DRAFT

Effectiveness of the National Earthquake Hazards Reduction Program

A Report from the Advisory Committee on Earthquake Hazards Reduction

May 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) 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 the resulting damage.

The 2010 earthquakes in Haiti (magnitude 7.0) and Chile (magnitude 8.8) are stark reminders of the value of earthquake preparedness and the importance of building codes. More than 200,000 people died in Haiti where building codes do not exist. In contrast, fewer than 1,000 deaths occurred in Chile where modern seismic building codes have existed since the 1960s. Where does the United States stand? Our communities in seismic regions that span 30 states have implemented seismic building codes to widely varying degrees and at widely varying times over the years. If an earthquake occurred today, we would expect many more deaths in communities that have only recently or have not yet adopted seismic building codes. And we would expect recovery to be slow in most communities due to low levels of resilience.

The activities carried out by NEHRP, such as shaping building codes, make a big difference. NEHRP activities can reduce earthquake casualties and shorten the time it takes for stricken communities to heal. The 2009–2013 NEHRP strategic plan stands as a comprehensive statement of what needs to be done in the near term to provide the information and tools needed for the Nation to build toward resilience. Unfortunately, given the slow pace at which NEHRP is currently able to implement its strategic plan, the Nation's vulnerability to earthquake hazards is steadily increasing and our Nation continues to head towards certain disaster. Human suffering will be intense, mega-losses will occur (from direct physical damage as well as from the cascading economic impacts of lifeline disruptions), and recoveries will be prolonged unless a more aggressive rate of plan implementation is enabled.

To protect society against catastrophic earthquake-induced losses, NEHRP must make lifelines a top priority. The American Society of Civil Engineers reports that more than $2 trillion needs to be invested in our Nation's aging infrastructure over the coming decades to support our high standard of living and economy. Ongoing investments in infrastructure should incorporate seismic resilience. Modern nations depend on their lifelines—energy, transportation, water, and communications—both on a daily basis and in post-earthquake environments. The interruption of any of these lifeline services following an earthquake can produce severe economic losses, harm quality of life, and disrupt citizens' livelihoods. Furthermore, the complex interdependencies that exist among lifelines can generate many unforeseen and potentially catastrophic

consequences that are likely to compound economic losses and hardships. Presently, the United States is at high risk, because there is no adequate effort to understand lifeline resilience and no development of performance-based design, construction, and renovation of lifeline systems. To achieve resilient lifeline services, the tasks outlined in the NEHRP strategic plan need to be implemented so that the investments needed at national, state, and local levels can be undertaken.

Leveraging the accomplishments of NEHRP requires immediate and universal access to the scientific information generated through those accomplishments. A national earthquake resource library is needed to preserve and disseminate the vast body of knowledge on earthquake science, engineering, social science, and preparedness. This library should include new field and analytical data collected after each major earthquake (which are in essence full-scale field tests of community resilience). Fundamental research findings are critical to advancing our knowledge. It is equally critical to transfer research findings into practice. Integrative research into the political, social, and economic circumstances that motivate society to achieve community resilience is needed to promote implementation of proven earthquake-resistant retrofit strategies.

The NEHRP strategic plan also needs to be expanded to make more effective use of the national resources focused on resilience. Over the past 5 years, the NEHRP Office, under the leadership of NIST, has made enormous progress. The office coordinates successfully with each of the participating NEHRP agencies—FEMA, NIST, NSF, and USGS—and has begun building an internal research team at NIST. Today, outreach beyond the NEHRP agencies would serve to accelerate progress toward needed levels of community earthquake resilience in the United States.

Call to Action

The NEHRP strategic plan recognizes that the traditional NEHRP goal of protecting lives needs to be expanded to improving resilience. It is critical for NEHRP to start addressing our aging infrastructure and to help steer the Nation toward security and 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 strongly urges that NEHRP focus on achieving community resilience, most importantly by supporting programs that implement earthquake risk-reduction measures, but also by supporting programs that advance our understanding of earthquake phenomena and that develop and evaluate cost-effective measures for strengthening resilience. Full and timely implementation of the 2009–2013 NEHRP strategic plan is the best next step.

Introduction

The National Earthquake Hazards Reduction Program (NEHRP), first authorized by Congress in 1977, is embodied in Public Law 108–360. It 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 failures. As with any emerging science and engineering technology, we are just beginning to understand how to best deal with the related hazards and risks. Today, there is a growing understanding that we need to expand our goals from safety to resilience.

The differing impacts of the recent major earthquakes in Haiti and Chile starkly illustrate what NEHRP is trying to achieve in the United States and the benefits of understanding and preparedness. The difference in death tolls alone strongly validates a national commitment to earthquake risk reduction and disaster resilience.

Program Effectiveness and Needs

Management, Coordination, and Implementation of NEHRP (Susan Tubbesing)

Since 2005 NEHRP has benefitted 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 of the Program Coordination Working Group (PCWG) and Interagency Coordinating Committee (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.

In reviewing the recommendations that were included in our 2010 report, we are dismayed to note that forces beyond the control of the NEHRP Office continue to challenge the effectiveness of the program.

- **2010 Recommendation**—The 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.

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 its 2011 report, "National Earthquake Resilience: Research, Implementation, and Outreach," the National Research Council (NRC) establishes a road map to achieve resilience and identifies 18 tasks that must be undertaken to fully implement the NEHRP strategic plan over the next two decades. The study estimates that it will cost approximately $307 million a year to achieve the goal of earthquake resilience for our Nation. Regrettably, instead of increasing the budget for NEHRP, the President's fiscal year (FY) 2012 budget for NEHRP is $122 million.

- **2010 Recommendation**—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.

The NRC study also focuses on the need to better understand the risks posed by the Nation's extensive lifeline networks. Task 15 specifically highlights the need to focus on understanding and improving lifeline systems that are critical to the nation's security, including energy, telecommunications, transportation, and water sectors. This report notes specifically the need to conduct collaborative research to better characterize infrastructure network vulnerability and resilience, to form the basis for the review and update of existing standards and guidelines. They also call 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.

The 18 tasks identified in the NRC study are critical to full implementation of the NEHRP strategic plan and will lead to a more fully resilient Nation. Of the 18 tasks, ACEHR has recognized five, in particular, for focused effort. The NEHRP Office has an important role to play, to support and encourage not only the NEHRP agencies, but also other government agencies and organizations in the public and private sectors to adopt the tasks outlined in this report and ensure that advances in knowledge and technologies are implemented throughout the country, to improve earthquake mitigation, response, recovery, and reconstruction.

As illustrated in the following table, NEHRP has a crucial role in coordinating each of the five NRC tasks emphasized by ACEHR.

Table 1—NEHRP agency roles in selected NRC tasks

NRC Report Tasks		NEHRP Agency Involvement			
No.	Title	NIST	USGS	NSF	FEMA
10	Socioeconomic research on hazard mitigation and recovery	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

18	Earthquake-resilient communities and regional demonstration projects	X	X

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, H.R. 3820, failed to pass in the last Congress and has again been introduced and passed in the House. Plans for the reauthorization of NEHRP in the Senate are still unclear. Unfortunately, the House legislation includes significant cuts to the authorization levels of NIST and 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 there is a limit to the effectiveness of the lead agency when its funding is continuously jeopardized, and that that limit has been reached.

The House authorizing legislation also transfers responsibility for post-earthquake investigations from USGS to NIST, a move that ACEHR has endorsed as appropriate to the 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. It will also fall to the NEHRP Office 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 to be held in 2012 to get a better understanding of the range and scope of NIST's plans pertaining to future earthquake coordination.

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 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 report there are clear directions for an all-nation approach to earthquake resilience.

Federal Emergency Management Agency **(Rich Eisner/Brent Woodworth)**

The significant impact of seismic events over the past year brings with a strong message and the need for our citizens, communities, private sector, and government to seriously focus on multiple aspects of community and national earthquake resilience. ACEHR is pleased to make the following recommendations (pending Committee acceptance) to FEMA in an effort to encourage and guide such actions. The recommendations are made with an understanding of the current budgetary and resource challenges being faced on a local, state, and federal level. ACEHR calls upon FEMA to leverage relevant expertise and programs within the Department of Homeland Security (DHS) to further the NEHRP strategic plan.

Suggested Recommendation 1: Encourage and expand the involvement of the Private Sector and Community Stakeholders in Earthquake and "All Hazards" disaster Preparedness, Mitigation, Response, and Recovery.

The private sector has proven that it can and does play a fundamental role in building the resilience of a society against potential impacts from disasters. The private 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 and/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 rational used to encourage private sector stakeholder investment in resiliency should be tied to individual and corporate values.

ACEHR recommends (pending Committee acceptance) FEMA take the following actions in communities where earthquakes pose a direct or consequential risk.

1. Encourage the development of local disaster preparedness, response, and recovery programs reaching across all major community stakeholder sectors including: business, government, agencies, academic institutions, faith based organizations, non-profits, volunteer organizations, and associations.
2. Customize local disaster preparedness, response, and recovery programs by setting the specific needs of local residents and community stakeholders as a priority while encouraging the sharing of information and cooperation in the creation of innovative and sustainable community resilience programs.
3. Provide disaster preparedness, mitigation, response and recovery information to local communities:
    a. In their language
    b. Tailored to their individual and local needs
    c. Formatted to be of direct benefit to the individual receiving the information
    d. Delivered by knowledgeable and respected individuals (including corporations)
4. Conduct a research project to provide private sector companies with a verified benchmark showing the return on investment the business sector has realized when investing in pre-disaster mitigation (structural and non-structural) over the past 10 years.

Suggested Recommendation 2: Protecting our schools and children from the impact of natural hazards is one of the cornerstones of a socially responsible community resilience campaign. Support for school safety programs pays dividends in terms of improved life quality, security, economic growth, and good public relations. School children have a right to learn in buildings that are safe from natural hazard events.

Understanding hazards is the first principle in building a comprehensive safety program. Educating students, teachers, parents and school staff about the science of natural hazards and actions they can take before and during an event can provide the buffer of protection that can save lives and reduce injuries. Even if schools have not been renovated to withstand disruptive earthquakes or other natural hazards, understanding the nature of the disaster forces and potential consequences gives communities added measures of personal agency when the event strikes. Having a structured approach to protective actions (such as duck, cover and hold-on during a seismic event) or developing and practicing procedures for evacuations when warnings are issued is a core competency that school communities must support.

ACEHR recommends (pending Committee acceptance) FEMA take the following actions to prepare and protect schools:

1. Stipulate the desired safety performance for school buildings and construct all new schools to meet this standard;
2. Update curriculum to educate students on natural hazards (including the primary science of earthquakes) and risk reduction measures;
3. Provide preparedness training;
4. Review conditions of all existing school buildings and retrofit, relocate or replace unacceptably vulnerable buildings;
5. Draft and enact plans for post-event continuity of education services.
6. Support the development and implementation of programs to increase children's safety.
7. Rebrand the phrase "Safe at School" to include protecting children from natural hazards
8. Consider the APEC Framework for school earthquake safety and implement the APEC program.

Suggested Recommendation 3: Support state and local efforts to assess the seismic preparedness of emergency facilities, infrastructure, and public buildings. Support the revitalization of state earthquake programs and provide strong support and leadership to state commissions to characterize and mitigate unacceptable risk in communities.

ACEHR recommends (pending Committee acceptance) FEMA take the following actions to prepare and protect emergency facilities, infrastructure, and public buildings:

1. Establish a program for the strengthening of essential community facilities (emergency operations centers, fire and police stations, schools and other shelter facilities and hospitals) as a priority.
2. Encourage and support collaborative efforts in disaster preparedness by utility and critical infrastructure providers and agencies. Provide direction, recognition, and education to gain support for proactive mitigation measures from local and national community stakeholders.

3. Expand the development and encourage the use of seismic event consequence modeling by building developers, owners, along with local government agencies and infrastructure providers.
4. Develop case studies of socioeconomic policies for cost-effective mitigation. Promote their adoption and implementation among stakeholders, and measure the impact.

Suggested Recommendation 4: Build on the lessons learned, observations, and discoveries made by researchers and professional engineers following seismic events in recent years. Recent earthquakes in Japan, Chile, New Zealand, and Haiti included many important lessons:

- Compound or cascading disasters were not well planned for and "Safe Enough" was underestimated
- Repetitive education and exercises can save lives. Over 1.4M residents did not hesitate to evacuate to higher ground when they received the Tsunami warning. This resulted in a low (yet tragic) percentage number of fatalities.

ACEHR recommends (pending Committee acceptance) FEMA take the following actions concerning lessons learned from recent earthquake events:

1. Information gathered from recent earthquakes need to be incorporated into a process of continuous improvement contributing towards more effective risk assessment, mitigation, and community resilience measures. The information gathered can be used to:
   a. Update earthquake preparedness practices and potential impact assessments
   b. Update lifeline standards,
   c. Identify and support technology transfer to and from the private sector,
   d. Identify standards for public education, alert and warning systems for the purpose of increasing the resilience of government and community stakeholders
   e. Update guidance and case studies on providing post-disaster shelter and housing
   f. Use research findings, standards, guidance, advocacy and training to increase the disaster resilience of government, NGO's and the private sector.

National Institute of Standards and Technology (John Hooper)

ACEHR provides two suggested (pending Committee acceptance) recommendations for the NIST research program:

- **Suggested 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.

- **Suggested Recommendation 2:** Continue to build multidisciplinary expertise within NIST and foster relationships with other public agencies, private-sector entities, and consultants to accomplish and manage the applied research.

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, resulting in meaningful technology transfer in the area of guideline and code development as well as technical information that is directly applicable to the practicing engineering community. The new staff is successfully implementing extramural research programs and is showing great promise on their internal research initiatives. NIST is also in the process of evaluating their new building-research plan for the next 10 years that will guide the future expansion of internal and external work.

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 an overall program that will promote implementation of risk reduction measures, support the development of performance-based earthquake engineering, ensure the use of social science research, 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 internal and extramural programs.

External research projects began in the fall of 2008, resulting in over two dozen projects being funded to date. These projects have all been directed at the high-priority objectives identified in prior planning. Numerous projects have already published, and the results have been well received; for example, the six completed technical briefs 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 those listed below, demonstrate that NIST is managing its research program 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”

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.

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 if financial support were made available.

The work to assist 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 research and manage the external component 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 programs. Planning for the future, which is under way, must also take into account the recommendations from the review of national needs for earthquake resilience, including the suggestions recently issued in the 2011 NRC report.

National Science Foundation (Jack Moehle)

ACEHR provides two suggested (pending Committee acceptance) recommendations for NSF:

- **Suggested Recommendation 1:** Commit to supporting coordinated earthquake reconnaissance, technology transfer, and dedicated research programs to learn from significant earthquakes occurring throughout the world. Provide this support in close coordination with the NEHRP Office. Earthquakes are the primary feedback mechanism available to the earth science, earthquake engineering, and social science communities for understanding the responses of actual systems, including effectiveness of mitigation, response, and recovery efforts.

- **Suggested Recommendation 2:** Assess large-scale experimental facilities throughout the United States, along with the equipment sites of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), to determine how best to ensure that state-of-the-art experimental capabilities for earthquake engineering are available. Experimental facilities are essential to increasing the resilience of the United States by supporting the development of performance-based design provisions for new construction and assessment procedures for existing infrastructure.

- **Suggested 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. 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 to efficiently achieve resilience objectives should be considered.

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.

In relation to Recommendation 1: NEHRP and the earthquake professional communities have relied on NSF's support of post-earthquake reconnaissance to provide feedback regarding the actual performance of the built environment and emergency management and recovery efforts. In recent past years, NSF has focused on funding of RAPID grants that support individual researchers to conduct 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 important results are being achieved by this program, ACEHR 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.

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 that NSF identify and fund an appropriate mechanism for coordinating earthquake reconnaissance, including coordination of RAPID grants; identify and fund mechanisms for technology transfer following earthquakes with important lessons; and aggressively pursue funding opportunities for transformative research opportunities exposed by earthquakes.

In relation to Recommendation 2: ACEHR notes that NSF has made a significant contribution to NEHRP through development, operation, and research using the large-scale simulation facilities of the George E. Brown Network for Earthquake Engineering Simulation (NEES). NEES plays a critical role in NEHRP by providing the facilities for large-scale testing both of vulnerable and resilient components and systems. NEES also provides simulation tools and data repositories 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 has 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; developing new, highly resistant systems; and advancing simulation capabilities. These are reflected in advances in engineering standards widely in use by engineers nationally.

NEES is approaching the tenth year of the original ten-year program. NSF in in the process of reviewing the performance of NEES and deciding a future path, considering input from the community and expert panels. Notwithstanding these activities, ACEHR urges that NSF continue to provide support for the NEES laboratories, data repository, and simulation capabilities, at least fully supporting those elements that have demonstrated their effectiveness during the initial program phase. Research activities using these facilities should continue at current or increased levels.

In relation to Recommendation 3: NSF has contributed substantially to the NEHRP program by providing mechanisms for collaboration within the areas of social science, 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. NSF also has supported smaller coordinated research programs, for example:

mitigation of existing hazardous construction; development of innovative precast construction; and special research programs to maximize learning from specific earthquakes. Since the sun setting of the EERC program, multi-disciplinary 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 areas of 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. Such centers and coordinated activities also provide opportunities to engage broad stakeholder communities in the NEHRP programs. ACEHR encourages NSF to continue support for coordinated research activities and to find avenues for increasing such activities.

U.S. Geological Survey (Norman Abrahamson)

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 of tasks in the 2009–2013 NEHRP strategic plan and new tasks that should be added to future plans.

Social Science (Michael Lindell)

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 project 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, 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, provision of complete warning information for 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 only be 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 Department of Transportation and the National Oceanographic and Atmospheric Administration. The Observatory Network recently recommended by the National Research Council would be an excellent mechanism for achieving this increased level of collaboration.

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Earth Science (Norman Abrahamson & Ralph Archuleta)

Geotechnical Earthquake Engineering (Tom O'Rourke)

Structural Earthquake Engineering (Jim Beavers)

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 now 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.

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 that following a damaging earthquake local and regional agencies have a need to identify those buildings and structures that are safe for continued occupancy and for use as centers for recovery. Following the earthquake, The Castle did not reopen its doors until after it was inspected by knowledgeable structural engineers. This highlighted 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. The HAZUS results showed 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 showed extensive damage to five homes. Volunteer code officials from the surrounding areas had identified four homes in a "major-major" damage category that equated to extensive damage in HAZUS. 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 earthquake engineering research centers 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 now been extended by 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 methodology and 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 "International Building Code" (IBC), "International Existing Building Code" (IEBC), and "International Residential Code" (IRC).

- 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 to implement in 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 rehabilitation of existing structures has become more commonplace, especially for high-profile projects. Typically, however, the performance goals for the majority of these projects are 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 addition, the Tall Building Initiative, sponsored by the Pacific Earthquake Engineering Research Center with funding from the Pankow Foundation and California’s Alfred E. Alquist Seismic Safety Commission, is preparing guidelines for the design of tall buildings using a performance-based seismic engineering approach.

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.

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. 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 2.

Table 2—Objectives from NEHRP strategic plan related to structural earthquake engineering (SEE)

No.	Objectives from NEHRP Strategic Plan	
	Directly Related to SEE	Indirectly Related to SEE
1	Improve post-earthquake information acquisition and management	Advance understanding of earthquake phenomena and generation process
2	Develop advanced loss estimation and risk assessment tools	Advance understanding of earthquake effects on the built environment
3	Develop tools that improve the seismic performance of buildings and other structures	Assess earthquake hazards for research and practical application
4	Develop tools that improve the seismic performance of critical infrastructure	Develop comprehensive earthquake risk scenarios and risk assessment
5	Support development of seismic standards and building codes and advocate their adoption and enforcement	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 NRC report, the tasks "are formulated as coherent activities that span from knowledge building to implementation." These crosscutting relationships are shown in tables 3–6 below. Table 3 shows which NRC tasks relate to each of the five NEHRP objectives that are directly related to SEE. Table 4 does the same, but also identifies the NEHRP strategic goals to which these tasks and objectives relate. Tables 5 and 6 are identical to tables 3 and 4, except that the NEHRP objectives are those indirectly related to SEE.

Table 3—NRC tasks related to those NEHRP objectives that are directly related to structural earthquake engineering (SEE)

NRC Tasks	NEHRP Objectives Directly Related to SEE*					Total Objectives
	1	2	3	4	5	
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
Total Tasks	9	7	4	5	7	

* These objectives are identified in table 2.

Table 4—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 EQ Processes and Impacts	Develop Cost-Effective Measures to Reduce Impacts	Improve Community Resilience
1	Tasks 1, 2, 3, 5, 8, 9, 10, 11, 15		
2		Tasks 4, 7, 9, 10, 12, 14, 15	
3		Tasks 9, 12, 13, 15	
4		Tasks 8, 9, 12, 15, 16	
5			Tasks 6, 7, 8, 9, 10, 14, 18

* These objectives are identified in table 2.

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

NRC Tasks	NEHRP Objectives Indirectly Related to SEE*					Total Objectives
	1	2	3	4	5	
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
Total	6	11	8	12	6	

Tasks						

* These objectives are identified in table 2.

Table 6—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		
3		Tasks 1, 2, 4, 5, 8, 10, 12, 18	
4			Tasks 1, 3, 4, 6, 7, 9, 10, 12, 13, 14, 15, 18
5			Tasks 3, 6, 7, 10, 15, 17, 18

* These objectives are identified in table 2.

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 2–6:

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 is 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

This section of the ACEHR 2010 report presented 10 significant needs, which are paraphrased briefly 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

Needs also include accomplishment of the NEHRP objectives that are directly and indirectly related to SEE. These objectives are excerpted from table 2 below.

Objectives directly related to SEE

1. Improve post-earthquake information acquisition and management
2. Develop advanced loss estimation and risk assessment tools
3. Develop tools that improve the seismic performance of buildings and other structures
4. Develop tools that improve the seismic performance of critical infrastructure
5. Support development of seismic standards and building codes and advocate their adoption and enforcement

Objectives indirectly related to SEE

1. Advance understanding of earthquake phenomena and generation process
2. Advance understanding of earthquake effects on the built environment
3. Assess earthquake hazards for research and practical application
4. Develop comprehensive earthquake risk scenarios and risk assessment

5. Promote the implementation of earthquake-resilient measures in professional practice and in private and public policies

Finally, ACEHR strongly recommends that more performance-based designs need to be supported and implemented.

Building Codes and Quality Assurance (Anne vonWeller)

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 International Building Code and International Residential Code (I-Codes) in 2000, successive editions of the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures 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 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 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 way 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 beyond its borders.

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 to 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 International Building Code 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 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 (Yumei Wang)

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 lack of water in damaged water distribution systems.

A multiyear study has been undertaken by the National Infrastructure Simulation and Analysis Center under 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 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 rehabilitation of their systems. These assessments have used 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 earthquake engineering research centers. 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 affecting 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 avoided derailment. In the United States, earthquake early warning 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 the NEHRP and national lifeline programs should be developed. 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 is 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 governmental agencies 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 (Brent Woodworth & Rich Eisner)