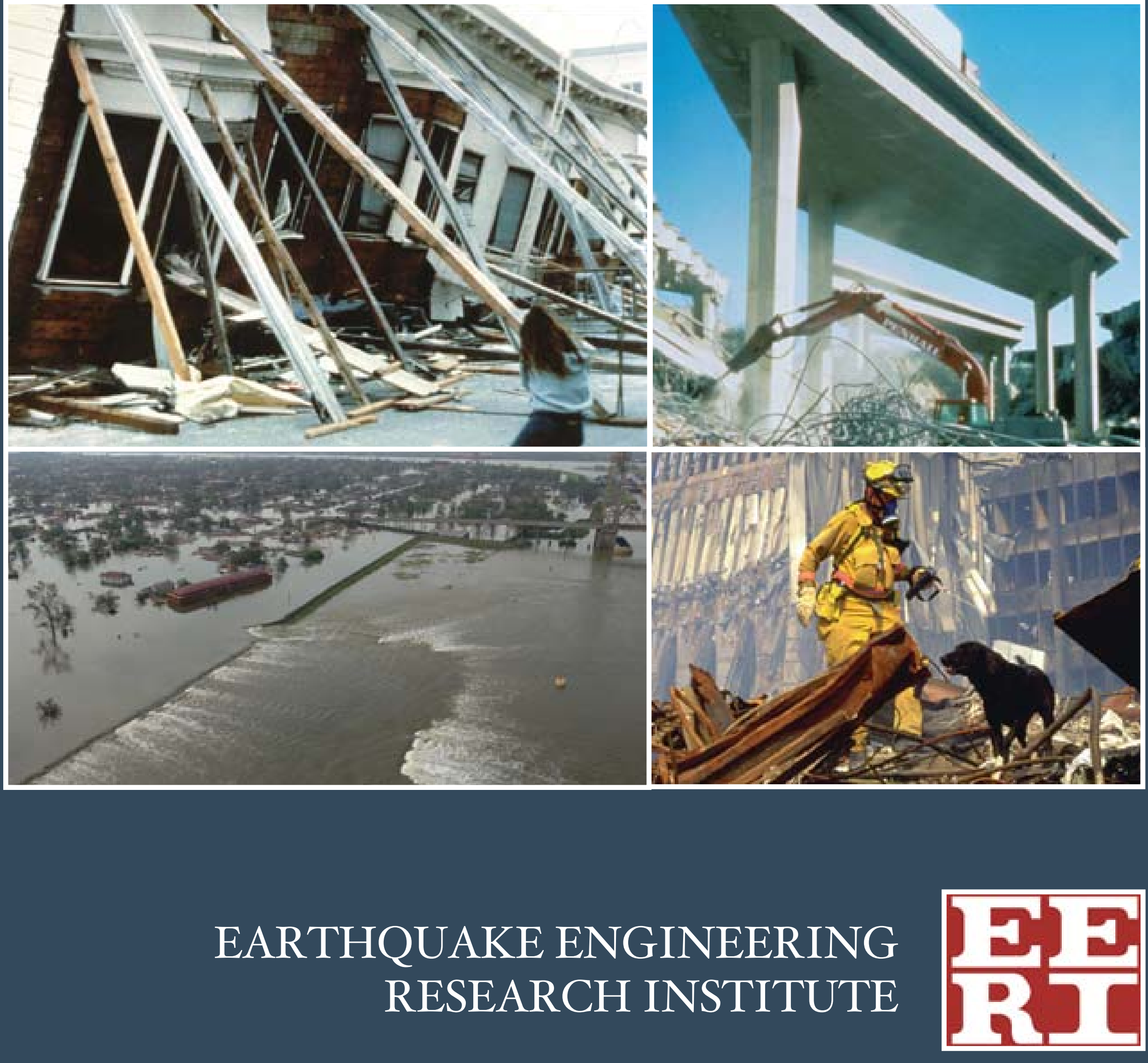
Contributions of Earthquake Engineering

to Protecting Communities and Critical Infrastructure from Multihazards



EARTHQUAKE ENGINEERING
RESEARCH INSTITUTE

Contributions of Earthquake Engineering
to Protecting Communities and Critical Infrastructure from Multihazards

A report prepared by
the Steering Committee of the EERI Workshop on
Contributions of Earthquake Engineering, Seismology,
and Social Science

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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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COVER IMAGES:

Top left: After the 1989 Loma Prieta, California, earthquake, buildings in the Marina District of San Francisco were braced by residents and firefighters to reduce the hazard of further collapse until they could be demolished under controlled conditions (source: Loma Prieta IV, Marina District, EERI Slide Set, #5, John Egan).

Top right: During the 1994 Northridge, California, earthquake, several spans of the Gavin Canyon Undercrossing, a tall, highly skewed bridge located on I-5, became unseated and fell. (source: Northridge I [Overview] EERI Slide Set, #25, Jack Moehle).

Bottom left (and Figure 32b, page 46): Break in the levee in the 9th ward, New Orleans, August 30, 2005, in the aftermath of Hurricane Katrina (source: Jocelyn Augustino/FEMA).

Bottom right (and Figure 27, page 37): Members of the Los Angeles County search-and-rescue team participated in operations after the World Trade Center disaster (source: Andrea Booher/FEMA).

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Preface

The National Earthquake Hazards Reduction Program (NEHRP) is the backbone of protection for U.S. citizens from the life-threatening and economically disruptive effects of earthquakes. NEHRP provides federal support for research, information dissemination, development and implementation of technology, and the application of planning and management procedures to reduce seismic risk. NEHRP is also an incubator for technology and policy that extend well beyond seismic risk to improve the security and economic well-being of U.S. citizens and other members of the world community.

The contributions of earthquake engineering are wide ranging. They affect our lives through improvements in the perception, quantification, and communication of risk. They involve advanced technologies for reinforcing and monitoring the built environment, loss assessment methodologies, emergency response procedures, and a process for achieving disaster preparedness. They also involve a unique, multidisciplinary culture that integrates basic and applied research into design codes, construction methods, and public policy.

The intention of this report is to lay out the contributions of earthquake engineering that enhance public safety and improve the protection of U.S. communities from hazards beyond earthquakes. Four categories are chosen to identify major contributions and present representative examples: planning, advanced technologies, emergency response, and community engagement.

At one level the purpose of this document is education. It is written to inform members of the earthquake community about their collective contributions to improvements in civil infrastructure and community resilience. It is also written for the general public, governmental agencies, and elected representatives and their staff. It is hoped that this document will be used by members of the earthquake community and others to articulate the importance and long-lasting benefits of programs made possible through NEHRP.

At another level the purpose of this document is to help define and encourage leadership. The earthquake community has earned a strong reputation for advances in technology, planning, and policy that reduce seismic risk. These achievements are well regarded by those who work on other natural hazards, engineering and planning personnel responsible for civil infrastructure, and organizations responsible for emergency response and public protection. Leadership in earthquake engineering, supported through NEHRP, sets a high standard of performance.

Future performance will be viewed increasingly in a multihazard context. Perhaps the most important leadership challenge, therefore, is for the earthquake community to define its role in a multihazard world. As indicated by the many examples in this report, the earthquake community plays an enormously important role in multihazard mitigation. By informing readers about contributions beyond earthquakes, it is hoped that this report will stimulate dialogue and planning for improvements in seismic risk reduction that are developed with both awareness and understanding of their contributions to multihazard mitigation.

It is important for the earthquake community to articulate its contributions. Given the importance of NEHRP, this articulation needs to be voiced with the governmental agencies that are either responsible for or can find partnerships in NEHRP. This message also needs to be voiced with elected representatives responsible for legislative support. It is again hoped that this document will provide a better understanding for those in public service of the impact and value of their investments in NEHRP.

Thomas D. O'Rourke
Past President, EERI, 2003-2004
Past Co-Chair, NEHRP Coalition, 2005-2008

Acknowledgments

The Earthquake Engineering Research Institute (EERI) acknowledges the support of the Federal Emergency Management Agency and the EERI Endowment Fund in the preparation of this report .

This report grew from a small project that was initially supported by EERI's Special Projects and Initiatives Committee. Its development was encouraged by participants in a two-day workshop that was organized by EERI to explore how national investments in earthquake engineering and science enhance public safety and improve the protection of U.S. communities from hazards beyond earthquakes. The workshop involved many experts in various engineering disciplines, geoscience specialties, and applied social sciences. Information gathered from participants in preparation for and during the workshop provided the initial material for developing this report. Additional information and contributions were obtained from other experts as various drafts of the manuscript were prepared and edited.

The members of the workshop steering committee were Thomas O'Rourke (chair), Thomas Holzer, Christopher Rojahn, and Kathleen Tierney. Other participants in the workshop included William Anderson, Richard Andrews, Martha Baer, Donald Ballantyne, Nesrin Basoz, Harvey Bernstein, Ian Buckle, Mary Comerio, C. Allin Cornell, Ronald Eguchi, Richard Eisner, Thomas Hanks, Robert Hanson, Eve Hinman, Jeremy Isenberg, Wilfred Iwan, Milagros Kennett, Michael Lindell, Sami Masri, Farzad Naeim, William Petak, Carla Prater, Keith Porter, Lawrence Reaveley, David Schwartz, Mark Sereci, Haresh Shah, Paul Somerville, Bill Spencer, Alex Tang, Charles Thiel, and Susan Tubbesing. All participants contributed important ideas and helped to develop early versions of the draft manuscript for the report, which was edited and added to by members of the steering committee. Others who made important written contributions to various chapters include Ronald Mayes, Andrei Reinhorn, Charles Scawthorn, Tsu-Teh Soong, and Andrew Whittaker.

The preparation of this report would not be possible without the dedication and contributions of the EERI staff. In particular, those members of the staff who helped to edit and organize the report include Marjorie Greene, James Godfrey, Eloise Gilland, and Susan Tubbesing.

Executive Summary

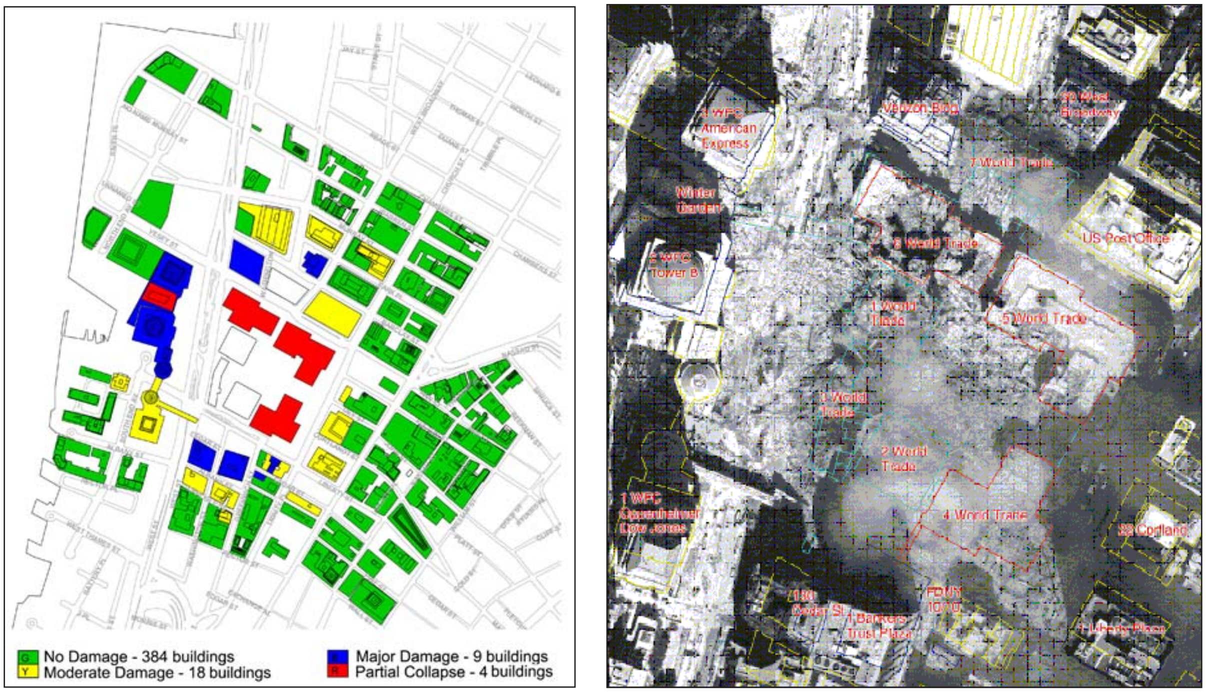
The purpose of this document is to articulate, with examples, the ways earthquake engineering has enhanced public safety and improved the protection of U.S. communities from hazards beyond earthquakes.

Incubator of New Ideas and Applications

For decades, earthquake engineering has been an incubator for new ideas, advanced technologies, and public policy. Earthquakes are associated with extreme, widespread disruption that occurs suddenly, without reliable short-term prediction. The technology used to reduce earthquake risk has been developed through multidisciplinary research and the implementation of methodologies that depart from conventional problem solving. This process encourages innovation and generates products and practices that fundamentally change our ways of modeling, design, and construction. Advances in earthquake engineering improve community safety against many different natural disasters such as fire, flood, and wind, and from human threats such as terrorism and severe accidents.

The development of probabilistic seismic hazard analysis (PSHA) is a good example of innovation stimulated by earthquake engineering. The concepts and procedures originally embodied in this hazard analysis approach have been applied to hurricanes, tornadoes, and other severe storms. The analytical process and modeling methods that evolved from PSHA are used worldwide by the insurance industry to distribute the risk associated with all types of natural hazards. The methodology also forms the underpinning for risk transfer to capital markets through catastrophe bonds.

The application of post-earthquake building inspection protocols to evaluate the state of damage of buildings surrounding the World Trade Center site after September 11, 2001, is an example of earthquake technology leveraged into critically important contributions for disaster recovery. Rapid procedures for post-earthquake building inspection were applied shortly after September 11 and helped speed the restoration of New York City businesses and world financial markets.



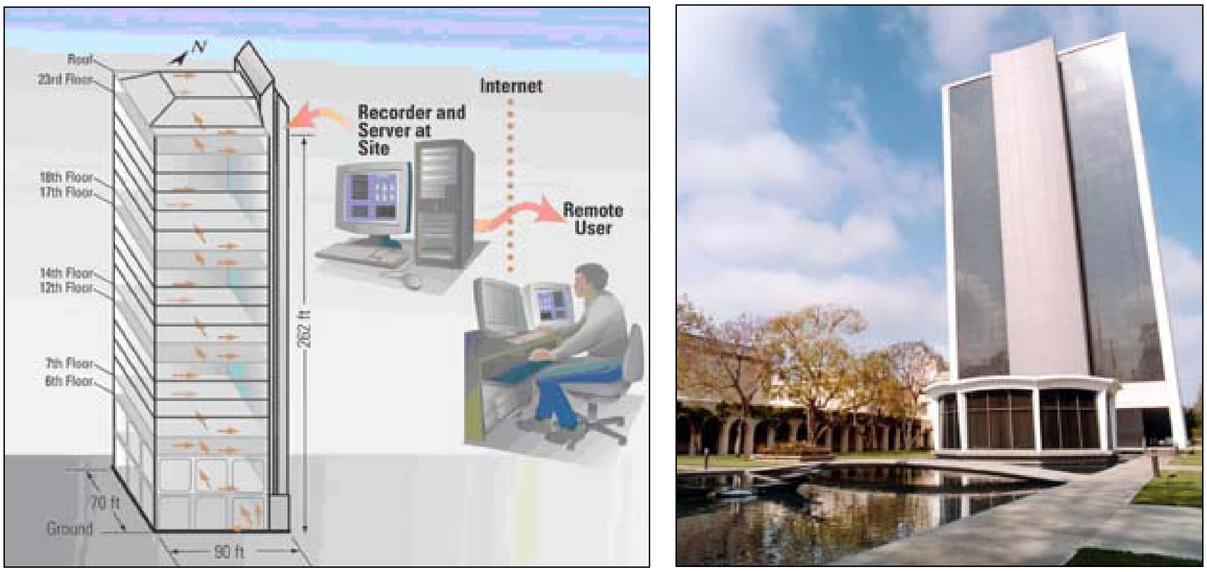
A map of buildings surrounding the World Trade Center. Within days of the tower collapses, the structural integrity of 406 buildings in the area was assessed using post-earthquake inspection guidelines (FEMA, 2002).

Improved Infrastructure Management

The U.S. infrastructure is complex and highly interdependent. Modeling and managing interdependent systems, such as electric power, water supplies, gas and liquid fuel delivery, and telecommunications, requires simulation capabilities that can accommodate the many geographic and operational interfaces within and among the different networks.

Earthquake engineering contributes powerful methods of modeling complex lifeline system performance. Characterization of diverse component behavior, multiscale modeling techniques, reliability-based decision making, and computer visualizations have been enhanced through investments in earthquake engineering. They are available now as a body of knowledge and technology for improved infrastructure management.

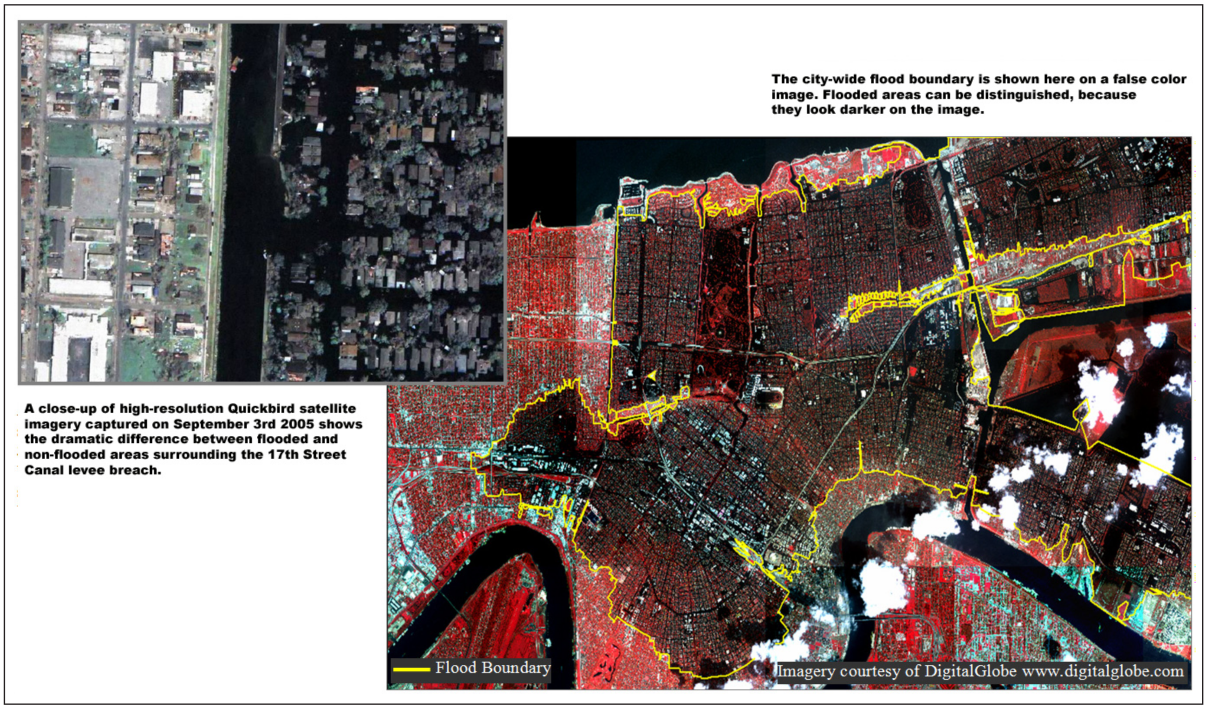
Structural health monitoring, protective systems, remote sensing, and Web-based GIS are technologies described in this report that were improved significantly through earthquake engineering applications. These technologies provide enormous benefits through improved surveillance and management of critical infrastructure in real time, and thus establish the platform for truly "intelligent" systems. The experience gained with wide-band wireless, massive high-end computation, and the processing of geographically distributed data with advanced seismic monitoring networks offers an important opportunity to improve the safety and operation of critical U.S. infrastructure.



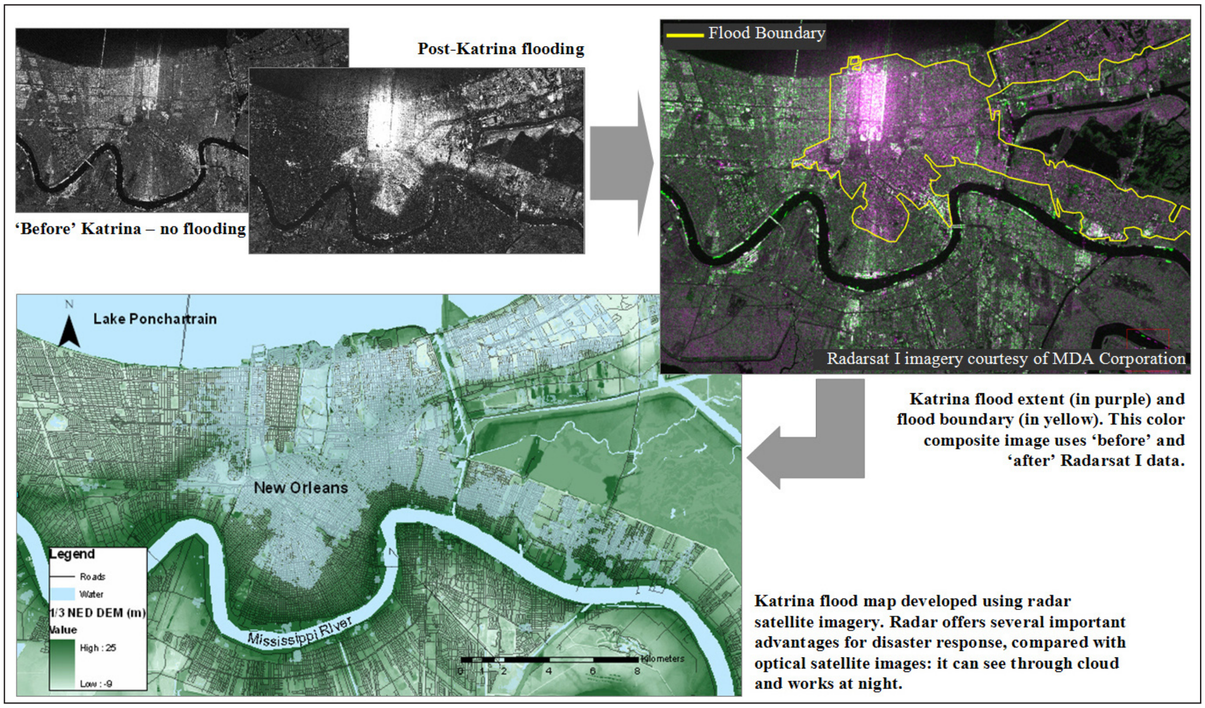
The structural integrity of a building can be monitored remotely in real time. (left) Information from sensors placed at various locations throughout the structure is collected by an on-site server and transmitted to building owners and managers via the internet (Celebi et al., 2004);. (right) Milikan Library at Caltech, an example of a monitored building.

Improved Multihazard Mitigation

Virtually every technology and planning or management process identified in this report can be extended to other natural hazards and, in most cases, to severe accidents and the destructive acts of terrorism. In several notable instances, technologies developed initially for earthquakes are being applied to hurricanes. For example, remote-sensing technologies and Web-based GIS developed for earthquake reconnaissance were applied in reconnaissance missions and response planning for Hurricane Charlie in 2004 and Hurricane Katrina in 2005. Reconnaissance, guided by high-resolution satellite images and aerial photographs in combination with GPS-coordinated databases and GIS, helps quantify the extent of damage and provides dynamic data systems to aid in the subsequent recovery of communities. In addition, the systematic collection and synthesis of regional data sets aid greatly in correlating the degree of damage with parameters such as wind speed, exposure, inundation levels, and building characteristics, enabling the application of improved loss estimation to future natural disasters.


The city-wide flood boundary is shown here on a false color image. Flooded areas can be distinguished, because they look darker on the image.

A close-up of high-resolution Quickbird satellite imagery captured on September 3rd 2005 shows the dramatic difference between flooded and non-flooded areas surrounding the 17th Street Canal levee breach.


Post-Katrina flooding

'Before' Katrina – no flooding

Katrina flood extent (in purple) and flood boundary (in yellow). This color composite image uses 'before' and 'after' Radarsat I data.

Katrina flood map developed using radar satellite imagery. Radar offers several important advantages for disaster response, compared with optical satellite images: it can see through cloud and works at night.

Satellite imagery, refined through earthquake reconnaissance missions, is used to assess flood damage in Louisiana after Hurricane Katrina, 2005 (images and text courtesy of ImageCat).

Magnetorheological dampers initially developed for the control of earthquake vibration applied to control wind- and rain-induced vibration of the Dongting Lake Bridge, Hunan, China (Spencer and Nagarajaiah, 2003).

Protective systems that use semi-active damping devices protect buildings during earthquakes and bridges during extreme wind and rainstorm conditions. Studies of the public's perception of earthquake warnings and forecasts supply information critical for effective preparation and management of evacuations during floods and hurricanes. Investigations of earthquake recovery led to improved procedures for post-disaster reconstruction applicable for all natural hazards and human threats.

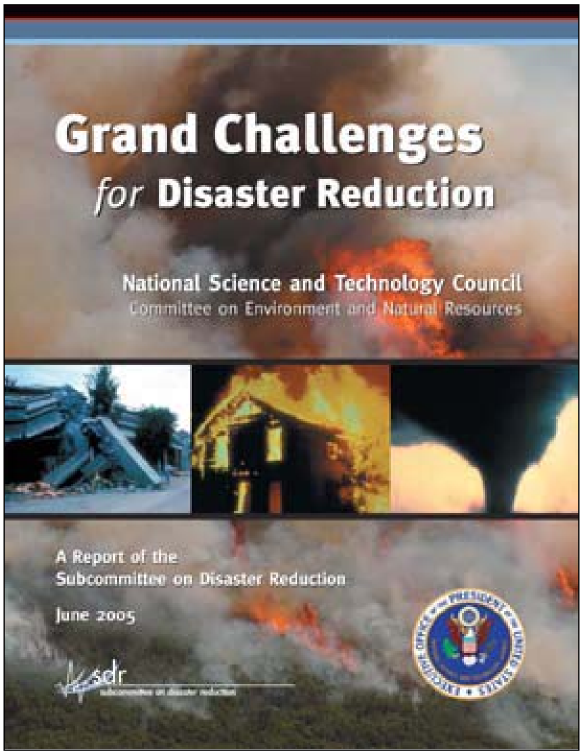
Multihazard Legislation and Policy

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

NEHRP has not only served as a model for legislation and a national program to mitigate the effects of windstorms, but has also informed federal policy for U.S. disaster reduction. Members of the earthquake community provided advice to the Subcommittee on Disaster Reduction of the National Science and Technology Council when formulating the six grand challenges for disaster reduction that are intended to guide federal investments in support of disaster-resilient communities (Subcommittee on Disaster Reduction, 2005). The earthquake community provides leadership for disaster reduction. Its members make notable contributions to address the disaster reduction grand challenges and promote the technical and social advances needed for effective multihazard risk mitigation.

Windstorm
Impact Reduction
Implementation
Plan

A Report of the National Science and Technology Council



Grand Challenges
for Disaster Reduction

National Science and Technology Council
Committee on Environment and Natural Resources

A Report of the
Subcommittee on Disaster Reduction

June 2005

sdr

The National Windstorm Impact Reduction Plan (left) and the Grand Challenges for Disaster Reduction (right) benefit from legislation and policy informed by NEHRP and the advice of engineers, geoscientists, and social scientists who work on earthquake hazards and risk reduction.

Culture of Multidisciplinary Innovation

Advances in earthquake risk reduction were accomplished through the collective enterprise of architects, emergency managers, engineers, geoscientists, and social scientists. This integrated approach is reflected in hazard-resistant design, guidelines, and codes; national loss estimation methodology; performance-based engineering; lifeline systems management; improved decision-making; and loss reduction partnerships. Federally funded earthquake hazard reduction programs consistently emphasize the social, economic, and policy factors that govern the adoption and implementation of loss reduction measures. Strategies for research and development are guided by the broader community and socioeconomic contexts in which they are applied.

The multidisciplinary nature of earthquake engineering is one of its most significant legacies, providing a model for the future mitigation of natural hazards and human threats. Substantial opportunities exist for the earthquake community to continue its leadership, with the recognition that its contributions have extraordinary value not only for seismic risk reduction, but also for multihazard mitigation and the improved performance of critical infrastructure.

Cragmont School in Berkeley, California, under construction. California has very strict requirements for new public school construction, legislation that has grown out of experience with damaging earthquakes, an increasingly sophisticated understanding of the hazard, and engineering and code developments. The state invests significant resources in a seismic hazard mapping program, and individual jurisdictions as well as property owners are making large investments in mitigation. This school in Berkeley is one such example — the "old" school, which was actually the newest school in the district, was torn down because of an increased understanding of its high seismic risk, and this new school erected (photo: City of Berkeley).