Effectiveness of the National Earthquake Hazards Reduction Program

A Report from the Advisory Committee on Earthquake Hazards Reduction

May 2008

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Executive Summary

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) is deeply concerned about the withering of appropriated funds for the National Earthquake Hazards Reduction Program (NEHRP). At $100 to $125 million per year, NEHRP funding has been essentially flat or below inflation levels for the past 30 years**.** Appropriations have been well below authorized levels. In 2004, Congress reacted to the Nation's need and significantly increased the authorization for NEHRP. Rather than strengthening NEHRP with investments linked to authorized levels, however, the reverse has been the case. For the past 5 years, NEHRP funding for FEMA's implementation programs to help safeguard states and communities has been substantially reduced, resulting in serious negative consequences with a dramatic increase in risk.

Despite reduced funding, ACEHR finds that NEHRP has achieved significant improvements, notably in its restructuring and broader collaborative efforts, since the 2004 reauthorization. NEHRP is committed to, and has made progress toward, becoming a fully effective, collaborative, and focused program to protect the Nation against unacceptable risks from seismic hazards.

NIST, as the newly designated lead agency for NEHRP, has formed a NEHRP office with a highly regarded NEHRP director. Each of the other participating agencies—FEMA, NSF, and the USGS—has a significant role in NEHRP, with the active participation of each agency's director. The agency directors serve on the newly expanded Interagency Coordinating Committee (ICC), which now includes the Directors of the White House Office of Science and Technology Policy (OSTP) and Office of Management and Budget (OMB).

NEHRP is responsible for ensuring earthquake risk reduction opportunities are made available to vulnerable communities. This responsibility ranges from conducting basic research to transferring research results into cost-effective mitigation. The overall success of NEHRP is highly dependent on legislative and administrative support for increased funding.

To protect society against catastrophic earthquake-induced losses, NEHRP must become a well recognized national priority. Risk reduction actions must be taken at the national, state, and local levels. First and foremost, the state grant programs through FEMA must be fully funded. Currently, there is a lack of financial support to state grant programs for assisting communities, residents, and businesses in understanding their risk, sponsoring pilot projects to illustrate cost-effective mitigation, and developing effective response plans to facilitate the immediate and long-term recovery process in the aftermath of a severe earthquake.

Earth science, engineering, and social science fundamental research is critical to advancing our knowledge and should be fully supported. It is equally critical to transfer research findings into practice. Without integrative research into the political, social, and economic circumstances that motivate society to achieve community resilience, implementation of proven earthquake resistant retrofit strategies will fall short. Sufficient attention is not being paid to the development of national standards for lifelines and existing buildings that will provide a resilient built environment. Strong motion recording equipment must be installed rapidly through full funding of the Advanced National Seismic System (ANSS) before the next major earthquake strikes. Through ANSS, the USGS provides critical information for emergency response, earthquake engineering, and a better understanding of the physics of earthquakes.

Key recommendations of the ACEHR are listed below by agency:

FEMA

- ***Recommendation 1***: Revitalize state earthquake programs and support pilot studies to characterize and mitigate unacceptable risk in communities.
- ***Recommendation 2***: Fund FEMA at the authorized level and assure funding is dedicated to earthquake risk reduction.
- ***Recommendation 3****:* Continue to develop and maintain guideline documents that will improve the effectiveness and reduce the cost of seismic protection for lifelines, existing buildings, new buildings, and applied socioeconomic policies for cost-effective mitigation. Promote their adoption and implementation to stakeholders.

NIST

- ***Recommendation 1*****:** NIST must secure the funding to effectively carry out its role as the lead agency for NEHRP and its role in applied research and assistance in implementation of cost-effective mitigation through codes and standards.
- ***Recommendation 2*****:** NIST must plan for the development of multidisciplinary expertise within its own staff and foster relationships with other public agencies and private-sector entities to accomplish the coordinated research to effectively fulfill its obligations.

NSF

- ***Recommendation 1****:* NSF should enhance its support for multidisciplinary research related to NEHRP, which can be used as a model for reducing risks associated with other natural and human-induced hazards. In particular, there is an opportunity for the Engineering and Geosciences Directorates to partner with the Social, Behavioral, and Economic Sciences Directorate to understand the social and economic factors that promote mitigation measures.
- ***Recommendation 2*****:** NSF should enhance its support for curiosity-driven basic research, which has been the foundation of many important technical discoveries. Basic research sponsored by NSF educates the next generation of engineers and scientists engaged in earthquake risk reduction. Such support is thus a means of expanding the workforce in earthquake engineering and science.

- ***Recommendation 3*****:** NSF should solicit support from other federal agencies to leverage the NSF investments in the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) to address critical research needs for the civil infrastructure. To date, research support for NEES has not matched the levels needed by the earthquake community to reduce earthquake risks significantly.

USGS

- ***Recommendation 1*****:** Fully fund ANSS at the level authorized in the current NEHRP legislation. The USGS must make a commitment to work through the Department of the Interior (DOI) and OMB to ensure that this objective is met.
- ***Recommendation 2*****:** Proceed with multihazard demonstration projects, such as the project being carried out in southern California that was initially funded by Congress in Fiscal Year (FY) 2007. The demonstration projects should expand the multihazard scope to include other high-risk areas as part of this effort.
- ***Recommendation 3*****:** Enhance the interaction of the USGS with its NEHRP partners in earthquake engineering (NIST and NSF), earth science (NSF), and earthquake preparedness (FEMA). The noteworthy level of coordination in some geographic areas, such as California, and in some project areas, such as the National Seismic Hazard Mapping project, should be extended to other geographic and project areas.

Management, Coordination, and Implementation

- ***Recommendation*****:** Consistent with the change in the leadership of NEHRP, ACEHR recommends that USGS delegate post-earthquake investigation leadership to NIST, including the organization and deployment of reconnaissance teams and sponsoring the publication of discipline-oriented interactive media that archive collected data.

The United States invests more than $1 trillion each year in new construction. It is now well recognized that the condition of our infrastructure is in crisis, with more than $2 trillion required over the coming decades to reconstruct and support a vibrant country and economy. The Nation depends on its lifelines—power, surface transportation, water, waste water, and communication—on a daily basis, and certainly after a natural disaster. The failure of any of these lifelines following an earthquake can have severe economic impacts on businesses and residents in the affected areas. Further, complex interrelationships of lifelines will produce many unforeseen and potentially catastrophic consequences that will likely significantly increase damage and economic losses. Consequently, the Nation is at high risk because there is no nationally sponsored effort to direct the system-wide consideration of these resources and development of appropriate design, construction, and renovation standards and programs. Moreover, a small percentage of existing buildings will kill people in the next major earthquake. These buildings must be identified and mitigated. Because these actions require more than engineering, we need to better understand the economic and political means to mitigate high risk buildings that have great societal importance.

Each dollar spent on NEHRP can save up to 10 times that amount in avoided losses. ACEHR urgently recommends refocusing NEHRP on achieving community resilience by fully funding implementation programs, followed by support for programs that advance our understanding and for programs to develop and evaluate cost-effective measures to achieve resilience against earthquakes.

1. Introduction

NEHRP, first authorized in 1977, is embodied in Public Law 108–360. During the most recent NEHRP reauthorization in 2004, the ACEHR was created to oversee the Program in four specific areas—new trends and developments, effectiveness, needed revisions, and management. By statute, the 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 is directed to report within 1 year of formation, at least once every 2 years thereafter, and with due consideration given to the recommendations of the USGS Scientific Earthquake Studies Advisory Committee (SESAC). This is ACEHR's first report. The Committee plans to deliver a report annually hereafter.

ACEHR met in May and October 2007 and again in April 2008, for a total of 6 days of hearings and deliberations. Multiple briefings were provided to the Committee by each of the four NEHRP agencies on their current activities, the extent to which the agencies are addressing their statutory requirements under NEHRP, the metrics being used to monitor effectiveness, and planned changes. The Committee invited testimony from four retired senior agency staff, one from each of the four agencies, to understand some of the history and potential of NEHRP. Committee members developed white papers related to new trends and developments in their areas of expertise that were collated and discussed. The Committee received and reviewed the NEHRP annual reports for 2007 and 2008 and was apprised of and consulted on the development of the 2008–2012 NEHRP Strategic Plan. The meeting summaries adequately capture the information provided to the Committee and the discussions that resulted in this first ACEHR report.

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 on NEHRP activities to date or strategic plans; those topics are adequately addressed in NEHRP's annual reports and strategic plans. It also does not attempt to outline the process used to develop the recommendations, as that is well noted in the meeting summaries, the trends and developments papers, and the assessment scorecard used to gather opinions related to effectiveness.

The report is organized around the task areas assigned to ACEHR by its authorizing legislation. Section 2, Program Effectiveness and Needs, is organized by NEHRP agency and focuses on past and current accomplishments, future plans, and modifications needed to address the goals of the 2008–2012 NEHRP Strategic Plan. Two or three prioritized recommendations are included that relate to augmenting each agency's activities beyond their current efforts. Section 3, Management, Coordination, and Implementation of NEHRP, includes complimentary assessments of the "new" NEHRP office within NIST, the effectiveness of the Program Coordination Working Group (PCWG), and the intrinsic value of the newly expanded ICC, which is composed of the Directors of NEHRP agencies and the Directors of the White House OMB and OSTP. This report also includes some suggestions on future ACEHR activities and membership and a single recommendation related to post-earthquake investigations. The Appendix, Trends and Developments in Science and Engineering, presents ACEHR's observations relating to six disciplines that are highly relevant to NEHRP. These observations provide the NEHRP agencies with an overview of the recent achievements that have been made and the issues and challenges facing the industry, with suggestions on where future strategic priorities should be focused.

2. Program Effectiveness and Needs

2.1 Federal Emergency Management Agency

ACEHR provides three recommendations for FEMA:

- ***Recommendation 1*:** Revitalize state earthquake programs and support pilot studies to characterize and mitigate unacceptable risks in communities.
- ***Recommendation 2***: Fund FEMA at the authorized level and assure funding is dedicated to earthquake risk reduction.
- ***Recommendation 3:*** Continue to develop and maintain guideline documents that will improve the effectiveness and reduce the cost of seismic protection for lifelines, existing buildings, new buildings, and applied socioeconomic policies for cost-effective mitigation. Promote their adoption and implementation to stakeholders.

FEMA is charged with the important mission of developing cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society-at-large, and improving the earthquake resilience of communities nationwide. For FEMA to succeed, NEHRP agencies must transfer research findings to end users, including states and communities.

ACEHR's most serious concern with FEMA is the steady erosion of its budget. The funds allocated to FEMA for NEHRP in 2008 are roughly one-third the level of its 2002 NEHRP funding. The loss of this support has greatly reduced the capabilities of an agency that has many significant accomplishments. Such past accomplishments include developing and promoting HAZUS software; providing grants to states and communities, including pilot studies; encouraging earthquake risk reduction for lifelines; providing information on seismic design and mitigation, including the nurturing of industry guidelines, standards, and codes for evaluating and mitigating existing buildings; and transferring NEHRP recommendations into model building codes.

In previous years, FEMA had tremendous success working with states and communities, providing guidance and support for risk-reduction implementation projects and policies. This important work, however, has been seriously hampered in recent years by a lack of prioritization, support, and funding from the Department of Homeland Security (DHS). FEMA's effectiveness appears to be tied to DHS, and the Department has cut deeply into the ability of FEMA to support NEHRP goals.

FEMA had a dedicated program until 2001 to provide assistance to states with high earthquake risks by directly supporting their state earthquake program managers. Since 2003, that assistance has been subsumed into other DHS state and local homeland security grant programs. The net effect has been to degrade the overall preparedness of most state earthquake programs, as well as the visibility and effectiveness of their managers. Few of these managers can identify or gain access to the resources they previously received. It is vital to increase the overall level of FEMA NEHRP support within DHS to help revitalize effective state programs.

Despite its declining budget, FEMA has been successful in developing and implementing earthquake risk reduction tools and disaster-resistant building codes. A noteworthy achievement is the successful development, through cooperative programs with the American Society of Civil Engineers, of earthquake-resistant design standards for new construction, the use of which are referenced in model building codes adopted by local governments and public agencies throughout the Nation. This success, particularly in the areas of lifelines and existing buildings, is now at risk as there is no funding available to maintain efforts and guidance documents.

FEMA's efforts to promote implementation of available earthquake risk-reduction tools have been less effective. The focus of these efforts has largely been on the public sector, including states and local agencies. However, not all communities have adopted the new building codes and, notably, some communities in the Nation's heartland continue to maintain inappropriate seismic design practices. There has been only limited success in promoting improvements in seismic resilience, particularly in existing privately owned facilities. In both cases, the lack of success can be tied to the private sector's perception of a lack of adequate return on investment for seismic resilience. There is an opportunity for FEMA to focus on educating decision makers in the private sector, in particular the financial community, on the risks associated with inaction and the benefits of proactive mitigation.

A number of FEMA's past, highly successful development efforts, including the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures,* have now been incorporated into national model building codes. FEMA should maintain these essential tools through the cooperative support of not-for-profit and private-sector organizations.

2.2 National Institute of Standards and Technology

ACEHR provides two recommendations for NIST:

- ***Recommendation 1****:* NIST must secure the funding to effectively carry out its role as the lead agency for the Program and its role in applied research and assistance in implementation of cost-effective mitigation through codes and standards.
- ***Recommendation 2****:* NIST must plan for the development of multidisciplinary expertise within its own staff and foster relationships with other public agencies and private-sector entities to accomplish the coordinated research to effectively fulfill its obligations.

In the years before the 2004 NEHRP reauthorization, NIST's role within NEHRP was relatively minor and not fully realized because of a very low level of funding. FY 2005 brought a substantial change to NIST: it became the designated lead agency for NEHRP. Although NIST's direct budget for NEHRP has not been increased, the agency internally reallocated funds to establish the NEHRP Secretariat and hire the Program director. It appears that NIST also has received some support from other NEHRP agencies.

Under the reauthorization, NIST was also assigned greater responsibility 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 *The Missing Piece: Improving Seismic Design and Construction Practices, Applied Technology Council*.

Given the relatively recent shift in the role of NIST to NEHRP lead agency, it is premature to assess fully the effectiveness of the agency. It is clear that NIST has taken seriously the assignment to lead the Program by providing overall coordination, direction, and support of joint efforts consistent with Congressional intent and centered upon objectives defined by the authorizing legislation. Interest from the highest level of the agency is apparent to and appreciated by ACEHR. The office of the NEHRP director is to be commended for its open approach to planning and leveraging resources by actively partnering with the earthquake professional community and by participating in regional consortia. NIST has fostered a strong level of interaction among the agencies participating in NEHRP. There has been notable outreach to interested stakeholders. The process employed in forming and supporting ACEHR, including the method by which nominations were solicited, is one example. The development process for the 2008–2012 NEHRP Strategic Plan is another. The future work to develop a comprehensive plan for earthquake engineering research will require a strong commitment to this inclusive philosophy.

It is apparent that NIST intends to develop a very strong Program. NIST has initiated a dramatic change in direction by going beyond the traditional scope of life safety in individual structures to a much broader approach that includes regional resilience.

A number of statutory responsibilities have not been met because of a lack of funding. Examples of some of the programs that are not adequately addressed include conducting applied research to enhance model building codes, promoting better building practices among architects and engineers, and working with national standards developers to improve seismic safety standards for new and existing lifelines.

NIST has begun on a small scale to implement the applied research program, which is intended to be a coordinated program of internal and external projects. The lack of funding, however, has kept the program at a very low level. The initial projects selected for external funding are clearly high-priority projects, but funding is insufficient to develop the staff within NIST needed for the program to be fully effective, and the individual projects are actually small steps.

The work to assist implementation of cost-effective measures for mitigation of the risk involves many technical disciplines, such as structural, geotechnical, and lifeline engineering, and has to be informed by research on communicating risk information and strategies for adopting mitigation policies, such as economic incentives, well enforced regulations and standards, and insurance. NIST faces a challenge: it must develop sufficient internal 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.

2.3 National Science Foundation

ACEHR provides three recommendations for NSF:

- ***Recommendation 1*****:** NSF should enhance its support for multidisciplinary research related to NEHRP, which can be used as a model for reducing risks associated with other natural and human-induced hazards. In particular, there is an opportunity for the Engineering and Geosciences Directorates to partner with the Social, Behavioral, and Economic Sciences Directorate to understand the social and economic factors that promote mitigation measures.
- ***Recommendation 2****:* NSF should enhance its support for curiosity-driven basic research, which has been the foundation of many important technical discoveries. Basic research sponsored by NSF educates the next generation of engineers and scientists engaged in earthquake risk reduction. Such support is thus a means of expanding the workforce in earthquake engineering and science.
- ***Recommendation 3***: NSF should solicit support from other federal agencies to leverage the NSF investments in NEES to address critical research needs for the civil infrastructure. To date, research support for NEES has not matched the levels needed by the earthquake community to reduce earthquake risks significantly.

The NEHRP statutory responsibilities 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 the NSF represents a combination of coordinated programs and unsolicited proposals, now referred to as curiosity-based projects, by individual investigators. The NSF has also funded numerous international workshops and post-earthquake investigations.

Historically, many of the early technical successes of NEHRP were tied to individual researchers conducting curiosity-based research. In the past 20 years, coordinated research projects and research centers have grown to represent a larger portion of the research portfolio within the NSF.

Over the past 10 years, each of the NSF-sponsored research centers (Mid-America Earthquake (MAE) Center, Multidisciplinary Center for Earthquake Engineering Research (MCEER), Pacific Earthquake Engineering Research (PEER) Center, and Southern California Earthquake Center (SCEC)) has made significant contributions to NEHRP. The Centers serve as models for large, collaborative research efforts and are demonstrated leaders in the development of community-based simulation models—for both earthquake physics and structural response—and integrated outreach to the K-12 and professional communities.

NEHRP has benefited greatly from multidisciplinary programs within the Earthquake Engineering Research Centers (EERCs) that have combined the contributions of social science, geosciences, and engineering. With the graduation of the EERCs from NSF support, successful long-term programs to support interdisciplinary research have been phased out. Action is needed to encourage and sustain vigorous interdisciplinary activities and to support research activities that benefit from the collaboration among investigators from different disciplines.

ACEHR is concerned about the level of funding for NEHRP research. Although the NSF made a substantial investment in the infrastructure and management of NEES, the level of funding for research projects has not increased to take advantage of the enhanced research infrastructure and larger pool of researchers. Success levels for NSF proposals related to earthquake engineering and social science research are low, which discourages many researchers from working to reduce risks associated with earthquakes.

NEES is an important part of NEHRP and a substantial part of the NSF NEHRP research program. Many of the current NSF-sponsored research projects could not have been conducted before the capabilities of the experimental facilities in the U.S. were dramatically enhanced by the NEES equipment sites. The success of NEHRP is therefore linked to the success of NEES activities, including research at the NEES equipment sites, development of information technology (IT) services, and effective outreach projects. ACEHR encourages strong and collaborative management of NEES with attention to engaging the support of other government agencies and industry, and productive education, outreach, and training activities to introduce the next generation of earthquake engineers to the many challenges yet to be resolved.

2.4 U.S. Geological Survey

ACEHR provides three principal recommendations for USGS[1]**:**

- ***Recommendation 1*:** Fully fund ANSS at the level authorized in the current NEHRP legislation. The USGS must make a commitment to work through the DOI and the OMB to ensure that this objective is met.
- ***Recommendation 2*:** Proceed with multihazard demonstration projects, such as the project being carried out in southern California that was initially funded by Congress in FY 2007. The demonstration projects should expand the multihazard scope to include other high-risk areas as part of this effort.
- ***Recommendation 3*:** Enhance the interaction of the USGS with its NEHRP partners in earthquake engineering (NIST and NSF), earth science (NSF), and earthquake preparedness (FEMA). The noteworthy level of coordination in some geographic areas, such as California, and in some project areas, such as the National Seismic Hazard Mapping project, should be extended to other geographic and project areas.

The USGS is accomplishing its statutory NEHRP responsibilities in an effective way, both through a host of active partnerships and through the professionalism of its own agency staff. It seems fair to say that the viability of the USGS Earthquake Hazards

[1] Two additional recommendations made by the USGS SESAC, listed on page 13, are also endorsed.

Program can be measured by the level of satisfaction among its many stakeholders in the national earthquake community. To its credit, the USGS has done a masterful job of engaging and working with this community—despite NEHRP-specific funding levels widely recognized to be persistently inadequate—to accomplish its first-order NEHRP tasks: (1) provide earthquake monitoring and notification; (2) assess seismic hazards; and (3) conduct research needed to reduce the risk from earthquake hazards nationwide.

One objective indicator of USGS effectiveness in relation to government performance criteria is the top rating given to the ANSS in 2007 and 2008 by the Investment Review Board of the DOI. "Among 60 major information technology investments, ANSS ranked highest for business value to the mission of the USGS and DOI and lowest for implementation and operational risk" (NEHRP Annual Report, March 2008, page 34). That said, only a small fraction of the authorized and required funding for ANSS has been appropriated. Without additional funding, ANSS will not achieve its directive to build a national seismic monitoring system.

The USGS has successfully engaged diverse stakeholders, including seismologists, engineers, emergency managers, and other varied users of earthquake data and information. Many diverse groups are collaborating with the USGS in developing ANSS, as well as in many other aspects of the agency's NEHRP mission. The effectiveness of these collaborations is enhanced by the openness and responsiveness of USGS to advisory groups such as SESAC, the ANSS National Steering Committee, regional advisory committees, and SCEC, among others.

While ACEHR's overall evaluation of the USGS NEHRP collaborations is positive, the Committee believes there are areas where improvements can be made within current levels of funding. The USGS should enhance the coordination of internal and external research activities in earthquake hazards more uniformly throughout the United States. Enhanced USGS interactions with its NEHRP partners in earthquake engineering (NIST and NSF), earth science (NSF), and earthquake preparedness (FEMA) would achieve greater NEHRP coherence. The noteworthy level of coordination in some geographic areas, such as California, and in some project areas, such as the National Seismic Hazard mapping project, can be extended to other geographic and project areas. For example, the USGS, which has an effective capability for public outreach, could involve engineers to help translate earthquake forecasts into implications for the built environment. Similarly, better outreach partnerships with the Earthquake Engineering Research Institute (EERI) and the California Office of Emergency Services could result in conveying a more complete "earthquake story" to the public.

Examples of NEHRP implementation activities being carried out by the USGS are described in the March 2008 NEHRP Annual Report, the DOI Budget Justification and Performance Information for Fiscal Year 2009, and the SESAC 2008 Annual Report. Many of these activities were also described to ACEHR at its meetings in May 2007 and October 2007. Core activities of the USGS include earthquake monitoring and reporting of earthquake information through the National Earthquake Information Center (NEIC), ANSS, and the Global Seismographic Network; urban and national seismic hazard mapping; and carrying out innovative earthquake research. Some of the agency's innovative, recent accomplishments include the following:

- Development of a new generation of national seismic hazard maps that utilize new ground motion attenuation relations as well as an improved understanding of earthquake hazards, especially in the western United States. These new maps, updated in 2007 for the first time since 2002, are critically important for the development of the 2012 version of the *International Building Code*.
- Release of a first-ever statewide earthquake rupture forecast model for California.
- Implementation of multihazard demonstration projects in southern California and the Pacific Northwest.
- Implementation of Prompt Assessment of Global Earthquake Response (PAGER), a system that can readily estimate societal impacts for major domestic and worldwide earthquakes by the NEIC.
- Success in drilling through the San Andreas fault at a depth of about 2 miles below the ground surface, carried out through the San Andreas Fault Observatory at Depth (SAFOD) project, a multi-year project funded by the NSF and led by scientists from Stanford University and the USGS. The results from this project impact research on earthquake mechanics in a number of fundamental ways.

Under its charter, ACEHR is instructed to consider recommendations of the USGS SESAC in developing its own recommendations. In April 2008, SESAC made the following four primary recommendations (in paraphrased form), representing their highest priorities, for the USGS component of NEHRP:

- **SESAC Recommendation 1:** Fully fund ANSS at the level authorized in the current NEHRP legislation. The USGS must make a commitment to work through DOI and OMB to ensure that this objective is met.
- **SESAC Recommendation 2:** Proceed with multihazard demonstration projects, such as the project being carried out in southern California that was initially funded by Congress in FY 2007. The demonstration projects should expand the multihazard scope to include other high-risk areas as part of this effort.
- **SESAC Recommendation 3:** Develop a comprehensive monitoring, analysis, and research program to study the significance of episodic tremor and slip events**.** It is especially important to better understand the significance of this phenomenon with respect to changes of earthquake probability.
- **SESAC Recommendation 4:** Increase the number of research scientists actively engaged in the Earthquake Hazards Program. Over the past two decades, there has been a dramatic decrease in the number of USGS scientists working to fulfill the agency's NEHRP mission. It is essential to reverse this trend to meet both the challenges and opportunities facing the Earthquake Hazards Program.

ACEHR endorses these recommendations of SESAC, amplifying in particular Recommendations 1 and 2. ACEHR notes that the issue of inadequate staffing is a cross-cutting one affecting all four NEHRP agencies. Another cross-cutting issue is the importance of interdisciplinary interactions. ACEHR believes each agency must ask itself: what is not getting done, or not getting done effectively, because of a lack of relevant multidisciplinary expertise within its NEHRP workforce? In the case of USGS, relevant in-house professional expertise might include, for example, social science, structural engineering, or other non-earth science specializations. To clarify, ACEHR's recommendation is not to duplicate core competencies in each agency but rather to advocate some useful presence of multidisciplinary expertise in each agency for carrying out its NEHRP mission more effectively.

3. Management, Coordination, and Implementation of NEHRP

ACEHR provides one recommendation related to Management, Coordination, and Implementation:

- ***Recommendation*:** Consistent with the change in the leadership of NEHRP, ACEHR recommends that USGS delegate post-earthquake investigation leadership to NIST, including the organization and deployment of reconnaissance teams and sponsoring the publication of discipline-oriented interactive media that archive collected data.

The 2004 reauthorization of NEHRP established an expanded ICC made up of the directors of NIST, FEMA, the NSF, the USGS, and the White House OMB and OSTP. The Congressional desire to encourage a higher level of coordination and collaboration between the agencies, their budgeting processes, and the President's science initiatives appears to have been well received and has resulted in very positive changes to NEHRP. The ICC has accepted briefings from the ACEHR chair on two occasions and has been receptive to ACEHR's observations. At the last briefing, the President's Science Advisor declared that ACEHR was "preaching to the choir," indicating that there is strong support for NEHRP and general agreement on what needs to be done, and pointed out that the ACEHR recommendations are consistent with the President's National Science and Technology Council report *Grand Challenges for Disaster Reduction*. ACEHR looks forward to a continuous dialogue with the ICC.

After 25 years of good, individual progress by NEHRP agencies, the Program now also benefits from a high level of interagency collaboration and a common focus. The 2007 NEHRP Annual Report offered the first signs of this benefit. The 2008–2012 NEHRP Strategic Plan outlines a wide variety of strategic priorities, each with a designated agency lead, and carries the expectation that the other agencies will do their parts in a coordinated and collaborative manner that leverages synergy and minimizes duplication of effort.

Consistent with the change in leadership, ACEHR believes that NEHRP would benefit from a similar change in leadership related to post-earthquake investigations. Section 11 of Public Law 108-360 establishes a post-earthquake investigation program within USGS that involves NSF, NIST, as well as other federal agencies and private contractors. ACEHR fully supports the need for post-earthquake investigation, believes the USGS Circular 1242 should be updated, and sees the following opportunities for significantly improving our ability to gather and utilize important perishable data after an earthquake.

- In addition to the current practice of dispatching an interdisciplinary investigation team for a rapid, overarching assessment of earthquake characteristics and effects, emphasis should be placed on discipline-oriented teams to investigate each facet of the earthquake. Each team should be funded by its related organization or agency. Teams should be identified to investigate earth science, geo-engineering, lifelines, structural, social, and economic aspects of each major event.

- USGS should delegate leadership to coordinating post-earthquake reconnaissance efforts to the lead NEHRP agency, NIST. NIST should serve as a single point of coordination, without any discipline-specific individual responsibility, to ensure that all key aspects of an event are captured in a balanced manner. Staff and funding must be provided to refine the response program, identify available participants, and maintain a state of response readiness.
- The results of the investigations and related research should be gathered and archived in the Post-Earthquake Information Management System (PIMS) and published in a set of discipline-oriented interactive media that archive collected data related to the immediate and long-term impacts of the event.

ACEHR recommends that this change in structure be incorporated during the next NEHRP reauthorization cycle.

ACEHR is deeply concerned about the withering of appropriated funds for NEHRP. Currently at $120 to $125 million per year, NEHRP funding has been essentially flat or increasing below inflation levels for the past 30 years. In 2003, EERI's report *Securing Society Against Catastrophic Earthquake Losses: A Research and Outreach Plan in Earthquake Engineering* determined that $330 million per year was needed, although just the opposite is happening. There is evidence that funds recently appropriated for NEHRP have in some cases been diverted. ACEHR recognizes that NEHRP is a small part of the federal budget, so small that it does not have line items in the Congressional budget. Funding decisions appear to be made at the department and agency level. ACEHR appreciates the need for balance in the budgets for each department and agency and their need to adhere to the President's priorities. The Committee respectfully submits that more priority be given to NEHRP and that full funding at authorized levels be appropriated. ACEHR also recommends that NEHRP revisit the EERI report to determine the true cost of implementing the strategic plan.

The ACEHR understands that a process has been developed for sharing information related to NEHRP program budgets and coordinating areas of common activities. The Committee believes that the availability of a fully supported strategic plan and a coordinated budgeting process will lead to opportunities to expand appropriations and achieve significant added value.

While implementation of NEHRP's new management structure is proceeding more slowly than was hoped for due to a lack of funding, the ACEHR sees no need to adjust any of the components. The ACEHR is pleased that NIST intends to dedicate 50 percent of its NEHRP research funds to an external grants program, and encourages NIST to follow through on this plan. Although much of the basic "missing link" research can be done in the NIST laboratories, there is a strong need for research to also be carried out at the various universities and professional organizations that have been active participants in NEHRP.

The ACEHR has developed into a collaborative group of earthquake professionals. The Committee appreciates the diversity of participants and balanced perspectives that are represented. The members of ACEHR appreciate the opportunity to review the NEHRP Strategic Plan during its development and would like that same opportunity for future strategic plans, annual reports, and other documents produced by the NEHRP Secretariat. The ACEHR's ability to use eTechnology to conduct its deliberations from remote sites and within public view was demonstrated during the completion of this report and makes such active participation a real possibility. The ACEHR also believes that it would benefit from more representation from the lifelines and financial industries, as well as from urban planners

Appendix —Trends and Developments in Science and Engineering

A. Social Sciences

A.1 General

The field of risk analysis has assumed increasing importance for the social sciences in recent years given the concern by both the public and private sectors in safety, health, and environmental problems. There is a need for more detailed studies on risk assessment, taking into account the built-in environment to complement the research that has been undertaken on hazard assessment (the nature of the earthquake risk).

A.2 Risk Assessment

Risk assessment encompasses studies that estimate the chances of a specific set of events occurring and/or their potential consequences. Scientists and engineers need to provide the users of these data with a picture of what is known regarding the nature of a particular risk and the degree of uncertainty surrounding these estimates. They also have to be sensitive to their role as assessors of these estimates. It is not uncommon for the public to hear Expert 1 and Expert 2 disagree about the level of risk. There may be many different reactions to these conflicting reports. One layperson may decide that he or she cannot rely on the judgment of any expert. Another may decide to focus on the expert supporting his or her own view of the risk. Someone else may seek out the views of other experts to see if there is a degree of consensus on the nature of the risk.

A key question to be addressed in undertaking risk assessment is the degree of uncertainty regarding both probability and outcomes. It is much easier to construct such a curve for earthquakes than for terrorist activities. However, even for these more predictable accidents or disasters, there may be considerable uncertainty regarding the likelihood of the occurrence for earthquakes and the resulting damage. Providing information on the degree of uncertainty associated with risk assessments should increase the credibility of the experts producing these figures. There is also a need for experts to state the assumptions on which they are basing their estimates of the likelihood of certain events occurring and the resulting consequences. The nature of these assumptions should enable the public to gain a clearer picture about why there is so much ambiguity surrounding estimates of some risks and much less uncertainty on others

A.3 Risk Communication

There is a need to present information to individuals so that they appreciate the meaning of low and high probabilities. Laypersons are not likely to process these data in ways that scientists and engineers would like them to. Most people believe small numbers can be easily dismissed, while large numbers get their attention. By stretching the time frame over which the probability of an extreme event is presented, people may pay attention to an event that they would otherwise ignore. The following example illustrates how the same probability, one presented using a long time horizon and the other using a short one, can influence the adoption of protective measures. If a company is considering earthquake protection over the 25-year life of its plant, managers are far more likely to take the risk seriously if they are told the chance of at least one earthquake occurring during the entire period is 1 in 5 rather than 1 in 100 in any given year.

A.4 Achievements

Since the inception of NEHRP, NSF has been responsible for funding basic and applied research on the societal dimensions of earthquakes, including research on earthquake mitigation, preparedness, response, recovery, and related topics, such as risk assessment and communication and earthquake loss reduction policy.

In 2004, the National Research Council Committee on Disaster Research in the Social Sciences was charged with assessing the importance and contributions of social science research sponsored over the years by NEHRP and with identifying new frontiers for research. Again, the vast majority of this work was supported by NSF. The Committee's report, *Facing Hazards and Disasters: Understanding Human Dimensions* (National Research Council, 2006), highlighted numerous ways in which NEHRP-sponsored research has improved our understanding of the societal aspects of earthquakes and other threats, including technological disasters and terrorism. The report also recognized the need for new research on a range of hazard-related topics. Examples highlighted in the report include research to identify better mechanisms for intervening into the dynamics of hazard vulnerability; to encourage the adoption of mitigation measures and evaluate the effectiveness of existing measures; to assess the impacts of changes over time in hazard-related laws, policies, and programs; and to better understand the challenges associated with near-catastrophic and catastrophic disaster events. Also emphasized were the need for funds to support data archiving, preservation, and sharing; stronger efforts directed to the development of a disaster research workforce; and research on enhancing multidisciplinary and interdisciplinary collaborations in hazard-related fields.

A.5 Challenges

There is a need for agencies concerned with implementation of NEHRP to fund research that advances the understanding of the social, psychological, and economic factors that encourage or inhibit residents and businesses from investing in mitigation measures. One key document published by the National Science and Technology Council's Subcommittee on Disaster Reduction, *Grand Challenges for Disaster Risk Reduction* (Subcommittee on Disaster Reduction, 2005), calls explicitly for research that makes it possible to provide hazard and disaster information when and where it is needed (Grand Challenge #1); develop hazard mitigation strategies and technologies (Grand Challenge #3); recognize and reduce critical infrastructure vulnerabilities (Grand Challenge #4); assess disaster resilience (Grand Challenge #5); and promote risk-wide behavior (Grand Challenge #6). None of these Grand Challenges can be addressed without the kind of research in the social, economic, and policy sciences that NSF has historically supported.

Securing Society Against Catastrophic Earthquake Losses: A Research and Outreach Plan in Earthquake Engineering, a consensus report developed by EERI (2003), contains an entire section devoted to needed research that can result in enhancing community resilience in the face of the earthquake threat. The topics identified as requiring additional research include factors that drive societal and community vulnerability to earthquake hazards; the relative cost and effectiveness of alternative risk management policies; earthquake impacts on households, businesses, and communities, along with strategies for reducing those impacts; demands that earthquakes place on response and recovery systems, as well as how to improve such systems; and factors that affect the adoption and implementation of risk management practices.

One way to encourage this research is to promote a risk analysis framework for future research in the hazards area. As noted above, the field of risk analysis has assumed increasing importance for the social sciences in recent years given the concern by both the public and private sectors in safety, health, and environmental problems. Risk analysis encompasses three interrelated elements: risk assessment, risk perception, and risk management.

Successful risk analysis requires scientists and engineers to undertake *risk assessments* to characterize the nature and uncertainties surrounding a particular risk. One also needs social scientists to characterize the factors that influence *risk perception* by individuals, groups, and organizations. While traditional risk assessment focuses on losses that are often measured in monetary units, risk perception is concerned with the psychological and emotional factors that have been shown to have an enormous impact on behavior. There is a need to develop *risk management* strategies that involve risk communication, economic incentives, standards, and regulations for managing these risks. Given the challenges in processing information on these risks, as well as the interdependencies between individuals and firms which create negative externalities, funding should support research that examines strategies for reducing future losses efficiently while addressing equity and affordability issues.

B. Earth Science

B.1 General

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.

Although there currently is no scientific capability to predict within narrow bounds the size, location, and occurrence time of future earthquakes, there is much that can now be predicted with some degree of certainty. For example, the likely locations and sizes of future earthquakes that threaten major metropolitan areas in many parts of the Nation are reasonably well known, and detailed predictions can be made of the severity of ground shaking that will result from these earthquakes, as well as the effects of the shaking on buildings, infrastructure, and facilities.

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

B.2 Achievements and Challenges

The March 2008 NEHRP Annual Report, the April 2008 SESAC Report, and other NEHRP reports summarize many notable achievements and developments in earth science relevant to NEHRP goals. Some selected items are presented to give the reader a sense of stimulating developments and important strides being made. The ACEHR also includes perspectives on some programmatic aspects of NEHRP that relate to these earth science developments, including challenges.

Episodic tremor and slip — One of the most exciting geophysical discoveries since the plate tectonics paradigm of the 1960s is the documentation of non-volcanic tremor and associated deep, episodic aseismic slip events in a number of subduction zones around the world. Now referred to as ETS (episodic tremor and slip), this remarkable geophysical phenomenon has been particularly well-documented in the Cascadia subduction zone that threatens the Pacific Northwest and western British Columbia. Deep episodic tremor has now also been found beneath the San Andreas fault in central California. Achieving an improved understanding of possible relationships between ETS events and potential future large earthquakes is an important and scientifically intriguing challenge.

Ground motion prediction modeling — An important development for ground motion prediction modeling, as well as for probabilistic seismic hazard analysis and earthquake engineering design, was the completion in 2007 of the PEER Center Next Generation Attenuation (NGA) models for shallow crustal earthquakes in the western U.S. Unfortunately, these models still suffer from sparse near-source recordings of strong ground motion. The new models provide improved reliability in the prediction of the median levels of ground motions, but their variability has not been reduced. The site-to-site variability in ground motions depends not only on the shallow geological structure, but also on features of the fault rupture process itself, such as rupture directivity, that cause spatial variations in ground motion levels. Dynamic models may provide an important approach to understanding the physical limits on strong ground motion levels. This may help to quantify the shape of the distribution of extreme ground motion values, which is difficult to discern in the strong motion data but has a large impact on seismic hazard analyses and design.

Earthquake early warning — During the last few years, significant progress has been made outside of the U.S. in the development of earthquake early warning systems designed to provide alerts ahead of the arrival of strong shaking in heavily populated areas. Such systems are currently operational in five countries (Japan, Mexico, Turkey, Italy, and Romania) and are under development in six others (Taiwan, Iceland, Switzerland, Greece, and Egypt). In the U.S., pre-prototype earthquake early warning tests are being conducted by member institutions of the California Integrated Seismic Network (CISN), a regional component of ANSS, as part of a 3-year program funded by the USGS. The assessment of SESAC is that much work remains to be done before this technology could be confidently used as part of a national program for earthquake public safety.

Multihazards demonstration project in southern California — An important new thrust for the USGS Earthquake Hazards Program is a Multihazard Demonstration Project (MHDP) in southern California, which will demonstrate how hazards science can be used to improve resiliency to a range of natural disasters. During 2007–2008, the major activity of the MHDP is the development of an earthquake planning scenario for southern California. The scenario assumes a magnitude 7.8 earthquake on the southern San Andreas fault, with fault rupture beginning near the Salton Sea and propagating northwestward past San Bernardino to just north of Palmdale. Damage assessments from the scenario will be incorporated into the November 2008 "Great Southern California ShakeOut" (a community outreach activity) and the Golden Guardian exercise for emergency managers in the 8 counties and more than 200 cities of southern California.

California statewide earthquake rupture forecast — In 2008, the USGS and its partners are delivering the first-ever statewide earthquake rupture forecast model for California. This model, developed collaboratively with the California Geological Survey (CGS) and the SCEC, provides input to the national seismic hazard maps and will be used to update earthquake insurance premiums in the state.

Large-scale, geographically distributed collaborations — Multi-institutional partnering is increasingly enabling the development and sharing of seismological data, geophysical models, and computational tools by a broad community of investigators. Examples are ANSS; the SCEC Community Modeling Environment, providing a virtual collaboratory for knowledge management, hypothesis formulation and testing, data conciliation and assimilation, and prediction; and the National Center for Engineering Strong-motion Data, a new "one-stop" access facility created by the USGS Earthquake Program and the CGS Strong-Motion Instrumentation Program, which not only makes strong ground motion databases widely available but will also support and integrate international data collection activities currently performed by the COSMOS Virtual Data Center.

NSF/Geosciences synergy with USGS — Synergy between NSF- and USGS-funded programs is becoming increasingly critical for the success of data acquisition, data processing/archiving/distribution, and seismological research relevant to NEHRP goals. Examples include: (1) joint funding of SCEC III, the current 5-year phase of SCEC; (2) joint operation of the Global Seismographic Network (GSN); and (3) contributions to NEHRP goals by all three EarthScope components (USArray, SAFOD, and Plate Boundary Observatory (PBO)). One challenge is to achieve greater coherence, where feasible, between NSF and USGS strategic planning as it relates to NEHRP goals.

NSF/EarthScope's USArray — The first 400-station complement of USArray (intended primarily to study deep earth structure) was completed in 2007, with a footprint covering a large part of the western U.S. (Washington, Oregon, California, Nevada, and the western parts of Montana, Idaho, Utah, and Arizona). Many of these non-NEHRP stations fill in large gaps in regional seismographic coverage of the western U.S., which unfortunately will reappear when the transportable stations progressively move after 18–24 months. Lack of ANSS funds to "adopt" a sizeable subset of these high-quality broadband stations to fill geographic holes in the system will mean a missed opportunity for NEHRP.

USGS's ShakeMap and FEMA's HAZUS — The ability to integrate ANSS ShakeMap data with HAZUS for loss estimation is proving to be an extremely valuable tool, both for rapid post-event impact assessment and for scenario planning. Coordination between the USGS and FEMA to develop and improve ground-motion-based HAZUS loss estimates is a NEHRP success story. Challenges still remain for automating the rapid production of HAZUS results, particularly in large metropolitan areas, when ShakeMap data are generated by a moderate to large earthquake.

The Need for Full Funding of ANSS — The USGS and its ANSS partners now produce in real-time, or near real-time, an unprecedented suite of Web-based information products on earthquake effects that assist disaster response agencies. ShakeMap, ShakeCast, and the PAGER system provide specific, detailed information on earthquake effects that could not have been imagined at the time of the 1989 Loma Prieta, 1994 Northridge, and 1995 Kobe earthquakes. The ability of the USGS to provide real-time earthquake data and products that enable rapid and efficient local, state, and federal response is dependent on the continued expansion of ANSS and funding to maintain and sustain operations. Progress in engineering seismology is being hindered by the inadequacy of strong motion recording systems throughout the U.S. Even in seismically active regions such as California and the Pacific Northwest, there are not enough recorded ground motion time histories for use in representing earthquake ground motions for structural design. The situation is even worse elsewhere. A particularly important need for strong motion recordings is to understand the seismic response of urban regions. There are not dense enough urban strong motion arrays to allow an understanding of the spatial variations in ground motions (and damage) that characterize most earthquakes. For a host of compelling reasons, full funding of ANSS is urgently needed.

Human resource problem — The April 2008 SESAC report calls attention to a critical human resource problem within the USGS. The problem afflicts other NEHRP agencies as well. Indeed, an aging workforce and decreasing numbers of students pursuing careers in NEHRP-related science could foreshadow a major human resource problem for NEHRP. In the case of the USGS, its ability to meet a number of mission-critical tasks is seriously threatened by the steady decrease in the number of research scientists actively engaged in the Earthquake Hazards Program—from a high of over 400 staff supported in the 1980s to 220 at the end of 2007.

C. Geotechnical Earthquake Engineering

C.1 General

Geotechnical earthquake engineering is traditionally placed between the disciplines of earth science and structural engineering, although it interfaces with all earthquake-related disciplines given its breadth. As a result of the geotechnical engineering profession's placement and its size relative to earth science and structural engineering, its true impact on earthquake resilience can be underappreciated at times. However, advancements in earthquake resilience require incorporation of important geotechnical effects of earthquakes, such as surface fault rupture, 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.

C.2 Achievements

The important effects of local ground conditions on earthquake ground motions is now widely appreciated and incorporated in the International Building Code. Liquefaction is also widely recognized as a critical hazard, 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. Geotechnical engineers have led the development of quantitative GIS-based documentation of the effects of earthquakes.

C.3 Issues and Challenges

Significant challenges remain, however, in the geotechnical earthquake engineering and related professions. Earthquake science and engineering should grow more interconnected and interdisciplinary. NEHRP can shepherd this emerging trend. Geotechnical engineering needs to be an integral part of multidisciplinary research. Although NIST's establishment of an external grant program fills a critical gap between NSF-funded basic research and applied research needed for effective implementation, the NIST earthquake research program should include the effective transfer of geotechnical engineering knowledge.

Levee and flood protection system reliability, including their seismic performance, must be addressed by the Nation. 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. 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.

High-end computing coupled with enhanced visualization software is transforming the manner in which we evaluate seismic performance. 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. Better models of ground shaking near faults and in the eastern and central U.S. are required. 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 codes, the Program should advance tools that move the profession toward true performance-based design.

D. Structural Earthquake Engineering

D.1 General

Recent developments in structural engineering include efforts to develop performance-based engineering and methods to develop tools for health monitoring and rapid assessment of structural condition following earthquakes.

Performance-based engineering comprises two primary parts: (1) the development of practical and reliable means of predicting the probable behavior of buildings and structures in earthquakes and the effects of this behavior on society; and (2) the development of technologies that can effectively control and limit earthquake damage and consequences in both new and existing structures.

Following earthquake disasters, society has a need to identify those buildings and structures that are safe for continued occupancy and for use as centers for recovery, as well as those structures damaged to an extent that renders them unsafe or otherwise unusable. In the past, assessment of structural condition could be conducted only through the efforts of individual engineers with the knowledge and skills to rapidly assess damage and make reliable judgments as to structural condition. In a large disaster, such as a major earthquake affecting Charleston, Los Angeles, Memphis, Seattle, San Francisco, or Salt Lake City, thousands of buildings and lifeline structures will be affected. There are not enough sufficiently trained engineers or government officials to perform the needed assessments in a rapid manner. Failure to identify safe, useable, and unusable structures places citizens in the affected regions at greater risk and hinders the ability of government to marshal the resources necessary to speed aid to the affected region.

D.2 Achievements

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 society's earthquake resiliency. Without this capability, it is impossible to understand the risks or to effectively allocate resources to mitigate these risks. Twenty years ago, such performance assessments could be made only by a very few expert engineers who had the knowledge and judgment to effectively perform this task. These experts numbered far too few to permit widespread and routine assessment of the risks.

The development and introduction of HAZUS approximately 10 years ago provided the capability to realistically assess earthquake risks at a community level, but did not provide engineers with the ability to reliably predict the likely performance of individual structures. Work undertaken at the three NSF-sponsored EERCs has begun 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. Many fledgling simulation tools and some significant amounts of data have been developed that enable the use of these tools to predict the performance of some classes of structures. These tools are slowly being disseminated to the practicing professionals in useable form.

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 they are to be effectively controlled. Twenty 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 to implement. Some noteworthy success has been achieved, including development and adoption by the 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 are becoming available, providing a capability to design and build a more damage-resistant environment. Work is continuing in both areas. 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, electrical systems, and similar items. This is particularly important because most of the economic losses associated with recent U.S. earthquakes have resulted from nonstructural rather than structural damage.

D.3 Issues and Challenges

Substantial additional work is required to enable effective implementation of performance-based engineering procedures. Needs include the following:

- Development of fragilities and consequence functions for the many types of structural systems and nonstructural components found in buildings and structures so that the performance of new and existing buildings and structures and the losses associated with this performance can be accurately predicted.

- Development of reliable means of predicting structural collapse so that existing structures that are truly hazardous can be identified and so that new structures can be reliably designed to protect life safety.

- Continued development of performance-based engineering tools that will enable engineers and other design professionals to reliably assess structural performance and design buildings and structures for improved performance.

- Development of practical and effective structural systems that can be used to minimize damage and loss in both new and existing structures.

- Development of tools that will enable the data collected from ANSS and privately-owned health monitoring instruments in buildings to instantaneously collect, process, and interpret the data so as to make rapid assessments on structural condition.

- Education of the design professional community so that they can effectively use these new tools.

E. Lifelines Earthquake Engineering

E.1 General

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. Taken individually, or in aggregate, these systems are essential for emergency response and restoration after an earthquake, and are indispensable for community resilience.

E.2 Achievements

Significant advances in lifeline earthquake engineering have been made in high-performance computational models that simulate complex networks. These models put out highly graphic, detailed scenarios that enable modelers and associated emergency personnel to visualize a wide range of responses from an entire lifeline system to a specific part of that system. By running multiple scenarios, with and without modifications of the system, operators can identify recurrent patterns of response and develop an overview of potential performance, helping them plan for many eventualities and improving their ability to improvise and innovate in the event of a real earthquake.

Major assessments of system-wide earthquake performance have been undertaken by water utility companies, including the East Bay Municipal Utility District, Los Angeles Department of Water and Power, and the San Francisco Public Utilities Commission, as the 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.

Lifeline system disruption has a direct effect on business losses that, in turn, have multiple related effects on other businesses. There is a growing body of research and applications associated with the economic and social consequences of lifeline damage and loss of functionality. The economic and community consequences of earthquake damage are being integrated with system simulations to create models and a modeling process that link the earthquake response of lifelines through system reliability to regional economic and social impacts.

A significant trend in lifeline and geotechnical earthquake engineering has been the implementation of large-scale and centrifuge testing facilities to assess lifeline response to earthquake loading. Examples include the large-scale and centrifuge experiments currently underway at NEES, as well as shake-table and full-scale tests at various universities, including those supported by the EERCs.

Both the process and specific applications being developed for lifeline earthquake engineering are transferable to other hazards, including natural hazards and human threats. Studies of lifeline system response to the World Trade Center Disaster have emphasized the remarkable degree of interdependence that exists among lifeline systems. The investigation of such interdependencies has been a cornerstone of lifeline earthquake engineering research and modeling. There is considerable benefit being derived from lifeline earthquake engineering for improving the security of civil infrastructure against natural hazards as well as major accidents and terrorism. Because of the cascading effects that can result from lifeline disruption, local lifeline damage can rapidly expand to have a regional, national, and even an international impact. Examples include the disruption of the New York Stock Exchange due to 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.

Since Hurricane Katrina, there has been a notable shift in emphasis from protecting critical infrastructure to ensuring that communities are resilient. Understanding and planning for effective lifeline response after extreme events is a key part of developing community resilience. 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 multihazard applications.

E.3 Issues and Challenges

Substantial work is needed to address lifeline system preparedness, improve performance, and coordinate improvements to achieve enhanced community resilience. Significant issues and areas include:

- NEHRP lost its only dedicated source of support for implementing lifeline risk reduction measures in practice when FEMA funding for the American Lifelines Alliance was removed after FY 06 and only no-cost extension granted thereafter. 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.
- National workshops could be convened to obtain balanced and multidisciplinary advice from the lifelines community on the development of a coordinated approach to lifeline earthquake risk reduction. The workshops could address the multihazard aspects of lifeline performance and could result in a consensus on how NEHRP activities can advance multihazard resilience. NIST is the most appropriate host of such workshops.
- Consistent with the Grand Challenges, NEHRP-related activities to improve lifeline earthquake engineering could support efforts to recognize and reduce the vulnerabilities arising from interdependencies among different lifeline systems.
- Support could be sought for critical lifelines from governmental agencies not part of NEHRP. Foremost among the departments with agencies with a vested interest in the security and functionality of lifelines are the DHS, the Department of Energy, the Department of Transportation, and the Department of Defense.
- Lifeline earthquake research and development could contribute to multihazard improvements in the Nation's critical infrastructure. Common lessons from earthquakes, hurricanes, floods, severe accidents, and human threats could be synthesized and general principles adopted for improving hazard-related lifeline component and system performance.

F. Disaster Response

F.1 General

NEHRP continues to be a uniting effort that provides concepts of planning, response, relief, recovery, and reconstruction in an all-hazards environment. NEHRP provides the backbone for learning lessons from other disasters and integrating science into emergency management. There is a long and close collaborative relationship between the USGS and FEMA in dealing with sudden onset events, as well as those that are catastrophic.

F.2 Achievements

Substantial new developments in disaster response, relief, recovery, and reconstruction are available and continue to be documented from the lessons learned from recent disasters, particularly Hurricane Katrina. Major NEHRP efforts include the regional catastrophic response planning efforts in northern and southern California and in the New Madrid Seismic Zone, which are driven by ground motion models developed by the USGS, generating losses from HAZUS, and planning and plans supported by FEMA. The scenarios based on the work of the USGS and FEMA are being paired with regional catastrophic planning and exercise efforts supported by the DHS and FEMA to identify response gaps and build organizational relationships between states and federal response capacity. Planning for response and recovery from extreme events such as earthquakes benefits many of the concepts and methodologies used to address other extreme loads. The multihazards demonstration project in southern California and the Golden Guardian earthquake response exercises undertaken in northern California and planned for southern California are noteworthy activities that will undoubtedly result in improved disaster response and recovery capabilities.

Additional achievements involve development and use of ShakeMap, ShakeCast, CISN Display, and other products affiliated with ANSS in alert and notification and response and recovery planning; the building code concepts of performance-based design; and the critical importance of nonstructural enhancements to build resiliency and reduce damage and losses, which have been influenced by seismic design. Technological developments related to earthquake early warning systems and the parallel assessment of the societal implications of such technology offer promise to assessment and communication of threats and risks to the public.

A critical element of NEHRP is the continuous gathering of knowledge and improvements to practice through the multidisciplinary Learning from Earthquakes (LFE) program. LFE provides the model for continuous improvement to engineering and emergency management practice that should be broadened to address the multihazard environment.

F.3 Issues and Challenges

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

- Develop catastrophic and disaster planning scenarios in major urban areas prone to earthquakes based on ground motion mapping from the USGS.
- Enhance the HAZUS loss estimation tools developed by FEMA to address tsunami inundation (USGS, NSF, and the National Oceanic and Atmospheric Administration (NOAA)); enhance the building inventory data (FEMA); update fragility functions (NSF, NIST, FEMA); and fully integrate ShakeMap, ShakeCast into a fully automated loss estimation tool.
- Continue to support the assessment of the technological and societal factors related to earthquake early warning methodologies.
- Undertake research to better understand the vulnerability of communities, particularly the impacts of disasters on fragile populations and the roles of non-governmental organization (NGO) service providers and volunteers (individuals, NGOs, and corporate sector) for post-disaster response, relief, and recovery.
- Continue the collaboration between USGS and NOAA in enhancing the regional seismic networks and coordinate timely tsunami warning with earthquake warnings in collaboration with the NOAA.
- Undertake comprehensive assessments of community relief, recovery, and reconstruction to inform and expedite post disaster recovery planning.

- Continue the assessment of post-disaster housing by exploring innovative technologies for construction and integration of interim housing into community restoration, reconstruction, and social and economic recovery.

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