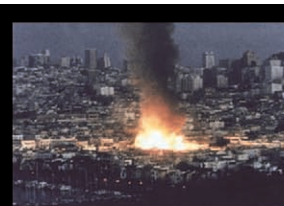
White Paper on the

SDR Grand Challenges for Disaster Reduction




Prepared by the **Executive Committee** of the
Multidisciplinary Center for Earthquake Engineering Research

December 2005

MCEER
MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
A National Center of Excellence in Advanced Technology Applications

The Multidisciplinary Center for Earthquake Engineering Research

MCEER is a national center of excellence dedicated to establishing disaster-resilient communities through the application of multidisciplinary, multi-hazard research. Headquartered at the University at Buffalo, State University of New York, the Center was originally established by the National Science Foundation (NSF) in 1986, as the National Center for Earthquake Engineering Research (NCEER).

Comprising a consortium of researchers from numerous disciplines and institutions throughout the United States, the Center's mission has expanded from its original focus on earthquake engineering to address a variety of other hazards, both natural and man-made, and their impact on critical infrastructure and facilities. The Center's goal is to reduce losses through research and the application of advanced technologies that improve engineering, pre-event planning and post-event recovery strategies. Toward this end, the Center coordinates a nationwide program of multidisciplinary team research, education and outreach activities.

Funded principally by NSF, the State of New York and the Federal Highway Administration (FHWA), the Center derives additional support from the Department of Homeland Security (DHS)/Federal Emergency Management Agency (FEMA), other state governments, academic institutions, foreign governments and private industry.

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16. Abstract (limit 200 Words)

This special report presents factors that should be considered in the formulation of a national research strategy for disaster loss reduction in response to the Grand Challenges for Disaster Reduction report published by the Subcommittee on Disaster Reduction (SDR). Recommended research initiatives emphasize a multi-hazard approach, including expanding loss assessment methodologies, developing intelligent buildings and lifelines, identifying new mitigation strategies and technologies, and building on accomplishments of regional economic modeling for earthquake impacts by extending these models to multi-hazard scenarios. In addition to structural considerations, the report emphasizes the need to understand societal diversity and its impact on warning dissemination and the response process. Color figures and references are included.

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White Paper on the

SDR Grand Challenges for Disaster Reduction

Prepared by the **Executive Committee** of the
Multidisciplinary Center for Earthquake Engineering Research

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A commentary on:

Grand Challenges for Disaster Reduction

A report of the **National Science and Technology Council**
Committee on Environment and Natural Resources
Subcommittee on Disaster Reduction (SDR)

December 2005

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Special Report MCEER-05-SP09

Executive Summary

The Executive Committee of the Multidisciplinary Center for Earthquake Engineering Research (MCEER) through this White Paper volunteers perspectives that should be considered in the formulation of a national research strategy for disaster loss reduction in response to the *Grand Challenges for Disaster Reduction* report published by the Subcommittee on Disaster Reduction (SDR). A critical part of this research effort should focus on the mitigation of, and response to, the impact of extreme events on critical facilities and lifelines. The failure of these key infrastructure systems is the cause of most of the disruption during and following disasters. In this context, national needs require that solutions be integrated across various hazards. However, the objective to achieve a synergy of solutions across the continuum of hazards is something that has just barely begun to be exploited or even investigated.

Recommended research initiatives that should be undertaken in a multi-hazard perspective include:

- Expand loss assessment methodologies and decision support tools to include multiple hazards, based on existing tools developed for earthquake engineering, calibrate them with ground-truthing, and automate and integrate data collection using remote sensing following disasters.

- Develop intelligent or "smart" public buildings and lifelines that provide real-time monitoring and decision making that is useful for both regular maintenance purposes and also for occupant safety, security and health monitoring to allow for rapid evacuation in the event collapse is imminent and for locating survivors within collapsed structures.

- Develop reliable methods to design structures to meet several specific performance levels under increasing levels of hazard intensity, providing design/retrofit concepts from a multi-hazard perspective and overcoming the shortcomings of purely "life-safety" design procedures.

- Investigate how new materials and advanced technologies developed for seismic retrofit can be modified or adapted to provide enhanced resilience of various critical facilities and lifelines against other hazards.

- Identify new mitigation strategies and technologies that can provide simultaneous protection against more than one hazard, for a single cost, and similarly develop new technologies that achieve the broadest possible level of protection at the least possible cost, aiming at more uniform, nationwide adoption of these technologies.

- Build on the accomplishments of regional economic modeling for earthquake impacts, and extend these models to multi-hazard scenarios, providing the ability to quantify economic consequences of disasters as an effective basis for setting priorities, as well as the communication of these priorities for public and/or private investments.

- Develop technologies to prevent cascading failures of complex lifeline systems that duly consider proximity of critical infrastructures, interoperability of various lifeline systems, and interactions among the institutions operating the lifeline networks, for a broad range of natural, technological and human-induced hazards.

- Expand the resilience framework built on the concept of robustness, rapidity, resourcefulness and redundancy, and the technical, social, economic and organizational dimensions, and provide quantification of these dimensions for critical infrastructures and lifelines exposed to various hazards.

- Take advantage of the body of social science research developed through the NEHRP program as a foundation to understand differences in social behavior related to various hazards, and formulate effective risk communication, detection, and warning dissemination systems across a range of hazards and timescales.

- Understand how societal diversity (including age, educational and income levels, race, ethnicity, language spoken at home, the "digital divide," etc.) is likely to influence the warning dissemination and response process, and how the decline of network broadcasting and the rise of niche-based "narrowcasting" influence the ability to both disseminate and receive effective warning information, so that the nation can develop audience-appropriate, customized warning systems and technologies.

The foregoing initiatives are illustrated by selected MCEER accomplishments relevant to the research requirements outlined in the *SDR Grand Challenges* report.

Contents

Introduction

Scope

The *Grand Challenges for Disaster Reduction* report published in June 2005 by the Subcommittee on Disaster Reduction (SDR) of the National Science and Technology Council outlines six challenges that are necessary to break the cycle of destruction and recovery by enhancing the disaster resilience of the nation. This report recognizes the need to consider the spectrum of possible disasters in a holistic manner if enhanced resilience is to be achieved.

In this perspective, members of the Executive Committee of the Multidisciplinary Center for Earthquake Engineering Research (MCEER) volunteer this White Paper as a vision of how available knowledge, to a large extent made possible by advances in earthquake engineering over the past two decades, can help advance the agenda formulated by the *SDR Grand Challenges*. While it is recognized that such a vision cannot encompass all the dimensions of the *SDR Grand Challenges*, it nonetheless provides valuable perspectives that should be taken into account in the formulation of a national strategy for disaster loss reduction. These are presented in the same order as the *Key Research Requirements* outlined in the *SDR Grand Challenges* document, as brief summaries of what has been done to date, and research needs that should be undertaken in a multi-hazard perspective.

Since its inception in 1986, MCEER has successfully brought together panels of experts to develop consensus-based documents (guidelines, guide specifications, and multiple other reports) on various topics, with many of these documents becoming the authoritative reference in their field. By their nature, the development of such consensus documents spans a significant time period and undergoes a rigorous review process to ensure consideration of all points of view towards the development of the broadest possible consensus. Should the occasion arise, MCEER would welcome the opportunity to undertake the development of such a consensus document outlining definitive research strategies to fulfill each of the key research requirements outlined in the *SDR Grand Challenges*.

Given the broad ranging scope of the *SDR Grand Challenges* report, its potential for significant impact on the development of national disaster resilience policies, and the urgency to immediately advance the agenda of disaster reduction, this White Paper is offered as a summary of MCEER's position and philosophy on the *SDR Grand Challenges for Disaster Reduction* in a multi-hazard perspective.

The Multi-Hazard Perspective

Recent extreme events such as the terrorist attacks of September 11, 2001 and hurricanes Katrina and Rita have tragically underscored our nation's vulnerability and its urgent need for solutions that not only limit the impact of extreme events, but do so in a manner that is cost effective. The process to enhance the resilience of our infrastructure against extreme events (natural disasters, technological disasters, and acts of terrorism) will not be simple nor will results come quickly. The substantial challenge to meet this pressing national need will require a research endeavor equal in substance to the need. The development of innovative and integrated solutions toward this goal will require collaborative involvement of experts with a wide range of knowledge from a variety of disciplines.

A critical aspect of this research effort should focus on the mitigation of and response to extreme events, a concept described in greater detail later, which defines a field of multi-hazard research. It effectively encompasses research activities in earthquake engineering, terrorism-resistant construction, fire engineering, multi-hazard engineering, risk assessment, remote sensing, human performance in disaster situations, post-disaster response and recovery, exposure to chemical, biological and nuclear agents, GIS science, medicine, and many others. It will require the integrated multidisciplinary efforts of experts benefiting from unique state-of-the-art experimental facilities. This will also require, to a significant degree, coordinated multi-campus and multidisciplinary engineering and social science research management, and a dedication to bring research results into practice in a speedy manner.

Failure of critical facilities and lifelines during extreme events is a significant cause of most of the disruption during and following disasters. Their survival in times of utmost need plays a key role in enhancing the disaster resilience of communities. These facilities are strategic to the economy nodes in infrastructure systems, or are essential to emergency management and public safety. Some have symbolic value, others (such as hospitals and schools) contain especially vulnerable populations and provide essential services in the wake of disasters, and still others are infrastructure whose failure translates into extensive economic and human losses, as well as causing a negative impact on quality and way of life.

Through investments of the National Earthquake Hazards Reduction Program (NEHRP) over the past decades, substantial knowledge has been created to address problems related to earthquakes. Considerable research has also been conducted focusing on other single hazards. Today, national needs are such that the integration of solutions across hazards is now necessary. However, the objective to achieve a synergy of solutions across the continuum of hazards is something that has just barely begun to be exploited or even investigated.

The following sections contain brief overviews of research initiatives that should be undertaken in a multi-hazard perspective for four of the six Grand Challenges described in the SDR report. Selected MCEER accomplishments, relevant to the *Key Research Requirements* outlined for Grand Challenges 3 to 6, provide examples of how concepts presented in this White Paper have been successfully addressed through MCEER's research program in the past.

Grand Challenge 3: Develop Hazard Mitigation Strategies and Technologies

Key Research Requirement 3.1. Encourage investment in developing, modeling and monitoring impacts of cost-effective and beneficial mitigation technologies

The *SDR Grand Challenges* report recognizes that hazard mitigation strategies and technologies are needed for natural, technological, health and environmentally-related disasters. It also acknowledges the importance of developing better linkages among hazard modeling, impact analysis, testing, and strategies for mitigating the effects of extreme events. This challenge essentially involves putting knowledge into practice through the development of decision support tools and the formulation of science-based guidance for entities and individuals charged with mitigating disaster losses. The practitioners involved in applying scientific knowledge include land-use planners and planning organizations; local governmental decision making bodies that have authority to adopt and alter building codes; and emergency managers who use scientific information and engineering analyses in their loss reduction programs.

The field of earthquake loss reduction has made significant contributions to reaching this goal. Engineering researchers constituted the core of the team that developed HAZUS, FEMA's loss estimation tool. Originally developed for earthquakes, HAZUS modules have also been developed for flooding and high wind. HAZUS and similar products serve as important decision support tools for local communities that wish to better understand their vulnerabilities and to make sound decisions with respect to mitigation. Engineers specializing in earthquakes and other extreme events played a major role in an independent study commissioned by FEMA and carried out under the auspices of the National Institute of Building Sciences, which documented the savings that will result from mitigation projects that have been undertaken nationwide. This newly-completed systematic study is the first to demonstrate that the adoption of mitigation measures actually pays off in U.S. communities, in terms of future losses avoided. In helping to answer longstanding questions on whether mitigation is cost-effective, the report should help promote mitigation at all governmental levels, as well as in the private sector.

Engineers and other experts concerned with earthquake loss reduction can readily transfer their knowledge and tools to the study of other hazards. Loss estimation methodologies originally developed for earthquakes have proven to be transferable to other hazards. Remote sensing technologies originally developed for earthquake loss estimation and post-disaster situation assessment have already been used in research on hazards other than earthquakes, including hurricanes and tsunamis. Moving into the area of terrorism and weapons of mass destruction, analytic approaches for establishing structural robustness under earthquake loads can also be used to assess potential blast impacts. Methodologies that blend engineering and economic analyses, again developed originally for earthquakes, are widely applicable to extreme events of all types, including those that negatively affect ecosystems.

It should be noted that one lesson from recent disasters (such as the 2001 World Trade Center terrorist attack, 2004 Indian Ocean Tsunami and 2005 Hurricane Katrina) which catastrophically impacted society on a national and international scale, is that mitigation strategies to prepare for and respond to large scale disasters may possibly require a significant shift from the prevailing disaster mitigation strategies. For some disasters, highest priority must be placed on

MCEER Research Highlight

Many MCEER research products can be used to assess the effectiveness of specific mitigation measures and support loss reduction decision making across the hazards cycle. Analyses of the earthquake vulnerability of different elements comprising lifeline systems have served as the basis for guidance on which elements in those systems make the most difference from the standpoint of mitigating future losses and societal disruption, as well as on which mitigation measures are most cost-effective. MCEER's comprehensive community recovery model can help decision makers better understand how both pre-event mitigation and post-event prioritization of restoration and early recovery measures affect overall losses and the time needed for recovery (Chang and Chamberlin, 2004; Chang and Shinozuka, 2004). A flow diagram of this model is schematically illustrated in Figure 1.

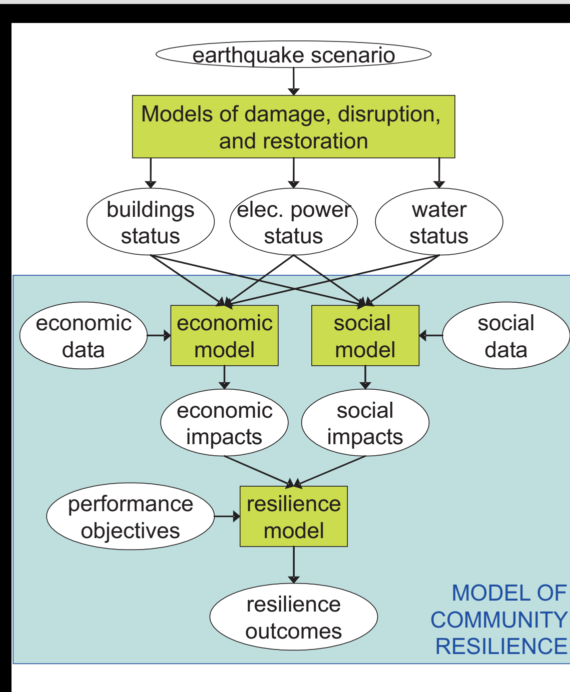


Figure 1. Schematic of community resilience model.

MCEER has played a leading role in the development of remote sensing technologies, both for developing building inventories during non-disaster times and for post-disaster situation assessment, loss estimation, and decision support (Shinozuka et al., 2000; Huyck and Adams, 2002). Figure 2 provides an example of post-hurricane damage assessment using remote sensing and satellite imagery following Hurricane Charley, which struck Florida on August 13, 2004.

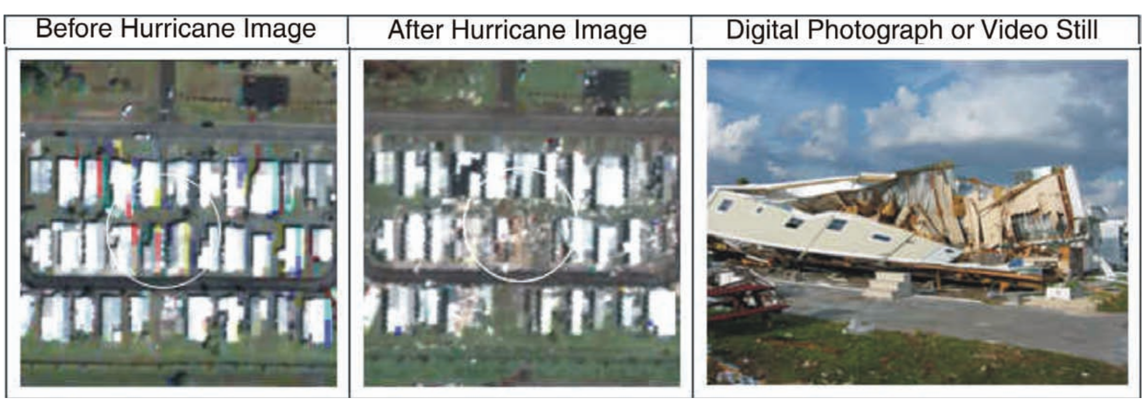
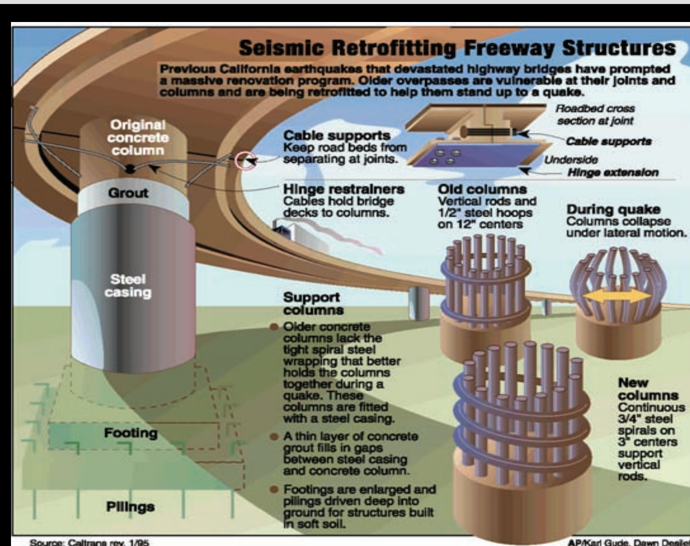


Figure 2. Remote sensing was used to survey damage and compare it to pre-event conditions following Hurricane Charley.

MCEER Research Highlight

Discount Rate	23% Retrofit		100% Retrofit	
	Benefit/Cost Ratio	Cost-effectiveness	Benefit/Cost Ratio	Cost-effectiveness
3%	**5.81**	**Yes**	**4.39**	**Yes**
5%	4.12	Yes	3.12	Yes
7%	3.11	Yes	2.36	Moderate

Table 1. Cost-benefit analysis summary.



-Courtesy of Caltrans

Figure 3. Seismic retrofit of reinforced concrete bridges in California using steel jacketing of columns.

Figure 3 and Table 1 show the result of a cost-effectiveness analysis by Shinozuka et al., 2005 of the retrofit of bridges by steel jacketing of columns involving 2,209 bridges in the freeway network covering Los Angeles and Orange Counties. The analysis was carried out using a number of assumptions on key parameters such as bridge seismic fragility with and without retrofit, traffic flow characteristics under normal and seismically damaged conditions, variable origin-destination matrix, repair strategies, losses related to drivers' delay and opportunity cost, etc. As shown in Table 1, 23% represents the completion rate of bridge retrofit as of November, 2005 and is used for comparison purposes with the case of 100% completion. The results show that under the existing seismic hazard in the region, 100% retrofit is not necessarily cost-effective.

the development of early warning, population evacuation, situation assessment, and emergency response and restoration (depending on the nature of the disaster). Obviously, early warning and pre-event evacuation are difficult to implement for terrorist attacks (except when reliable intelligence makes it possible), and not practical for earthquake events. However, in some instances these are the only implementable pre-event mitigation measures. In addition, post-event situation assessment is the key to effective emergency response, effective again in the sense of minimizing human and property loss and duration of the ensuing restoration process. Finally, the appropriate mitigation strategy for specific disasters may vary regionally depending on circumstances. For example, while technologies can be developed to make all coastlines resilient to tsunami, it may be necessary for each community to investigate their exposure and risk, taking into consideration topography, bathymetry of coastal water, existence of coastal structures, vegetation, etc., before selecting an appropriate mitigation strategy. Tsunami scenarios with different levels of annual probability of occurrence and simulated on the basis of computational hydrodynamics could be used to evaluate vulnerability of coastal structures, and assess the tsunami risk in terms of annual expected human, property, and economic losses.

These related benefits of implementing early warning systems, population evacuation strategies, and effective emergency response and restoration plans, would help decision makers select the most effective approach to mitigate the risk of a disaster of catastrophic dimension. Such a systematic and rational approach is obviously applicable to a broad range of hazards, and not limited to the tsunami case considered in this example.

Key Research Requirement 3.2. Continue development of smart structural systems that detect and respond to changes in structure and infrastructure condition, and that predict failure

Buildings and infrastructure systems have been continually improved to provide safety, security, maintainability and comfort to the occupants at reasonable cost. With the rapid development of advanced technologies in recent years, it is also reasonably prudent to invest in furthering research in "smart structure technologies." Use of earthquake response reduction technologies – based on principles of structural dynamics – has matured to the point that such technologies offer promise for many other hazardous loading conditions, such as wind and blast. No other natural hazard reduction research has accomplished as much as earthquake engineering in terms of structural design against dynamic loading conditions.

Many advances have been made in the development of passive, semi-active, and active control devices, base isolation systems, and vibration reduction using energy dissipation devices, to control the dynamic response of buildings during earthquakes. The need for the future is to modify existing technologies and develop new technologies for multiple hazard response control. Of particular interest is the development of smart, passive devices that can create a fail-safe condition when a structure is subjected to loads beyond those for which it is designed. Real-time monitoring and decision making that is useful for both regular maintenance purposes and also for occupant safety, security and health monitoring is needed to allow for rapid evacuation in the event collapse is imminent and for locating survivors under collapsed structures. Such concepts are being developed at this time for application to earthquake and hurricane protection of bridges.

MCEER Research Highlight

MCEER has played a leadership role in developing and advancing innovative technologies in earthquake hazard mitigation (Constantinou et al., 1998), and in pioneering the research frontier in formulating multiple hazard design guidelines for critical facilities protection. For example, MCEER researchers are investigating bridge damage from Hurricane Katrina and developing smart technologies that can enhance the performance of these bridges against multiple hazards based on those already developed for earthquakes (see Figure 4). Preliminary findings by MCEER investigators are available from *http://mceer.buffalo.edu/research/Reconnaissance/Katrina8-28-05/default.asp*.

Figure 4. Bridge span collapses during Niigata earthquake (top) compared to similar damage due storm surge during Hurricane Katrina.

MCEER Research Highlight

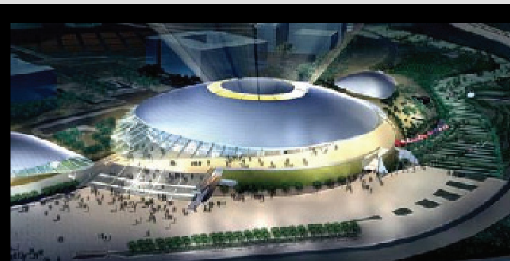


Figure 5. 2008 Olympic gymnasium with multi-hazard monitoring, detection, damage control and evacuation system.

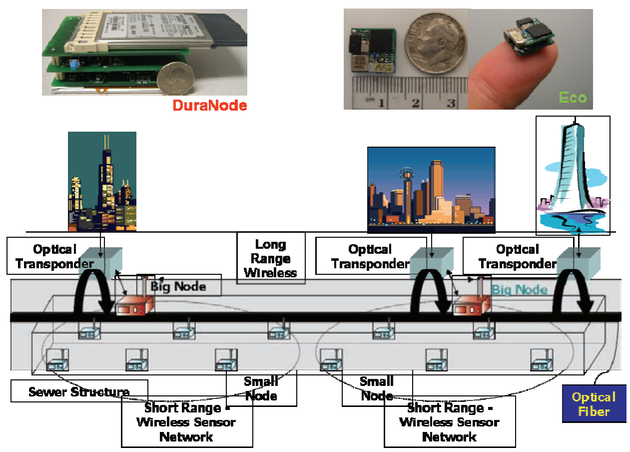


Figure 6. Wireless sensors for acceleration and other measurements.

MCEER researchers are engaged in an international cooperative research project with researchers from the People's Republic of China to develop and implement a health monitoring system for a badminton arena on the campus of Beijing University of Technology for the 2008 Olympic Games (see Figure 5). This real-world demonstration project is co-sponsored by NSF and the equivalent funding agency in China on "multiple hazard protections of public buildings" (earthquakes, wind gusts, blast, fire, and indoor air quality). Various state-of-the-art sensors (wireless sensor networks) will be implemented. For rapid post-disaster situation assessment, a network of wireless MEMS sensors (see Figure 6) are useful in capturing the data needed to analyze, in real time, the propensity of a structure weakened by a given hazard to collapse, which can provide early rapid assessment and opportunity to advise emergency responders to evacuate. This project engages a team of multidisciplinary experts (different hazards experts, wireless sensor network specialists, structural engineers, mechanical engineers, architects, and emergency response professionals) to advance the state-of-the-art of smart structure technologies for buildings and infrastructure systems (Lee et al., 2003 and 2004).

Key Research Requirement 3.3. Continue development of new materials and cost-effective technologies to retrofit existing inventory of buildings, bridges, and other lifeline structures

The design and retrofit of buildings, bridges, and other lifeline structures against natural hazards under existing codes has been traditionally based on the philosophy of exclusively insuring life safety and not continued functionality. When a structure resists collapse during its exposure to a natural hazard, and the occupants can evacuate safely, it is considered that this structure has fulfilled its function even though it may never be operational again. Because of the current socio-economic reality in the U.S., this traditional design/retrofit philosophy needs to be significantly expanded through the use of new materials and cost-effective technologies. Critical infrastructure such as hospitals, police stations, communication centers and critical bridges must remain functional when exposed to natural hazards because they are conduits of emergency response. Furthermore, facility owners are increasingly considering the impact of major natural disasters on their facilities as an economic decision tool. The cost of a new structure designed to meet higher performance levels or the cost of an upgrade to an existing structure needs to be weighed against the estimated future losses avoided associated with damage, loss of property and downtime in the event of the occurrence of a natural hazard.

In the field of earthquake engineering, achieving a specified seismic performance level for critical facilities requires that all components of a facility perform in harmony with each other. In a hospital, for example, the simultaneous performance of structural and nonstructural components must both be considered in the design/retrofit process. Even if the design of structural components ensures a level of immediate occupancy following a seismic event, failure of nonstructural components inside the facility can diminish or even fully destroy the functionality of the entire hospital. Additionally, failure of nonstructural components could create safety hazards and/or affect the safe movement of occupants evacuating or rescue workers entering the facility. In most critical infrastructure, the investment in nonstructural components, i.e., equipment and contents, is far greater than that of the structural components and framing.

Advanced technologies used in earthquake engineering, such as supplemental damping and seismic isolation systems are becoming the most proven construction method to achieve cost-effective seismic performance. Supplemental damping systems use mechanical dampers that are activated through deformations of the main structural system, thereby reducing the shaking of the structure during a major earthquake. Seismic isolation systems involve the installation of mechanical isolators beneath every supporting point of the structure, effectively separating the main structure from the ground motions. The development of supplemental damping and seismic isolation systems represents an earthquake engineering success story in the development of new materials and cost-effective technologies to retrofit existing buildings, bridges, and other lifeline structures against seismic attacks.

Some earthquake engineers have suggested that current seismic design provisions, including the use of supplemental damping and seismic isolation systems, could improve the performance of critical facilities when exposed to other natural hazards. However, there have been few attempts so far to quantify such improvement. These benefits are not "automatic" and a better solution would involve a multi-hazard design from the onset, looking for solutions that can effectively achieve multi-hazard protection with a cost similar to that of single hazard protection. There is an urgent need, however, to investigate the potential benefit that seismic design provisions may have on the resistance to a variety of other hazards, natural, technological and man-made.

The expected performance of critical infrastructure against multiple hazards must be explicitly defined and communicated to facility owners as well. For example, the design and retrofit of buildings, bridges, and other lifeline structures against natural hazards has been traditionally based on the philosophy of exclusively insuring life safety. Owners, however, are often of the misperception that because a structure is designed to code, it should survive the severe tests of all hazards addressed in the code. Thus, this misunderstanding of the life-safety intent of codes is in part the cause of significant economic loss in earthquakes. Over the last decade, an important advancement in earthquake engineering has been the elaboration of performance-based concepts for the seismic design of structures. This approach, based on the coupling of

MCEER Research Highlight

In the last 20 years, MCEER investigators have been pioneering the development of supplemental damping, alternative seismic isolation technologies, and other innovative seismic protection systems for the seismic design/retrofit of structures. For example, the development and experimental validation of fluid dampers for the seismic design/retrofit of structures in the U.S. has been single handedly conducted by MCEER investigators with strong partnerships with industry (see Figure 7). Furthermore, MCEER investigators have made many key contributions to the country's most advanced building codes and seismic guidelines over the years (Ramirez et al., 2001 and 2003; ATC/MCEER, 2003). These innovative protection systems are particularly efficient in reducing the seismic forces experienced by nonstructural components and expensive equipment inside acute care facilities, thereby improving the seismic resilience of these facilities. Novel damper and isolation features including compact size, very large displacement capacities and capabilities to adjust behavior for achieving specific target resilience levels, such as re-centering in weak earthquakes and minimization of impact on secondary systems and equipment, have been validated experimentally by the state-of-the-art experimental facilities affiliated with MCEER (Berman and Bruneau, 2005; Chu et al., 2002; Kitane et al., 2004; Reinhorn et al., 1992; Riley et al., 1998; Roussis and Constantinou, 2005; Sigaher and Constantinou, 2003 and 2004; Soong and Spencer, 2002; Soong et al., 2000; Symans and Constantinou, 1999; Whittaker et al., 1998). These large-scale system tests often constitute the last step to implementation.

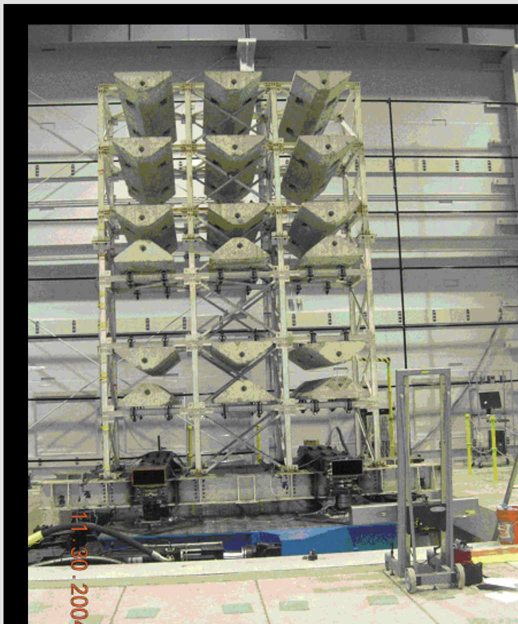


Figure 7. Structural model equipped with an innovative seismic isolation system is tested on a shake table in the Structural Engineering and Earthquake Simulation Laboratory (SEESL) at UB, one of the experimental facilities affiliated with MCEER.

multiple performance and seismic hazard levels, overcomes several of the shortcomings of the life-safety seismic design procedure. This is reflected in recent codes of practice, such as the International Building Code, which favors performance-based design and assessment approaches, where structures are designed to meet several specific performance levels under increasing levels of seismic intensity. There is an urgent research need to develop similar performance-based design/retrofit concepts from a multi-hazard perspective.

While the above discussion focuses on critical facilities, the need for advanced mitigation strategies is equally acute for lifelines. It is well established that U.S. civil infrastructure has been aging and is subject to levels of deterioration and distress that affect both its current serviceability and life expectancy (NRC, 1994). For over twenty years, reports commissioned by the Federal government have pointed out the loss of functionality and the risks to safety and economic well-being associated with aging infrastructure (for example, NRC, 1987; National Council on Public Works Improvement, 1988; NRC, 1994). Any strategy for retrofitting the existing inventory of buildings, bridges, and other lifelines must start with the recognition that improving infrastructure performance through the application of technology needs to be a selective process. It must start by identifying those facilities in most urgent need of repair and restoration. Setting priorities requires a two-fold approach in which facilities are identified as being 1) most critical in terms of functionality and 2) most vulnerable in terms of exposure and state of repair. The development of new materials and cost-effective retrofit technologies should therefore be coupled with the development of assessment and detection systems to locate and characterize the condition of infrastructure facilities.

For example, using fiber reinforced polymers (FRP) enhances the strength and ductility of high pressure pipelines and critical water trunk and transmission lines, and arrests ductile fracture propagation in natural gas pipelines. Preventing propagating fractures is especially important to protect against natural deterioration as well as terrorism. Inverted lining procedures have also been refined and are now used on a routine basis for installing internal FRP linings in pipelines and conduits with substantial benefits for improved flow, continuity, and strength. Continuing development of this technology holds promise for strengthening and rehabilitating a multitude of critical infrastructure facilities.

Additional development is also needed to improve thermal welding procedures and quality control for structural polymers, composite design and construction with polymers, and retrofit applications for buildings and lifelines that take advantage of their lightweight, ductility, and resistance to corrosion.

MCEER Research Highlight

MCEER, in collaboration with the Los Angeles Department of Water and Power, has developed FRP technology for strengthening critical water trunk and transmission pipelines that are composed of steel with welded slip joints (O'Rourke et al., 2000). As shown in Figure 8, such joints are susceptible to buckling from compressive loads generated by earthquakes. As illustrated in Figure 9, FRP can be used to retrofit existing pipelines and strengthen new joints during fabrication in the field. MCEER has also worked with gas utility companies to show that internal FRP linings are able to sustain substantial ground deformation, thus providing safety and continuity of flow, even when brittle cast iron pipelines with FRP linings are subjected to undermining and ground failure.

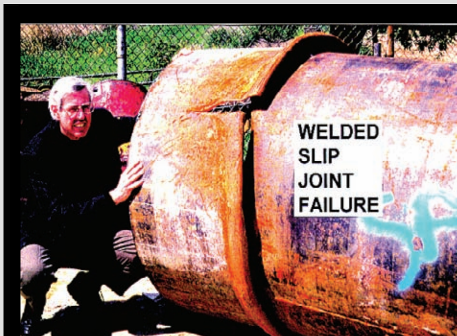


Figure 8. Welded slip joint failure due to the Northridge earthquake.

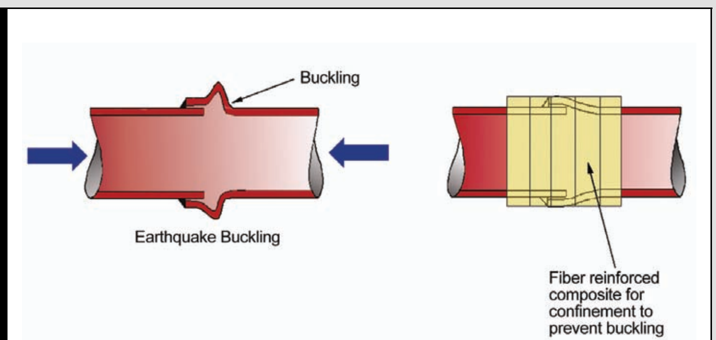


Figure 9. Performance of non-retrofitted and retrofitted slip joints.

Key Research Requirement 3.4. Create integrated all-hazard methodologies for engineered systems

There are significant challenges in achieving nationwide implementation of mitigation strategies that provide protection against a single hazard. In regions where an acute awareness of a specific hazard exists, implementation of mitigation measures for that hazard are usually achieved. However, significant barriers to implementation exist in other regions where the risk and consequence of a disaster remains high, but awareness is low due to the long return period of damaging events. The prevailing "stove-pipe" approach to disaster mitigation thus creates significant challenges if true enhancements of disaster resilience are to be achieved through mitigation. Typically, immediately following a disaster, mitigation measures are enacted regionally that enhance resilience for the hazard that has led to the latest disaster, while relaxation of these measures inevitably occurs when a long time period has elapsed since the last occurrence. Observation of past trends thus suggests that the single-hazard approach to mitigation is of limited effectiveness as a long-term policy toward significantly enhancing disaster resilience across the nation (even though it can be highly effective regionally where an acute awareness of a specific hazard exists and actual actions are taken to mitigate this risk).

Therefore, the objective is to identify new mitigation strategies and technologies that can provide simultaneous protection against more than one hazard, for a single cost. For example, synergies exist in the strategies to mitigate structural damage due to blasts and earthquakes, and to mitigate nonstructural damage for blasts, hurricanes and earthquakes. The objective is to identify the spectra of such synergies and develop new technologies that achieve the broadest possible level of protection at the least possible cost, aiming at more uniform, nationwide adoption of these technologies.

MCEER Research Highlight

There are some similarities between seismic and blast effects on structures: both major earthquakes and terrorist attacks/accidental explosions are rare events that can induce large inelastic deformations in key structural components of buildings, bridges, and other structures. Since many bridges are (or will be) located in areas of moderate or high seismic activity, and because many bridges are potential terrorist targets, there is a need to develop structural systems capable of performing equally well under both events. As part of its FHWA-funded research project, MCEER investigators have developed a multi-hazard bridge pier concept capable of providing an adequate level of protection against collapse under both seismic and blast loading (see Figure 10). Satisfactory results from both blast and seismic testing demonstrated the multi-hazard viability of the proposed concept.

Figure 10. Blast testing of concrete-filled steel tube bridge pier concept, and resulting acceptable residual deformations.

Programs for research and development should build on the accomplishments of regional economic modeling for earthquake impacts, and extend these models to multi-hazard scenarios. Through the systematic quantification of regional economic losses, it will be possible to evaluate a particular hazard or human threat on a comparative basis with mitigation costs, and thereby identify the most cost-effective mitigation measures. Quantifying the economic consequences of disasters provides an effective basis for setting priorities, as well as the communication of these priorities for public and/or private investments to enhance system performance.

MCEER Research Highlight

There is a growing body of research and applications associated with the economic and social consequences of lifeline damage and loss of functionality. Methodologies for quantifying the socioeconomic impacts of lifeline losses have been pioneered by the earthquake community through multidisciplinary studies of seismic disruptions in water supply and electric power systems (e.g., Shinozuka and Chang, 2004; O'Rourke et al., 2004; Chang, 2003; Rose and Liao, 2003 and 2005; Chang et al., 2002; Chang et al., 1996; Shinozuka and Hwang, 1998). These types of models provide a significant resource for modeling the regional impacts of other disasters such as hurricanes and terrorism (see Figure 11).

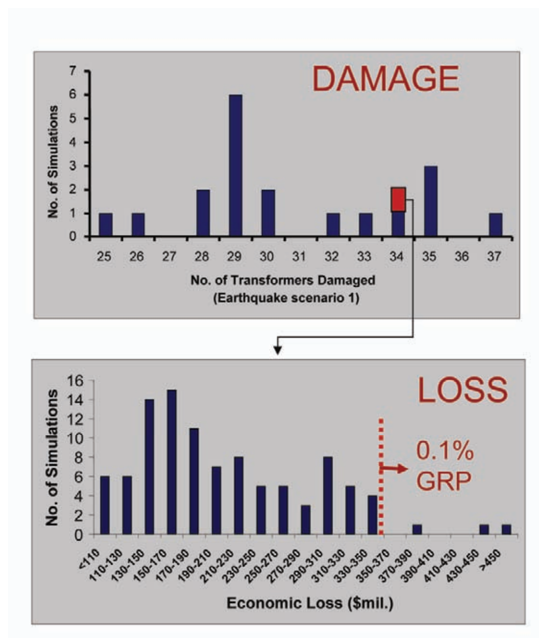


Figure 11. Economic losses due to lifeline failure.

Grand Challenge 4: Recognize and Reduce Vulnerability of Interdependent Critical Infrastructure

Critical infrastructure systems, or lifelines, provide the resources and services essential for safety, security, and the economic well-being of modern communities. They are vitally important for emergency response and regional recovery after disasters. Lifelines are generally grouped into six principal categories: electric power, gas and liquid fuels, telecommunications, transportation, waste disposal facilities and water supply. Transportation, in turn, can be divided into highways, railroads, mass transit, ports and waterways, and air transportation.

Major challenges for reducing the vulnerability of lifeline systems are the development of technologies to prevent cascading failures and the enhancement of protective measures before and after a hazard event. To meet these challenges successfully, it is important to set a strategy that is consistent with the three main features of interdependent infrastructure. The grand challenge of disaster reduction must account for *proximity* of critical infrastructure by promoting measures that identify key areas where system facilities are collocated and

MCEER Research Highlight

MCEER, since its inception, has studied the performance of lifelines during earthquakes in a systematic way, with emphasis on the interdependencies among different lifeline systems. MCEER work has expanded in recent years to include other types of disasters, such as human threats like the 2001 World Trade Center (WTC) disaster, and Hurricanes Charlie and Katrina in 2004 and 2005. Moreover, MCEER researchers (O'Rourke, 1993; O'Rourke et al., 2003) have performed systematic investigations of the cascading effects of critical infrastructure damage through case history analyses of severe accidents in New York City and the WTC disaster. They have also studied the effects of electric transmission line failure on cascading damage in large regional electric power systems, such as the one operated by the Western States Coordinating Council (Shinozuka et al., 2003). At one time, the concept of cascading damage was associated exclusively with electric power failure, but now the concept has been extended to the greater complex of critical infrastructure systems. For example, the catastrophic Hyogoken-Nambu earthquake in Japan struck Kobe and neighboring communities causing gas pipe damage leading to gas leaks as shown in Table 2. The restoration of electric power was delayed in some areas to prevent fires that would result from reactivation of electricity, which is a situation caused by the complex interaction between critical lifelines. A noteworthy accomplishment of MCEER researchers is the re-definition and assessment of cascading damage to include disruption that is transferred and amplified from one system to many others.

Table 2. Gas pipeline leaks reported after the Hyogoken-Nambu (Kobe) earthquake.

	Medium Pressure			Low Pressure				Total
	MP-A	MP-B	Total	Main	Branch	S.P.	Total	
Joint Part (Inc. Welding)	35	71	106	549	4,607	6,184	11,340	11,446
Pipe Body	0	0	0	34	0	0	34	34
Total	35	71	106	583	4,607	6,184	11,374	11,480

*Pressure
M.P. - A : Medium Pressure A system (3~10 bar)
M.P. - B : Medium Pressure B system (1~3 bar)
Low Pressure system : 100~250 mm H_2O
*Main & Branch
Main : Pipeline with diameter of 100 mm or over
Branch : Pipeline with diameter of less than 100 mm

Courtesy of Osaka Gas

developing management tools to reduce the vulnerabilities that arise from such conditions. Disaster reduction must account for *interoperability* of different lifeline systems through systematic procedures that identify and quantify the risks inherent to multi-system, multi-hazard operations. It must also address *institutional interactions* by promoting effective cooperation among the institutions responsible for supervising and operating the complex of lifeline networks.

Key Research Requirement 4.1. Develop improved assessment methods for analyzing the vulnerability and interdependence of infrastructure systems

A hierarchical process is required to identify key interdependencies among lifeline systems in which logical pathways between systems can be charted from primary sources of damage to their potential ultimate effects on global performance. There are many existing approaches to draw upon, such as fault tree analyses performed for nuclear power and petrochemical plants, as well as probabilistic risk analysis performed by NASA for multi-system risk assessment of space craft missions. The effective application of these technologies to critical civil infrastructure needs substantial work and refinement. Civil infrastructure involves considerable uncertainty with respect to the location and condition of system components, especially within crowded urban and suburban environments. Moreover, the effective identification of fault paths for risk assessment requires information sharing and cooperation among multiple institutions. There are significant social and technical dimensions to this challenging management problem.

A comprehensive assessment of system interdependencies requires the integration of multi-system and multi-hazard scenarios. In combining the two, it will be possible to take advantage of loss estimation procedures developed for earthquakes, for which mature models have evolved that provide guidance for multi-hazard applications. An advantageous strategy is to focus first on the multi-system procedures for identifying and quantifying risks related to interdependencies, followed by the integration of loss estimation procedures within a multi-hazard context.

Although there are notable interdependencies among all systems, evidence obtained from disasters shows that the effect of electric power outage is likely to be most disruptive on the operation of other networks. Accordingly, understanding the role of electric power and implementing protective measures that ensure its continuity are essential for controlling cascading damage. The second feature involves the role that supervisory control and data acquisition (SCADA) systems play in the successful operation of all networks. Understanding the ways in which telecommunications influence system monitoring and operation are of substantial importance for identifying vulnerabilities and designing protective measures that stabilize local disruptions. Moreover, telecommunications in combination with advanced sensors and information technology provide opportunities for improvements in the security and efficiency of all systems.

Operational interactions and interdependence, and even sharing equipment at the interface between critical infrastructure systems, are commonly found in urban settings and hence, under disaster conditions, functional loss of one system often impedes the operation of other systems with possible severe consequences. In this respect, the impact of power failure is most well-known in its cascading effects on other infrastructure systems. According to the *U.S.-Canada Power System Outage Task Force Final Report Summary*, and the US DOT final report, *Effects of Catastrophic Events on Transportation Systems Management and Operations, August 2003 Northeast*

Blackout, Great Lakes Region, the August 14, 2003 blackout that struck the northeast affected 50 million people and many population centers including New York City, Cleveland, Ohio and Detroit, Michigan in the U.S., and Toronto and Ottawa in Canada. Aside from 21 power plants that went off-line including 10 nuclear power plants, cascading blackout destabilized the Niagara Mohawk power grid. The impact on other infrastructure systems was devastating. Indeed, in addition to Internet service systems, transportation systems (including air, highway, subway and railroad), water delivery systems and hospitals in the affected areas all suffered significantly from the blackout that took 30 hours to restore 90 % of the normal operational load.

In the case of a major disaster such as caused by Hurricane Katrina, interactions of a much broader sense must be considered and analyzed. In fact, an emergency communication system in New Orleans was disabled when the emergency power generation station was damaged by flying debris caused by Hurricane Katrina. The resulting loss of emergency communication capability must have had a devastatingly negative impact on the emergency response effort, which could have been more effective in minimizing the degree of the dysfunction of other infrastructure systems. This indicates that simplistic reliance on system redundancy is not necessarily as reliable as expected, and more importantly, the system interactions, under a disaster of catastrophic dimension, can become so indirect that they can no longer be modeled from a mechanistic point of view. Reliable statistical methods are recommended for these cases to allow prediction of the consequences of the disaster on the basis of empirical correlations developed between urban damage and the disaster from past damage data. In general, this recommendation also applies to all types of disasters when the intensity escalates to a catastrophic level. In these situations, the crisp and mechanistic causality relationship which governs interactions cannot be traced in the face of overwhelmingly complex and probabilistic nature of interaction.

The reliable functioning of financial markets requires robust and secure telecommunications, electric power, and transportation systems. Cybersecurity has received much attention with respect to the vulnerability of telecommunications and its effect on financial transactions. After 9/11, it is now recognized that the financial markets are also vulnerable to threats affecting the physical condition of telecommunication facilities at system nodes and critical fiber optic lines. Electric power is required for telecommunications and critical building facilities, and transportation systems are needed to bring investment and banking personnel to business locations. Work is needed in understanding and characterizing the ways in which telecommunications, electric power, and transportation networks support the finance and banking industry, and for identifying and hardening locations of potential vulnerability.

To achieve the goal of disaster resilient communities, it will be necessary to promote cooperation and develop specific procedures for information sharing among public/private utilities and municipal, state, and Federal agencies. These organizations operate with different missions, reward systems, and management objectives, and are often in competition with each other. Research is needed on the most effective ways to manage the interfaces among infrastructure systems, develop incentives for interagency cooperation, and formulate policy related to Federal government involvement. Work in this area should be undertaken by applied social scientists as well as business management and public policy experts.

MCEER Research Highlight

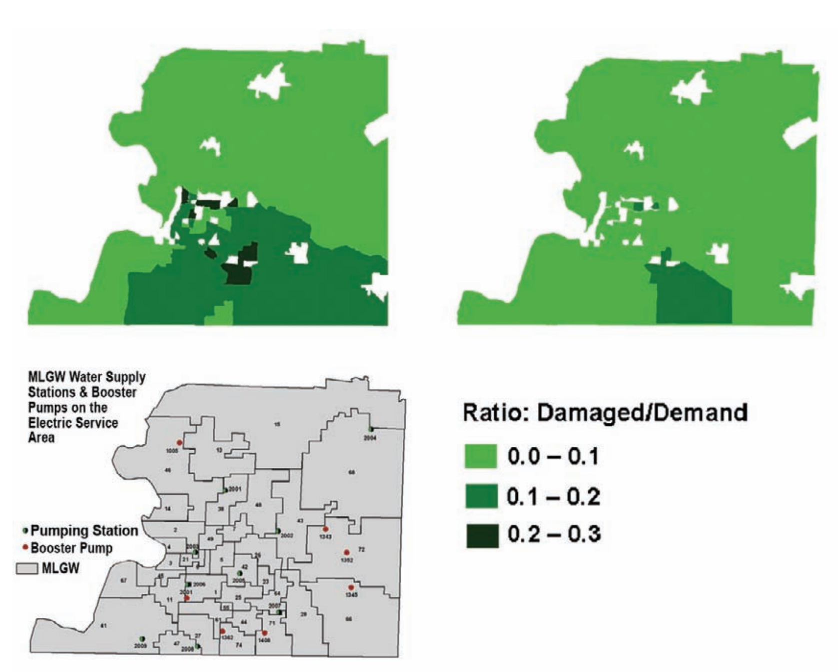


Figure 12. Locations of pumping stations, one for each water service area in Memphis, Tennessee (bottom left), effect of power failure on water supply capability considering interaction between power and water systems (upper left) and without interaction (upper right).

Depending on the type of interactions between systems, their impact can be evaluated mechanistically. For example, water distribution systems can suffer from a sudden power blackout that takes a single pumping station out of operation for a matter of seconds before a standby diesel engine is able to function. If the station is expected to provide significant water flow and pressure to the network, the sudden stop of its operation could produce transient pressure effects so intense that it would easily damage pipes even some distance away. MCEER's lifeline program addresses these and other cascading effects that can be mechanistically dealt with. In fact, MCEER researchers developed a quantitative method to evaluate the reduction in the system-wide water supply due to the seismically induced interruption of pumping operations in 1994 (see Figure 12) and successfully applied the method to the water supply system in Memphis, where all the water had to be pumped from regional aquifers. This was the first successful study in which seismic interaction between two different lifeline systems was evaluated (Shinozuka et al., 1994).

Legitimate concerns about security and attendant restrictions on information have become barriers to the effective use of information in developing more reliable and efficient systems. There is a pressing need for guidance related to the accessibility and dissemination of information. It is extremely important to develop a policy regarding the need to know versus the need to secure information and databases about critical infrastructure systems.

Key Research Requirement 4.2. Develop innovative assessment models for emergency response procedures including addressing all threats to public health rapidly and effectively

Among the most promising areas for research and development are advanced sensors and geographical information systems (GIS). There have been substantial advances in sensor technology, as methods for miniaturizing sensing devices have evolved at both micro- and macro-scales. These technological advances have taken place contemporaneously with the development of wide-band wireless coverage and impressive progress in designing self-configuring sensor networks. Information technology capabilities in the U.S. have progressed to the stage where major breakthroughs are now possible in the real-time monitoring, data acquisition, and analyses of distributed infrastructure systems. Disaster management research should focus on the application of advanced sensor technology in real systems. Encryption procedures and cyber-security for sensor data should also be explored.

Data and information associated with condition assessment for complex systems needs to be visualized relative to network configurations and their relationships with interdependent networks. An effective way to accomplish this is to use GIS. Research and development needs to promote web-based GIS technology, advanced visualization, and data management for critical infrastructure systems. At the same time, visualization and decision support procedures should be combined with emerging sensor and sensor networking technology to create "smart" lifelines that can monitor and report on their condition and functionality in real time.

MCEER Research Highlight

Whereas GIS is a proven technology for map-based management of information, its potential for rapid response to disasters has been constrained by data acquisition and system architecture. Recent developments supported by MCEER in web-based GIS (Lembo et al., 2004) have brought revolutionary improvements to map-based data management (see Figure 13). Through the Internet, it is possible to assemble data rapidly on an as-needed basis from multiple server sources at other locations. New system architectures are emerging in which an internal map server (IMS) replaces the external one inherent in conventional approaches. The IMS technology allows for a GIS with query logic to be assembled in a matter of hours as opposed to days with conventional approaches. Examples of data integration using GIS following Hurricane Katrina show the potential of this approach for rapid response activities (see *http://mceer.buffalo.edu/research/Reconnaissance/Katrina8-28-05/damage_reports_VIEWS.asp*).

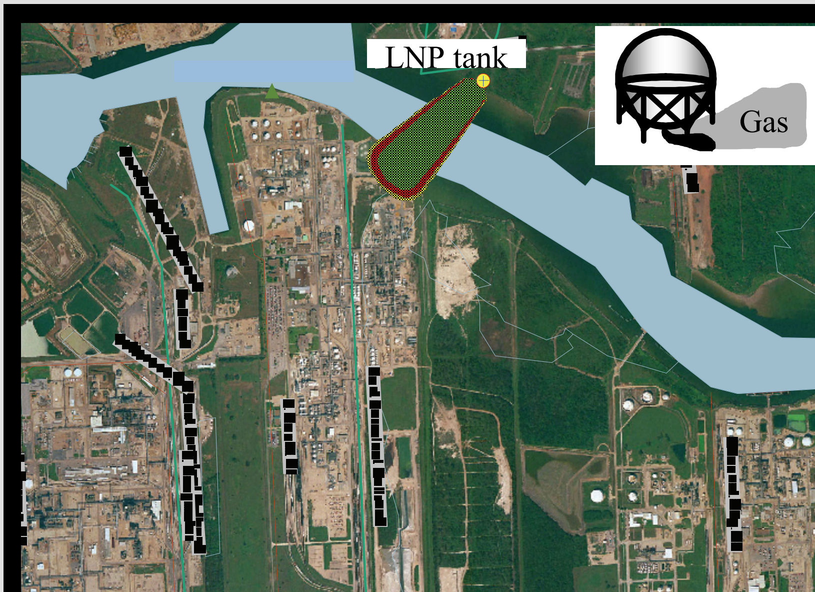


Figure 13. Tracing of simulated hazardous gas diffusion from a LNP tank (10 minutes from leakage due to an earthquake). Web-GIS capability can reflect the real-time wind and other weather conditions for the analysis. Inset schematically shows liquid leakage and diffusion of evaporated gas.

Grand Challenge 5: Assess Disaster Resilience Using Standard Methods

Key Research Requirement 5.1. Establish methods and standards for evaluation of resilience to hazards to include economic, ecological, and technological consequences of disasters. Base risk assessments on this data

and

Key Research Requirement 5.2. Use standard methods to gauge improvement in resilience following investments in planning and mitigation. This research must include contributions from all disciplines that play a role in understanding hazards and mitigation, including the social sciences

Many agencies and groups engaged in disaster mitigation have placed great emphasis in recent years on the objective of achieving disaster-resilient communities. Scholarship in the hazards field has also increasingly emphasized strategies that are needed to make communities disaster resistant while addressing long-term issues of sustainability and quality of life (Mileti, 1999).

The concept of resilience is routinely used in research in disciplines ranging from environmental research to materials science and engineering, psychology, sociology, and economics. The notion of resilience is commonly used to denote both strength and flexibility. Resilience has been defined as ''the capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back'' (Wildavsky, 1991) and as ''the ability of a system to withstand stresses of 'environmental loading'...a fundamental quality found in individuals, groups, organizations, and systems as a whole" (Horne and Orr, 1998). Focusing on earthquake disasters and specifically on post-disaster response, Comfort (1999) defines resilience as ''the capacity to adapt existing resources and skills to new situations and operating conditions.'' The term implies both the ability to adjust to ''normal'' or anticipated levels of stress and to adapt to sudden shocks and extraordinary demands. In the context of hazards, the concept can be thought of as spanning both pre-event measures that seek to prevent hazard-related damage and losses and post-event strategies designed to cope with and minimize disaster impacts.

Here, community resilience to hazards is defined as the ability of social units, e.g., organizations and communities, to mitigate hazards, contain the effects of hazard-related disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future hazards. The objectives of enhancing disaster resilience are to minimize loss of life, injuries, and economic impacts – in short, to minimize any reduction in quality of life due to the effects of these hazards. Resilience can be achieved by enhancing the ability of a community's infrastructure, e.g., lifelines and structures, to perform during and after a hazard, as well as through emergency response and strategies that effectively cope with and contain losses and recovery strategies that enable communities to return to levels of pre-disaster functioning (or other acceptable levels) as rapidly as possible.

As such, the goal of enhancing the disaster resilience of communities requires that standard methods be established to measure states of resilience, define the dimensions of resilience, and thus gauge improvements in resilience.

Progress in earthquake engineering research (Bruneau et al., 2003) has shown that the evaluation of resilience to hazards can be expressed in general terms by the concepts illustrated in Figure 14.

This approach is based on the notion that a time-varying measure of the quality of the infrastructure of a community can be defined. Specifically, infrastructure quality can range from 0% to 100%, where 100% means no degradation in service and 0% means no service is available. If the infrastructure is subjected to a hazard at time t_0, it could cause sufficient damage to the infrastructure such that the quality is immediately reduced during the occurrence of this disturbance (for example from 100% to 50%, as shown in Figure 14). Restoration of the infrastructure is expected to occur over time, as indicated in the figure, until time t_1 when it is completely repaired (indicated by a return to 100% of infrastructure quality). Hence, the loss of resilience with respect to the exposure to a specific hazard (area shown in green in Figure 14), can be measured by the size of the expected degradation in quality (probability of failure) over time (that is, time to recovery). Obviously, resilience must be measured in light of the full set of potential hazards that threaten a community and, therefore, must include joint probabilities of occurrences of various hazards.

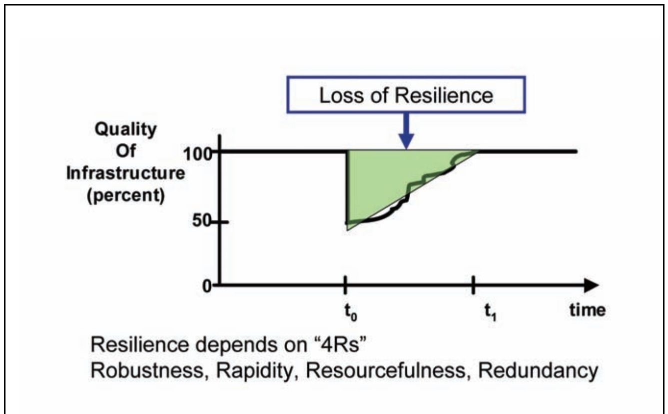


Figure 14. Evaluation of resilience to hazards – conceptual definition.

The framework and measurement of seismic resilience has formed the foundation to guide MCEER's research for the last five years. The measure of seismic resilience for both physical and social systems has been further defined by MCEER investigators by the following properties:

- **Robustness:** strength or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function;

- **Redundancy:** the extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality;

- **Resourcefulness:** the capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some elements, systems, or other units of analysis. Resourcefulness can be further conceptualized as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals; and

- **Rapidity:** the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption.

MCEER Research Highlight

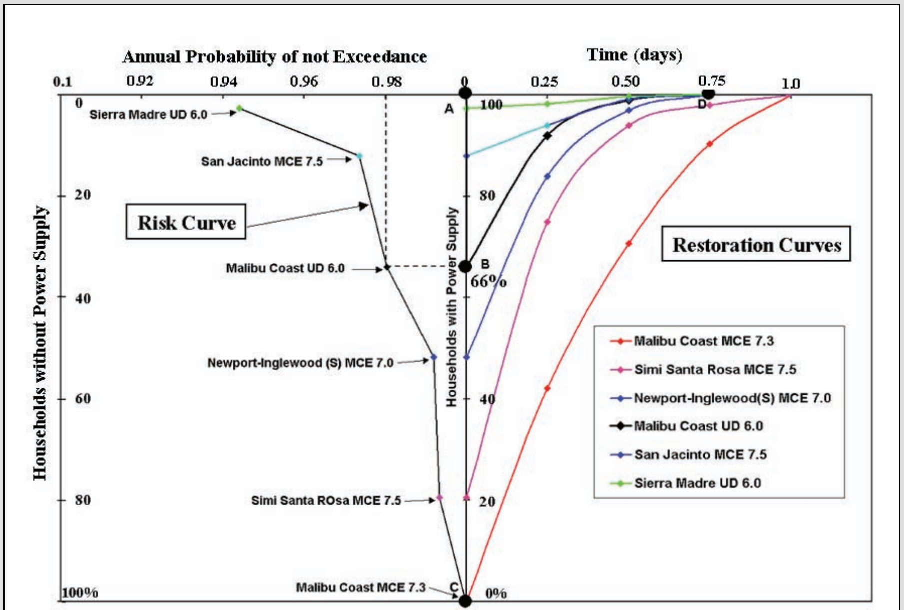


Figure 15. Performance analysis and repair management model for LADWP's power transmission system.

With respect to the seismic performance of the power transmission system in Los Angeles, California, robustness is defined in terms of performance indices of different dimensions such as power supply still available (technical), percentage of customers still having power (social) and level of regional gross product (economic) following a severe earthquake event. Resourcefulness is induced in the repair and restoration model, where the resources are assumed to be available through Federal and State assistance, utility emergency response contingency funds, mutual aid, etc. Redundancy is handled at different technical levels, for example, taking into consideration the inherently redundant design of bus configuration consisting of bus, circuit breaker, disconnect switches, and redundancy of transmission lines connected to nodes of receiving stations. The redundancy issues involve a much larger scale of networks and grids are not considered here. Rapidity is obviously highly dependent on all the R's and it demands complex modeling, which is an important future research subject. Indeed, rapidity is the culmination of how well preparedness, situation assessment and emergency response are managed and implemented.

MCEER has developed models for performance analysis and repair management for the Los Angeles Department of Power and Water's (LADWP) power transmission system, calibrated with the Northridge earthquake event and used for simulation of risk and restoration curves under a set of scenario earthquakes representing the seismic hazard of Los Angeles and Orange Counties, California. Figure 15 demonstrates the resilience characteristics of the transmission system. Under the regional seismic hazard considered, the figure shows that the annual reliability is 98% that at least 66% of customers will have power following an earthquake.

Resilience to the earthquake hazard has been further conceptualized by MCEER as encompassing four inter-related dimensions: technical, organizational, social, and economic. The *technical* dimension of resilience refers to the ability of physical systems (including components, their interconnections and interactions, and entire systems) to perform to desired levels when subject to earthquake forces. The *organizational* dimension of resilience refers to the capacity of organizations that manage critical facilities and have the responsibility for carrying out key disaster-related functions to make decisions and take actions that contribute to achieving the properties of resilience outlined above – that is, that help to achieve greater robustness, redundancy, resourcefulness, and rapidity. The *social* dimension of resilience consists of measures specifically designed to lessen the extent to which earthquake-stricken communities and governmental jurisdictions suffer negative consequences due to the loss of critical services as a result of earthquakes. Similarly, the *economic* dimension of resilience refers to the capacity to reduce both direct and indirect economic losses resulting from earthquakes.

These four dimensions of community resilience – technical, organizational, social and economic (TOSE) – cannot be adequately measured by any single measure of performance. Instead, different performance measures are required for different systems under analysis. MCEER's research activities address the quantification and measurement of resilience in all its inter-related dimensions – a task that has never been addressed before by the earthquake engineering research community. This is an extremely complex and difficult task. It requires integrated research tasks aimed at developing, testing, and refining quantitative measures of resilience.

The above framework is flexible and sufficiently general to broadly address disaster resilience in quite a generic manner. Quantification approaches are already being developed that can encompass any type of extreme condition, although it is recognized that specific resilience dimensions will be expressed differently to recognize infrastructure-specific parameters and constraints, as well as disaster-specific conditions.

MCEER Research Highlight

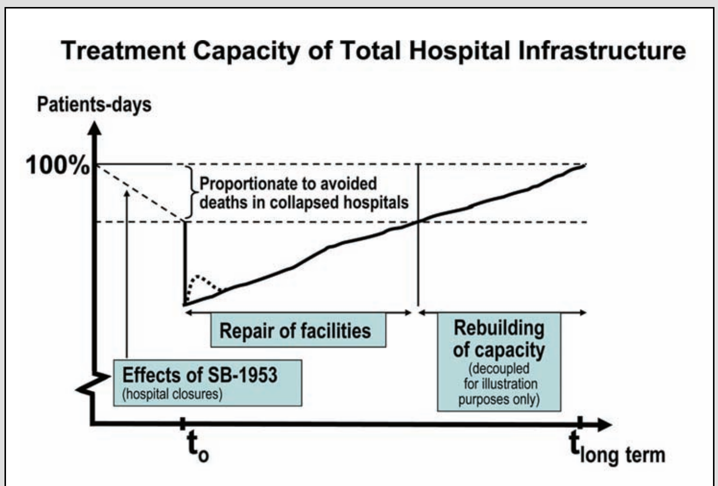


Figure 16. Quantification of seismic resilience of acute care facilities as patients/day treatment capacity of the total available hospital infrastructure.

Mathematical relationships have been developed for quantification of the technical dimension of resilience for critical facilities (e.g., Bruneau, 2005, Filiatrault, 2004 and Aref et al., 2004). Concurrently, an operational resilience framework has been developed for acute-care facilities (Figure 16). The former provide important necessary input to be able to assess the effective resilience provided by the latter. These can be used as a key step toward attainment of the operational resilience, expanded as the number of patient-days that can be provided as a measure of the treatment capacity of the health care facilities. This could be done for a single institution or for all facilities across a geographical region. The integrated focus on the physical infrastructure and their ability to provide their intended function was found, by the California Office of State Health and Planning, to provide a practical and effective framework to assess the effectiveness of policies in enhancing disaster resilience.

Grand Challenge 6: Promote Risk-Wise Behavior

Key Research Requirement 6.1. Facilitate research in the social sciences to understand and promote individual and institutional mitigation actions in the face of hazards

The promotion of risk-wise behavior is a fundamental grand challenge upon which other loss reduction strategies depend. Scientific and engineering solutions will do no good unless they are adopted and implemented. Social science research indicates that the diffusion of risk-wise behavior at various levels of societal analysis is hampered by a wide variety of factors. Examples of such factors include: myopic world views that fail to consider the potential consequences of events that could occur in the future; limitations on the ability to anticipate and manage low-probability/high-consequence events, both among the public and within political institutions; the low priority placed on extreme events by both the general public and political institutions during "normal" non-disaster times; difficulties in communicating scientific and probabilistic information to policy makers and the general public; the scarcity of incentives for risk-wise behavior; lack of institutional capacity to implement recommended loss reduction measures; and social factors, such as poverty, lack of access to needed information, and other socially-induced barriers to the adoption of self-protective measures.

Because of the existence of NEHRP, a large share of the social science research that has been conducted on hazards and disasters has focused on the earthquake threat. Studies conducted during the 1970's yielded many insights regarding factors that affect the public's perception and assessment of earthquake hazards, as well as their willingness and ability to prepare for future earthquakes. Many subsequent studies have focused on impediments and incentives to the adoption of seismic loss reduction measures (and self-protective measures for other hazards) for both households and businesses, as well as on social factors that are associated with the adoption of risk-wise protective strategies. Community-level studies, such as those conducted on community adoption of seismic retrofit codes (Alesch and Petak, 1986), have led to a greater understanding of the politics and economics of earthquake loss reduction. Other studies have focused on agenda-setting for disaster loss reduction, the social construction of the earthquake threat, and the special challenges that accompany the fact that earthquake hazard reduction is often considered "a policy without a public," in that earthquakes have not been recognized as a social problem by the general public—even those living in high-risk areas.

Social science research tends to be less "hazard specific" than physical science and engineering research. Social scientists are not so much interested in hazard or disaster agents (earthquakes, tornadoes, wildfires) than they are in the social processes involved in mitigating, preparing for, responding to, and recovering from all types of extreme events. Because social scientists are less specialized in this respect, their findings are broadly generalizable to the multi-hazard context. This is not to say that disaster agents do not differ from one another. Rather, the emphasis in social science is on generic features of different types of threats and disasters, such as whether they are familiar or unfamiliar; the extent to which forecasts and warnings are possible, as well as the potential time allowed for warnings; and scope and severity of impact. These generic attributes of different extreme events have important implications for how societies and communities respond to hazards and disasters. A considerable amount of social science research has focused on the relationship between hazard and disaster attributes and actions that can be taken to promote risk-wise behavior.

MCEER Research Highlight

Most research on risk-wise behavior and the adoption of self-protective measures has focused on households. During the 1990's, MCEER was a pioneer in the study of businesses and disasters. MCEER-funded studies included research on earthquake hazard vulnerability, risk perception, and the adoption of protective measures among businesses in Memphis and Shelby County, Tennessee, as well as research on business impacts and recovery following the Northridge earthquake (Dahlhamer and Tierney, 1998; Rose and Lim, 2002; Webb et al., 2000). MCEER support was also leveraged in additional NSF-sponsored studies on the business impacts of the 1993 Midwest floods and long-term business recovery following the Loma Prieta earthquake and Hurricane Andrew. This research has led to a greater understanding of factors that are associated with risk-wise behavior on the part of businesses; how disasters affect businesses; and which businesses are most vulnerable to experiencing negative outcomes following disasters.

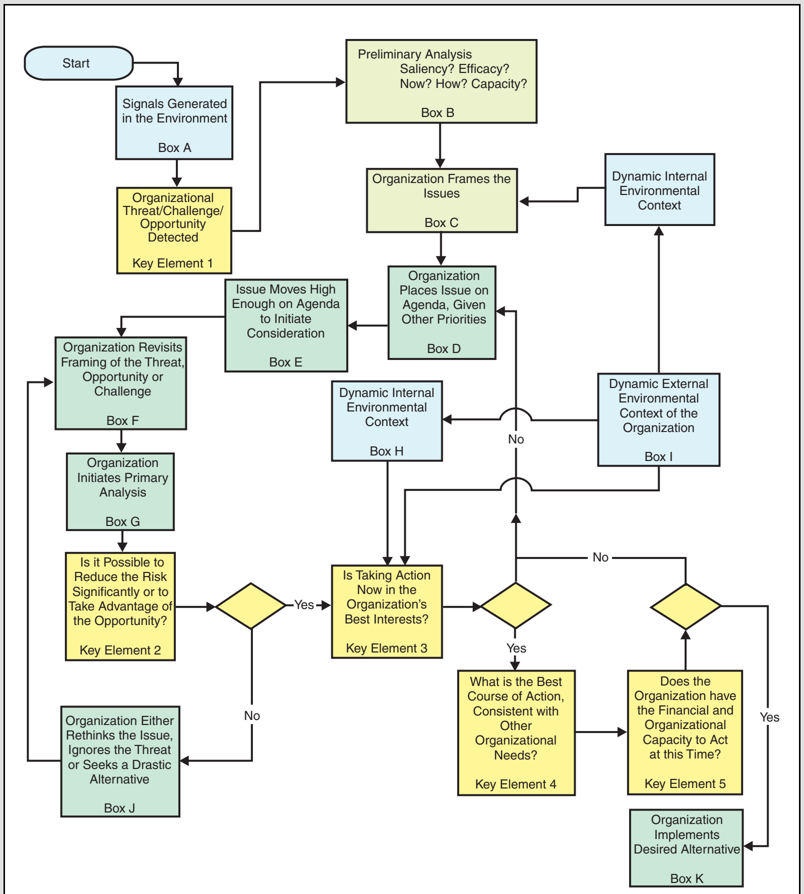


Figure 17. Preliminary model of the healthcare organization seismic safety investment decision.

With respect to societal institutions and risk-wise behavior, MCEER investigators studied the health-care sector's response to post-Northridge legislation (California's Senate Bill 1953) and accompanying mandates requiring extensive hospital retrofitting to meet new standards (see Figure 17). This research has highlighted both the factors that have made it difficult for hospitals to comply with new requirements and the negative unintended consequences of SB 1953. The SB 1953 extended case study contains many insights on challenges associated with the implementation process for hazard loss reduction measures (Alesch et al., 2005; Alesch and Petak, 2004; Petak and Alesch, 2004). It also explains how and why many well-intentioned policy efforts fail to meet their ultimate objectives, as well as how such efforts can result in perverse effects never anticipated by their original constituencies.

Key Research Requirement 6.2. Develop an enhanced understanding of effective techniques for educating the public and gaining community support for preparedness and disaster prevention activities

Improving risk communication and enhancing warning capability for extreme events is also a key element in the promotion of risk-wise behavior. Scientifically-informed strategies are needed to better inform the public about the risks associated with a range of extreme events and to encourage the adoption of mitigation and preparedness measures before disasters strike. There is also a need for better detection and warning disseminating systems across a range of hazards and timescales—from early monitoring and long-term forecasting to the issuance of rapid warnings immediately before and perhaps even during disaster impact. Again, social science research provides a substantial foundation for addressing problems associated with effective risk communication and warning dissemination.

With respect to earthquakes, risk communication challenges resemble those that accompany other low-probability/high consequence events; where probabilities are seen as very low, the public and policy makers have a tendency to perceive events as so unlikely that advance preparations are not warranted. Consequently, they tend not to be receptive to risk communications and not to engage in risk-wise behavior. There are several strategies that can be used to encourage risk-wise behavior for low-probability/high-consequence events. These strategies include sustained public education campaigns aimed at increasing awareness and motivation; the development of tools and scenarios that enable at-risk publics to better visualize the impacts of events that they have never experienced; and the formulation of policy instruments and other measures that make it easier for those affected to adopt risk-wise procedures and more difficult for them to avoid doing so.

Effective risk communication campaigns play a crucial role in encouraging the public to respond effectively when actual disaster warnings are issued. The point of public education and preparedness programs is to help those at risk understand what they need to do—and when they need to do it—when disaster threatens. Social science research highlights a number of attributes that enhance the effectiveness of warning systems. These include:

- A socio-technical systems approach that recognizes that warning systems must seamlessly integrate scientific monitoring and detection, warning technologies, warning policies and authorities, and pre-event public education;

- The development of strategies that enable warning recipients to receive warnings in a timely manner; understand and confirm warnings; understand whether they themselves are at risk; understand the nature of the risk and the likely consequences of impending events; know what to do to avoid danger; and engage in self-protective actions in a timely manner; and

- Enhanced efforts to employ compatible warning systems, terminologies, and messages, regardless of the type of threat agent, so as to minimize the confusion experienced by warning recipients during different types of extreme events.

MCEER Research Highlight

With funding from FEMA's NEHRP program, MCEER published a report in 2004 entitled *Promoting Seismic Safety: Guidance for Advocates* (see Figure 18 and Alesch et al., 2004). The purpose of the publication was to provide social science-based guidance for those seeking to encourage the adoption and implementation of earthquake loss reduction programs. The report's overarching emphasis was on enhancing the ability of promoters of seismic safety to communicate with various audiences and to mobilize public support for earthquake safety. In addition to lengthier white papers, the report provided brief and succinct guidance on the following topics: how to successfully advocate for earthquake safety; the basics of earthquake science and seismic building codes; seismic safety legislation and policy; advice for advocates on appearing before legislative and other committees and on working with experts; how to communicate risk, including how to use the mass media effectively; and how to inform, persuade, and build coalitions that will promote earthquake loss reduction.

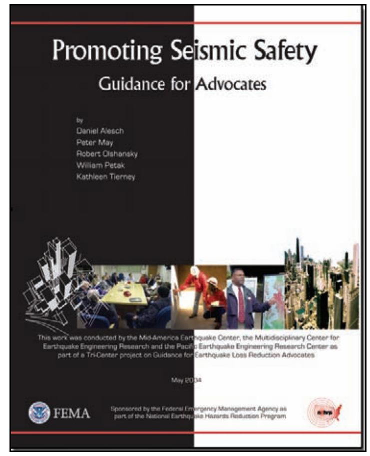


Figure 18. This report provides guidance for adopting and implementing earthquake loss reduction programs.

Figure 19. Undergraduate students (seen here on the Cooper River Bridge construction site) conduct research projects with faculty and present their research results as part of the REU program.

Key components of MCEER's education and outreach efforts include stimulating the interest and educational pursuit in diverse science subjects, developing future leaders in these areas, and promoting the interaction between research conducted by academicians and technological applications developed by practitioners. For example, MCEER currently has in place the Research Experience for Undergraduates (REU) (see Figure 19) and the REU Diversity programs, both of which sponsor outstanding junior and senior undergraduate students in civil engineering to conduct individual research projects exploring new directions in earthquake studies. Augmenting the REU Diversity program is a Ph.D. Fellowship aimed at future engineering educators to become faculty by providing them with funded research opportunities and relevant mentoring experiences. Regardless of the hazard, MCEER's objectives are to encourage prospective students to pursue degree coursework in relevant fields, to establish professional relationships with colleagues, and to educate the public on their areas of expertise, all of which incorporate outreach efforts with the intended objective of mitigating disasters.

Key Research Requirement 6.3. Research the effectiveness of, and human responses to, new communications technologies, including mobile phones, the Internet, and cable television on the delivery and successful use of public warnings

Both risk communication and warning system improvements depend on understanding which information sources different sub-populations typically rely upon for information, as well as the communications media they employ in their day-to-day activities—media that are becoming increasingly diverse and different from those used in the past. Current warning programs depend in part on agreements between organizations that engage in scientifically assessing threats and more traditional electronic media outlets, such as radio and television. More recently, newer technologies such as the Internet, cell phones, "reverse 9-11" telephone systems, NOAA weather radio, and text messaging have increasingly been explored to disseminate warning information in different hazard contexts. In the earthquake safety area, progress continues to be made in the areas of real-time seismic alert systems and rapid dissemination of earthquake-related impacts, both via the Internet.

MCEER Research Highlight

Stemming from MCEER's longstanding interest in disaster response and recovery, several MCEER investigators are currently participating in a NSF large information technology research (ITR) project entitled "Responding to Crises and Unexpected Events (RESCUE). RESCUE's objectives are to better understand the implications of new technologies for the ability of both organizations and the public to manage extreme events. MCEER investigators are involved in projects focusing on customized information dissemination tools and processes for use during crises, as well as on transportation system and evacuation research aimed at ensuring the safety of the public during extreme events, including both major earthquakes and crises resulting from intentional acts of terrorism. Figure 20 shows a result of the research under this project (Seligson et al., 2004).

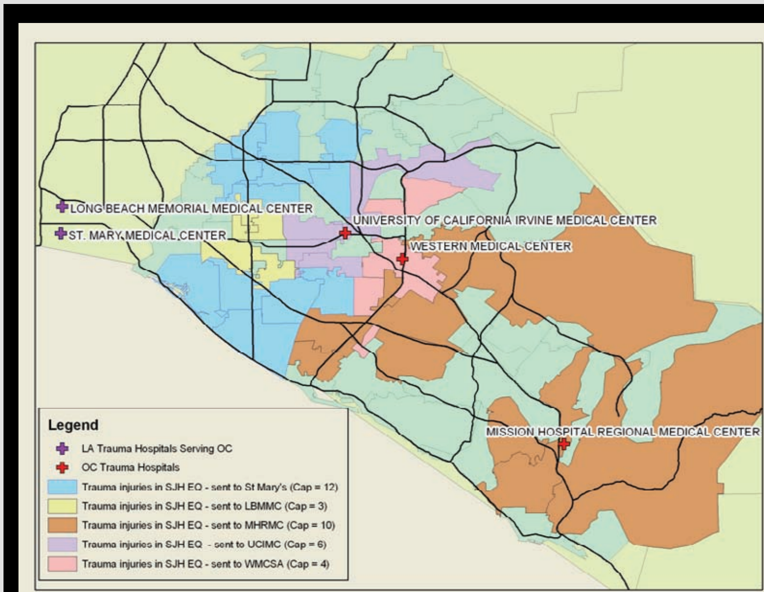


Figure 20. Optimal transportation routes of the seismically injured in the aftermath of a simulated San Joaquin Hills earthquake (M7.3) are given taking into account hospital capacity and minimum travel time through damaged highway networks.

To effectively warn the public, it is important to understand how societal diversity is likely to influence the warning dissemination and response process. Key diversity factors include age, educational and income levels, race, ethnicity, and language spoken in the home. Such factors are associated with day-to-day choices regarding the use of different communications media. They are also associated with the ability to receive and understand warning messages; the degree of trust diverse sub-populations place in official warning sources; and factors that make it easier or more difficult to carry out recommended self-protective actions. How does the existence of the "digital divide" affect the ability of the poor, non-English-speakers, and many in the elderly population to receive warnings and other hazard-related information via the Internet? How does the decline of network broadcasting and the rise of niche-based "narrowcasting" influence the ability to both disseminate and receive warning information? Does access to multiple communications channels—radio, television, cable, cell phones, instant messaging, etc.—make for more effective warnings, or are multiple channels a source of conflicting information and confusion? How far is the nation from developing audience-appropriate, customized warning systems and technologies?

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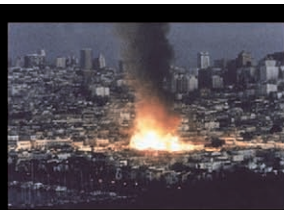


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