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Testimony: Thomas D. O'Rourke
School of Civil and Environmental Engineering
Thomas R. Briggs Professor of Engineering
School of Civil and Environmental Engineering
Cornell University
Ithaca, NY 14853

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R&D for Disaster Resilient Communities
Subcommittee on Technology Innovation
U.S. House of Representatives Committee on Science
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TESTIMONY

The National Earthquake Hazard Reduction Program (NEHRP) is the backbone for seismic protection in the United States. It provides federal support for research, information dissemination, development and implementation of technology, and the application of planning and management procedures to reduce seismic risk. It provides the resources and leadership for understanding and reducing U.S. vulnerability to earthquakes, and supplies the support base for seismic monitoring, mapping, research, testing, code development, mitigation and emergency preparedness. This support is critically important because the United States faces serious earthquake risk. This risk is growing because population density, property, and infrastructure are increasing in locations affected by earthquakes. The Federal Emergency Management Agency (FEMA) estimates that 45 states and territories are destined to experience earthquake damage. This exposure equals an annualized loss exceeding $6 billion dollars per year, with a single event loss potential of $100 to $200 billion dollars and tens of thousands of casualties. (FEMA, 2001, adjusted to 2009 dollars).

NEHRP is administered through four government agencies, with the National Institute of Standards and Technology (NIST) as the lead agency and the U.S. Geological Survey (USGS), National Science Foundation (NSF), and Federal Emergency Management Agency (FEMA) as the other partnering agencies. The USGS is the applied geosciences arm of NEHRP. It has successfully developed a procedure for translating earth science into the information needed for seismic design. It reports on earthquakes worldwide, produces seismic hazard maps for use by design professionals, monitors for earthquake motions and effects, and helps develop public awareness, planning, and response preparations through coordination with the other NEHRP agencies and local communities. The NSF is the basic research arm of NEHRP, which supports research in engineering, earth sciences, and the social sciences. It provides the engine that drives fundamental discoveries related to earthquake processes; seismic response and failure mechanisms of

the ground, buildings, and lifeline networks; and human behavior, social response, and the economic conditions pertaining to earthquakes. FEMA is the primary implementation arm of NEHRP. It sponsors the development of guidelines and standards for the seismic evaluation and rehabilitation of existing buildings and for the design of new structures. It also provides technical and financial support to states, multi-state consortia, and individual communities to improve earthquake mitigation with grants to enhance public awareness, adopt earthquake resiliency measures, and support local projects. In addition to its role as lead agency, NIST supports the development of seismic codes and standards, and thus provides a critical link between the basic research supported by NSF and the implementation of that research, led largely through FEMA.

NEHRP is an incubator for technology and policy that extend well beyond seismic risk to improve the security and economic well-being of U.S. citizens through the reduction of risk from other hazards, such a floods, windstorms, hurricanes, and human threats. The contributions of NEHRP affect our lives through improvements in the perception, quantification, and communication of risk (EERI, 2008). They involve advanced technologies for strengthening the built environment, loss assessment methodologies, emergency response procedures, and a process for achieving disaster preparedness. They also involve a unique, multidisciplinary culture that integrates basic and applied research into design codes, construction methods, and public policy (EERI, 2008).

Not only does NEHRP protect lives and property from earthquake hazards, it contributes markedly to improvements in U.S. civil infrastructure. For example, research supported by NEHRP has substantially improved the modeling of complex lifeline systems, structural health monitoring, protective systems for buildings and bridges, and remote sensing for response and recovery from extreme events (EERI, 2008). Lifeline systems, including electric power, water supplies, gas and liquid fuel delivery, and telecommunications, are essential for the proper functioning and economic stability of modern communities. NEHRP sponsorship of lifelines research has led to break-through discoveries about the functionality and interdependence of critical infrastructure systems, and has stimulated interdisciplinary work among social scientists and engineers to quantify and reduce the community and economic impacts of lifeline losses after extreme events.

U.S. civil infrastructure is made all the more vulnerable to earthquakes and other natural hazards by its poor state of repair. Grades issued by the American Society of Civil Engineers (2009) are barely passing for every element of the built environment at a time when conditions have underscored the importance of infrastructure for a viable and competitive economy. NEHRP, through its basic research and implementation agencies at NSF, NIST, and FEMA, is ideally positioned to provide proof of concept for emerging technologies as well as the evidence needed to sustain their implementation. For example, the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) supported by NSF provides a national resource for demonstrating the cost-effectiveness of performance-based design, new materials to reduce the impact of earthquakes and other extreme events, and improved retrofit strategies that improve infrastructure performance on a daily basis as well as under conditions of unusual stress. The current

reconstruction of the nation's transportation networks has significantly benefited from NEHRP-sponsored research, including the USGS mapping program. The newest design guidelines and codes for bridge design include advanced seismic design and characterization provisions. Thus, the hundreds of billions of dollars our nation is investing in infrastructure reconstruction are better protected from significant earthquake effects because of the NEHRP program.

NEHRP distinguishes the U.S. as being at the forefront of globally important and life-saving technology. Our nation gains leverage from earthquake engineering research through worldwide improvements in safety, protection of life, and the exportation of our technology and engineering services overseas.

INTERAGENCY COORDINATION

There are several distinguishing features of the last NEHRP reauthorization (Public Law 108-360), including the establishment of NIST as Program Lead Agency, creation of the NEHRP Interagency Coordinating Committee (ICC), and appointment of an external committee of experts, known as the Advisory Committee on Earthquake Hazards Reduction (ACEHR), to provide recommendations to the NEHRP agencies on implementing the program. The last NEHRP reauthorization also requires the preparation of a strategic plan by the ICC to guide and coordinate interagency activities within the program. All these aspects of NEHRP have been helpful in stimulating interagency coordination.

The establishment of the ICC has worked especially well. The ICC is composed of the Directors/Administrators of the four partner agencies plus the Directors of the Office of Science and Technology Policy and Management and Budget. The ICC met on numerous occasions since its inception in 2006. The meetings have been regularly attended by the National Science Advisor and prominent leaders of the other agencies, including the Directors of NSF and USGS. Such high level, active involvement has given NEHRP significant program visibility among agency leaders, which in turn has encouraged interagency coordination. Increased coordination has been achieved through ICC oversight of the NEHRP Strategic Plan, annual reports, and exchange of partnering agency budget preparation plans well in advance of the President's annual budget request.

NIST has provided focused and positive leadership for NEHRP. It has been active in developing a sound Strategic Plan, coordinating with the partnering agencies and the external earthquake community, and convening the ACEHR for guidance on the program.

Sixteen experienced earthquake professionals were first convened as members of the ACEHR in 2007. Biannual meetings of ACEHR have been held with representatives of the partnering agencies. The meetings have been held at the NIST headquarters in Gaithersburg, MD, and also at key locations around the U.S., such as the USGS National Earthquake Information Center in Golden, CO and the Pacific Earthquake Engineering Research Center at the University of California at Berkeley, CA. In addition, there have been several conference calls, in which the ACHER members have exchanged views and

made recommendations about program content. All meetings and conference calls have been open to the public. Frequent meetings and interchange with ACEHR have fostered interagency cooperation by providing a forum for collective agency reporting, collective dialogue with the external advisory committee, and the circulation of ACHER recommendations on NEHRP to all agencies. In its first annual report ACEHR (2008) observes that NEHRP "benefits from a high level of interagency coordination and a common focus." An excellent example of this collaboration is the NEHRP Strategic Plan for FY 2009-2013 (ICC, 2008). The plan outlines strategic priorities, each with a designated agency lead, and provides a template for coordinated and collaborative efforts among the NEHRP partner agencies.

A key opportunity to improve coordination is to increase the level of effort at NIST in NEHRP. The previous NEHRP reauthorization envisioned leadership at NIST that would grow from 2004 to 2009 with increasing levels of funding authorized to support expanding managerial and technical activities. This makes sense. As lead agency, NIST has stewardship for the entire program and requires a level of support commensurate with oversight of the sizeable NEHRP portfolio of projects and activities. As of FY 2008, NEHRP support enacted for NIST was only 1.4% of the enacted budget.

As discussed previously, NIST plays a pivotal and integrating role in NEHRP by acting as the vehicle for channeling basic research from NSF projects to implementation with the assistance of FEMA. Enabling this role with the support that was envisioned in the last NEHRP reauthorization would help greatly to foster increased coordination by tying together more effectively the programs at NSF, FEMA, and USGS. The funds enacted for NIST account for only 12.8% of its support authorized for FY 2008. This is too low, and presents an opportunity to increase the productivity of NEHRP. Increasing support for NIST to be consistent with current authorized levels is perhaps the most effective way to improve interagency coordination as well as increase the overall effectiveness of NEHRP.

Enhanced interagency coordination and support is needed for earthquake reconnaissance. Because earthquake occurrences are rare, it is imperative to invest substantial resources in learning from them. Reconnaissance of an earthquake affected area within a short time after the event will capture unique, time-sensitive and perishable data of great value for improved understanding of earthquake effects and a real-world test bed for existing models. There should be coordinated support for earthquake reconnaissance activities from all NEHRP agencies.

Recommendations by ACEHR (2008) call for a transfer of leadership from USGS to NIST for coordinating post-earthquake reconnaissance efforts. ACEHR recommends that "NIST should serve as the 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". This change is recommended for incorporation in the current reauthorization cycle.

Preparing for earthquake reconnaissance and coordinating missions is time-intensive and demanding work. Adequate staff and funding are required for successful reconnaissance,

thus emphasizing further the need for additional resources to NIST to fulfill its NEHRP leadership role.

Care and coordination needs to be exercised in the collection and archiving of data from earthquake reconnaissance. ACEHR (2008) recommends archiving reconnaissance data in a Post-Earthquake Information Management System (which is introduced in the new Strategic Plan), where data would be available in a set of discipline oriented interactive media with information related to the short- and long-term effects of earthquakes.

PRIORITIES FOR EARTHQUAKE ENGINEERING R&D

Earthquake engineering R&D must be judged in context of the earth science quantification of design hazards and the societal impact associated with the engineering and construction that are proposed for the real world. Hence, a robust engineering R&D program must be integrated with strong earth and social science R&D activities.

USGS is building the Advanced National Seismic System (ANSS) that will modernize and expand the earthquake monitoring system in the U.S., with concentrations in urban environments and the collection of data pertaining to actual building response. If we are to arrest the growth of earthquake risk in the United States, the USGS must enhance our understanding of earthquake ground motion throughout the country so we can identify areas that need concentrated mitigation activities, recognize those areas where conservatism can be reduced (thus realizing considerable savings), and refine our modeling and design procedures for seismic soil-structure interaction. This problem is so large and expensive that we can not afford to rely solely on the current information to guide our engineering approaches and policy decisions. The ANSS is currently deployed at about 15% of its planned capacity. The deployment of ANSS needs to be accelerated with a strong commitment to achieving the completion of this program in a timely manner.

NSF is operating the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), which consists of state-of-the-art experimental facilities distributed across the U.S. working in unison through advanced telecommunications and high performance Internet. The network is focused on the large-scale behavior of critical facilities under complex earthquake loadings and the validation of analytical and computer models needed for effective engineering. NEES links sites throughout the U.S. and globally to create a shared resource that benefits from open access and the contributions of leading researchers at multiple locations. If we are to arrest the growth of earthquake risk in the U.S., we must discover how large-scale structures and lifelines actually respond to earthquake effects and develop more cost efficient methods for reducing their vulnerabilities to acceptable levels. NEES is critically important for accomplishing this. As discussed previously, NEES is a national resource for advancing technologies to improve U.S. infrastructure. Recent ACEHR (2008) recommendations include developing support from other federal agencies to leverage NSF investments in NEES.

The resilience of communities and the built environment are interrelated, and thus research into the social and behavioral aspects of community response to earthquakes is a natural complement to research that increases the resiliency of the built environment. The National Research Council report, *Facing Hazards and Disasters: Understanding Human Dimensions* (National Research Council, 2006) identifies a number of research priorities, including the effects of changes over time in hazard-related laws, policies, and programs; human dynamics and incentives for adopting mitigation measures; and the challenges of catastrophic events. The most recent ACEHR report (2008) calls attention to this report and encourages an integrative R&D effort into the political, social, and economic circumstances that motivate society to achieve community resilience to earthquakes.

As discussed previously, lifeline systems are critically important parts of the built environment. They deliver the resources and services necessary for the health, economic well-being, and security of modern communities, which are susceptible to malfunctioning under the effects of severe hazards, such as earthquakes. Thus, a strong R&D effort focused on lifeline systems is important for NEHRP. Research and development in lifeline earthquake engineering was supported within NEHRP by FEMA under the American Lifelines Alliance. Unfortunately, this program was discontinued in 2007 with no replacement. Future R&D within NEHRP should place more emphasis on lifelines. To accomplish this, it would be appropriate to ask NIST, the lead agency, to convene a workshop of experts from academia, public and private utility companies, practicing engineers, social scientists, and economists to advise the NEHRP partner agencies on the most promising areas of R&D and the most effective process for achieving and implementing the needed research. Greater emphasis on lifelines is recommended by ACEHR (2008), which points out that there has not been sufficient attention given to the interdependencies among lifeline systems or the national impact that a single outage can have. ACEHR recommends that all NEHRP agencies expand their activities related to lifeline systems.

R&D support should be increased for Performance-Based Seismic Design (PBSD). A recent report by NIST (2009) provides a blueprint for the needed research. PBSD is a process that supports the design of new buildings or upgrades to existing buildings, with a realistic understanding of the risk of life, occupancy, and economic losses that may occur as a result of future earthquakes. The design of the building is adjusted so that the projected risks of loss are deemed acceptable, given the cost of achieving the intended level of performance. With PBSD, buildings are designed with an explicit understanding of the risk of loss (physical, direct economic, and indirect economic). The PBSD concepts can be applied readily to other hazards, such as wind, flood, and blast effects.

A serious life safety threat exists with respect to nonductile concrete, soft story, and unreinforced masonry buildings. A nonductile concrete building is one that does not contain sufficient reinforcing steel to accommodate deformation during earthquake shaking with the result that failure of concrete structural members can occur catastrophically with loss of life. Catastrophic failure can also occur in buildings with soft stories, unable to accommodate the transient distortion imposed by earthquake motion,

and in unreinforced masonry buildings. Additional work is needed to identify and either remove or retrofit such buildings. Thousands of nonductile concrete structures exist in various parts of the U.S. with more than 2000 in southern California alone. Research is needed both to identify such structures and to develop cost-effective methods to rehabilitate them.

A research and outreach plan was developed by the Earthquake Engineering Research Institute (EERI, 2003), called *Securing Society Against Catastrophic Earthquake Losses*. The plan was developed by a broad and multidisciplinary cross-section of experts. It includes both practical and basic research, and contains an outreach component that addresses implementation, education, and technology transfer. The plan calls for a five-fold program, consisting of research and development pertaining to Understanding Seismic Hazards, Assessing Earthquake Impacts, Reducing Earthquake Impacts, Enhancing Community Resilience, and Expanding Education and Public Outreach. Detailed descriptions of topics and work are provided in the document for each program area, with a recommended level of funding of $330 million per year to achieve national resiliency against earthquakes within a 20-year time frame. Enacted NEHRP funding for FY 2006 through 2008 has averaged $119.5 million, which is only 64% of the FY 2008 authorized level.

TECHNOLOGY TRANSFER

A major component of technology transfer in earthquake engineering is the promulgation of codes and standards. Much has been accomplished by the earthquake engineering community under NEHRP with respect to the development of codes and standards, including methods for predicting earthquake damage, evaluating the seismic capacity of existing buildings, rehabilitating buildings to improve their seismic resistance, and evaluating and repairing earthquake-damaged buildings. The bridge community has developed seismic design specifications through the American Association of State Highway and Transportation Officials. Earthquake-resistant design procedures have been incorporated into the *International Building Code* (ICC, 2006), which is promulgated by one recognized building code authority, and into the standard, *Minimum Design Loads for Buildings and Other Structures*, issued by the American Society of Civil Engineers (ASCE, 2006).

As previously discussed, FEMA is the NEHRP agency with primary responsibility for implementation. Its roles include sponsorship of guidelines and standards for the design of new structures and for the seismic evaluation and rehabilitation of existing buildings, as well as the support of states, multi-state consortia, and individual communities to improve earthquake mitigation. It is a critically important agency for technology transfer.

Until 2001, FEMA had a dedicated program to provide assistance to states with high earthquake risks through direct support to their state earthquake program managers. Since 2003, that assistance has been subsumed into other state and local Department of Homeland Security grant programs. The net effect has been to reduce markedly the

overall preparedness of many of the state earthquake programs as well as the visibility and effectiveness of the earthquake managers of those state programs. Numerous state earthquake program managers have lost there identity and very few can gain access to the resources they previously received. It is important now to re-establish support for the state programs so they can be ready to respond in a future earthquake. There are indications that this is beginning to occur in 2009, which is a promising development that needs encouragement and continued support.

In FY 2008 NEHRP funds enacted for FEMA were only 26% of their authorized level. ACEHR (2008) recommends revitalizing the state earthquake programs and support for pilot studies to mitigate earthquake risk in communities. In addition to the continued development of guideline documents for code preparation and practice, ACEHR further recommends funding for FEMA at authorized levels. Additional support for FEMA and restoration of the state programs is the most effective way to promote technology transfer and assure support dedicated to risk reduction.

RESEARCH AND DEVELOPMENT FOR NATURAL HAZARDS

One of the best ways to support natural hazards mitigation is to support a strong and effective NEHRP. Investments in earthquake engineering through NEHRP make a significant impact on life safety and the protection of property from all kinds of natural hazards such as wildfires, flood, wind, and hurricanes, and from human threats such terrorism and severe accidents. The Earthquake Engineering Research Institute (2008) has produced a report, *Contributions of Earthquake Engineering to Protecting Communities and Critical Infrastructure from Multihazards*, which documents the ways by which NEHRP has been the incubator for new ideas, advanced technologies, emergency management practices, and public policy affecting multihazard reduction and improvements in critical civil infrastructure. The report was assembled with input from a multidiscliplinary team of experts, representing practicing engineers, geoscientists, applied social scientists, and academic researchers.

The contributions of NEHRP are legion, and have had a substantial impact on public perception and assessment of seismic risk, advanced technologies for reinforcing and monitoring the built environment, loss assessment methodologies, emergency preparedness and response procedures, and a culture for integrating basic and applied research into design codes, construction methods, and public policy. Among the notable achievements of NEHRP with significant impact outside earthquake engineering are the modeling methods for probabilistic seismic hazard assessment, which are used worldwide by the insurance industry to distribute risk associated with all types of natural hazards. NEHRP is responsible for advanced remote sensing technologies, initially developed for post-earthquake reconnaissance, but also applied to damage assessment and recovery after hurricanes, such as Hurricanes Katrina and Rita. Other examples include methodologies for modeling and managing interdependent lifeline systems, active and passive control systems to protect buildings and bridges during transient loading, seismological contributions to nuclear test and explosion monitoring, developments in the Incident Command System for multi-agency response to earthquakes and other natural

disasters and human threats, and post-earthquake building inspection protocols that were adapted to evaluate New York City buildings after the World Trade Center Disaster.

NEHRP has been a cornerstone program for technologies and methodologies applied to natural hazards. At the same time, it has generated a culture of multidisciplinary innovation through the collective enterprise of architects, emergency managers, engineers, geoscientists, and social scientists. The multidisciplinary character of NEHRP is one of its most enduring legacies, providing a model for future mitigation of natural hazards and human threats.

As pointed out by EERI (2008), the reauthorization of the Earthquake Hazards Reduction Act in 2004 was used as the legislative vehicle for introducing and passing the National Windstorm Impact Reduction Act of 2004. The multi-agency oversight of NEHRP was used as the model for the National Windstorm Impact Reduction Program (NWIRP). Both programs are administered with the assistance of a federal interagency committee for coordination and an external national advisory group that provides guidance and recommendations for program activities.

Designating NIST as the lead agency for NWIRP would provide NIST with oversight of both NEHRP and NWIRP. Common leadership would provide an opportunity to promote dialogue and coordination between the earthquake and windstorm research communities. There should be separate funding sources for NEHRP and NWIRP. Strong and secure funding for NEHRP is needed to build on the foundation of a successful, multidisciplinary earthquake program to support multihazard R&D.

Coordinated hazards R&D is being promoted through USGS with a Multihazard Demonstration Project in Southern California (USGS California Water Science Center, 2009). The objective of this project is to increase resiliency to natural hazards by using southern California as a test bed. Partners include state, county, and city governments, public and private utilities, private businesses, academic researchers, emergency response agencies, and representatives of USGS, FEMA, and NOAA. The hazards involved in the project are earthquakes, floods, wildfires, landslides, coastal erosion, and tsunamis. Similar projects in other locations would help develop better coordination of hazards R&D across the Federal Government.

Coordinated hazards research involves diverse research communities and constituencies associated with earthquakes, windstorms, floods, coastal hazards, wildfires, etc. Each hazard involves scientific causes, modeling processes, and engineering practices that differ from those related to the other hazards. Coordinating hazards research must accommodate different institutional cultures and stakeholders as well as a multitude of different government agencies, all of which need to be carefully integrated in an effective collaboration. Given the complexity of this undertaking, expert advice should be sought from the National Academies through the National Research Council (NRC). A comprehensive, multidisciplinary study by the NRC should be convened to explore the barriers, opportunities, and most promising strategies for coordinated hazards research within the Federal Government.

CONCLUDING REMARKS

The National Earthquake Hazard Reduction Program (NEHRP) provides the underpinning for the resilience of U.S. communities to earthquakes. It provides federal support for research, information dissemination, development and implementation of technology, and the application of planning and management procedures to reduce seismic risk. This support is critically important because the United States faces serious earthquake risk. NEHRP also serves as an incubator for technology, practices, and policy for the reduction of risk from other hazards, such a floods, windstorms, hurricanes, and human threats. A strong NEHRP not only protects U.S. citizens from seismic hazards, but provides a cornerstone program for the multihazard resilience of U.S. communities.

The most recent reauthorization of NEHRP has brought about changes that have been effective in promoting interagency coordination as well as a more integrated and cohesive program. An excellent example of interagency collaboration is the NEHRP Strategic Plan for FY 2009-2013, which outlines strategic priorities, and provides a template for coordinated and collaborative efforts among the NEHRP agencies. One of the best ways to promote interagency coordination is to increase support for NIST to be consistent with current authorized levels. NIST plays a pivotal and integrating role in NEHRP, and enabling this role with the support envisioned in the last NEHRP reauthorization would help greatly to foster increased coordination and effectiveness of the program.

Priorities for earthquake engineering R&D include enhanced support for ANSS and NEES. They include a strong and collaborative research effort on lifeline systems, with emphasis on the interdependencies of critical infrastructure and the national impact of critical lifeline losses on regional and national economies. Priorities involve research on the social and behavorial aspects of community response to earthquakes and other natural hazards, and the interaction of social and political factors with engineering design and construction. R&D emphasis should be given to Performance Based Seismic Design and the identification and development of cost-effective retrofitting technologies for nonductile concrete and other life-threatening buildings.

To promote technology transfer and implementation of research findings in U.S. communities, it is vitally important to increase support for FEMA. There has been serious erosion in FEMA's dedicated program to provide assistance to states with high earthquake risks through direct support to their state earthquake program managers. The FEMA state earthquake programs and community pilot studies to mitigate earthquake risk should be re-vitalized during this reauthorization.

Of critical importance is the enactment of support for NEHRP that was envisioned in the last reauthorization. As expressed in the first annual report of the Advisory Committee for Earthquake Hazards Reduction (ACEHR), there is concern for the withering of enacted funds. Funding for the program has either been flat or below inflation levels for the last 30 years. Many effective NEHRP projects important for life safety and community resilience have been successfully undertaken within the limits of the enacted budgets. These successes show the potential for greater impact and effectiveness if the

authorized levels of support can be realized. Support consistent with authorized levels represents the highest priority investment in developing disaster-resilient communities.

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