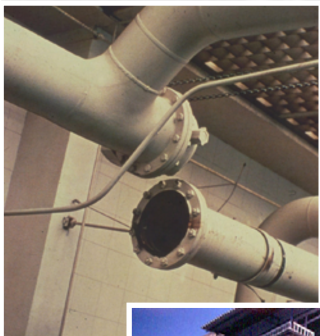
Earthquake Risk Reduction: Addressing the Unmet Challenges

The Need for an Interdisciplinary Research Approach



EARTHQUAKE ENGINEERING
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An EERI White Paper

Earthquake Risk Reduction: Addressing the Unmet Challenges

The Need for an Interdisciplinary Research Approach

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EERI is a nonprofit corporation. The objective of EERI is to reduce earthquake risk by advancing the science and practice of earthquake engineering; by improving the understanding of the impact of earthquakes on the physical, social, economic, political, and cultural environment; and by advocating comprehensive and realistic measures for reducing the harmful effects of earthquakes.

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Executive Summary

Disasters are systems problems—a failure in one sector often has cascading repercussions in other sectors. The extent to which the system can respond to and recover from a disaster is dependent on technical, societal, economic, and governmental strengths and vulnerabilities. This paper addresses some of these complex vulnerabilities in earthquake risk reduction and the role that interdisciplinary research plays to improve our understanding of vulnerabilities and potential solutions. While the paper focuses on earthquake issues, the lessons of disaster vulnerability are widely applicable to hurricanes, floods and other disasters.

The major challenge now facing the earthquake risk reduction community and its chief research sponsor, the National Science Foundation (NSF), is to provide opportunities that will give continuity to the types of interdisciplinary and problem-focused collaborative research that have emerged in the last few decades. These efforts have come to be valued as advancing knowledge and have spawned a new generation of researchers who feel comfortable working with those from other disciplines to produce integrated knowledge. The complex nature of earthquake risk reduction dictates that new research opportunities and approaches be identified. The recommendations listed here are targeted at the many audiences for this white paper, including NSF and other potential funding agencies, policy makers in executive and legislative branches of various levels of government, universities and academic researchers, and professional societies that support the earthquake risk reduction community:

1. Policy and legislative bodies at all levels of government and in the nonprofit and business sectors should provide leadership that acknowledges the critical value of an interdisciplinary research approach.

2. Funding agencies should provide innovative, risk-taking leadership.

3. Funding agencies, including the National Science Foundation in the Network for Earthquake Engineering Simulation (NEES), should support additional grand challenge research projects.

4. Funding agencies should advocate for problem-focused research in earthquake risk reduction, by setting aside a certain percentage of their budgets for this purpose.

5. Funding agencies should support the study of earthquakes as systems-level, natural laboratories.

6. Funding agencies and partners should develop or expand mentoring programs.

7. Funding agencies and academic departments should establish programs to promote the involvement of junior faculty in interdisciplinary hazards research.

8. Funding agencies should develop proposal evaluation strategies that recognize the rich and complex nature of problem-focused research by involving reviewers from a broad range of relevant disciplines.

9. Funding agencies should support interdisciplinary research centers.

10. Academic institutions should build communities of scholars and students open to cross-disciplinary collaboration.

11. Funding agencies and academic institutions should create mechanisms to reward researchers whose research interests and capabilities cut across disciplinary and departmental boundaries.

12. Academic institutions should pool resources across academic departments—and across hazards.

13. Professional societies should develop specific strategies to reinforce the importance of interdisciplinary research and practice.

Earthquake Risk Reduction: Addressing the Unmet Challenges

The successful application of new knowledge and breakthrough technologies, which are likely to occur with ever-increasing frequency, will require an entirely new interdisciplinary approach to policy-making: one that operates in an agile problem-solving environment and works effectively at the interface where science and technology meet business and public policy.

--Neal Lane, former presidential science advisor and former director of the National Science Foundation (Science 2006)

1. Introduction

One of society's more complex challenges is that of earthquake risk reduction, requiring input from many technical and policy disciplines working together to understand the complex issues associated with earthquakes. And, although research has been supported and continues to be supported by U.S. funding agencies, it is fair to say that such research is at a threshold. It is likely that the future will look different from the past, for a number of reasons, not the least of which is a changed funding paradigm for the multidisciplinary earthquake engineering research centers, a federal shift away from natural hazards to homeland security, and the considerable investment by the National Science Foundation in the Network for Earthquake Engineering Simulation (NEES) collaboratory.

As vividly demonstrated by Hurricane Katrina, disasters are systems problems—a failure in one sector often has cascading repercussions in other sectors. The extent to which the system can respond to and recover from a disaster is dependent on technical, societal, economic, and governmental strengths and vulnerabilities. This paper addresses some of these complex vulnerabilities in earthquake risk reduction and the role that interdisciplinary research plays to improve our understanding of vulnerabilities and potential solutions. While the paper focuses on earthquake issues, the lessons of disaster vulnerability are widely applicable to hurricanes, floods, and other disasters.

Earthquake risk reduction is a prime example of a current problem that requires a problem-focused rather than discipline-specific approach to cut across political, social, and technological boundaries to find lasting solutions. Edward Wenk, a former presidential science advisor, notes, "Unless engineers appreciate the social context of technology…and the role of human performance…they are unable to deal with demons that undermine the intended benefits of engineered structures…" (Wenk 1996). Rosalind Williams, director of the MIT Program in Science, Technology and Society, has noted that "the basic engineering model is rapidly being displaced by much more complex interactions of 'techno-science'—a constant process of interaction in interdisciplinary projects where the projects, not the disciplines, define the terms of engagement" (Williams 2003).

Much of the discussion on the following pages echoes the findings of several National Academy of Science reports, particularly a report on *Facilitating Interdisciplinary Research* published in 2005 (NAS 2005). That report, prepared by the Committee on Facilitating Interdisciplinary Research and the Committee on Science, Engineering and Public Policy, makes a number of recommendations targeted at academic institutions, industry, funding organizations and professional societies. The report identifies innovative practices and suggested "toolkits" and should be required reading for anyone interested in how best to address complex systems-level societal problems.

Our community

The earthquake engineering community is unique in recognizing the interdisciplinary nature of seismic risk reduction. Not an "engineering" community in the strict sense of the word, it is a diverse community of researchers and practitioners from many walks of life and from a wide array of disciplines. The "community" includes the design and engineering disciplines (including architects, structural engineers, civil engineers, geotechnical engineers, mechanical engineers, and electrical engineers); the earth science disciplines (including seismologists, geologists, and geophysicists); and the health, social, and policy sciences (including medicine, public health, epidemiology, sociology, social psychology, history, urban planning, economics, emergency management, and public administration). This community is populated by individuals from all levels of government, the private sector, and universities.

The professional association that serves this community in the U.S. is the Earthquake Engineering Research Institute (EERI). The membership of this association has been broadly multidisciplinary since its inception and includes engineers, architects, and those in the earth, social, and policy sciences. Teams that investigate damaging earthquakes, as well as committees and projects of the Institute, include a range of perspectives and expertise.

Background

When the U.S. Congress first created the National Earthquake Hazards Reduction Program (NEHRP) in 1977, the intent was to have the full participation of the physical sciences, engineering, and the social and policy sciences. While earlier interdisciplinary earthquake research had been supported by NSF (Petak and Atkisson 1982, Alesch and Petak 1986), the establishment by NSF of the first National Center for Earthquake Engineering Research in 1986 at the State University of New York, Buffalo, provided the first sustained opportunity to realize this vision to its fullest. The program was to revolutionize engineering research and education by focusing on complex earthquake risk reduction problems. The change was viewed by many as a challenge to basic science because of its use of research funding generally reserved for single investigator-initiated projects to carry out problem-focused research from a team approach.

Over the years, there has been a slow but evolutionary growth in multidisciplinary research. In the early years, members of these disciplines worked, at best, in parallel, dealing with their own research interests, and only rarely collaborating to address a common challenge. Over the course of two decades we have seen the establishment of two additional earthquake engineering research centers (EERCs), one in the Midwest, the Mid-America Earthquake Engineering (MAE) Center, and another on the west coast, the Pacific Earthquake Engineering Research (PEER) Center, and the evolution of the National Center for Earthquake Engineering Research into the first Multidisciplinary Center for Earth-quake Engineering Research (MCEER), and now MCEER, where the EE stands for Earthquake Engineering to Extreme Events.

Recognizing the need for an interdisciplinary approach in southern California, where millions of people inhabit a high seismic region, NSF has also funded an earthquake science center—the Southern California Earthquake Center (SCEC)—with joint funding from the U.S. Geological Survey. SCEC is currently a consortium of 62 institutions, with participation from over 600 scientists, students, and others. SCEC's basic science goal is to understand the physics of the Southern California fault system and encode this understanding in a system-level model that can predict salient aspects of earthquake behavior. Southern California's network of several hundred active faults forms a superb natural laboratory for the study of earthquake physics and their impacts on a complex social system that contains 23 million people and an extensive built environment exposed to high seismic hazard; this region accounts for nearly one-half of the national earthquake risk (Benthien 2007).

There are a number of other centers that recognize the importance of an interdisciplinary approach to understanding natural hazards, particularly earthquakes, and that receive funding from NSF, including the Consortium of Universities for Research in Earthquake Engineering (CUREE), the Center for Earthquake Research and Information (CERI), and the Natural Hazards Center. CUREE is a nonprofit organization established in 1988 for the purposes of representing the interests and capabilities of engineering faculty members and programs in developing research projects that mobilize these capabilities in the effort to solve significant earthquake problems (CUREE 2007). CERI is a research center at the University of Memphis focusing on earthquake activities and campus vulnerability studies. One of its goals is to use its status as an independent center to assist the university in its efforts to increase interdisciplinary research and educational activities (CERI 2007). The mission of the Natural Hazards Center at the University of Colorado at Boulder is to advance and communicate knowledge on hazards mitigation and disaster preparedness, response, and recovery. Using an all-hazards and interdisciplinary framework, the center fosters information sharing and integration of activities among researchers, practitioners, and policy makers from around the world; supports and conducts research; and provides educational opportunities for the next generation of hazards scholars and professionals (Natural Hazards Center 2007).

NSF-funded earthquake centers have become the backbone for NSF-sponsored interdisciplinary earthquake research, education, and technology transfer activities. Several factors in this development were critical: (1) the centers were provided enough funds to develop and sustain such efforts; (2) NSF made it clear that it expected such efforts and exerted enough pressure to finally make it happen, coupled with the emergence of real champions of interdisciplinary research at the centers themselves; and (3) the activities have been carried out in the context of NEHRP, whose authorization by Congress required giving at least some attention to cross-disciplinary research, education, and outreach.

Many research teams at these centers have evolved from those containing representatives of several disciplines to those that have become genuinely interdisciplinary, enabling integrated teams to tackle multi-faceted engineering and science problems that have direct bearing on professional practice and the extent to which society and the economy will be affected by and recover from future earthquakes. According to the June 21, 2006, Draft NSF Strategic Plan, "*…centers enable academic institutions and their partner organizations to integrate discovery, learning, and innovation on scales that are large enough to transform important science and engineering fields and cross-disciplinary areas through extensive organized efforts….provide opportunities for students to broaden their research horizons and for industrial partners to interact with top academic researchers…The Center model promotes opportunities for cross-fertilization of ideas between and among theoretical and experimental scientists and students, as well as between the scientists and students and the educators and technologists who turn their results into real-world applications.*"

In addition to earthquake-focused interdisciplinary research, many of the lessons, procedures and technologies have been successfully applied to other hazards and events. For example, following the collapse of the World Trade Center twin towers, engineers and social scientists previously trained in post-earthquake safety evaluations played major roles. The engineers immediately formed teams to canvass the area, applying the ATC-20 safety evaluation methodology to assess structures in lower Manhattan, thus allowing the financial district to quickly reopen offices in structures deemed safe. MCEER dispatched a multidisciplinary team to study the impacted area and response issues, using methodologies developed by sociologists through earthquake and all-hazards research. Following Hurricane Katrina, earthquake researchers analyzed remote satellite images to provide emergency responders with information on the location and extent of levee breaks and severe damage caused by the storm surge throughout coastal Louisiana and Mississippi (O'Rourke, forthcoming).

Now, twenty years after the funding of the first engineering center, NSF support for the earthquake engineering research centers (EERCs) is coming to an end. While changes in funding streams will certainly present a challenge to these centers, it is also an opportunity to reflect on the role and importance of interdisciplinary research in the broader earthquake risk reduction community, and to recommend strategies that will encourage and facilitate an effective approach in the future.

Approach

This paper was commissioned by NSF to address the challenges to earthquake risk reduction research. The specific impetus for the project was the termination of NSF funding for the three earthquake engineering research centers under Engineering Research Center (ERC) program funding. A small working committee met several times to prepare a draft of this white paper. At the same time, a short survey was circulated to earthquake center researchers, asking about their participation in center research and their experiences with interdisciplinary approaches. The draft paper was posted on EERI's website for comment, and a number of thoughtful comments from the broader earthquake community were received. A workshop was held in September 2007 (see Appendix A for a list of participants), where participants spent the day discussing the draft white paper and their opinions on future research challenges. Fairly substantial revisions were made to the white paper, incorporating written comments and workshop discussion.

2. What is Interdisciplinary Research?

Interdisciplinary research can be one of the most productive and inspiring of human pursuits—one that provides a format for conversations and connections that lead to new knowledge. As a mode of discovery and education, it has delivered much already and promises more—a sustainable environment, healthier and more prosperous lives, new discoveries and technologies to inspire young minds, and a deeper understanding of our place in space and time (National Academy of Sciences 2005*).*

Various terms have been used to describe research that crosses traditional disciplinary boundaries (see Chapter 5, National Research Council 2006 for a complete discussion). Such blurring of disciplinary boundaries is often conceptualized as a continuum, with *disciplinary* at one end—e.g., research that is being pursued by investigators from only one established discipline, such as civil engineering, or sociology, or geology, with the theoretical basis for the research grounded in that discipline; to *multidisciplinary*—e.g., research that is pursued by investigators from at least two established disciplines, but the work does not necessarily require interaction, integration, or collaboration, so researchers could work on parallel but separate tracks; to *cross-disciplinary*—research that is being pursued by investigators from at least two established disciplines, e.g., civil engineering and sociology, but at least some of the research does involve interaction, integration, and collaboration across the disciplines; to *interdisciplinary*—research that is being pursued by investigators from at least two established disciplines, but where most of the work involves interaction, integration, and collaboration across the disciplines. Furthermore, the theoretical foundation for the interdisciplinary research is a merging and integration of theoretical concepts and frameworks from the two disciplines (Wenger 2007).

As a further illustration of Wenger's continuum described above, one of the center researchers describes what he observed as three very different levels of engineering/-social science collaboration:

- *On a very fundamental level, experts from one discipline benefit from hearing or understanding the outcomes of experts from another discipline. For example, engineers benefit from the outcomes of social science research. This sort of collaboration is "parallel," where each group works on part of a global topic, and one group essentially benefits from understanding the perspective of the other groups. As such, their single disciplinary research is enriched in a general sense by the findings and recommendations of various other disciplines.*

- *A second level of collaboration is when social scientists and engineers work together on a project, but where this togetherness is in the form of a sequential collaboration where one group needs the findings of the other group to be able to advance its own research. Engineers may need to know the results of a specific social science research task to be able to move forward, or it may be the reverse.*

- *A third level, and by far the most integrative level of engineering/social science collaboration, is when both social scientists and engineers work together at the same time on a given project in which both groups need real-time information on the progress of the research, and both contribute a vital part to the creation of integrated knowledge (whereby one cannot advance without the other one advancing at the same time). This third level requires collaboration through continuous exchanges and coordination meetings through the lifetime of the project, and the findings are usually published simultaneously at the end, typically with multiple authors from both fields of expertise listed on individual papers.*

It is important to point out that the term interdisciplinary can apply to different engineering disciplines working together, or different earth science or social science disciplines working together, as well as to problems that require engineering, physical scientists, and social scientists to collaborate. Directly relevant to the consequence-based problems of earthquake risk reduction, Karl Popper pointed out, "We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline" (Popper 1963, quoted in NAS 2005: p 16).

Challenges to interdisciplinary collaboration are numerous. Some of these pertain to issues of attitude and communication, such as researcher hostility or indifference, disciplinary jargon, and lack of common vocabularies. Others relate to organizational issues such as lack of funding and incompatibility with academic incentive and reward structures. The National Research Council report on hazards and disasters research (2006) found that the EERCs, to the extent that they were successful in catalyzing interdisciplinary research, succeeded because of persistent NSF pressure to meet the interdisciplinary mandate, as well as factors such as center leadership and duration of contact among researchers, which was necessary for developing trust and respect across the disciplines.

3. Major Challenges in Earthquake Risk Reduction

Understanding the complex challenges in earthquake risk reduction requires understanding the context of the problem. Environmental constraints, development pressures, demographic changes, technical challenges, and a fragmented institutional framework all shape the nature of these challenges. As noted in the NEHRP strategic plan, vulnerability to earthquakes in the United States is growing at an alarming rate, fueled in part by population growth in moderate to high seismic zones, increasing urbanization, and an aging infrastructure (FEMA 2003). A single large earthquake could cause losses in excess of $100 billion to the built and human environment, more than twice the losses in the 1994 Northridge earthquake, the most costly U.S. earthquake to date (EERI 2003: p 1). Hurricane Katrina demonstrated interconnections between society, the environment and the regulatory and policy framework, all of which contributed to the extraordinary vulnerability of New Orleans.

In 2003, an interdisciplinary panel of scientists and engineers produced a research plan to address the following factors contributing to increasing seismic vulnerability (EERI 2003: p 4):

- **Codes**: The primary objective of building codes and regulations is to protect the lives of occupants, rather than avoid future economic loss. Despite recent advances, current building codes are based on incomplete knowledge of structural and foundation performance, resulting in the construction of facilities that, while code-compliant, may have significant vulnerability and therefore lead to economic losses.
- **Knowledge**: The knowledge of earthquake hazards and their impact is still evolving, and we continue to design and construct new facilities without fully understanding the potential hazards.
- **Costs**: The cost of using current technology to rehabilitate older construction is often high, as is the cost of improving new construction to minimize risk. Decision makers either do not completely understand the risk, or do not perceive adequate economic incentives to warrant sufficient investment. They lack the decision-making tools necessary to identify these incentives.
- **Systems**: The growing interconnectedness of society, enabled by extensive transportation systems and modern communications, greatly expands the impacted area of a damaging earthquake far beyond the epicentral region. Global trade, commerce, and defense may all be affected if a critical link in a communications or distribution network is taken out of service by an earthquake. A local disaster can quickly become a

national one, which in turn can lead to an escalation in financial loss not seen after earthquakes a decade ago.

Building on this report, authors of the National Research Council report, *Facing Hazards and Disasters*, in writing on interdisciplinary research needs, identified several research needs (see Chapter 5, National Research Council 2006: p 197) that cut across disciplinary boundaries, including:

- System-level simulation and loss assessment tools
- Assessment of cost effectiveness of loss mitigation
- Financial instruments to transfer risk
- Advanced and emerging technologies for emergency response and effective recovery
- Methodologies and measurement of progress in reducing vulnerability and enhancing community resilience to earthquakes

Several major challenges confronting the earthquake risk reduction community were identified by the project committee and workshop participants:

- **Understanding nonstructural damage**: Much of the progress over the past 20 years has come in improved models of structural damage, but nonstructural damage has been largely unaddressed even though it accounts for about 75% of economic losses and is a key factor in determining post-earthquake functionality (downtime of businesses and critical facilities).
- **Understanding and forecasting social and economic consequences**: The social sciences have done an excellent job of characterizing the kinds of social consequences that flow from earthquakes and other natural hazards. We have some initial models of economic loss, casualties, and shelter demand, but we still have a long way to go to produce the kinds of consequence estimates that will get the attention of decision makers and support better emergency response planning.
- **Understanding the decision-making process**: Although significant progress has been made on describing the decision-making process, we still do not know the key leverage points that can affect decisions by public officials and building owners as well as the larger public. As part of this challenge, we need to improve our ability to characterize and communicate risk and uncertainty. New technology provides many new ways to communicate earthquake risk information, but much of our work still relies on paper maps and conditional probability statements.
- **Incorporation of advanced sensors**: Low-cost sensors can now provide almost real-time information on the state and performance of buildings and infrastructure systems. As the built environment becomes "smart," we need to understand how to use this information to provide real-time adjustments and emergency response. This can involve a range of responses from valve shut-offs to automated warning systems.
- **Motivation for action**: The infrequent nature of catastrophic earthquakes presents challenges for preparedness at the individual and organizational levels. Understanding how to motivate desired behavior is a major hurdle in the earthquake risk reduction community.

In 2005, the Subcommittee on Disaster Reduction (SDR) of the President's National Science and Technology Council took a broad look at issues in disaster risk reduction. The SDR facilitates national strategies for reducing disaster risks and losses that are based on effective use of science and technology. Their report notes that while the number of lives lost each year to natural disasters is falling, their costs are continuing to increase. The report argues that communities need to enhance their disaster resilience, and they identified six Grand Challenges that need to be addressed to facilitate this resilience (SDR 2005):

#1. Provide hazard and disaster information where and when it is needed. Mechanisms for real-time data collection and interpretation must be readily available to and usable by scientists, emergency managers, first responders, citizens, and policy makers.

#2. Understand the natural processes that produce hazards. Scientists and engineers must continue to pursue basic research on the natural processes that produce hazards and understand how and when processes become hazardous.

#3. Develop hazard mitigation strategies and technologies. Scientists must invent, and communities must implement, affordable and effective hazard mitigation strategies.

#4. Recognize and reduce vulnerability of interdependent critical infrastructure. Protecting critical infrastructure systems is essential to developing and maintaining disaster-resilient communities.

#5. Assess disaster resilience using standard methods. Consistent actors and regularly updated metrics will support comparability among communities and provide a context for action to further reduce vulnerability.

#6. Promote risk-wise behavior. Develop and apply principles of economics and human behavior to enhance communications, trust, and understanding within the community to promote "risk-wise" behavior.

These grand challenges reflect complex systems-level problems that demand interdisciplinary teams of experts to take them on.

4. The Interdisciplinary Nature of these Problems

The director of the National Science Foundation in recent Congressional testimony noted, "The current scientific era is characterized by interdisciplinary research with much of the promise of future work occurring at the interstices between traditional scientific disciplines...We must continue to push the frontiers through interdisciplinary, transformative research" (Bement 2007). Edward Stone of the Jet Propulsion Laboratory observed that "Interdisciplinary research is becoming more important as we try to understand how systems work. While many fundamental, single-discipline questions remain to be addressed, science and engineering are ready to address much bigger questions, such as ecologic and planetary systems. No single discipline has the capability to even start addressing whole systems" (NAS 2005).

The National Academies Committee pointed to four fundamental forces that have led to an increased need for interdisciplinary research:

1. the inherent complexity of nature and society
2. the desire to explore problems and questions that are not confined to a single discipline
3. the need to solve societal problems
4. the power of new technologies (NAS 2005)

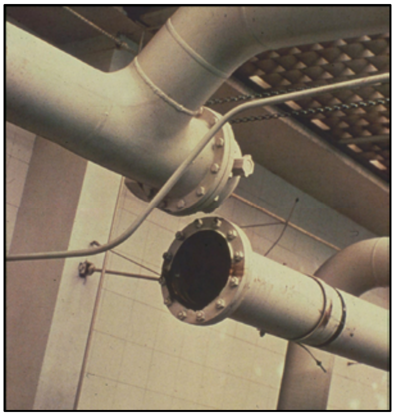
Other fields, outside of earthquake risk reduction, appear strongly committed to the concept of interdisciplinary research and are moving ahead with new institutes and programs, particularly in the environmental sciences. In a National Academies report commissioned by NSF on Grand Challenges in Environmental Sciences, it was pointed out that most of the major challenges in the environmental sciences require multidisciplinary solutions, as "environment" can be conceptualized in biological, chemical, physical, or social scientific terms. Natural systems—ecosystems, oceans, drainage basins, etc.— are not divided along disciplinary lines (National Research Council 2001). The interim director of the recently created Graham Environmental Sustainability Institute at the University of Michigan has stated:

> *The issues are complex. They cut across political and geographical boundaries. They involve understanding the intricate linkages among living and inanimate life-support systems… The practical solutions are not at all clear…Many of the most pressing problems cut across disciplines and methodologies and fall between institutional boundaries…Not only are the issues cross-disciplinary, but often require significant commitments of human and capital resources (Talbot 2007).*

There are even some scientific fields where interdisciplinary research has led to the creation of new disciplines, such as geobiology and geomicrobiology. For example, in 2000, the American Academy of Microbiology held a colloquium on "Geobiology: Exploring the Interface Between the Biosphere and the Geosphere," where participants called for the interdisciplinary training of researchers and funding of research projects in this new field. Subsequently, the American Geophysical Union formed a section on Biogeosciences, and the Geological Society of America created a Division on Geobiology and Geomicrobiology (NAS 2005: p 142).

In recognition of the need for an interdisciplinary approach in complex engineering problems, the National Science Foundation provides funding for a variety of engineering centers throughout the U.S., with a goal to "enable transforming systems technologies and educate a globally competitive and diverse engineering workforce in an integrated, interdisciplinary research environment, where academe and industry join in partnership to advance fundamental engineering knowledge, enabling technology, and engineered systems" (NSF 2007). NSF views these engineering centers as change agents for academic engineering programs and the engineering community at large.

The three earthquake engineering centers that received funding from NSF under this ERC program are examples of such an environment, where problems that cut across disciplines and institutional boundaries can be addressed. The NSF-funded earthquake science center at SCEC is another example, where the "major research issues of earthquake science are true system-level problems—they require an interdisciplinary, multi-institutional approach that considers the nonlinear interactions among many fault-system elements" (Benthien 2007). The following section highlights some of the successes of these centers, along with other examples in the earthquake field of important interdisciplinary projects.



5. Examples of Effective Interdisciplinary Approaches

While it is not the intent of this white paper to catalog all the successes of the earthquake centers in particular (see various annual reports from the centers for detailed descriptions of their projects and results—MCEER 2007; PEER 2007c; MAE 2007) or other programs that address earthquake risk reduction, it is important to understand that there are some achievements that are more directly the result of an interdisciplinary framework than others. Identifying these achievements helps us understand the value of this approach, and provides clues as to how such an approach could be maintained in the future.

In helping the authors of this white paper understand the role of an interdisciplinary research approach in earthquake risk reduction and at the EERCs in particular, a short survey was sent to center researchers and others interested in the topic. The responses have been used to inform the discussion on the next few pages.

Emphasizing problem-focused research

By focusing on a broad problem rather than a discipline-based issue, the earthquake community has undertaken a number of inherently interdisciplinary projects. One example is the development of HAZUS, a powerful risk assessment software program that was originally developed for analyzing potential losses from earthquakes and has now been adapted to floods and hurricane winds (HAZUS-MH or multi-hazard). In HAZUS-MH, current scientific, engineering, and social science knowledge is coupled with the latest geographic information systems (GIS) technology to produce estimates of hazard-related losses before or after a disaster occurs (FEMA 2007). An ongoing interdisciplinary project is the FEMA-funded ATC-58 project, to develop next-generation performance-based seismic design procedures and guidelines. Performance-based seismic design is a process that permits the design of new buildings or the upgrade of existing buildings with a realistic understanding of the risk of life, occupancy, and economic loss that may occur as a result of future earthquakes. An important component of these design procedures is that the performance expected of a structure is explicitly stated. This provides building owners, tenants, lenders, insurers, regulators, and other stakeholders the opportunity to specify the desired performance that can then be used by design professionals as the design basis (ATC 2007).

One very effective strategy developed by the earthquake engineering research centers has been the use of multidisciplinary research teams to undertake large-scale, test-bed projects, such as the Loss Assessment of Memphis Buildings (LAMB) project (NCEER), the Memphis Test Bed (MAE), and the Next Generation Attenuation (NGA) Models (PEER). The test bed was typically a defined problem or geographic area, and the projects forced interdisciplinary collaboration on a common problem. The output of the seismology models had to link with the fragility curves and structural damage models; the structural damage models had to produce outputs that could be used by the social scientists and economists. These test bed projects drew upon methods and technologies developed within the centers. NSF's earthquake science center, SCEC, is also using a test-bed approach to build a system-level model that can predict salient aspects of earthquake behavior (Benthien 2007).

Another example of an interactive and integrated framework is a demonstration project performed by MCEER. This study examined the engineering and socioeconomic impacts of earthquakes by analyzing electric power disruptions in a New Madrid earthquake (Shinozuka et al., 1998). In addition to the traditional examination of electric power disruption (damage to key facilities, impact on system performance, restoration of service), this study also focused on the direct and regional economic impacts of power disruption, local business vulnerabilities (expressed in terms of preparedness and resiliency), socioeconomic and interregional impacts, and implications for effective lifeline risk reduction policy formulation and implementation. This study involved engineers, economists, social scientists, and planners.

When applied to specific problems, interdisciplinary research can influence public policy. For example, interdisciplinary research has helped determine how best to communicate hazard information and mitigation measures to the public. Turner (2007) listed some projects that have benefited from this approach, including the *Homeowner's Guide to Earthquake Safety* and the *Commercial Property Owner's Guide to Earthquake Safety*, developed by the California Seismic Safety Commission, as well as *Putting Down Roots in Earthquake Country*, developed by an alliance of government agencies and SCEC, both of which built on research on risk communication and earthquake science. Interdisciplinary research on the Alquist-Priolo Act in California, which regulates construction close to earthquake faults, resulted in changes to the name of the program and in how information is conveyed to the public. Interdisciplinary research on post-disaster emergency shelter and interim housing needs has helped state and local agencies in California better plan for the extraordinary demands that are anticipated after future earthquakes, to speed recovery. Research on earthquake predictions helped establish scientific evaluation and public communication protocols. Research on demolition decisions about unreinforced masonry buildings both pre- and post-earthquake has helped state and local governments better manage efforts to reduce collapse risks.

Two other successful mitigation programs in the San Francisco Bay Area built on problem-focused research conducted by UC Berkeley researchers that showed that over half the damage in earthquakes and other disasters occurs to and in housing (Comerio 2000). First, the efforts of CUREE in identifying wood-frame home vulnerabilities has been translated to some extent into "Plan Set A," a standard for the seismic retrofit of cripple walls in residences. Second, local engineers, planners, and policy officials are spearheading an effort to encourage local governments to inventory and mandate the retrofit of soft-story buildings. Both these programs involve continuous interaction among various disciplines (Perkins 2007).

Creating a valuable educational experience

Engaging students as team members is key to building a foundation for the sustainability of this collaborative research model. As noted by a prominent engineering educator, "Students need to be educated in an environment where they get used to justifying and explaining their approach to solving problems and also to dealing with people who have other ways of defining and solving problems" (Williams 2003). Over the last 20 years, the EERCs as well as other science centers and university-based programs have developed model practices for bringing together earth scientists, structural and geotechnical engineers, social and policy scientists, emergency and land use planners, and members of government and private industry to work collaboratively to solve complex engineering problems that have a direct bearing on society. These practices have had an important impact, not only by producing research that has been integrated into practice, but also by creating an educational experience in which students learn the value of applying an interdisciplinary approach to risk and loss reduction.

Students in the EERCs were given opportunities to work on research projects and to participate in leadership councils, field research, international visits, short courses, and competitions. Students involved in the various student leadership councils (SLCs) have been afforded opportunities to attend meetings and conferences and to interact with a broad spectrum of industry leaders, collaborators, researchers, students, and professors from a variety of disciplines. Students have worked collaboratively with students at other educational institutions and in other fields. SLC students from the three EERCs have also participated in international field trips that have introduced them to fellow SLC students as well as counterparts in other countries. A practicing engineer associated with one of the EERCs stated that he has "been very impressed by the students that I have been in contact with and their ability to see the big picture." A center researcher noted:

> *Most importantly, [the center] students have been able to develop an ability to work in teams and see the grand picture of how multi-million dollar multidisciplinary projects are managed and led to successful completion. This is a substantial skill that will serve them through their lifetime. The challenge, of course, remains in the availability of research funding opportunities that will allow them to lead these kinds of research projects.*

In addition to opportunities to work on various problem-focused projects, the curriculum in earthquake risk reduction has been slowly changing, based in part on faculty exposure to an interdisciplinary approach. For example, a three-credit course is now part of the master of engineering program at the University at Buffalo in which social science aspects of earthquake engineering and disaster engineering are presented to engineering students. This course is now routinely offered every year as part of the graduate curriculum.

Building partnerships with industry and communities

One model of partnership between researchers and practitioners that has been successful is collaborative research, where a university researcher teams up with a practicing engineer or other practitioner (planner, architect, etc.) to conduct focused research. In the 1980s and 1990s, a series of very successful projects on methods to seismically strengthen existing structures for improved seismic performance was conducted using such collaborative teams. In fact, NSF required such collaborative teams in their request for proposals (Wyllie 2007). Such collaboration can easily lay the groundwork for further interdisciplinary research.

Industry participants—particularly the lifelines such as power, water, and transportation—are active and vital players in earthquake risk reduction and in the interdisciplinary research that is necessary to solving the complex problems in this field. The NSF-supported center structure encourages the universities to create partnerships beyond the boundaries of academic disciplines and to work directly with industry. Such problem-focused research has concentrated on the need to support the basis for enabling tools, model building codes and standards, and guidelines for community and industry practices. As noted by one of the earthquake center industry partners:

> *Our program [with the earthquake center] is an industry-led applied research program. We are problem-focused instead of discipline-focused, so a multidisciplinary approach is a natural extension of the desire for "good answers." An important component of our success is that our Joint Management Committee (which is responsible for developing and managing research projects) is multidisciplinary (two seismologists, one geotechnical engineer, and two structural engineers). Many projects include multidisciplinary advisory panels. Researchers are subject to quarterly coordination/progress meetings. These meetings involve making presentations in front of other funded researchers, resulting in constructive (though informal) review (often from other disciplines).*

One successful example of university-industry collaboration was a set of projects at PEER related to the seismic reliability of electrical systems. These projects included seismologists, utility engineers, and structural engineers. One of the immediate outcomes from these projects has been the development of input motions for shake table testing of electrical equipment. The input motions were adopted by the IEEE Standard for seismic testing of large equipment at the national level.

The longer time frame associated with center funding (typically five-year cycles) has been helpful in creating these industry partnerships, because time is needed to develop effective relationships. Additional time is also needed for partnerships in the development of community resilience and risk reduction programs, which tend to be more difficult than in other areas, since (1) there is typically limited funding available to create community/university partnerships; and (2) engineering solutions themselves require acceptance by a political process.

As the EERCs move forward without NSFs support, they are looking towards continuing or expanding cooperative partnerships with industry. In particular, the utility and transportation sectors are making major investments in center-based, problem-oriented research. These sectors, which emphasize networks and interdependencies, will likely be rich sources for interdisciplinary research projects. It is also possible, however, that some industry-based funding streams will be more narrowly focused on particular problems facing that industry, and the centers will have to look for ways to promote interdisciplinary collaboration in solving these problems.

Changing the academic culture

Creating an environment that is conducive to interdisciplinary research can be difficult, often requiring a change in the culture, additional time, and additional resources. Creation of the NSF-funded EERCs was a significant institutional change of great importance to the engineering-based earthquake research programs. While traditional university systems tend to build barriers to participants in interdisciplinary research, the centers provided a formal structure within the university that legitimized the research and made it possible to reward work conducted as a team member. One of the primary contributions of the EERCs may therefore be one of the most intangible and difficult to quantify: namely, an emergent *culture* of multidisciplinary and interdisciplinary collaboration.

This change in culture was noted by a number of survey respondents as an important factor in the EERCs success. In identifying what he believes are the most effective strategies for multidisciplinary research, one center researcher identified these overarching factors:

- Center leadership—a center leader who is curious and open to different perspectives.
- An active research committee comprised of scholars from different disciplines.
- A research organization that moved away from disciplinary concerns to cross-cutting concerns, brought about by shared goals of advancing performance-based methodology.

As noted by another center researcher, "a challenge of multidisciplinary collaboration is that it typically takes some years for a multidisciplinary team to learn to operate ...This level of integration does not occur simply by juxtaposing experts from various disciplines to work on a specific project. It requires open-minded individuals and a framework that values the time and efforts required to establish the substantial level of commitment needed for multidisciplinary research to be successful." The NAS report supports this, by pointing out that "without sustained and intense discussion of such possibilities, and without special effort by researchers to learn the languages and cultures of participants in different traditions, the potential of interdisciplinary research might not be realized and might have no lasting effect" (NAS 2005: p 21).

Developing new tools and technologies

What have the EERCs in particular done to produce an environment that supports multidisciplinary research? First, they have created long-lived multidisciplinary teams that can undertake true multidisciplinary research projects. The ten-year lifespan of the centers provided ample opportunity for researchers from a variety of disciplines to get to know each other and to learn what various disciplines have to offer. Creating a functioning interdisciplinary team does not happen overnight or during the course of most two- to three-year projects. Building an interdisciplinary team that is able to work together requires substantial "soak time"—time for disciplinary blinders and prejudices to be eroded. In addition to their other purposes, annual meetings, annual reports, and site visits can be thought of as team-building exercises that create esprit de corps among center participants. The EERCs served as incubators that allowed interdisciplinary research teams to grow and mature.

At MCEER, geographers, engineers, agronomists, computer scientists, and others have been working together on the development of remote sensing as a tool that can be used to enhance our understanding of the effects of earthquakes on the built environment, including its use in disaster response to quickly determine the extent and general nature of the damage. Structural and geotechnical engineering researchers and computer scientists at PEER have developed an open-source, computational software tool that can simulate the performance of structural and geotechnical systems subjected to earthquakes. The MAE Center has developed MAEViz, an open-source, next-generation seismic risk assessment software, leveraging high-end computing capabilities with many of the more traditional disciplines involved in earthquake engineering. Collaboration between SCEC and the USGS has led to OpenSHA, an open-source, web-enabled tool that provides a flexible platform for seismic hazard analysis. OpenSHA allows investigators to easily perform strong-motion simulations and seismic hazard analyses, accounting for multiple potential earthquake models and multiple approaches to ground motion prediction (Benthien 2007).

One of the tools of great value to the practicing engineering community developed over the last decade is performance-based earthquake engineering (PBEE). Traditional design procedures and building codes prescribe forces that are intended to represent the effects of earthquakes on structures. In many instances, codes also prescribe specific construction detailing requirements. Engineers must make sure that structures are strong enough to resist these forces and that the detailing procedures are followed. The implication of prescriptive codes is that structures will perform to meet the life safety goals of the codes during earthquakes. PBEE is a relatively new concept that goes beyond prescriptive procedures to base design decisions explicitly on the expected consequences of earthquakes in terms of life safety, protection of structures and their contents, and the ability to use facilities after earthquakes. PBEE procedures have been developed by the engineering and social science disciplines to predict the cost of damage, casualties, and downtime that facilities are likely to experience. This information allows the designer and owner to make better decisions about the effectiveness of various alternatives in controlling those consequences. As a result, performance-based designs can be more reliable as a risk management tool than traditional, prescriptive-only designs. PBEE is a tool that enables engineers, owners, policy makers, and regulators to all communicate with each other and with the broader community in terms that are easily understood—deaths, dollars and downtime. Furthermore, PBEE enables the design profession to assess the performance of different structural design alternatives (including more recently developed higher performing structural systems) in terms of their overall relative performance (damage costs and downtime) rather than just the initial costs of the different structural systems. An approach involving many disciplines in earthquake risk reduction was necessary to facilitate the development of this tool, and these many disciplines will be necessary to ensure widespread successful implementation of PBEE.

The NEES Grand Challenges

The substantial investment by NSF in the NEES collaboratory (see NEES 2007) has shifted some of the focus of research funds in earthquake engineering. Every project that is supported by NEES must have a testing and experimental component. Such a requirement makes it less likely that the social science disciplines can successfully drive proposed projects. In spite of this, research conducted as part of a NEES Grand Challenge is quite interdisciplinary, involving researchers from several engineering disciplines working with various social and policy scientists to tackle complex issues. Three such grand challenge projects have been funded to date, each briefly described below:

Georgia Tech's Grand Challenge: Seismic Risk Management for Port Systems (see Georgia Tech 2007)

Earthquakes pose a significant threat to many U.S. seaports, which serve as crucial gateways for international trade. This NEESR Grand Challenge project is integrating geotechnical and structural earthquake engineering research with expertise in port system operations and risk and decision analysis to develop a practical, risk-based framework for seismic risk analysis of containerized port systems. This framework will offer improvements over current practice for seismic design or retrofit of port structures. This systems approach will allow port officials and other stakeholders (e.g., terminal operators and ocean carriers) to manage seismic risks to achieve fundamental objectives such as minimizing business interruption losses following an earthquake.

PEER's Grand Challenge: Nonductile Concrete Buildings (see PEER 2007a)

The Pacific Earthquake Engineering Research Center (PEER) is studying the collapse potential of older nonductile concrete buildings during earthquakes. These buildings were a prevalent construction type in highly seismic zones of the U.S. prior to enforcement of codes for ductile concrete in the mid-1970s, and are widespread in many countries. In California alone, it is estimated there are 40,000 of these buildings, including residential, commercial, and critical service facilities. PEER's research will develop procedures to identify the truly dangerous buildings from among the large building population, thereby turning an intractable problem into one that can be addressed by building owners and communities with available resources. Effective mitigation strategies will also be developed to promote action for risk reduction. These strategies can also inform strategies to mitigate for other natural and man-made hazards, such as hurricanes and explosions.

University of Nevada Reno Grand Challenge: seismic Performance of Nonstructural Systems (see Univ. of Nevada 2007).

The Grand Challenge funded at the University of Nevada, Reno, is focused on studying the seismic performance of nonstructural systems. These systems represent approximately 75% of the value of typical buildings that are exposed to earthquakes in the U.S. Among the various nonstructural systems, ceiling-piping-partition systems are widely used in many types of buildings and represent a major portion of nonstructural earthquake vulnerability. This project will integrate multidisciplinary, system-level studies to develop a simulation capability and implementation process for enhancing the seismic performance of ceiling-piping-partition systems.

6. Recommendations

The major challenge now facing the earthquake risk reduction community and its chief research sponsor, NSF, is to provide opportunities that will give continuity to the problem-focused collaborative research that has emerged in the last few decades. These efforts have come to be valued as advancing knowledge and have spawned a new generation of researchers who feel comfortable working with those from other disciplines to produce integrated knowledge. The complex nature of earthquake risk reduction dictates that new research opportunities and approaches be identified. The recommendations below are targeted at the many audiences for this white paper, including NSF and other potential funding agencies, policy makers in executive and legislative branches of various levels of government, universities, academic researchers, and the professional societies that support the earthquake risk reduction community.

1. Policy and legislative bodies at all levels of government and the nonprofit and business sectors should provide leadership that acknowledges the critical value of the interdisciplinary research approach.

Work needs to be done to help policy makers understand that additional funding for such research projects can produce major changes and propel the field of earthquake risk reduction to further advances. Funding agencies, industry, and community organizations should realize that their continued funding can have significant pay-offs. They should be required to set aside a portion of their research budgets to support such projects.

2. Funding agencies should provide innovative, risk-taking leadership.

The NEHRP funding agencies and particularly NSF, the primary funding agency for research in earthquake risk reduction and a supporter of interdisciplinary research, should play a leadership role in advocating for such research. Truly multidisciplinary problems require relatively large funding amounts over relatively long periods, so that different disciplines can be materially involved and can learn to interact with their counterparts in other disciplines.

3. Funding agencies, including NSF's NEES program, should support additional grand challenge research projects.

The grand challenge research projects that are currently supported by NSF as part of the NEES program are good models. They offer two significant elements: sufficient funds and a time frame that is long enough to build the necessary relationships. Other divisions at NSF, other federal agencies, and in fact other potential partners, including industry and international agencies, should recognize their potential role in supporting this type of research. Such projects have major societal benefits; for example, the current PEER Grand Challenge Project should result in specific recommendations that will enable society to deal effectively with its existing nonductile concrete frame building problem (PEER 2007b).

While the NEES grand challenges are good models, to date only three have been funded. Since the NEES program absorbs much of the funding in earthquake engineering, additional opportunities should be explored. There might be research strategies inside the NEES framework, such as small-scale test-bed (region-based) projects, and projects that are focused on interdisciplinary lessons and applications. NEES could support more interaction among various research teams, and could make this part of its mission. NEES could build into its structure more communication with and priority-setting by potential users of research from broader, multidisciplinary audiences.

4. Funding agencies should advocate for problem-focused research in earthquake risk reduction, by setting aside a certain percentage of the budget for this purpose.

Potential funding agencies, including the major NEHRP agencies that support research and implementation in this area—the National Science Foundation, the U.S. Geological Survey, the National Institute for Standards and Technology, and the Federal Emergency Management Agency—need to look for ways to encourage these efforts. Special research programs could be established to require potential grantees to bring together interdisciplinary research teams focused on problems rather than teams organized by disciplines. These agencies often conduct workshops on research needs. These workshops should always include some focus on interdisciplinary and problem-based opportunities. RFPs from the NEHRP agencies also offer opportunities to encourage collaborative, interdisciplinary projects. This approach could also be extended to multihazard teams that would transfer knowledge from one hazard to others where it has not as yet been applied. Such a program or set of programs would include research that ranges from specific structures to examination of salient issues at the community level or beyond.

5. Funding agencies should support the use of earthquakes as systems-level, natural laboratories.

The very complex nature of systems-level problems makes it difficult to simulate such environments purely in a laboratory. As noted in the NRC report on "Grand Challenges in Environmental Sciences," "the key to future environmental research will be to develop a capability to examine such regions comprehensively, instead of examining one variable or one issue at a time" (NRC 2001). That report argues for analyzing environmental phenomena in "natural laboratories." The field of earthquake risk reduction is similar in many ways, where natural laboratories allow for an understanding of a systems model of the ecological and human systems.

Earthquakes are already seen as natural laboratories, but further commitment needs to be made to take advantage of the short window for field research. Post-earthquake assessments should involve interdisciplinary teams and researchers. Further commitment should be made to rapid and thorough data collection after earthquakes, to capture as much as possible in this natural laboratory.

In the absence of, or in addition to earthquakes, it is also possible to study systems-level problems for a particular geographic region, building on the test-bed approach used by the EERCs and SCEC.

6. Funding agencies and partners should develop or expand mentoring programs.

Two enabling projects were supported some years ago by NSF and could serve as models for future mentoring projects. These projects grew out of the perception that special measures were needed, beyond the traditional graduate education programs, to increase the size of the social science hazards research workforce, projected to be significantly depleted in the near future through the retirement of senior researchers. The objective was to introduce aspiring researchers to the culture of hazards and disaster research, including its rewards as a career. Each participant was assigned mentors for the duration of the two-year projects and had scheduled consultation visits with them. Workshops were also arranged for participants. These meetings provided the opportunity for young faculty members to discuss research opportunities and challenges in the field with senior researchers and NSF officials, as well as the expectations of research sponsors and proposal preparation. An important requirement was that by the end of the project period, each participant would have prepared, through the cooperation of senior advisors and other participants, a credible proposal for submission to NSF or some other sponsor.

Faculty and graduate students in the various disciplines associated with earthquake engineering could benefit from mentors who encourage and support their involvement in interdisciplinary research.

7. Funding agencies and academic departments should establish programs to promote the involvement of junior faculty in interdisciplinary hazards research.

The successful enabling program, described above, could also serve as a model for the establishment of a program to promote the involvement of junior faculty members in interdisciplinary hazards research. Such a program could target junior faculty members in the relevant natural science, social science, and engineering disciplines that show an interest in hazards-related interdisciplinary research, including both seismic and comparative hazards research.

In addition to mentoring projects, NSF should also be encouraged to leverage the enthusiasm and interest of young hazards researchers by developing funding programs that encourage them to perform interdisciplinary research. For example, the CAREER program, NSF's premier funding source for young researchers, is targeted at individual research.

A similar program encouraging cross-disciplinary collaboration between young researchers would provide one important stepping stone for young researchers to continue on an interdisciplinary career path (Berman 2007).

8. Funding agencies should develop proposal evaluation strategies that recognize the rich and complex nature of problem-focused research by involving reviewers from a broad range of relevant disciplines.

One of the problems in getting interdisciplinary research projects supported by funding agencies is the need for very broad-based reviewers who are not solely focused on discipline-specific approaches. Reviewers who have been active in such projects may be better able to understand and evaluate the approach, time, and budget needs of these projects.

9. Funding agencies should support research centers.

Centers have traditionally led the way in addressing problems that cross disciplinary boundaries. The National Research Council study specifically pointed to the need for a social science-focused research center, addressing societal problems in risk and hazard management (NRC 2006). Others have suggested new centers to investigate hazard mitigation from different perspectives, in particular integrating the reduction of hazard risk with sustainable communities and the effects of increased urbanization and urban density in the coastal metropolitan areas of high hazard risk (Berman 2007). NSF has a long history of supporting science and technology centers and the engineering centers. The National Academies recommended an R&D structure for the Department of Homeland Security that is based on an interdisciplinary model, the Defense Advanced Research Projects Agency (DARPA) (NAS 2005: p 122). Policy makers at various levels of government should be encouraged to implement research centers that address issues in risk reduction.

10. Academic institutions should build communities of schoolars and students open to cross disciplinary collaboration.

Academic researchers in earthquake risk reduction should use their leadership to advocate on behalf of problem-focused, interdisciplinary research and education. This might involve developing strategies for collaborative efforts in research, education, and outreach and the leveraging of scarce resources. This could also involve continuing to sponsor some activities that they currently participate in, particularly with students, and strongly advocating the advantages of problem-focused research to the more mission-based, narrowly focused agencies that may support their future work.

11. Funding agencies and academic institutions should create mechanisms to reward researchers whose research interests and capabilities cut across disciplinary and departmental boundaries.

In the current system, academic institutions are impediments rather than enablers of interdisciplinary collaboration. Interdisciplinary research is not the norm in most academic institutions, nor is it typically rewarded. Academic administrators need to allow, and in fact encourage, the traditional rewards structure to accommodate researchers who may be conducting research, teaching classes, or publishing papers in related disciplines. Frequently younger academics fear that their involvement in such research will result in products and publications not "counted" towards tenure or career advancement and are thus reluctant to participate (Seligson 2007).

12. Academic institutions should pool resources across academic departments—and across hazards.

While the traditional academic model is focused on single discipline departments, academic institutions interested in investing in larger, systems-based societal and environmental research problems could consider pooling resources across departments. This could result in sharing faculty and laboratory and office space as well as jointly preparing proposals, holding colloquia, etc.

In addition, the research community could pool resources for investigation of community, systems-based problems that cut across individual hazards. For example, significant research funds are currently available to support social science research on terrorism. It could be beneficial for the earthquake engineering community to look for linkages and the kinds of problems that cut across hazards so that research in one community is relevant to another. Community resiliency could be the general goal, with the focus on how any and all hazards could impact a human settlement.

In the call to action prepared by the American Society of Civil Engineers one year after Hurricane Katrina, most of the recommendations are equally applicable to the earthquake engineering community, including safety as a top public priority, quantifying risks, communicating risks, deciding on levels of acceptability, and correcting deficiencies (ASCE 2006). Working together with other hazard communities could create a synergy of ideas and solutions, and lead to innovative and different funding sources for future research.

13. Professional societies should develop specific strategies to reinforce the importance of interdisciplinary research and practice.

The NAS report (2005) highlights the important role that professional societies can play in fostering interdisciplinary research. The report notes that a new breed of professional society has arisen, mostly after World War II, that is primarily interdisciplinary. As noted above, in the field of earthquake risk reduction the primary professional society, EERI, is most definitely interdisciplinary. The NAS report makes a series of suggestions about how professional societies can design and promote change, particularly through their journals, meetings, workshops, interdisciplinary panels or divisions, and through developing tools that will help researchers broaden their understanding of other fields. EERI and the many other professional societies that touch on earthquake risk reduction (including the American Society of Civil Engineers, the state structural engineers associations, the Seismological Society of America, the Geological Society of America, etc.) should evaluate these recommendations with an eye to opportunities to play a larger role. In addition to supporting interdisciplinary research, professional societies can play an important role in demonstrating the value of interdisciplinary collaborations in addressing critical problems.

Concluding statement

By working together to build strategies that promote problem-focused research, the earthquake research community, funding agencies, practitioners, and policy makers can move forward to reduce earthquake risk. Encouraging collaboration among the many disciplines and defining research activities around critical problems are important steps in this direction. The earthquake community must continue to work together to address the complex challenges that remain to be solved.

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