequence functions for structural and nonstructural systems and components
2. Reliable means of predicting structural collapse
3. Continued development of performance-based engineering tools
4. Quantifiable performance definitions, goals, and associated building rating systems
5. Practical and effective structural systems that can be used to minimize damage and losses
6. Quality control and quality assurance in design and construction to achieve resilient structures
7. Tools for rapidly assessing data generated by ANSS and by health monitoring instruments in buildings
8. Seismic monitoring of buildings
9. Continued education of professionals in performance-based design and in the use of health monitoring and assessment tools
10. Increased collaboration between engineers and seismologists

Augmenting these needs is the ongoing need to accomplish the NEHRP objectives that are directly and indirectly related to SEE. These objectives are listed in table 3 above and are described in the NEHRP strategic plan (www.nehrp.gov/pdf/strategic_plan_2008.pdf).

An additional need relates to the procedures used to evaluate and tag buildings after earthquakes to inform occupants and the public about their safety and suitability for continued use. There is a need to assess whether and how these procedures should be modified in light of the information that is emerging about the change in seismic hazard that follows large earthquakes during energetic aftershock sequences (see "U.S. Geological Survey," above, for a discussion of the code implications of these emerging findings). A final need concerns performance-based designs; ACEHR strongly recommends that the production of more such designs be supported and implemented.

Building Codes and Quality Assurance

The Federal Government declared disasters in 42 States in 2011 with a record 99 declared disasters for the entire year. In addition to earthquakes, disasters such as hurricanes, tropical storms, landslides, wildfires, tornadoes, and floods cost the Federal Government tens of billions of dollars for response and relief efforts every year. The subsequent loss of jobs and economic activity cost additional billions when affected communities are unable to rebuild after an overwhelming disaster. While the 2010 earthquake in Haiti, which left 200,000 people dead and over 1 million homeless, illustrated the massive human suffering that an earthquake can inflict, it also demonstrated how the subsequent economic disaster can exacerbate the suffering. Moreover, major disasters in economically advanced countries, such as the March 11, 2011, earthquake and tsunami in Japan, not only have the ability to inflict similar human misery and economic devastation, they can also have detrimental impacts on trade and the globalized economy.

One of the most effective ways to improve disaster resistance, and specifically post-event economic viability, is to ensure that buildings are constructed according to the current national standards. A substantial majority of fatalities and injuries from earthquakes are due to the failure of buildings. A resistant building stock mitigates the initial damage, minimizes harm to people and property, speeds economic recovery, and conserves resources. The following statement appears on the FEMA website: "There is no more important factor in reducing a community's risk from an earthquake than the adoption and enforcement of up-to-date building codes."

Developments

For the past four decades NEHRP has been working, along with the structural engineering community, within the model code system to improve seismic performance criteria for new buildings. In the past decade building codes produced by the International Code Council have achieved dominance as the basis for construction regulation in the United States.

Beginning with the first editions of the IBC and IRC (I-Codes) in 2000, successive editions of the NEHRP Recommended Provisions have served as the basis for the seismic regulatory code language; this has resulted from the participation of FEMA and USGS in the council's code development process. NEHRP recommendations continue to be incorporated into the new editions of the I-Codes and the ASCE/SEI 7 structural reference standard. The most up-to-date ground motion maps have been incorporated into the 2012 editions of the I-Codes.

Trends and Challenges

Code Content and Development

At present, there is widespread sentiment that life-safety issues have been substantially addressed in the model codes. Thus, there is currently a push to change the focus to sustainability and energy conservation. While few will dispute the need for improved energy and resource conservation standards, industry and government stakeholders must remain focused on continually improving disaster resistant specifications in the applicable codes and standards, especially in the area of multi-hazard design.

A recent trend that continues is the migration of basic construction requirements from the text of building codes to multiple reference standards. Regrettably, the effort has moved some indispensable elements out of the latest editions of the codes. Although these critical seismic-resistant construction details are technically incorporated into the codes through reference standards and are used extensively by structural engineers for building design, their absence from the codes themselves is troublesome. While construction inspectors generally keep a building code with them for ready reference, they generally do not carry reference standards. Undoubtedly, this lack of readily available detail will negatively impact the quality of construction. Additionally, certification testing for building inspectors is based only on the building code, thus making it possible to be fully certified as an inspector with little to no knowledge of basic seismic-resistant construction detailing such as concrete reinforcement or suspended ceiling bracing.

Adoption and Enforcement

Authority for regulating building construction remains with the States. Therefore, such construction is regulated by State and local governments and while the contemporary model building code has been adopted in every State to some extent, State and local adoption is neither universal nor comprehensive. There is enormous diversity in the ways that codes are adopted and applied in the United States, ranging from full attainment, to limited adoption, to marginal enforcement, to exclusions of disaster-resisting provisions, and, in some smaller communities, to having no effective building code.

Modern and adequately enforced codes help safeguard the built environment and reduce the cost of State and Federal disaster aid as well as preserve the valuable base for economic activity in affected communities. The 2011 earthquake and tsunami in Japan has brought much needed public attention to the need for appropriate disaster mitigation efforts and the effect a prolonged recovery can have on the globalized economy. The ability of a community, or a country for that matter, to implement appropriate disaster and earthquake mitigation efforts and, consequently, to quickly recover from an event is indeed critical and can have far reaching economic repercussions.

Creating and developing an earthquake-resistant building stock is a long-term proposition. With comparatively little initial investment, savings to building owners and the taxpayers at large after an event can be substantial. It is a wasted opportunity if we do not insist that all new buildings are constructed in ways that will limit future damage and conserve resources. Code-compliant new buildings can be constructed at minimal additional expense while providing considerable enduring life-safety and economic benefits.

A major challenge facing earthquake-resistant construction in some areas is the resistance of local developers even when the incremental cost of such construction is extremely low. A developer's goal to turn over a project as quickly as possible for a profit is understandable. But the proposition of risking billions of taxpayer dollars in disaster response and potentially sacrificing the ability of a community to recover economically is exactly what's at stake. Obviously, local elected officials support development because of its contribution to a community's economic well-being. Unfortunately, a lack of political will and inadequate understanding of the long-term risks involved, place many communities at risk of losing the very economic stimulants they are seeking.

Finally, since 2009 there has been a sharp decrease in new building construction. Consequently, permit revenues have dropped and thousands of building inspector and plans examiner positions have been eliminated. Many of the individuals lost to the profession have been the most experienced and qualified. The best code in the world is of little use if it is not enforced by knowledgeable inspectors and plans examiners. The most successful way to ensure that buildings are actually constructed according to the code and per their engineered plans is through the use of competent public officials with sufficient resources to do thorough and accurate inspections as well as skilled structural plan reviews.

Performance-Based Codes

The intent of the IBC is "to establish the minimum requirements to safeguard the public health, safety and general welfare . . . and safety to life." While modern codes do a good job of saving lives and preserving certain essential facilities, they are not intended to ensure that most buildings will be usable after an earthquake. Many code-compliant buildings will save lives, but may not remain operational during repair or will need to be demolished after a large earthquake. These code limitations are beginning to be addressed through the valuable work being done in the area of performance-based design, which is discussed in the "Structural Earthquake Engineering" section of this appendix.

Needs

Quality Control

Because building codes are a State and local issue, there need to be powerful incentives for those who do not currently support a strong code and enforcement philosophy. We ask again for consideration of the following ideas:

- FEMA currently ties part of the recovery money for a federally declared disaster to preparedness and mitigation. The possibility of including building code compliance as a criterion for reimbursement should be investigated.
- An earthquake insurance program patterned after the National Flood Insurance Program could be effective. There are existing evaluation services available such as the Insurance Services Office (ISO) Building Code Effectiveness Grading Schedule (BCEGS) or the International Accreditation Service. Also, some insurance companies provide discounted rates to the private sector based on the ISO-BCEGS. This practice should be encouraged and expanded.

Existing Structures

Existing buildings present additional challenges. Every community will have some older buildings that are not constructed to modern codes. It may not be practical to retrofit all existing structures in disaster-prone areas, but essential buildings and those that represent a substantial hazard must be analyzed and strengthened. There are a number of good standards available for voluntary strengthening of existing buildings. However, especially in difficult economic times, we must continue to search for ways to lower the cost and provide incentives if significant improvements are to be made. Tax credits or other incentives should be considered to encourage improving seismic performance.

Lifeline Earthquake Engineering

Lifelines provide the networks for delivering resources and services necessary for the economic well-being and security of modern communities. They are frequently grouped into six principal systems: electric power, gas and liquid fuels, telecommunications, transportation, waste disposal, and water supply. Since Hurricane Katrina, there has been increasing attention given to regional systems of levees and floodwalls as important lifelines. Examples include work to evaluate and remediate the earthquake vulnerability of levees in the Sacramento River Delta. Taken individually, or in aggregate, lifeline systems are essential for emergency response and restoration after an earthquake, and are indispensable for community resilience.

Developments

Lifelines have received increasing attention with respect to national security. For example, the National Infrastructure Protection Plan includes 18 different sectors of critical infrastructure that include or are directly related to the lifeline systems traditionally studied under NEHRP. Emphasis has been placed on the development of high-performance computational models that simulate the regional response of complex networks. 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. Earthquake impacts on water supplies, energy generation and delivery systems, and transportation networks were an important part of the exercise. Over half of the fatalities and a substantial part of the $210 billion in economic losses arising from the scenario earthquake resulted from fires that were exacerbated by the lack of water in damaged water distribution systems.

A multiyear study has been undertaken by the National Infrastructure Simulation and Analysis Center in the DHS Office of Infrastructure Protection of the impact of a major earthquake in the New Madrid Seismic Zone. The study includes damage to lifeline systems and the interdependencies among various systems, with assessments of electric power outages, transportation network disruptions, and the degradation of natural gas and petroleum/refined products supply systems. Complementing such regional studies are assessments of system-wide earthquake performance undertaken by water utility companies, including the East Bay Municipal Utility District, the Los Angeles Department of Water and Power, and the San Francisco Public Utilities Commission, as a basis for planning and rehabilitating their systems. These assessments have employed advanced system simulations and seismic hazard characterization using the results of NEHRP-supported research and development programs.

Significant research in lifeline and geotechnical earthquake engineering has been accomplished at large-scale and centrifuge testing facilities. Examples include the large-scale and centrifuge experiments currently under way at NEES, as well as shake-table and full-scale tests carried out at various universities, including those supported by the NSF-supported EERCs. With NEES support, there has been consistent, systematic research to evaluate lifeline facilities at full scale to understand better and quantify the seismic performance of bridges and electrical components and the soil-structure interaction of underground pipelines.

Substantial emphasis has been placed on electric power systems by the American Recovery and Reinvestment Act of 2009, with $4.5 billion directed to development of the smart grid. At the same time, initiatives have been undertaken to enhance renewable energy through wind and solar contributions to the U.S. electric power system, with legislation passed in many States to achieve 20 percent of electric power through renewable energy within 10 to 20 years. The broad changes under way for U.S. electric power raise questions with respect to system resilience, particularly the effects of increasing reliance on renewable energy sources. There are significant opportunities for using the distributed intelligence of the smart grid to make better decisions about the locations of potential damage and the optimal restoration of post-earthquake power.

Trends and Challenges

Both the vulnerability assessments and analytical procedures developed for lifeline earthquake engineering are being applied to other hazards, including natural hazards and human threats. Studies of lifeline system response to the 2001 World Trade Center disaster emphasize the remarkable degree of interdependence that exists among lifeline systems. The investigation of lifeline interdependencies has been a cornerstone of NEHRP-based research and modeling. Because of the cascading effects that can result from lifeline disruption, local lifeline damage can rapidly expand to have a regional, a national, and even an international impact. Examples include the disruption of the New York Stock Exchange due to the loss of telecommunications and electricity after the World Trade Center disaster, and the impact of Hurricane Katrina on the U.S. petroleum and natural gas delivery infrastructure, which affected the worldwide cost of both commodities.

Earthquake early warning systems can provide lifeline customers an advance warning of approaching seismic waves on the order of a few tens of seconds. In the March 11, 2011, earthquake and tsunami in Japan, the bullet trains successfully received early warning and slowed fast-moving trains, which averted derailments. In the United States, EEW systems are in their infancy and no lifeline operators have the ability to receive advance warning.

Since Hurricane Katrina, there has been growing emphasis on developing hazard-resilient communities. NEHRP-supported programs have led the way to understanding and planning for the disruption of critical lifeline services and to providing important tools and modeling procedures for multi-hazard applications. Notable accomplishments include models for the economic and community consequences of earthquake damage and the integration of these models to predict indirect economic losses and community disruptions on a regional basis.

Because of the enormous national security implications of electric power systems, ports and harbors, oil and natural gas delivery systems, water supplies, and telecommunications, it is important to ensure that best practices are being implemented and that the vulnerabilities associated with the interdependencies among different lifeline systems are being corrected. Improving the resilience of lifeline services for both new and existing systems is essential for regional economic stability and the public good. The expert resources of the natural hazards professional community are available to identify performance goals, best practices, and standards, to define appropriate peer review procedures, and to develop specific mitigation practices that can be applied across the Nation.

It is surprising therefore that there is an absence of unified or even loosely coupled performance standards for lifelines. Clear expectations for emergency service and plans for the coordinated response of different lifeline systems are generally absent. Levels of vulnerability are unnecessarily high and the ability to recover from extreme events is much less effective than most communities recognize.

Needs

Substantial work is needed to address lifeline system preparedness, improve performance, and coordinate improvements to achieve enhanced community resilience and national security. Significant issues and areas of high priority include the following:

- A national workshop should be convened in the near future to obtain balanced and multidisciplinary advice from the lifelines community on the development of a coordinated approach to and road map for lifeline earthquake risk reduction. Short-, medium-, and long-term goals for NEHRP and national lifeline programs should be developed. As indicated in the 2011 NRC report's task 15, guidelines for earthquake-resilient lifeline systems should be developed. Also, performance standards should be addressed at the workshop and the steps to an appropriate level of regulatory oversight should be explored. The workshop should address the multi-hazard aspects of lifeline performance and should result in a consensus on how NEHRP activities can advance multi-hazard resilience. NIST would be the most appropriate host of such a workshop.

- NEHRP lost its only dedicated source of support for implementing lifeline risk reduction measures in practice when FEMA funding was terminated in 2007 for the American Lifelines Alliance. Support for implementation needs to be restored, with a new model for the collaborative setting of priorities and programmatic support for measures to mitigate lifeline earthquake hazards.

- Support should be sought for critical lifelines from government agencies that are not part of NEHRP, such as the U.S. Departments of Energy, Transportation, and Defense. There should be collaboration between NEHRP and the DHS Office of Infrastructure Protection to address earthquake hazards and the integration of NEHRP-supported technology and approaches into an all-hazards approach and broader definition of homeland security. Common lessons from earthquakes, hurricanes, floods, severe accidents, and human threats should be synthesized and general principles adopted for improving hazard-related lifeline component and system performance.

Disaster Preparedness, Response, and Recovery

NEHRP is an essential, unifying effort that provides concepts for planning, mitigation, response, relief, recovery, and reconstruction in an all-hazards environment at local, State, and Federal levels. NEHRP provides the backbone for learning lessons from disasters and integrating science into emergency management by bridging between USGS, NIST, NSF, and the practitioner communities of the earthquake professions and emergency management. There has been a long and close collaborative relationship between USGS and FEMA in dealing with sudden-onset events, as well as events that are catastrophic. This relationship should continue and be expanded to include those agencies and programs that play a significant role in preparedness and response, particularly the National Oceanic and Atmospheric Administration's (NOAA) flood and tsunami programs and agencies that play a significant role in post-disaster sheltering, housing, and reconstruction.

Developments

Substantial new developments in disaster response, relief, recovery, and reconstruction are emerging and continue to be documented from lessons learned through the recent disasters on the Gulf Coast and in Haiti, Chile, China, New Zealand, and Japan. These lessons are in the areas of seismology, probabilistic hazard assessment, impacts of cascading lifeline failures, demands of catastrophic disaster response, disaster early warning, public education, evacuation planning, disaster logistics, disaster management, community resilience, and recovery planning. They are reflected in NEHRP efforts that include the regional catastrophic-response planning initiatives in Northern and Southern California and in the New Madrid Seismic Zone, which are driven by ground motion models developed by USGS, estimated losses generated by HAZUS, and planning supported by FEMA. Earthquake scenarios based on the work of USGS and FEMA are being paired with regional catastrophic planning and exercise efforts supported by DHS and FEMA to identify response gaps and build organizational relationships between State and Federal responders. Planning focused on responding to and recovering from earthquakes benefits many of the concepts and methodologies used to address other extreme natural and human-caused events.

The expanded USGS multi-hazard demonstration project in Southern California continues to provide an excellent example of the efficacy of collaboration among preparedness and response players across hazards. Paired with a landmark social science research base study (funded by DHS), the Southern California effort has been able to build, along with other such programs across the country, public education and preparedness based on the latest social science findings on educational program effectiveness.

ShakeMap, ShakeCast, CISN Display, PAGER, and other products affiliated with ANSS continue to make enhancements related to alerting, notification, and response and recovery planning that support national, State, and local emergency management capacities. Advances in EEW technology offer the potential to provide warnings of earthquakes as they nucleate. EEW methodologies developed by USGS are benefiting from assessments of the Japanese EEW system that provided the warning that stopped Shikansen (high-speed) trains in northern Japan as seismic waves from the 2011 earthquake were propagating toward the Tokyo region.

The Tohoku earthquake provided a number of examples of the strengths and challenges of both hazard and risk estimation and real-time warnings, which should be incorporated into EEW projects in the United States. Parallel assessments of the societal implications of such technology hold promise for assessing and communicating threats and risks to the public. These loss estimation and warning tools are based on earth science knowledge and on analytic and communication technologies, but interface with the emergency management and broader business communities when warnings are issued. Their success is as dependent on the underlying science as on the delivery of information to the public and the ability of the public to rapidly and appropriately process such information.

Continued development and implementation of performance-based building code design, and increasing recognition of the critical importance of nonstructural enhancements for building resilience and reducing damage and losses, will have a positive impact on community resilience and building performance.

Key determinants of a community's capacity to respond and recover from disasters are the preparedness and resilience of individuals, families, organizations, businesses, government agencies, and infrastructure. From its inception, NEHRP has been a leader in promoting preparedness, community resilience, and partnerships with the private sector and non-governmental organizations (NGOs). NEHRP needs to continue in this role by advocating for "DHS/FEMA Private Sector Preparedness" and other outreach and partnership activities, and for standards against which to gauge the capacity of partners. To foster a resilient Nation, FEMA, as the primary advocate for preparedness and resilience for all hazards, must maintain its leadership role in outreach and advocacy to government agencies, NGOs, and the private sector.

A critical element of NEHRP is the continuous accretion of knowledge and improvements to practice through the multidisciplinary Learning from Earthquakes (LFE) program. LFE provides a model for the continuous improvement of engineering and emergency management practice that should be broadened to address the multi-hazard environment. After the recent earthquakes in Chile, New Zealand, and Japan, LFE provided rapid assessments that are both shaping the research agenda and challenging engineering and emergency management practitioners.

Needs

Additional work is required to enable effective implementation of planning for disaster response, relief, recovery, and reconstruction. This work includes the following:

- Initiate the development of "interim emergency building code" provisions that recognize the potential for continuing damaging aftershocks (or triggered earthquakes), the uncertainties in aftershock forecasting, and the need for rapid safety assessments of structures to accommodate relief, recovery, and reconstruction after a disaster. It is recommended that FEMA and USGS (with the Building Seismic Safety Council, ASCE, and other players) begin the development of recommendations for interim post-earthquake building standards that recognize the vulnerability of both damaged and undamaged buildings to aftershocks, and provide for expedited occupancy of structures that are determined to have adequate strength to withstand additional earthquakes.

- Review and update the procedures and standards for post-disaster assessment of buildings ("ATC–20 Procedures for Postearthquake Safety Evaluation of Buildings," prepared by the Applied Technology Council). Initiating response, relief, and recovery operations requires standards and procedures for evaluating residual earthquake resistance in damaged (or undamaged) structures during post-earthquake inspections. Posting structures utilizing the procedures in ATC–20 assumes that buildings can be posted as "safe to enter or occupy" if, in the judgment of the inspectors, the structure has a residual capacity to withstand expected aftershocks without collapsing. The recent, robust aftershock sequences (both in number and size of earthquakes) in New Zealand and Japan, which produced earthquakes that in and of themselves were damaging, have raised questions about the ATC–20 process. In addition, USGS should review the processes and content used for post-earthquake aftershock advisories issued to emergency management agencies and the public.

- Complete the development of catastrophic and disaster planning scenarios in major urban areas prone to earthquakes based on ground motion mapping from USGS, building on the lessons about mitigation, structural design, emergency management, response, and recovery from Japan, New Zealand, and Chile.

- Continue to enhance the HAZUS loss-estimation tools developed by FEMA to address tsunami inundation (USGS, NSF, and NOAA); improve building inventory data (FEMA); update fragility functions (NSF, NIST, FEMA); and integrate ShakeMap and ShakeCast into a fully automated loss-estimation tool.

- Continue to support assessment of the technological and societal factors related to effective EEW methodologies.

- Undertake research to better understand the vulnerability of communities, particularly the impacts of disasters on fragile populations and the roles of NGO service providers and volunteers (individuals, NGOs, and the corporate sector) in post-disaster response, relief, and recovery.

- Continue the collaboration between USGS and NOAA in enhancing the regional seismic networks, and coordinate timely tsunami warnings with earthquake warnings in collaboration with NOAA. Monitor continuing research on the performance of the Japanese earthquake and tsunami warning systems in the Tohoku earthquake, and on the effectiveness of pre-disaster education, evacuation planning, and the designation and use of evacuation routes and refuge areas.

- Undertake comprehensive assessments of community relief, recovery, and reconstruction efforts to inform and expedite further development of methodologies and processes for post-disaster recovery planning.
- Continue the assessment of post-disaster housing issues by exploring innovative technologies for constructing interim housing and for integrating such housing into community restoration, reconstruction, and social and economic recovery.
- To ensure that the most current information about disaster preparedness, mitigation practices, crisis and disaster management, and recovery methodologies are implemented by Federal, State, and local governments, FEMA in collaboration with its NEHRP partners should undertake a comprehensive assessment of the effectiveness of dissemination and implementation methodologies.

FEMA needs to assume a central role in implementing the five tasks identified in the 2011 NRC report that are being emphasized by ACEHR. These tasks are reiterated in table 8 below.

Table 8—NRC tasks that need substantial FEMA participation

NRC task no.	Description
10	Socioeconomic research on hazard mitigation and recovery
11	Observatory network on community resilience and vulnerability
15	Guidelines for earthquake resilient lifeline systems
17	Knowledge, tools, and technology transfer to/from the private sector
18	Earthquake resilient community and regional demonstration projects