MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

VOLUME I

Year 8: Annual Report on Progress and Plans for Continuing Support
(10/1/04 - 9/30/05)

Submitted to:
NATIONAL SCIENCE FOUNDATION
DIRECTORATE FOR ENGINEERING
EARTHQUAKE ENGINEERING RESEARCH CENTERS (EERC) PROGRAM
Engineering Education & Centers Division
4201 Wilson Boulevard, Suite 585
Arlington, VA 22230

May 16, 2005

EEC - 9701471
Project Summary

Goals, Thrust Areas, and Recent Accomplishments of MCEER

The overall goal of the Multidisciplinary Center for Earthquake Engineering Research (MCEER) is to enhance the seismic resiliency of communities through improved engineering and management tools for critical infrastructure systems (water supply, electric power, and hospitals) and emergency management functions. Seismic resiliency (technical, organizational, social, and economic) is characterized by reduced probability of system failure, reduced consequences due to failure, and reduced time to system restoration.

Community earthquake resilience is defined as the ability of social units (e.g., organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes. The objectives of enhancing earthquake resilience are to minimize loss of life, injuries, and other economic losses; in short, to minimize any reduction in quality of life due to earthquakes. To accomplish its mission of enhancing the seismic resiliency of communities, MCEER research focuses on improving the resilience of facilities and organizations whose functions are essential for community well-being in the aftermath of earthquake disasters. These critical facilities consist of water and power lifelines (MCEER Research Thrust Area 1), acute care facilities (MCEER Research Thrust Area 2), and organizations that are responsible for emergency management at the local community level (MCEER Research Thrust Area 3). These research activities are augmented by educational efforts and outreach programs to address the needs of their various end-user communities.

Intellectual merit: The above-stated mission provides a synergistic cross-disciplinary strategy to focus research on the problem of earthquake hazard mitigation. A research center approach and focus on advanced technologies is required to develop the integrated tools and methodologies needed for that purpose. MCEER’s investigators are recognized both as experts in their field and for their ability to effectively work in teams. Together, they are generating innovative system approaches that integrate the use of probabilistic fragility frameworks, evolutionary algorithms, and advanced technologies, and merging them with social and engineering attributes to assess the seismic resilience of critical facilities in terms of both preparedness and response/recovery. MCEER’s approach is truly unique in the field of earthquake hazard mitigation.

Broader Impacts: MCEER’s investigators, geographically distributed across the nation, are helping to advance seismic resiliency in all areas of the country exposed to seismic risk. Research outcomes are widely published, and are achieved through implementation in codes and other design documents, as well as in actual seismic retrofit projects (for lifelines and hospital buildings). Therefore, MCEER’s research results provide a direct benefit to society by creating more seismically resilient structures and infrastructures. All of the MCEER-affiliated experimental facilities have become nodes of the George E. Brown Jr. Network for Earthquake Engineering Simulation, thus positioning MCEER for continued excellent contributions in this field.

Recent Accomplishments: MCEER researchers have received broad recognition for their recent accomplishments and outstanding contributions to earthquake engineering. To advance these
research accomplishments, MCEER has worked with a variety of media outlets to enhance earthquake awareness of the public; pioneered the use of webcasting to broadcast earthquake engineering seminars to a worldwide audience; actively contributed to, and have had a major impact on, design codes; developed advanced systems analysis tools to predict the seismic resilience of power networks; investigated the relationship between technological and natural disasters (using the World Trade Center disaster and the tsunami/earthquake tragedy in South Asia as case studies); formulated and applied an evolution theory design approach to earthquake engineering; developed new materials and technologies for the seismic retrofit of pipelines, electrical transformers, buildings, and nonstructural components; and established a set of network tools to share MCEER’s emerging earthquake engineering research. These and many other accomplishments are documented in a number of MCEER “Research Progress and Accomplishments” volumes that can be downloaded from MCEER’s website at http://mceer.buffalo.edu.
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<td>(with specialty)</td>
<td>(Dept. and University)</td>
<td>Year 8</td>
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<td><strong>I. MCEER Key Personnel</strong></td>
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<tr>
<td>Michel Bruneau</td>
<td>Director</td>
<td>MCEER, SUNY at Buffalo</td>
<td>X</td>
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<tr>
<td>Andre Filiatrault</td>
<td>Deputy Director</td>
<td>MCEER, SUNY at Buffalo</td>
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<tr>
<td>Makola Abdullah</td>
<td>Diversity Program Director</td>
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<tr>
<td>Donald Goralski</td>
<td>Business Development and Strategic Partnerships</td>
<td>MCEER, SUNY at Buffalo</td>
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<tr>
<td>George Lee</td>
<td>Special Tasks Director</td>
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<td>Gerald Meyers</td>
<td>Business &amp; Contracts Manager</td>
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<td>Jane Stoyte</td>
<td>Publications Manager</td>
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<tr>
<td>S. Thevanayagam</td>
<td>Director of Education</td>
<td>MCEER, SUNY at Buffalo</td>
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<td><strong>II. Investigators from Core Institutions</strong></td>
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<tr>
<td>Amjad Aref</td>
<td>Structural Engineering</td>
<td>Civil, Structural and Environmental Engineering SUNY at Buffalo</td>
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<td>Michel Bruneau</td>
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<td>M. Constantinou</td>
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<td>Gary Dargush</td>
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<td>Rachel Davidson</td>
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<td>Mircea Grigoriu</td>
<td>Risk and Reliability Engineering</td>
<td>Civil and Environmental Engineering Cornell University</td>
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<td>George Lee</td>
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<td>Arthur Lembo, Jr.</td>
<td>Geospatial Technologies</td>
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<td>Gilberto Mosqueda</td>
<td>Structural Engineering</td>
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<td>Thomas O'Rourke</td>
<td>Geotechnical and Lifeline Engineering</td>
<td>Civil and Environmental Engineering Cornell University</td>
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List of EERC Personnel during Current and Next Reporting Period

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<tr>
<td>Andrei Reinhorn</td>
<td>Structural Engineering and Information Technology</td>
<td>Civil, Structural and Environmental Engineering SUNY at Buffalo</td>
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<tr>
<td>M. Shinozuka</td>
<td>Risk, Reliability and Lifelines Engineering</td>
<td>Civil Engineering Department University of California/Irvine</td>
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<tr>
<td>Kathleen Tierney</td>
<td>Sociology</td>
<td>Natural Hazards Research and Applications Information Center, University of Colorado/Boulder</td>
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<tr>
<td>Andrew Whittaker</td>
<td>Structural Engineering</td>
<td>Civil, Structural and Environmental Engineering SUNY at Buffalo</td>
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#### III. Researchers from other institutions affiliated with MCEER

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<tr>
<td>Makola Abdullah</td>
<td>Structural Engineering</td>
<td>Civil Engineering Florida A&amp;M University</td>
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<tr>
<td>Anil Agrawal</td>
<td>Structural Engineering</td>
<td>Civil Engineering City University of New York</td>
<td>X</td>
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<tr>
<td>Daniel Alesch</td>
<td>Public Administration/Public Policy</td>
<td>University of Wisconsin – Green Bay</td>
<td>X</td>
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<tr>
<td>Stephanie Chang</td>
<td>Civil Engineering and Regional Science</td>
<td>School of Community and Regional Planning, University of British Columbia</td>
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<tr>
<td>Tsen-Chung Cheng</td>
<td>Electrical Engineering</td>
<td>Electric Power Program University of Southern California</td>
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<tr>
<td>Ronald Eguchi</td>
<td>Civil Engineering, System Engineer, and Lifeline Engineering</td>
<td>ImageCat, Inc. Irvine, California</td>
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<tr>
<td>Maria Feng</td>
<td>Mechanical Engineering</td>
<td>Civil and Environmental Engineering University of California/Irvine</td>
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<tr>
<td>Bijan Houshmand</td>
<td>Electrical Engineering</td>
<td>Electrical Engineering University of California/Los Angeles</td>
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<tr>
<td>E. Maragakis</td>
<td>Experimental and Structural Mechanics</td>
<td>Civil Engineering Department University of Nevada/Reno</td>
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<tr>
<td>George Mylonakis</td>
<td>Geotechnical Engineer</td>
<td>Civil Engineering City University of New York</td>
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<tr>
<td>William Petak</td>
<td>Public Administration/Public Policy</td>
<td>School of Policy, Planning and Development Univ. of Southern California</td>
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<tr>
<td>Rupa Purasinghe</td>
<td>Structural Engineering</td>
<td>Civil Engineering, California State University, Los Angeles</td>
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<tr>
<td>Adam Rose</td>
<td>Economics</td>
<td>Geography Pennsylvania State University</td>
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<td>Ala Saadeghvaziri</td>
<td>Structural Engineering</td>
<td>Civil and Environmental Engineering NJ Institute of Technology</td>
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<tr>
<td>B. F. Spencer, Jr.</td>
<td>Structural Engineering</td>
<td>Civil and Environmental Engineering University of Illinois, Urbana Champaign</td>
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<tr>
<td>Detlof von Winterfeldt</td>
<td>Psychology/ Decision Science</td>
<td>School of Policy, Planning and Development, Univ. of Southern California</td>
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<td>Name</td>
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<tr>
<td>John Abruzzo*</td>
<td>Senior Associate</td>
<td>The Thornton-Tomasetti Group</td>
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<tr>
<td>Sreenivas Alampalli*</td>
<td>Director, Bridge Program and Evaluation Services Bureau</td>
<td>New York State Department of Transportation</td>
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<tr>
<td>Jefferson W. Asher</td>
<td>President</td>
<td>KPFF Consulting Engineers, Inc.</td>
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<tr>
<td>Edward Bortugno*</td>
<td>Senior Geologist</td>
<td>Governor’s Office of Emergency Services, Disaster Assistance Division</td>
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<tr>
<td>Ildefonso Burgo-Gil*</td>
<td>Director, Design Area</td>
<td>Puerto Rico Highway and Transportation Authority</td>
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<td>Terry Burley*</td>
<td>Civil Engineer</td>
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<td>Scott Campbell*</td>
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<td>David Dickson</td>
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<td>Mohammed Ettouney</td>
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<td>Andrew X. Feeney*</td>
<td>First Deputy Director</td>
<td>New York State Emergency Management Office</td>
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<td>John Gavan</td>
<td>Division Manager, Structural Div.</td>
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<td>John Gillengerten</td>
<td>Senior Structural Engineer</td>
<td>State of California, Office of Statewide Health Planning and Development</td>
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<td>Thomas H. Hale</td>
<td>Senior Structural Engineer</td>
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<td>Gary Hart</td>
<td>Principal and Division Head</td>
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<td>Paul Hough*</td>
<td>Technical Manager</td>
<td>Armstrong World Industries, Inc.</td>
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<td>Don Hubbard*</td>
<td>President</td>
<td>WorkSafe Technologies</td>
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<td>Jeremy Isenberg</td>
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<td>Anurag Jain*</td>
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<td>Thomas Jung*</td>
<td>Director</td>
<td>New York State Department of Health</td>
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<td>Annie Kammerer*</td>
<td>Senior Geotechnical Engineer</td>
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<td>Amarnath Kasalanati*</td>
<td>Director of Engineering</td>
<td>Dynamic Isolation Systems, Inc.</td>
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<td>Leon Kempner, Jr.*</td>
<td>Principal Transmission Facilities Design Engineer</td>
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<td>D. Stanton Korista*</td>
<td>Director-Structural/Civil Engineering</td>
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<td>David Lee*</td>
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<td>Peter Lee</td>
<td>Associate Partner</td>
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<td>Jay Lewis*</td>
<td>President and CEO</td>
<td>Terra Firm Earthquake Preparedness, Inc.</td>
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<td>Walterio A. Lopez*</td>
<td>Associate/Sr. Engineer</td>
<td>Rutherford &amp; Chekene, Inc.</td>
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<td>R. Jay Love*</td>
<td>Senior Principal</td>
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<td>Patrick C. Marks*</td>
<td>Product Engineer, Acoustics &amp; Vibration</td>
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<tr>
<td>Jim Massey*</td>
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<td>International Seismic Application Technology</td>
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<td>Greg Meeuwsen*</td>
<td>Staff Engineer, Acoustics &amp; Analysis Technology</td>
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<td>Jon Mochizuki*</td>
<td>Structural Engineer</td>
<td>City of Los Angeles, Department of Water and Power</td>
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<td>Anoop Mokha*</td>
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<td>Charles Pickel*</td>
<td>Manager, Gas and Water Engineering</td>
<td>Memphis Light, Gas and Water Division</td>
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<tr>
<td>Jean-Robert Pierre*</td>
<td>Paraseismic Specialist Engineer</td>
<td>Transenergie Hydro Quebec</td>
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<td>Anshel Schiff*</td>
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<td>Precision Measurement Instruments</td>
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<td>Paul Senseny*</td>
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<td>Mark Sereci*</td>
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<td>Michael Siino</td>
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<td>Andrew Thompson</td>
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<td>Christos Tokas*</td>
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<td>Thomas Zemanek*</td>
<td>Vice President, Sales and Marketing</td>
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1. SYSTEM VISION AND VALUE ADDED/BROADER IMPACTS OF CENTER


The ultimate vision of the Multidisciplinary Center for Earthquake Engineering Research (MCEER) is to help establish earthquake resilient communities.

This current vision, along with MCEER’s focus on engineered systems, are embodied in MCEER’s mission statement, which states:

“The overall goal of MCEER is to enhance the seismic resilience of communities through improved engineering and management tools for critical infrastructure systems (water supply, electric power, and hospitals) and emergency management functions. Seismic resilience (technical, organizational, social, and economic) is characterized by reduced probability of system failure, reduced consequences due to failure, and reduced time to system restoration.”

Community earthquake resilience is defined as the ability of social units (e.g., organizations, communities) to mitigate seismic hazards, contain the effects of earthquake related disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes. The objectives of enhancing earthquake resilience are to minimize loss of life, injuries, and other economic losses; in short, to minimize any reduction in quality of life due to earthquakes.

For MCEER to successfully accomplish its mission of enhancing the seismic resilience of communities, it must focus on improving the resilience of facilities and organizations whose functions are essential for community well-being in the aftermath of earthquake disasters. These critical facilities consist of water and power lifelines, acute care facilities (hospitals), and organizations that have the responsibility for emergency management at the local community level. An NSF-funded study on public performance expectations for the built environment [1] showed that residents of high-risk communities assign great importance to these particular infrastructural elements, ranking water supply systems, major hospitals, and electrical power systems as the three most important elements that they believe must remain operational in the event of a major earthquake. Survey respondents also expressed a greater willingness to contribute financially to the seismic upgrading of hospitals and other public safety buildings, utility and transportation lifelines, than they would for other types of infrastructures.

The research challenge for MCEER is to develop the advanced knowledge and technologies needed to achieve integrated engineering tools, decision support systems, and related techniques and procedures that can provide cost-effective quantitative enhancements of the seismic resilience of these highly critical infrastructures. Without such knowledge, interventions remain individual accomplishments on a case-by-case basis whose impact on enhancing seismic resilience may be tangible but difficult to accurately and reliably quantify. Decisions with respect
to alternative allocation of resources will also remain subjective and disconnected from one another, lacking a unified quantitative basis.

The availability of such advanced knowledge and integrated resilience-enhancing tools and technologies will make it possible to overcome these limitations, resulting not only in the capacity to make more rationally-based investments and allocations of finite resources, but also in the quantification of expected outcomes in forms that can be communicated to the public and policy makers. Benefits to society can be substantial, both in terms of enhanced seismic safety and effective utilization of limited resources. With the new knowledge derived from MCEER’s research, engineering practice will be greatly transformed, because the newly generated knowledge will make it possible for engineers to better anticipate and adjust the outcomes of their designs and to work with their clients to review credible scenarios and apply appropriate loss-reduction measures. MCEER’s research will also make it possible for emergency management agencies to develop more reliable post-earthquake scenarios and to optimize their response and recovery activities through the use of advanced technologies and decision support systems, thus enhancing resilience by improving post-disaster response and accelerating the time to recovery after a major disaster.

Research on electrical power and water delivery systems (the focus of MCEER Thrust Area 1), together with transportation systems (which are addressed in MCEER’s Federal Highway Administration research component), focuses on problems germane to the infrastructural backbone of all communities. Research on acute care facilities (addressed by MCEER Thrust Area 2) addresses issues related to highly complex physical and organizational structures that must provide essential services following earthquakes. If cost-effective solutions are found to achieve the higher levels of resilience required in these types of facilities, many of those solutions will also be applicable to a wide range of other infrastructures. Furthermore, recognizing that in spite of efforts to strengthen existing structures and better design for new ones, the built environment of many communities will remain highly seismically vulnerable and unretrofitted, and that heavy losses and extensive social dislocation can be expected when the next major earthquake strikes. MCEER’s research also concentrates on bringing about improvements in community disaster response and recovery capacity (the focus of MCEER Thrust Area 3).

A2. Expanded Systems Vision for Multi-Hazard Research

In year 8, MCEER management has initiated a strategic planning process leading towards its successful post-year 10 “graduation” from the EERC program. This process centered on the development of an MCEER Business Plan based on the strength of various input collected through a series of retreats and meetings to strategically discuss MCEER’s future based on its existing strengths and potential new developments.

This process has led to the establishment of an expanded ultimate vision for MCEER, focused on the development of engineering systems to help establish resilient infrastructure for communities that are faced with potential extreme events from natural and man-made multi-hazards.

This expanded vision, along with MCEER’s continued focus on engineered systems, are embodied in MCEER’s post-graduation mission statement, which states:
“The overall mission of MCEER is to be a leading multidisciplinary research center that focuses on the development of innovative and integrated solutions to enhance the resilience of infrastructure against extreme events (natural disasters, technological disasters, and acts of terrorism against our society), and is known worldwide for its ability to deliver superior products on time and budget to its sponsors.”

To successfully execute this expanded mission, MCEER investigators will be consolidating their expertise and track records on multi-hazard research starting in year 9 of the current NSF-EERC. This will be achieved by dedicating a portion of the Center’s research budget into research tasks that mutually benefit the current and future system vision of MCEER. The structural changes required to execute this plan are described in Section 5, while the individual proposed year 9 research tasks that address some aspects of multi-hazard extreme events are described in Section 2 of this annual report.

B. Value Added and Broader Impacts

Selected Accomplishments in the Last Year

PEOPLE – ENGAGING A DIVERSE AND INTERNATIONALLY COMPETITIVE WORKFORCE OF ENGINEERS, SOCIAL SCIENTISTS AND WELL PREPARED CITIZENS

ENGAGING AWARD-WINNING RESEARCHERS: MCEER Investigator Honored by the American Society of Civil Engineers Delivers Keynote Address at the 13th World Conference on Earthquake Engineering

MCEER investigators developing integrated decision support tools for lifeline systems are continuing to be recognized as leaders in the field of earthquake hazard mitigation. Professor Tom D. O’Rourke from Cornell University, who received the prestigious Ralph B. Peck Award from the American Society of Civil Engineers in 2005, delivered a keynote address at the 13th World Conference for Earthquake Engineering (13WCEE) held in Vancouver, Canada. The Ralph B. Peck Award was presented to Professor O’Rourke for his outstanding contributions to the geotechnical engineering profession. The keynote address by Professor O’Rourke at the 13WCEE entitled “Advances in Lifeline Earthquake Engineering” was based largely on the work that he conducted as the leader of Thrust Area 1 on lifeline systems at MCEER.


At the invitation of Janet Benini, Director of Response and Planning at the White House, MCEER investigator Dr. Beverley Adams traveled to Washington D.C. this past September to present post-disaster damage detection research and a field data collection system to the Homeland Security Council. The distinguished audience, which included White House staffers and senior professionals from Federal agencies such as NASA, DHS, DOE and USACE, heard about the recent use of very high-resolution Quickbird satellite imagery in the aftermath of Hurricanes Charley and Ivan and the Bam, Iran, earthquake. Dr Adams went on to describe the accompanying deployment of the VIEWS system for in-field
ENGAGING INTERNATIONAL COLLABORATORS: MCEER Joins Multi-lateral Reconnaissance Team to Investigate the Effects of the Tsunami/Earthquake Tragedy in South Asia

MCEER joined a multi-lateral Thailand-Japanese reconnaissance team to investigate the effects of the tsunami/earthquake in Thailand, ranked as one of the most catastrophic events in recent times. The reconnaissance team was led by Professor Fumio Yamazaki of Chiba University in Chiba, Japan and Dr. Pennung Warnitchai of the Asian Institute of Technology in Bangkok, Thailand. Shubharoop Ghosh of ImageCat, Inc. represented MCEER on the reconnaissance team. Other researchers in the team included Dr. Masahiko Honzawa of Japan International Cooperation Agency (JICA), and Dr. Masashi Matsuoka of Earthquake Disaster Mitigation Research Center (EDM), Kobe, Japan. The objective of this field deployment was to collect perishable information about building and lifeline damage characteristics. The field-based damage assessment was conducted using the VIEWS (Visualizing the Impacts of Earthquakes With Satellites) notebook-based system developed by ImageCat under the auspices of MCEER. These ground-based observations can be later used to validate damage characteristics identified on satellite imagery. It is envisioned that such perishable data will be invaluable for future research in evaluating damage from tsunami hazards. To learn more about this topic, visit the MCEER website at http://mceer.buffalo.edu/research/tsunami/page1.asp.

ENGAGING PRACTITIONERS: MCEER Establishes Electrical Utility Consortium

Responding to the need of electrical utilities, MCEER established a new industry-funded research program focusing specifically on the seismic behavior of electrical substations. These include shake table testing of large and seismically vulnerable substation equipment such as transformer bushings and disconnect switches. This new MCEER-Electrical Utility Consortium (EUC) was established through collaboration with and funding from the Electrical Power Research Institute (EPRI), which regroups electrical utilities in North America (US, Canada and Mexico) and is investigating unresolved issues related to the IEEE-693 Standard on Recommended Practice for Seismic Design of Substations. The research work is conducted by MCEER investigators Andrei Reinhorn and Andre Filiatrault at the University at Buffalo under the guidance of a technical oversight committee that sets overall strategy, goals and work schedule for the EUC research program. The committee is composed of one representative from each participating electrical utility. It is chaired by Dr. Anshel J. Schiff from Precision Measurement Instruments, who is well known for his expertise on the seismic qualification of electrical substation equipment.

ENGAGING LEADERS: MCEER Hosts Visions of Leaders Forum

As part of the activities celebrating the Grand Opening of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) facility at the University at Buffalo (UB), MCEER hosted a morning forum featuring presentations from leaders representing various federal and state agencies. Following introductions by Michel Bruneau, MCEER Director, Mark Karwan, Dean, UB School of Engineering and Applied Sciences, and Michael Constantinou, Chair, UB Department of Civil, Structural and Environmental Engineering, the distinguished speakers were: A. Galip Ulsoy, Division Director, Civil and Mechanical Systems, National Science Foundation, M. Myint Lwin, Director, Office of Bridge Technology, Federal Highway Administration, Michael Mahoney, Mitigation Division, Building Science and Technology Section, Federal Emergency Management Agency, Rick
Land, Director, Engineering Services, Structure Design, California Department of Transportation, Sreenivas Alampalli, Director, Bridge Program and Evaluation Services Bureau, New York State Department of Transportation, Kurt Schaefer, Deputy Director, Facilities Development Division, California Office of Statewide Health Planning and Development, John Filson, Scientist Emeritus, United States Geological Survey and Robert Hall, Geotechnical and Structures Laboratory, U.S. Army Engineer Research and Development Center, United States Army Corps of Engineers. The purpose of the forum was for these leaders to share their visions for earthquake engineering research – structural and geotechnical – for the next decade. Formal presentations were followed by a one-hour session during which audience participants were given the opportunity to voice their research visions. This session was moderated by Chris Poland, Chairman, CEO and President of Degenkolb Engineers, from the practicing community. To learn more, visit the MCEER website at http://mceer.buffalo.edu/research/nees/grandopen/default.asp.

IDEAS – ENABLING DISCOVERY ACROSS THE FRONTIER OF SCIENCE AND ENGINEERING, CONNECTED TO LEARNING, INNOVATION, AND SERVICE TO SOCIETY

EARTHQUAKE ENGINEERING EDUCATION FOR UNDERGRADUATE STUDENTS: MCEER Hosts First Undergraduate Seismic Design Competition

With the objective of providing civil engineering undergraduate students an opportunity to do a hands on project and gain practical experience by designing and building a cost effective frame structure, which will withstand severe earthquake motions, MCEER hosted its first Undergraduate Seismic Design Competition. Five teams of undergraduate students participated in the competition held in the Structural Engineering and Earthquake Simulation Laboratory at the University at Buffalo. Undergraduate students from Florida A&M, University of Nevada-Reno, University at Buffalo, New Jersey Institute of Technology and City College of New York saw how well their structures made of balsa wood performed when subjected to large earthquakes. Each structure was scored on its seismic performance, economics, construction cost, workmanship and architecture. The winning team from Florida A&M University will go on to compete in a Tri-Center competition later this year. To learn more about this topic, visit the MCEER website at http://mceer.buffalo.edu/education/slc/SeismicDesComp/default.asp.

EARTHQUAKE ENGINEERING EDUCATION FOR K-12 STUDENTS: MCEER Hosts “2005 UB-MCEER Quake and Shake”

MCEER reached out to K-12 students with the objective to promote career opportunities in science and engineering and to foster higher education as a path to these opportunities. Twenty-four third-graders from Sheridan Hill Elementary School in Clarence, New York participated in the 2005 UB-MCEER Quake & Shake. At the event, the students built popsicle-stick structures according to earthquake design principles and then tested them on the shake table in Ketter Hall at the University at Buffalo. A few weeks before the event, MCEER deputy director Andre Filiatrault made a presentation to the class on earthquake design and provided pointers on how to build the structures, which were required to support a masonry brick at a height of 12” above a wood base. Each team built a structure using 150 popsicle sticks, a bottle of Elmer's glue and a roll of dental floss that was then subjected to ground motions from historical earthquakes. After the famous “UB Rumble,” all structures were declared “earthquake proof,” and each student received a certificate naming him or her an "honorary structural engineer." The event was covered by local media, including CBS Channel 4's "Why Guy" Kevin O'Neill. To learn more about this topic, visit the MCEER education website at http://mceer.buffalo.edu/education/k-12/05QuakeandShake/default.asp.
TECHNOLOGY TRANSFER: MCEER Delivers One-Day Hospital Seminar to California OSHPD Engineers

As part of the activities leading to the 2005 MCEER Annual Meeting in the Sacramento area at the invitation of the California Office of Statewide Health Planning and Development (OSHPD), a vital partner in MCEER’s hospital research thrust, MCEER investigators delivered a one-day hospital seminar to 50 engineers from OSHPD. The one-day seminar entitled Hospital Research and Retrofit Seminar provided a unique opportunity to MCEER investigators conducting research in the hospital research thrust to transfer new knowledge on socio-economic and public policies issues, transfer new technologies on structural and nonstructural engineering that have reached the implementation phase and that hold promise for the future. The OSHPD seminar is the first of several major activities planned for years 8 to 10 of the current NSF-EERC program aimed at transferring the technology and know-how developed at MCEER in the past 10 years.

NEW ENGINEERING DESIGN APPROACHES: Innovative Seismic Base Isolation System under Study

A novel Double-Concave Friction Pendulum (DC-FP) isolation system that can be particularly efficient in reducing the seismic forces experienced by nonstructural components and expensive equipment inside acute care facilities is being investigated at MCEER. Novel features of the DC-FP system are compact size, very large displacement capacity and capability to adjust its behavior for achieving specific objectives such re-centering in weak earthquakes and minimization of impact on secondary systems and equipment. Preliminary shake table testing on a six-story model structure incorporating various designs of the DC-FP have demonstrated its capabilities. These types of experimental investigations conducted at MCEER are instrumental in assessing and demonstrating new seismic protective technologies such as base isolation systems. These large-scale tests often constitute the last step to implementation. To learn more about this topic, visit the UB-NEES website at http://nees.buffalo.edu/docs/dec304/FP-DC%20Report-DEMO.pdf.

TOOLS – BROADLY ACCESSIBLE, STATE OF THE ART AND SHARED RESEARCH AND EDUCATION TOOLS

TOOLS FOR SEISMIC DESIGN AND RETROFIT: Evolutionary Aseismic Design and Retrofit Software near Completion

An innovative framework for Evolutionary Aseismic Design and Retrofit (EADR) developed at MCEER is near completion. The EADR framework was successfully applied to a series of multistory steel moment-resisting frame retrofit examples, incorporating several advanced seismic protective technologies including metallic, viscous and viscoelastic dampers. The initial version of the software was developed for a single processor by utilizing a genetic algorithm for discrete optimization under uncertain seismic environments. Within this approach, each structural evaluation is performed via a nonlinear transient dynamic analysis utilizing continuum level models of various advanced protective technology. Recently, efforts were directed toward enhancing the functionality, robustness and efficiency of this evolutionary approach. For example, a more realistic seismic environment was incorporated that is compatible with the seismic hazard model developed by the United States Geological Survey (USGS). Work on EADR during the last year has focused on improving computational efficiency in order to make this approach a viable option for the engineering community. This has been accomplished by
introducing new multi-level techniques and by migrating the framework to a desktop PC environment. There is now significant interest from several engineering firms to utilize the EADR software. Beta-versions are now being released for initial collaborative work with MCEER industry partners.

TOOLS FOR ASSESSING SEISMIC PERFORMANCE OF NONSTRUCTURAL COMPONENTS: National Seismic Testing Facility for Nonstructural Components to be Commissioned

Through a creative and original highly modular and versatile framework and substantial leveraging achieved by enhancing/upgrading the existing equipment available at the University at Buffalo NEES Facility (UB-NEES), MCEER investigators are designing a National Testing Facility for Nonstructural Components that will allow integrated experimental and analytical research to investigate the seismic performance of nonstructural components. The Nonstructural Components Simulator (NCS) consists of actuators and special modular testing platforms that make it possible to answer the challenges of dynamically replicating the large displacements, velocities, and accelerations to which equipment and nonstructural components are typically subjected during earthquakes, as well as the interactions of this equipment with the structural systems (and other equipments). This new facility will empower MCEER investigators and practitioners, particularly those involved in MCEER’s hospital research thrust, to think at the systems level and to understand, quantify and control the seismic response of nonstructural components as part of the total building system.

TOOLS FOR TRI-CENTER COLLABORATION: MCEER Software for Seismic Risk Analysis of Highway Systems

For the past several years, MCEER has been developing, under the sponsorship of the Federal Highway Administration (FHWA), a new methodology for deterministic and probabilistic seismic risk analysis of highway systems nationwide. MCEER has recently implemented this new methodology into a public-domain software package named REDARS (Risks from Earthquake Damage to Roadway Systems). This software has since become an important tool in enabling research collaboration between the three Earthquake Engineering Research Centers (EERCs). For example, the California Department of Transportation (Caltrans) has initiated a trial study to apply REDARS to a region of the Bay Area Highway Network. While Caltrans funding for this project is from outside the three EERCs, the Pacific Earthquake Engineering Research (PEER) Center and MCEER-FHWA are providing input to the project. MCEER-FHWA is providing technical support for a more user-friendly demonstration version of REDARS. PEER is sharing data-sets developed previously in its own Highway Demonstration Project of the Bay Area and is interested in cooperating on the implementation of enhanced bridge performance models and hazard modules in REDARS. Also, the Mid-America Earthquake (MAE) Center is exploring whether REDARS could potentially be used for a small region (e.g., Memphis) to serve as a validation/calibration to the more global loss modeling work by MAE researchers. Facilities and modules in REDARS that are amenable to implementation within the MAE Center Visualization module MAEVIZ are also being considered as part of this tri-center collaboration.

Quantifiable Outputs and Benchmarking

Additional information is provided in Database Table 1: “Quantifiable Outputs,” and Table 1A: “Benchmarking the ERC.”

MCEER has published “Research Progress and Accomplishments” reports that provide more details about specific accomplishments in a number of MCEER activities. They are available on

- [http://mceer.buffalo.edu/publications/resaccom/0304/default.asp](http://mceer.buffalo.edu/publications/resaccom/0304/default.asp)
- [http://mceer.buffalo.edu/publications/resaccom/0103/default.asp](http://mceer.buffalo.edu/publications/resaccom/0103/default.asp)
- [http://mceer.buffalo.edu/publications/resaccom/0001/default.asp](http://mceer.buffalo.edu/publications/resaccom/0001/default.asp)
- [http://mceer.buffalo.edu/publications/resaccom/9900/default.asp](http://mceer.buffalo.edu/publications/resaccom/9900/default.asp)
- [http://mceer.buffalo.edu/publications/resaccom/9799/default.asp](http://mceer.buffalo.edu/publications/resaccom/9799/default.asp)

In a complementary and coordinated manner, MCEER’s Student Leadership Council has also prepared similar volumes of “Student Research Accomplishments” for years 2003-2004, 2002-2003, 2001-2002, and 2000-2001 to further highlight research in progress and is in the process of preparing a similar document for 2004-2005. Past volumes can be downloaded from:

- [http://mceer.buffalo.edu/publications/resaccom/04-sp06/default.asp](http://mceer.buffalo.edu/publications/resaccom/04-sp06/default.asp)
- [http://mceer.buffalo.edu/publications/sp_pubs/03-SP06/default.asp](http://mceer.buffalo.edu/publications/sp_pubs/03-SP06/default.asp)
- [http://mceer.buffalo.edu/publications/sp_pubs/02-SP09/default.asp](http://mceer.buffalo.edu/publications/sp_pubs/02-SP09/default.asp)
- [http://mceer.buffalo.edu/publications/sp_pubs/01-SP02/default.asp](http://mceer.buffalo.edu/publications/sp_pubs/01-SP02/default.asp)

MCEER has also achieved a considerable reputation for its research on the seismic evaluation, retrofit, and design of bridges and highway structures. The MCEER Highway Project is sponsored through contracts with the Federal Highway Administration, the Transportation Research Board of the National Academy of Sciences, the State of New York, and other agencies. A separate MCEER Research Committee oversees this bridge research, and it has its own Research Agenda and Advisory Committees. However, much of this work builds on, and provides enhancements to, related efforts supported under NSF sponsorship. The work conducted under the Highway Project is significantly enhanced by the organization and structure of the NSF-sponsored component of MCEER, and provides for multidirectional leveraging of institutional resources between various sponsors and agencies. The Highway Project has also significantly benefited from the readily available expertise that MCEER can access across multiple engineering and social science disciplines, to deliver research outcomes and products that are implemented. One such example of a major Highway Project product that has benefited from the multidisciplinary character of MCEER is a two-volume set of manuals that has been developed for evaluating and retrofitting lifeline highway transportation systems, which will be promoted and distributed to all States’ Departments of Transportation by the Federal Highway Administration.
2. STRATEGIC RESEARCH PLAN AND RESEARCH PROGRAM

A. Strategic Research Plan

The overall objective of MCEER is to enhance the seismic resilience of communities through improved engineering and management tools for critical infrastructure systems (water supply, electric power, and hospitals) and emergency management functions. MCEER has demonstrated through its research program that advanced technologies provide the basis on which these tools can be developed.

Achievement of this objective requires quantifiable measures for each of the dimensions of seismic resilience: technical, organizational, social, and economic. Seismic resilience can be characterized by reduced probability of system failure, reduced consequences due to failure, and reduced time to system restoration. The enhancement of seismic resilience also requires a strategic research plan using the advanced technologies deemed most appropriate based on a systems evaluation of needs and benefits.

The strategic research plan of MCEER is built on a number of important concepts described in the following sections. These concepts are embodied in a three-plane system approach model, the definition of Center-wide measures of resilience and of the dimensions of resilience, the quantification of system performance criteria, and a Center-wide systems diagram.

MCEER Center-Wide Three-Plane Systems Model

Figure 1 illustrates a three-plane systems model that defines MCEER’s Center-wide approach for achieving its goals in the areas of research, education, and industry partnerships. As indicated at the top of this three-plane chart, MCEER’s research is driven by societal and industry needs with respect to loss-reduction solutions. As indicated in the three-plane model, the objectives of MCEER’s activities are to carry out basic and applied research, develop a suite of technologies and tools designed to enhance seismic resilience, and apply and test those technologies and tools to testbed organizations and systems, with the ultimate aim of producing resilience-enhancing research and educational products that meet societal and industry needs.

The coordinated activities that need to be undertaken in order to accomplish these goals and objectives consist of the following:

Systems Architecture and Technology Integration: The systems integration plane focuses on validation studies of technologies, tools, and strategies that have been shown empirically to contribute to higher levels of resilience for critical systems and facilities. Through work centering on real-world and/or simulated demonstration projects (hospitals, water and power
systems, emergency response organizations) multidisciplinary teams assess the extent to which MCEER-generated research products result in quantifiable improvements in resilience. Such resilience enhancements include (but are not limited to) improved system performance for lifelines and hospitals, as assessed through reliability and fragility analyses; improved emergency response and restoration times for critical system functions; demonstrated ability to reduce direct and indirect economic losses through technology applications; and demonstrated ability to reduce social disruption through the application of resilience-enhancing measures by emergency response organizations. MCEER’s approach to defining, quantifying, and measuring resilience, which forms the basis for systems integration, is outlined in the next section of this report. Other outputs produced at the integrated systems level include products aimed at enhancing the quality of engineering and earthquake loss-reduction education, including wider availability of networked databases, experimental facilities, and testbeds.

**Figure 1: MCEER Center-Wide Three-Plane Chart and Systems Approach.**

*Enabling Technologies:* The objectives of the activities undertaken in this plane are to develop, test, and refine technologies and tools that make it possible to assess key dimensions of resilience for critical systems. The end-products of the activities undertaken at this plane are a set of decision support tools and analytic results that constitute candidate resilience-enhancing technologies, as well as educational courses and modules that disseminate these research findings. The enabling technologies identified at this level are further integrated, tested, and
validated at the systems integration level. Included in this plane are both engineering approaches that offer the promise of enhancing structural and system robustness and decision support tools that have the potential for enhancing resilience through improving organizational decision-making. These enabling technologies, decision aids, and methodologies include pre-earthquake loss assessment and mitigation measures (e.g., state-of-the-art loss estimation methodologies, advanced energy dissipation systems and seismic response modification technologies, measures for strengthening key system components, and other approaches for mitigating damage to engineered systems); technologies aimed at enhancing resilience through improving emergency response and early recovery capability (e.g., remote sensing for damage detection, crisis decision support systems, decision tools that make it possible to prioritize system restoration); and decision tools that provide rationales for choosing among alternative resilience-enhancing strategies and that can be used to increase the likelihood that such measures will be adopted by users (e.g., cost-benefit analysis, multi-attribute utility analysis, stakeholder analysis). As research proceeds, each approach is tested and enhanced as new data become available.

Fundamental Research: Research activities at this level consist of studies that seek to identify and incorporate the best-available data on seismic hazards; assess technologies for their potential applicability to earthquake loss reduction and resilience enhancement for critical facilities; develop a basic understanding of various dimensions of resilience, including technical, organizational, social, and economic aspects of resilience; and carry out the kinds of studies that are needed in order to systematically investigate, validate, and implement the next generation of loss-reduction tools. It is at this stage that researchers begin developing the basic knowledge and the “technology toolbox” that will become the focus for systematic and integrated studies on the second and third planes.

Center-Wide Measures of Resilience

Community earthquake resilience is defined as the ability of social units (e.g., organizations, communities) to mitigate seismic hazards, contain the effects of earthquake related disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes. The objectives of enhancing earthquake resilience are to minimize loss of life, injuries, and other economic losses; in short, to minimize any reduction in quality of life due to earthquakes. Earthquake resilience is achieved by enhancing the ability of a community’s infrastructure (e.g., lifelines, structures) to perform during and after an earthquake.

Therefore, for MCEER to accomplish its mission of enhancing the seismic resilience of communities, it must focus on improving the resilience of facilities and organizations whose functions are essential for community well-being in the aftermath of earthquake disasters. These critical facilities consist of water and power lifelines, acute care facilities, and organizations that have the responsibility for emergency management at the local community level.

Improving the resilience of these lifelines is critical for overall community resilience. For example, since no community can cope adequately with an earthquake disaster without being able to provide emergency care for injured victims, hospital functionality is crucial for community resilience. Water supply is another essential lifeline service that must be provided to sustain disaster victims. MCEER’s research thus focuses on services and functional activities
that constitute the backbone of a resilient community. The continued operation and rapid restoration of these services are a necessary condition for overall community resilience.

Resilience can be understood as the ability of the system to absorb the effects of a sudden disturbance (abrupt reduction of performance) and to recover quickly after the disturbance (re-establish normal performance). More specifically, a resilient system is one that shows:

- Reduced failure probabilities and reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences,
- Reduced time to recovery (restoration of the system to its “normal” level of performance)

A Center-wide measure of resilience that captures these key features can be expressed, in general terms, by the concepts illustrated in Fig. 2.

![Quality of Infrastructure](image)

**Figure 2: Measure of Seismic Resilience – Conceptual Definition.**

This approach is based on the notion that a time-varying measure $Q(t)$ of the quality of the infrastructure of a community has been defined in terms of organizational dimensions. Specifically, infrastructure quality can range from 0% to 100%, where 100% means no degradation in service and 0% means no service is available. If an earthquake occurs at time $t_0$, it could cause sufficient damage to the infrastructure such that the quality is immediately reduced following the occurrence of this disturbance (for example from 100% to 50%, as shown in Fig. 2). Restoration of the infrastructure is expected to occur over time, as indicated in that same figure, until time $t_1$ when it is completely repaired (indicated by a return to 100% of infrastructure quality).

Hence, community earthquake loss of resilience, $LR$, with respect to a specific earthquake, can be measured by the size of the expected degradation in quality (probability of failure), over time (that is, time to recovery). Mathematically, it is defined by:

$$LR = \int_{t_0}^{t_1} [100 - Q(t)] \, dt$$

Obviously, community earthquake resilience must be measured in light of the full set of potential earthquakes that threaten a community, and therefore must include joint probabilities of occurrences of various earthquakes. This complexity, and others taken into account in the course of MCEER’s research, do not change the basic concept presented here. This framework forms the foundation for the Center-wide measure of resilience that has been adopted to guide MCEER’s research from year 5 until year 10 of its research agenda. Further details on MCEER’s resilience framework can be found in a recent refereed publication [2].
Dimensions of Resilience

Seismic resilience is defined as the ability of both physical and social systems to withstand earthquake-generated forces and demands and to cope with earthquake impacts through situation assessment, rapid response, and effective recovery strategies (measured in terms of reduced failure probabilities, reduced consequences, and reduced time to recovery). Resilience for both physical and social systems can be further defined as consisting of 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;
- **Rapidity**: the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption.

As such, the vertical and horizontal axes in Fig. 2 address the ends of resilience, namely robustness and rapidity. However, Fig. 2 can be expanded to capture the means of resilience, namely resourcefulness and redundancy. This is illustrated in Fig. 3 where a third axis added for each plot to the type shown in Fig. 2 illustrates that added resources can be used to reduce recovery time beyond what is expected by the benchmark “normal” condition illustrated by Fig. 2. In theory, if infinite resources were available, time to recovery would asymptotically approach zero. Practically, even in the presence of enormous financial and labor capabilities, human limitations will dictate a practical minimum time to recovery. This was demonstrated, for example, by the replacement of the Santa Monica freeway bridges following the 1994 Northridge earthquake in the Los Angeles region. The replacement of this critical infrastructure for the transportation network of the region was accomplished 2.5 months faster than originally projected, at a reported bonus cost of over $14,000,000 paid to the contractor for early completion. Likewise, in a less technologically advanced society where resources are scarce, time to recovery lengthens, approaching infinity in absence of any resources.

Figure 3 also illustrates redundancy by grouping multiple plots of the type shown in Fig. 2. For example, while each individual resilience space in Fig. 3 could represent resilience of a single hospital, the collection of those represents the resilience of all acute care facilities over a geographical area (whether or not these would be owned by a single health care provider just depends on which problem one wishes to model). As such, the seismic resilience of a system of health care facilities could be assessed using that integrated framework, allowing one to investigate the impact of resource allocation policies with various emphases on robustness, rapidity, resourcefulness, and redundancy. One should note, however, that highway networks provide linkages between hospitals and that the seismic resilience of highway systems also would play a role on the global resilience of this distributed inventory of hospitals.
Resilience can be further conceptualized 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 aim at developing, testing, and refining quantitative measures of resilience, as will be described in each MCEER Research Thrust Area.

Figure 3: Impact of Resources and Redundancy on the Resilience Concept.
Figure 4 relates the four dimensions of resilience to MCEER’s research program and its focus on electric power network, water supply, hospital, and local emergency management systems. These systems are to some extent interdependent (e.g., electric power is needed for water delivery, water is needed by hospitals). As noted earlier, improving the performance of these systems is critical for improving overall community resilience to disasters. For each of these critical systems, technical and organizational performance measures refer to the ability of the physical system and the organization that manages it to withstand earthquake forces and recover quickly from earthquake impacts. The performance of these systems critically affects the seismic resilience for the community as a whole. At the community level, social and economic performance measures refer to the ability of the community to withstand and recover quickly from the disaster.

Note that community resilience can be quantified and measured in various ways, and much of MCEER’s research focuses on identifying and quantifying performance measures for resilient systems and in assessing the extent to which various technologies and tools result in improvements in performance. MCEER validates the quantification of these different measures by engaging in demonstration projects and Center-wide systems research.

For illustrative purposes, Table 1 lists some of the tools, measures, and technologies MCEER is either in the process of, or considering developing and validating. In all cases, these tools and measures are tied to dimensions of resilience and to performance measures for resilient systems. Again, for purposes of illustration, the table divides research products and activities according to their contribution to the MCEER systems-wide three-plane model and according to the technical, organizational, social, and economic dimensions of resilience. However, it is important to recognize that many tasks straddle multiple dimensions or levels on the three-plane model, and it is not MCEER’s objective to compartmentalize research activities, but rather to integrate them.
Table 1: MCEER Research Activities and Products, Classified by Resilience Dimensions and Planes on the Three-Level Chart.

<table>
<thead>
<tr>
<th>Resilience Dimension</th>
<th>Fundamental Research</th>
<th>Enabling Technologies</th>
<th>Systems Architecture and Technology Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>Seismic Hazard Characterization&lt;br&gt;Fundamental Research on Component, Structural, Nonstructural, and System Fragility&lt;br&gt;Fundamental &amp; Proof of concept Studies on Advanced Technologies</td>
<td>Evaluation and Validation of Advanced Technologies (such as response modification technologies, remote sensing, advanced materials, etc.)&lt;br&gt;Retrofit Strategies (e.g., for lifeline or hospital systems)&lt;br&gt;Modeling and Simulation: Component and System Performance</td>
<td>Systems-Integrated Loss-Reduction Strategies for Structures and Systems, Including: Improved Design Guidelines&lt;br&gt;Improved Educational Modules and Training Tools&lt;br&gt;Integrated Socio-Technical Approaches to Enhancing Resilience Using Advanced Technologies&lt;br&gt;Quantitative Assessments of Improvements in Resilience for Components, Structures, Nonstructural Elements, and Systems</td>
</tr>
<tr>
<td>Organizational</td>
<td>Fundamental Studies on Organizational Resilience&lt;br&gt;Analyses of Stakeholder Loss-Reduction Preferences</td>
<td>GIS Visualization of Lifeline Damage Patterns&lt;br&gt;Improvements in SCADA Technologies&lt;br&gt;Decision Support Tools for Facilities, Organizations, and Systems</td>
<td>Integrated Decision Support Tools for Organizations (lifelines, hospitals, emergency response organizations)&lt;br&gt;Quantitative Assessments of Improvements in Organizational Resilience</td>
</tr>
<tr>
<td>Social</td>
<td>Community Vulnerability and Resilience Analyses</td>
<td>Social Impact Modeling</td>
<td>Integrated Decision Support Tools for Communities (e.g., comprehensive community restoration and recovery modeling)&lt;br&gt;Quantitative Assessments of Improvements in Community Resilience</td>
</tr>
<tr>
<td>Economic</td>
<td>Economic Vulnerability and Resilience Analyses</td>
<td>Direct and Indirect Economic Loss Modeling&lt;br&gt;Cost-Benefit Analysis for Structural and Nonstructural Mitigation Measures</td>
<td>Quantitative Assessments of Improvements in Economic Resilience</td>
</tr>
</tbody>
</table>

Quantification of System Performance Criteria – Measures of Resilience

In principle, the strategy for measuring community resilience is to quantify the difference between the ability of a community’s infrastructure to perform community services prior to the occurrence of an earthquake and the expected ability of that same infrastructure to perform after an earthquake. Some of the factors that must be addressed by such a measure include:
The quality of the community infrastructure prior to any earthquakes;

The expected reduction in quality of the infrastructure over time due to the occurrence of any earthquake;

The expected length of time that the infrastructure quality is below the pre-earthquake level; and

The set of all possible earthquakes that threaten a community and their joint probabilities of occurrence.

Examples of system-wide measures of performance of the various critical systems studied by MCEER (electrical power and water lifelines, hospitals, and community emergency response systems) are presented in Appendix I. These measures are defined in terms of the four R’s (robustness, redundancy, resourcefulness, and rapidity) and TOSE dimensions (technical, organizational, social, and economic). A distinction is also made in the matrices between “ends” and “means” dimensions of resilience. For example, robustness and rapidity are essentially the desired “ends” that are accomplished through resilience-enhancing measures and are the outcomes that more deeply affect decision makers and stakeholders. Redundancy and resourcefulness are measures that define the “means” by which resilience can be improved. For example, both robustness and the rapidity with which a system returns to pre-earthquake levels of functionality can be enhanced by adding redundant elements to the system. All elements of resilience are important, but robustness and rapidity are seen as being key in measuring system and community resilience, particularly in terms of the resilience measures expressed by Fig. 2.

Conceptually, system performance criteria (defined by technical and organizational measures) are defined in terms of desired community performance outcomes (reflected by social and economic measures). Therefore, key research foci for MCEER are to refine the social and economic measures of community resilience and to translate these measures into system performance criteria (technical and organizational).

Two caveats must be kept in mind with respect to Appendix I. First, it must be noted that the matrices are provided for illustrative purposes only. Second, future work will favor research on those resilience factors that represent the “end product” of resilience (robustness and rapidity) versus those that help to enhance resilience (redundancy and resourcefulness).

**System Diagram**

The system diagram in Fig. 5 identifies the key steps required to quantify infrastructure systems and community resilience. This system diagram describes how the performance criteria specified earlier is used to determine the extent to which systems are resilient. In addition, the diagram shows how advanced technologies and decision support systems are incorporated to improve the resilience of an infrastructure system.
This process is implemented in a series of analytical steps, briefly summarized here. This framework addresses how the multitude of resilience measures illustrated in the matrices presented in Appendix I are integrated into a consistent and defensible method of quantitatively evaluating resilience and resilience improvement, at both the infrastructure system and community levels.

The analytical framework focuses on the two desired “ends” of resilience – robustness and rapidity – and assumes that quantitative measures can be developed, as suggested in Appendix I.

For an infrastructure system, technical and organizational resilience is measured as the annual probability that the system can satisfy the robustness and rapidity criteria with respect to earthquake risk. This probability can be evaluated, for example, by examining the performance...
of an infrastructure system in a series of scenario earthquakes. The expected reduction in performance (e.g., rolling blackouts for an electric power network system, or reduction in patient/day capacity for a hospital) and expected time to recovery can then be evaluated for each of the earthquake scenarios. Identifying those scenarios that meet technical and organization resilience criteria, and aggregating the scenario probabilities of occurrence, yields an estimate of annual probability, indicating overall resilience reliability. At the community level, social and economic resilience is evaluated analogously. For example, advanced loss estimation models are applied to estimate the economic consequences of damage and disruption sustained by the electric power, water supply, hospital, and emergency response and recovery systems. The initial loss of gross regional product (GRP) following an earthquake is an indicator of economic robustness, for example, and the time for GRP to recover to pre-earthquake levels of economic activity is a measure of the rapidity dimension of economic resilience. Measures of social resilience are evaluated similarly. The number of scenarios in which robustness and rapidity criteria are met, along with their associated probabilities of occurrence, then indicates the annual probability that resilience criteria are satisfied at the community level.

Both at the infrastructure systems and community levels, the annual probability of achieving a given resilience level can be evaluated for cases with and without the application of specific advanced technologies (e.g., new materials, seismic response modification technologies). The difference between the two cases directly indicates the resilience improvement that would result from applying the technology. While advanced technologies will generally yield improvements in system robustness, some advanced methodologies (e.g., decision support systems) can foster resilience by improving restoration rapidity. Other advanced methodologies (e.g., system models and advanced economic models) are needed to quantitatively estimate resilience more accurately, with reduced levels of uncertainty associated with resilience estimates.

The Center-wide system diagram functions as an important management tool for MCEER, in that it links specific research tasks to the quantification or enhancement of systems and community resilience. It is used on an ongoing basis both to manage MCEER’s research agenda and to set priorities and allocate resources. To be included in MCEER’s research program, each research task must play a key role in quantifying, enhancing or improving the process described by the systems diagram. A research task may address the need for fundamental research, help in improving the quality of resilience assessments, or identify a technology that would enhance system or community resilience if implemented. The research task selection process is described in more detail in Section 5 of this annual report.

**Fragility and Resilience Curves**

For the technical (engineering) dimensions, the resilience curve must be derived from fragility curves. For some types of engineering systems, the resilience parameter can serve both as the engineering and organizational dimension of resilience, whereas for other types of engineering systems, the linkage between the two dimensions is challenging. Acute care facilities fall into the latter case. Furthermore, an additional challenge occurs when satisfactory performance depends on multiple limit states that must all be achieved simultaneously. Note that all these limit states are random variables, including “time to recovery.”
In this situation, one way to achieve quantification of engineering seismic resilience is through the concept of Sliding an Overlaid Multidimensional Bell-curve of Response for Engineering Resilience Operationalization (SOMBRERO), using, for example, an Orthogonal Limit-space Environment (OLE). Therefore, for the purpose of this discussion, a probability distribution surface is used, schematically shown in Fig. 6 by iso-probability contours. Spherical contours are used here for expediency. Building floor pseudo-accelerations (PSA floor) and interstory drifts (Sd floor) express the OLE, with specific structural and nonstructural limit states shown by dotted lines; for the former, a serviceability limit state (cracking of concrete structural elements for example) and a collapse limit state are indicated. Deterministic limit states are used here, but need not be. Floor acceleration and interstory drift are therefore the structural response probabilistic parameters considered here by the SOMBRERO concept. As graphically shown in Fig. 6, the probability that response exceeds a specific limit state can be directly calculated from the volume under the surface distribution exceeding the specified limit. For a given structural response, nonstructural retrofit measures that would allow the nonstructural components to resist greater floor accelerations (i.e., move up the acceleration limit state dotted line in Fig. 6) would directly translate into a smaller volume under the probability distribution surface, and thus a smaller probability of exceedence of the limit state. The same observations could be made for any limit state along the Sd-floor axis. However, modifications to the structural system change the probable structural response, which is equivalent to sliding the multidimensional bell-curve within the OLE (i.e., moving along the dotted arrows in Fig. 6). For example, stiffening the structural system in a manner that reduces interstory drifts would move the response surface to the left of the OLE in Fig. 6, and could also move it upward or downward, depending on the initial structural period (although the former is more likely). Structural damage during an earthquake would weaken the structure, moving the response surface toward the right and possibly downward (solid arrow in Fig. 6), resulting in greater intersect with the drift-controlled limit states, meaning increased probability of violating the limit state should another identical earthquake occur. Note that the shape or width of the probability distribution surface may also change for each case considered. Work underway as part of the Overarching Center-wide Thrust Area to numerically quantify this concept has shown it to be a viable and workable approach.

Figure 6: Probability that Response Exceeds Limit Space.
B. Research Program (by Thrust Area)

Center-wide research activities that provide support to multiple thrust areas are grouped together into an “Overarching Tasks” category. Research activities to enhance seismic resilience of critical infrastructure systems (water supply, electric power, and hospitals) and emergency management functions, are clustered into specific thrust areas. Also, another Center-wide activity focuses on the establishment of an effective experimental and analytical network to facilitate the exchange of information between MCEER researchers located in various institutions across the country. Finally, it is proposed to establish a new multi-hazard research thrust in year 9 that will regroup new tasks that involve significant multi-hazard infrastructure mitigation components.

The following major areas of MCEER activity are described in more detail in this section:

- Overarching Center-wide cross program research activities
- Thrust Area 1: Seismic evaluation and retrofit of lifeline systems
- Thrust Area 2: Seismic retrofit of acute care facilities
- Thrust Area 3: Emergency response and recovery
- User networks for seismic assessment and retrofit of critical facilities
- Mitigation of infrastructure against multi-hazard extreme events

These research activities are complemented by, and integrated with, other MCEER activities in education, outreach, technology transfer, and industry partnerships.

MCEER’s research strategy is sensitive and responsive to the fact that significant earthquakes and other extreme events that provide opportunities for research may occur at any time. These events have the potential to cause shifts in governmental and organizational priorities, eliminating barriers that had existed earlier and opening "windows of opportunity" for change. As demonstrated most recently following the tragic events of the tsunami/earthquake in South Asia, MCEER’s research planning and management strategy is to act when such circumstances arise.

Database Table 2 provides a description of the Research Program Organization and Effort.
Overarching Center-wide Cross Program Research Activities

<table>
<thead>
<tr>
<th>Year 8 Research Team</th>
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<tbody>
<tr>
<td><strong>Task Leaders:</strong> MCEER Executive Committee Members</td>
</tr>
<tr>
<td>M. Bruneau, Civil, Structural and Environmental Engineering, University at Buffalo</td>
</tr>
<tr>
<td>S. Chang, School of Community and Regional Planning, University of British Columbia</td>
</tr>
<tr>
<td>R. Davidson, Civil and Environmental Engineering, Cornell University</td>
</tr>
<tr>
<td>T. O'Rourke, Civil and Environmental Engineering, Cornell University</td>
</tr>
<tr>
<td>A. Reinhorn, Civil, Structural and Environmental Engineering, University at Buffalo</td>
</tr>
<tr>
<td>A. Rose, Geography, Pennsylvania State University</td>
</tr>
<tr>
<td>M. Shinozuka, Civil Engineering, University of California/Irvine</td>
</tr>
<tr>
<td>K. Tierney, Natural Hazards Research and Applications Information Center, University of Colorado/Boulder</td>
</tr>
</tbody>
</table>

Overarching Center-wide cross program research activities are those whose outcomes are most closely linked to the overall Center vision, while at the same time providing both focus and integration for thrust area tasks. This section of the report discusses progress that has been made in increasing integration both within and among thrust areas.

In year 6, MCEER initiated a new major area of research activity called “Definition and Quantification of Resilience – Development and Application of Center-wide Resilience Measures.” This research initiative consisted of the development of system-integrated definitions and the quantification of community resilience measures, to ensure a set of consistent, practical and workable measures of resilience that are applicable to all MCEER research. A multidisciplinary paper summarizing these findings was published in “Earthquake Spectra” in November 2003 [2]. Research activities undertaken as part of this task sought to further MCEER’s objective of providing organizations and communities with a suite of resilience-enhancing tools that will subsequently be validated through testbeds and demonstration projects—specifically projects focusing on lifeline services in Los Angeles and hospitals in both Los Angeles and New York State. This Center-wide approach is designed to ensure the development of reliable, validated, and replicable criteria and measures of resilience at component, network, system, and community levels for both lifelines and hospitals.

As discussed earlier in this report, seismic resilience is characterized by “reduced probability of system failure, reduced consequences due to failure, and reduced time to system restoration.” These three desired outcomes constitute the essence of the framework proposed by MCEER to quantitatively define seismic resilience. MCEER’s research activities are predicated on the notion that improvements in resilience are achieved through the application of advanced technologies and decision tools in both the pre- and post-earthquake context. Research activities seek to obtain quantitative data on the extent to which those measures result in improvements in resilience for infrastructure systems, hospitals, and communities and to explore their impacts in testbed-based studies.
In year 8, several overarching research activities received emphasis. First, building on the framework outlined in the 2003 “Earthquake Spectra” publication [2], work continued on further operationalizing the concept of resilience and on the development of resilience measures for critical facilities. In particular, the SOMBRERO-OLE concept presented above is one outcome of this process that emerged from work in Thrust Area 2: Seismic Retrofit of Acute Care Facilities. Second, additional improvements were made in loss estimation models, such as the computable general equilibrium modeling approach that MCEER is using to analyze the resilience of individual businesses and regional economies following earthquakes. Modeling of the restoration process for lifelines was simulated, addressing the question of how rapidly lifeline systems can be restored following earthquakes, which is a critical factor contributing to resilience. Parallel work was conducted on acute care hospitals, quantifying resilience in ways that recognize that hospital facilities consist of substantially different interdependent systems that provide complex services and that, like lifelines, require multidimensional performance and resilience measures. Research started to focus on the integration of both engineering and organizational aspects of these critical facilities.

As years 7 and 8 unfolded, significant integration took place not only within the Overarching Thrust area, but also across the other thrust areas. As such, the MCEER Executive Committee observed that the progress of researchers in operationalizing the resiliency concepts were Center-wide in application (as expected), but that these advances could be more rapidly implemented if integrated within specific thrust areas (logically, since the thrust areas are anchored to specific test-beds). Therefore, for year 9, it was decided to keep two tasks in the Overarching Thrust Area focused on advancing the conceptual framework of resilience and the higher-level aspects of its operationalization – the other tasks that contribute to the development of the resilience framework were re-assigned to relevant thrust areas, with the understanding that interactions and contributions to Overarching Center activities would continue. In particular, the tasks led by A. Rose, S. Chang, K. Tierney and R. Davidson will contribute to advancing the response dimension of resilience within Thrust Area 3, where improvements in definition and resolution can benefit the models of the post-earthquake lifeline restoration process.

Starting in year 9, work will be conducted to extend the MCEER resilience to other natural or man-made hazards. The MCEER work on resilience is finding a receptive audience from a broader multi-hazard perspective, which is helpful in identifying opportunities to ensure the viability of MCEER as a financially independent research center beyond year 10.
Thrust Area 1 - Seismic Evaluation and Retrofit of Lifeline Systems

<table>
<thead>
<tr>
<th>Year 8 Research Team</th>
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<tbody>
<tr>
<td><strong>Task Leaders:</strong> T. O'Rourke, Civil and Environmental Engineering, Cornell University and M. Shinozuka, Civil Engineering, University of California/Irvine</td>
</tr>
<tr>
<td>T.C. Cheng, Electric Power Program, University of Southern California</td>
</tr>
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<td>S.E. Chang, School of Community and Regional Planning, University of British Columbia</td>
</tr>
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<td>R. Davidson, Civil and Environmental Engineering, Cornell University</td>
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<tr>
<td>M. Feng, Civil Engineering, University of California, Irvine</td>
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<td>M. Grigoriu, Civil and Environmental Engineering, Cornell University</td>
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<tr>
<td>A. Rose, Geography, Pennsylvania State University</td>
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<tr>
<td>M. Ala Saadeghvaziri, Civil and Environmental Engineering, New Jersey Inst. of Technology</td>
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</table>

**Overview**

Thrust Area 1 closely supports the Center-wide effort to construct an overarching strategic framework for the measures of resilience and associated decision support tools. Specifically, this thrust area focuses on the development of GIS-based analytical, experimental and empirical procedures to evaluate and enhance the seismic resilience of lifeline systems which involves system robustness, or resistance to seismic loads, as well as the rapidity with which repair/restoration can be implemented after an earthquake. MCEER is dedicated to developing the next-generation lifeline systems through advanced geospatial modeling technologies, innovative materials and manufacturing, improved loss estimation and high performance simulation of system reliability, intelligent monitoring and remote sensing, and regional socio-economic modeling.

Research is undertaken in collaboration with the Los Angeles Department of Water and Power (LADWP), both as a testbed for the development of advanced technologies and as the agency through which implementation of these advanced technologies and management tools is pursued. LADWP is well suited for this role. It operates one of the largest and most complex water supply and electric power networks in the U.S. Because LADWP operates both systems, MCEER researchers are able to work across institutional boundaries and explore system interdependencies with full support from its engineering and managerial staff.

The specific objectives of Thrust Area 1 research are to 1) create a combined electric power and hydraulic network model for the Los Angeles power and water systems that allows for a comprehensive evaluation of their earthquake performance, 2) develop an integrated systems reliability model for the water supply and electric power networks that is approved and supported by LADWP management, and 3) use the results of 1) and 2) to create a decision support platform for critical lifelines that addresses seismic resilience in technical, organizational, societal, and economic dimensions. The third specific objective involves integrating research performed by MCEER’s social science and engineering researchers in the evaluation of earthquake damage.
effects on the regional economy and the ability of communities to perform emergency services and restoration activities. Specifically, MCEER is in the process of developing and delivering a fully functional, state-of-the-art network model of the LADWP water and electric power system for earthquake resilience assessment. The model and the attendant community interaction to develop the model are the testbeds for defining and evaluating community resilience, predicting regional economic impact, and developing restoration models to optimize emergency operations and system recovery.

**Previous Years’ Research**

The engineering research work of Thrust Area 1 has focused on systems analysis and simulation, large-scale experimentation, and high performance computational modeling of both systems and components behavior. For water supply networks, experimentation and component modeling have concentrated on the welded slip joints of critical trunk lines as well as pipeline couplings and bends. For electric power systems, experimentation and component modeling have concentrated on critical transmission and network components.

For electric power systems, a comprehensive GIS inventory has been performed for the LADWP transmission network. Fragility characteristics of systems, subsystems and equipment were determined on the basis of analysis and available empirical damage data from past significant earthquakes. Base isolation technology was investigated for the seismic protection of transformers. Base isolation devices were designed, manufactured and tested using the shake table at the National Center for Research on Earthquake Engineering (NCREE) in Taipei, Taiwan under a joint research project between MCEER and NCREE in collaboration with the Taiwan Power Company and Bridgestone Corporation in Tokyo, Japan. A global model of the repair/restoration process was created by using LADWP systems performance data collected after the 1994 Northridge earthquake. The effects of strong ground motions on electro-magnetic anomalies were assessed, and the relationship between electric power failures and the disruption of water supply pumping stations was explored. MCEER achieved an unprecedented level of systems analysis capability to assess the seismic performance of the transmission network, making it possible to evaluate the loss of power supply immediately after an earthquake. This capability has been harnessed to evaluate the effectiveness of rehabilitation measures in terms of reduction in the loss of electric power supply through the use of the WECC (Western Electricity Coordination Council) database and EPRI (Electric Power Research Institute) IPFLOW computer code.

GIS-based research focused on the LADWP system has resulted in the largest U.S. database ever assembled for spatially distributed transient and permanent ground deformation in conjunction with earthquake damage to lifeline systems. The research has led to improved procedures for delineating geotechnical and seismic hazards, as well as correlations between repair rates for a variety of trunk and distribution pipelines and seismic parameters, such as peak ground acceleration and velocity. Full-scale tests have confirmed the effectiveness of fiber-reinforced polymer (FRP) strengthening for critical steel pipelines with welded slip joints. FRP products have been commercialized. The largest laboratory simulation ever performed of ground rupture effects on buried pipelines was successfully conducted with support from Tokyo Gas, Ltd. These experiments were used to validate a hybrid numerical model to evaluate soil-structure interaction effects at pipeline elbows and bends, and recommend construction procedures to minimize
earthquake damage. Full scale tests, also performed with support from Tokyo Gas, have for the first time established models for soil-structure interaction in partially saturated soils, resulting in improved analysis/design for the great majority of pipelines and conduits that are subjected to these conditions.

MCEER has pioneered regional direct and indirect economic loss estimation due to lifeline damage, principally through computable general equilibrium (CGE) models. The CGE models are now being applied to the LADWP electric and water distribution systems so that the effects of combined network interruption on regional business losses can be evaluated.

An important outgrowth of the work involves hospitals and acute care facilities. Research on the aggregation of seismically-induced economic losses is being extended to assess the physical and functional losses sustained by multiple critical care facilities in earthquake-vulnerable regions.

**Year 8 Research and System Integration**

MCEER Thrust Area 1 research in year 8 has set the stage for implementation of a comprehensive decision support system by LADWP that addresses technical, social, and economic issues in network planning, repair, and new construction. A key activity in defining performance/resilience objectives was the MCEER-LADWP workshop in May, 2004 at which social science and engineering researchers, LADWP, and LA stakeholders identified and discussed the implementation of water supply and electric power performance objectives. Follow-on work involved interviews with lifeline operators by S. Chang, refinements in CGE models by A. Rose, and meetings and coordination with the LA Fire Department involving T.D. O’Rourke.

A comprehensive seismic hazard assessment, funded fully by LADWP, was performed for the combined LADWP water supply and electric power systems by leading engineering seismologists at URS, Inc. This work provides state-of-the-art characterization of seismic strong motion hazards for geographically distributed systems.

New software, GIRAFFE (Graphical Iterative Response Analysis for Flow Following Earthquakes), was produced for analysis of damaged hydraulic networks. The advantages of this program, which replaces GISALLE++ for MCEER work, are that it is open source, operational with the most widely used hydraulic network engine for water supplies, and completely compatible with the LADWP system model. The program was validated through the very favorable comparison of its network simulation output with pre-and post-Northridge earthquake SCADA (Supervisory Control And Data Acquisition) measurements at multiple locations in the LADWP system. The program has been used for multi-scale modeling in which earthquake damage to the 10,000 km of LADWP distribution pipelines can be simulated by fragility relationships that model demand on the trunk line network as a function of damage.

Substantial progress has been achieved in developing a preliminary decision support system centered on the MCEER hydraulic network program, fragility models developed by M. Grigoriu and T.D. O’Rourke, a system restoration model by R. Davidson, regional economic impact by A. Rose, community resilience by S. Chang, and continuous engineering, operations, and technical
guidance by LADWP. The preliminary decision support system is expected by the end of summer, 2005, and will continue to be enhanced for implementation by LADWP in 2006.

Working with the results of an inventory of key pump units in the LADWP water system prepared by T.C. Cheng, M. Shinozuka analyzed the results of sudden pump interruption on water pressure surges in the pipeline network. The pressure surge analyses were used to develop an advanced SCADA system that identifies the location and extent of pipeline damage by detecting and measuring pressure changes with a distributed system of sensors. This work was presented at a joint AWWARF-JWWA (American Water Works Association Research Foundation – Japan Water Works Association) conference in Kobe. Support for continued SCADA research was received from the Irvine Ranch Water District, which offered its water delivery network as a testbed for further development. Research by A. Saadeghvaziri was focused on transformer-bushing interaction and base isolation under large displacement conditions. Preliminary design charts for friction pendulum bearings were developed for more effective base isolation of transformers under near-field earthquake conditions that involve large transient displacements. In collaboration with industrial partners, Bridgestone and Enidine, two types of seismic protective bushing connectors were developed by M. Feng for improved earthquake performance of transformer bushings. Preliminary studies of electromagnetic anomalies in power transformers after earthquakes were carried out, and the principal causes of such difficulties were shown by T.C. Cheng to be related to partial discharges in the transformer insulation system. Work was undertaken under the supervision of M. Shinozuka to organize an inventory of data for the Southern California Edison (SCE) power system. Work was initiated on the combined SCE and LADWP power systems to understand better the regional effects of seismic damage.

**Year 9 Research Plan and System Integration**

The prime goal of year 9 research is to demonstrate the application of the lifelines decision support system, utilizing its capabilities with respect to the engineering, operations, planning, and assessment of the economic and social consequences of combined water and electric power performance. The work will draw upon research by A. Rose on the regional economic impact of combined water and electric power losses, and will deliver an integrated accounting for the economic disequilibrium generated by simultaneous loss of water and electricity. S. Chang will refine and apply her models for community impact in the LADWP decision support system through vigorous interaction with LADWP and LA community stakeholders and coordination with other MCEER researchers.

MCEER Thrust Area 1 investigators will work with URS engineering seismologists and LADWP to harmonize the seismic hazard characterization for both water and electric power, and to deliver a decision support system applicable for both LADWP and water supplies in other cities. M. Grigoriu will continue to develop and apply fragility characterizations for the MCEER hydraulic network model to assess the impact of system damage states. He will also help develop the probabilistic seismic hazard model with specific attention to characterizing the hazard for a large geographically distributed system.

R. Davidson will work with LADWP to model water system repair and recovery operations, quantify the uncertainty associated with these activities, and estimate the expected restoration
time for the combined water and electric power networks under various earthquake scenarios. Discrete event modeling will be applied by R. Davidson for fires following earthquakes, which is a key factor in the post earthquake performance of both the water and electric power system.

There will be continued close collaboration with LADWP engineers and managers to implement the MCEER decision support system for the combined seismic performance of electric power and water delivery. Improved models for post-earthquake restoration/recovery developed by R. Davidson in collaboration with T. D. O’Rourke and M. Shinozuka will be applied to the LADWP water supply and electric power systems. The work initiated by T.C. Cheng and A. Saadeghaziri in year 8 will continue, with emphasis on advanced SCADA sensor development and deployment in LADWP and SCE networks.

Year 9 research by R. Davidson and A. Rose will be performed as Thrust Area 3 projects. Their work will be integrated into the effort to develop broader decision support systems for response and restoration activities, which will significantly enhance seismic resilience of an urban community as a whole in which not only critical facilities but also societal organizations play a critical role in supporting the community resilience.

Top management at LADWP has expressed its commitment to develop with MCEER a state-of-the-art decision support system that is fully implemented and demonstrated by year 10. MCEER remains ahead of schedule in achieving this goal. Managers at the East Bay Municipal Utility District and the San Francisco Public Utility Commission have also expressed strong interest in the decision support system process being pioneered by MCEER. The research continues to be coordinated with AWWARF and Memphis Light, Gas, and Water.

The research conducted in Thrust Area 1 has received significant recognition by the earthquake engineering community. For example, T. O’Rourke delivered a keynote address entitled “Advances in Lifeline Earthquake Engineering” at the 13th World Conference on Earthquake Engineering, summarizing the research conducted as part of the MCEER Thrust Area 1 program. Overall, the nine MCEER PI’s listed above participated in more than 50 conferences, workshops, and invited lectures; published 69 refereed and other papers, and supervised 49 students, researchers and visitors during 2004-2005, thus contributing significantly to outreach and education. They also worked jointly with or received in-kind support from the National Center for Research on Earthquake Engineering, Taipei, Taiwan, LADWP, AWWA Research Foundation, SCE (Southern California Edison), EBMUD (East Bay Municipal Utility District), MLGW (Memphis Light, Gas and Water) Division, Tokyo Gas Company, Ltd., Bridgestone Corporation, Taiwan Power Co., Irvine Ranch Water District, ABS, Inc., Manifold, Inc., Enidine Co., Inc., Bonneville Power Administration, Master Builders, Inc., R.J. Watson Co., and the Fyfe Co.. Among these, LADWP (both Water and Power Divisions), MLGW, EBMUB, SCE and Bridgestone are members of MCEER’s Industry Advisory Board.
Overview

MCEER’s objective of developing engineering and management tools to help enhance seismic resilience requires that the general parameters of resilience presented earlier be further defined to provide a framework that addresses the issues germane to the specific earthquake protection and response requirements of individual facilities. Within the focus of Thrust Area 2, the operationalization of the Center-wide seismic resilience concept for acute care facilities is accomplished within the overarching Center-wide cross program described earlier, in collaboration with other thrust area leaders (with input from investigators involved in Thrust Area 2 and the Industry Advisory Board), to ensure that the results will be compatible with integrated Center-wide implementation requirements.

Due to the complexity of acute care facilities, and depending on the extent of seismic deficiencies in any specific hospital, considerable investment may be required to ensure that an acute care facility remains operational following an earthquake. The extensive resources that would be required to achieve such a level of resilience would likely not be available at the onset, and activities to upgrade the facilities would have to be staggered over many years. Ideally, using the limited resources available at any time along this multi-year upgrading process, the objective would be to first make the investments that provide the largest enhancements to seismic resilience, and to sequence all subsequent investments following the same logic. This approach presents a significant challenge to decision makers and their specialist consultants, as there is no integrated tool that could support such a decision on factual engineering data. Note that within the spectrum of possible decisions, building new facilities must also be considered. The research work in Thrust Area 2 investigates how such integration could be achieved.
Thrust Area 2 research is structured such that efforts aimed at the development of seismic response modification technologies provide data that can be used in integrated decision engines. Thrust Area 2 therefore addresses research needs for seismic retrofit technologies (using advanced technologies per the MCEER mandate) that can provide effective solutions for acute care facilities, and research needed to formulate the integrated decision support systems that would be required to identify the most appropriate seismic mitigation actions, taking into account both engineering issues (structural and nonstructural) and organizational constraints (technical and organizational dimensions of resilience).

It is important to note that the objective of this research endeavor is not to produce decision-making software, but rather to develop sound engineering concepts and data that could be used both to produce such software, and to retrofit acute care facilities or to build new ones.

Data from past earthquakes as well as engineering experience demonstrates that functionality of a hospital building can be lost due to structural failure, geotechnical failure, or damage to nonstructural building components (i.e., medical equipment). Furthermore, these are closely inter-related as damage to nonstructural building components, for example, is directly tied to structural response. In other words, modifying structural response solely for the purpose of reducing damage to the structure may have positive or negative impacts on the seismic performance of nonstructural building components. Therefore, the research tasks of Thrust Area 2 focus on the integrated issues of performance, including both structural and nonstructural systems and components and their functionality.

**Previous Years’ Research**

MCEER’s research in its first five years focused of the development of advanced technologies to enhance the seismic performance of foundations, structures, and nonstructural components, each taken independently. Although valuable research results were obtained, only in year 6 did the research mature to a point where close integration of research activities became possible. This integration centered on the response of nonstructural building components, which represent the bulk of the investment in acute care facilities, matured in year 7. Selected noteworthy Research Progress and Accomplishments in the first seven years of MCEER are summarized below.

In years 1 to 4, an extensive online database of nonstructural damage suffered by hospitals in past earthquakes was compiled (see [http://mceer.buffalo.edu/publications/reports/docs/99-0014/default.asp](http://mceer.buffalo.edu/publications/reports/docs/99-0014/default.asp)). This is the only such database in existence, and as such, provides a valuable perspective on the seismic vulnerability of hospital contents. Over the same period, the fragility of some types of equipment was quantified through extensive shake table testing. Restraint designs for equipment were developed, from simple mitigation techniques to more advanced energy dissipation approaches. Work on piping systems progressed significantly in year 5; in collaboration with the California Office of Statewide Health Planning and Development (OSHPD), a representative piping system was designed and constructed for shake table testing. Shake table testing of various types of pipes (e.g., threaded steel pipes and brazed copper pipes) took place in years 5 to 7. Fragility modeling work was conducted as an integrated part of this experimental effort.
Significant research progress was achieved on the development of advanced technologies for the response modification of structural and nonstructural systems and components. A design procedure for metallic infill energy dissipation systems was developed, with proof of concept specimens designed and partly tested in year 5. The development of simplified models of composite infill panels to be incorporated in general-purpose structural analysis software was initiated in year 6. Development of leveraged-damping systems (e.g., scissor jacks) was completed in year 5. Construction of a very large modular shake table specimen was completed in year 4 and used for experimental research on hybrid systems in year 5.

Shake table studies completed in year 7 on the behavior of structures with seismic isolation and damping systems resulted in a wealth of experimental results on systems of contemporary design. This included data related to secondary system response, and comparisons of analytical and experimental responses that demonstrated the capability of nonlinear response history analysis methods to predict the response of nonstructural (secondary) systems.

In years 4 and 5, computer-based technologies were also extensively developed, including the innovative use of an evolutionary algorithm for the automated optimum “Computational Aseismic Design and Retrofit” of structures using advanced technologies. Years 5 to 7 brought breakthroughs in enhancing the functionality, robustness and efficiency of this platform, providing strong indications that the computational complexities of this approach could be resolved so as to not become a barrier against implementation. The enormous advantage and promise of this procedure is its flexibility, as evolutionary constraints can include both engineering and non-engineering parameters, such as socio-economic decision support. This unique capability has intensively been investigated in year 7.

Also in year 5, an extensive and intensive cross-disciplinary review of literature on obstacles to earthquake hazard policy and program implementation was completed, and results of this work were presented to practicing engineers, building officials, and other invited professionals with experience in seismic policy implementation, during a workshop held in March 2001 at the offices of Degenkolb Engineers. A condensed version of the literature review appears in MCEER’s “Research Progress and Accomplishment 2000-2001” volume. Input from this workshop was used to refocus the results into useful, workable resolutions. Additionally in years 3-5, a series of focus group interviews were conducted with decision makers in hospital facilities in the western, central, and eastern U.S. Those group discussions centered on the importance assigned to different hospital functions and systems on seismic loss reduction decisions.

MCEER investigators led by M. Constantinou have made many key contributions to the most advanced codes and guidelines related to the implementation of passive energy dissipation systems: the “FEMA 273/274 Guidelines for the Seismic Rehabilitation of Buildings,” published in 1998, and the “NEHRP 2003 Guidelines for Seismic Regulations for New Buildings and Other Structures.” The first of these documents provides structural engineers with new information on procedures for the analysis and evaluation of existing structures, and design of seismic retrofit strategies. The second document introduces robust procedures for the analysis and design of passive energy dissipation systems (Chapter 15) using force-based methods of analysis that are consistent with those used for analysis and design in conventional construction. The development of force-based analysis and component-checking methods for highly nonlinear
or velocity-dependent energy dissipation devices proved to be a most demanding task, and MCEER researchers developed the technical basis in support of these provisions.

MCEER investigators have continued to contribute to the development of codes and guidelines in years 6 and 7 through their participation in the Applied Technology Council (under sponsorship of the Federal Emergency Management Agency of the Department of Homeland Security) ATC-58 project. The next-generation performance-based seismic design procedures developed under this project will express performance directly in terms of the quantified risks that the building owner or decision maker will be able to understand. M. Bruneau is a member of the Steering Committee of the ATC-58 project. A. Whittaker is the Structural Performance Products Team Leader, while A. Filiatrault is serving on a special task force for the development of testing protocols to evaluate the seismic performance of nonstructural building components.

**Year 8 Research and System Integration**

Year 8 is the third year of implementation of MCEER’s new strategic plan, which intensifies integration of research activities in Thrust Area 2. To ensure integration from an organizational point of view, quarterly investigator coordination meetings are being held to ensure close integration of research activities and develop a stronger shared understanding of the means to operationalize the vision and goals of MCEER into Thrust Area 2 activities. Furthermore, regular video tele-conferences (VTC) and meetings are being held with OSHPD representatives to ensure that they are kept abreast of the research progress in this thrust area. The research program of year 8 is also directed toward integrating engineering and social science research in order to create robust decision support tools. On February 24, 2005, MCEER Thrust Area 2 investigators delivered a one-day hospital seminar to 50 OSHPD engineers. The one-day seminar entitled *Hospital Research and Retrofit Seminar* provided a unique opportunity for MCEER to transfer newly acquired knowledge on the socio-economic and public policies issues related to hospitals and expose new technologies on structural and nonstructural engineering that have reached the implementation phase or that hold promise for the future.

The “roadmap” needed for Thrust Area 2 to quantify and enhance the seismic resilience of acute care facilities, developed in year 6, is shown in Fig. 7. This roadmap continues to be the backbone of the research activities in year 8 and remains the primary tool to focus and integrate MCEER’s research activities in this thrust area, listing the steps toward the objective, and the essential dependencies.

The roadmap emphasizes that seismic resilience may be compromised by failure of both engineered and non-engineered systems. It also conceptually illustrates the probabilistic fragility framework that must be integrated to quantify seismic resilience of acute care facilities, and where interventions can be made to enhance this resilience. As illustrated in Fig. 7, a first interim quantification of resilience is possible at the physical dimension level. From there, social science research input is needed to generate the knowledge to elevate the resilience quantification to the organizational dimension level by translating the physical system resilience into operational consequences.

The roadmap also emphasizes the pivotal need for information on the fragility of nonstructural building components to achieve the research objectives through the above methodology. Indeed
achieving a given target seismic resiliency for acute care facilities requires the harmonization of performance levels between structural and nonstructural components. Even if the structural components of a hospital building achieve an immediate occupancy performance level after a seismic event, failure of architectural, mechanical, or electrical components of the building can lower the seismic resiliency of the entire building system. Furthermore, the investment in nonstructural components and building contents for a hospital is far greater than that of its structural components and framing. Therefore, it is not surprising that in many past earthquakes, losses from damage to nonstructural building components exceeded losses from structural damage.

Figure 7: Roadmap toward Achieving Seismically Resilient Hospitals.

The MCEER West Coast demonstration hospital (located in Northridge, California) serves as the main Thrust Area 2 testbed for verification of the concepts and strategies developed as part of this research integration plan. Work on this testbed is complemented by another research task focusing on enhancing the multi-hazard disaster preparedness of New York State hospitals, as MCEER’s unique commitment to New York State, which provides matching funding to
MCEER. The MCEER East Coast demonstration hospital (located in Jamestown, New York) serves as the testbed for this task.

Fundamentally, the development of equipment fragilities is not within the purview of academic NSF-funded research, but rather the responsibility of industry. However, to allow development of the methodology to proceed forward unhampered by the current absence of a fully populated database of equipment fragility curves, MCEER research proceeds by taking into account the existing reliable fragility curves currently available for some types of equipment (e.g., suspended ceiling systems data generated at MCEER through an associated project), and complementing this information by developing fragility curves for specific nonstructural building components and equipment, and by the theoretical development of fragility curves for nonstructural distributed systems (e.g., piping systems). Additional information on the fragility of medical equipment also needs to be included into this methodology. As described below, it is proposed to continue this focus on experimental research aimed at quantifying the seismic fragilities of nonstructural building components and contents in year 9 and beyond. For this purpose, a general research methodology was initiated in year 8. This methodology for the experimental fragility assessment of nonstructural components in acute care facilities can be broken down into four distinct phases, as described below.

Phase 1: Generation of Ensembles of Strong Ground Motion Records
Ensembles of synthetic strong ground motions representative of the range of seismic hazard levels for a given region have been generated in year 8. Ensembles of 25 tri-axial strong ground motions for the two MCEER demonstration hospital sites of the west coast and east coast of the United States were generated for four different probabilities of exceedence (2%, 5%, 10%, and 20%) in 50 years. The Specific Barrier Model (SBM) developed at MCEER under the leadership of A. Papageorgiou was adopted for generating the horizontal ground motions and a spectral-compatible procedure was used to generate the corresponding vertical accelerograms. All these MCEER ground motions are available at the following ftp site: [ftp://mceer.buffalo.edu/filiatrault/MCEER_Ground_Motions](ftp://mceer.buffalo.edu/filiatrault/MCEER_Ground_Motions).

Phase 2: Generation of a FloorAcceleration Database
A floor acceleration database for the two MCEER demonstration hospitals is being generated in year 8 based on time-history dynamic analyses of various structural framing systems of the two MCEER demonstration hospitals using the ensembles of strong ground motion records generated in Phase 1. These analyses are being conducted as part of several integrated research projects within Thrust Area 2 that are looking at enhancing the seismic performance of structural systems. The structural models required to conduct these numerical studies were developed under the leadership of A. Whittaker in year 7. This floor acceleration database represents demand functions for various seismic hazard levels, locations, floor levels, and structural systems incorporating various advanced protective technologies (e.g., dampers, base isolation).

As part of the establishment of this floor acceleration database, several numerical studies were conducted to evaluate the influence of advanced seismic protective systems on structural and nonstructural seismic fragilities for the MCEER west coast demonstration hospital. Various protective systems were used to improve the structural response of the hospital building containing different types of nonstructural systems attached at various levels of the building.
Using the MCEER ground motions described above as input, the performance of each passive damping system in reducing the structural and nonstructural seismic fragilities was evaluated.

Phase 3: Experimental Assessment of Seismic Fragility of Selected Medical Equipment
In year 8, the shake table fragility testing of a centrifugal liquid chiller provided by one of MCEER’s industry partners was carried out under the leadership of A. Filiatrault. A general view of the chiller unit rigidly mounted to one of the two shake tables available at the University at Buffalo is shown in Fig. 8. Seismic qualification tests were first performed on the chiller unit according to the AC-156 test protocol. In the second phase of the project, seismic fragility tests were conducted using floor acceleration time-histories generated from the numerical study described above and obtained from other Thrust Area 2 tasks involving various structural framing systems on the MCEER west coast demonstration hospital. Note that the most common locations for centrifugal liquid chiller in hospitals are either the ground floor or roof level. Floor motions from both of these locations were investigated in the shake table tests. At the time of writing, data are being analyzed.

This experimental fragility research initiated in MCEER’s year 8 research program for heavier equipment, such as liquid chilling and air handling units, has generated much interest among equipment manufacturers, which has resulted in a sharp increase in the number of MCEER industry partners in the last two years (see Section 5 of this Annual Report).

![Figure 8: Centrifugal Chiller on Shake Table at the University at Buffalo.](image)

Phase 4: Formulation of Structural Design Objectives
Once the relationship between the seismic fragility of selected medical equipment and the structural demands has been established, structural design objectives will be established for various target probability of exceeding prescribed limit (damage) states of these types of nonstructural components. These structural design objectives can then be used to optimize the structural design of acute care facilities using particular advanced technologies, thereby providing a feedback loop to the research projects within Thrust Area 2 that are looking at enhancing the seismic performance of structural systems.
Implementation of the above concept hinges on two important research activities as part of Thrust Area 2: creation of methodologies for integrated decision-making platforms, and research on structural and nonstructural response modification techniques to enhance seismic resilience.

**Methodologies for integrated decision-making platforms**

Two decision-support platforms have been identified as having the potential to integrate the key issues identified as part of Thrust Area 2. The research focus in year 8 remains on advancing the development of each of these two platforms to the proof of concept stage, demonstrating how the multiple dimensions of enhancing resilience for acute care facilities can be taken into account and integrated.

The first MCEER decision-making platform, developed by G. Grigoriu, investigates the fragility approach and how multiple systems can be integrated within that framework. This platform has been embodied in year 8 into a Rehabilitation Decision Analysis Toolbox (RDAT) through a user friendly MATLAB interface. This tool is now available through the MCEER User’s Network (http://civil.eng.buffalo.edu/users_ntwk/index.htm).

This fragility-based decision-support platform is supported by the work of D. von Winterfeldt, which considers decision tree analysis and identification of the key parameters required for such constructs for the case at hand. In year 8, the state-of-the-art capital resource allocation software STRATACAP (http://www.strata-decision.com/capitalplanning.asp) is being integrated into MCEER’s fragility-based decision-support platform. A screenshot of STRATACAP’s user interface is shown in Fig. 9. This interface allows users in group settings to explore various ways of ranking project proposals, to identify the sure winners (two green marks) and the sure losers (two red marks) and to focus the discussion on the few contenders (shaded in blue). In its current form, STRATACAP does not handle uncertainties and risks. The main innovation associated with the integration of STRATACAP with MCEER’s fragility-based decision-support platform is to add the capability to compare projects with relatively little risk (e.g., building a new addition to the emergency room) with projects with high risks (e.g., seismic retrofits). D. Kleinmuntz from Strata Decision Technology, the principal designer of STRATACAP, has agreed to make the STRATACAP software available to MCEER investigators and will actively participate in this integration in both in years 8 and 9.

The second MCEER decision-making platform, developed by G. Dargush, investigates the use of an evolutionary analysis procedure for structural systems incorporating advanced protective technologies in an uncertain seismic environment that can integrate multiple flexible constraints and rules including non-engineering organizational and socio-economic constraints. This evolutionary-based decision-support platform has been embodied in year 8 into the PC-based Evolutionary Aseismic Design and Retrofit (EADR) software. An initial beta-version of the software will be made available by July 2005 and will be distributed to selected members of the Industry Advisory Board for their evaluations.

This evolutionary-based decision-support platform is supported by the work of W. Petak and D. Alesch that is investigating how quantitative social science knowledge can be integrated into engineering decision-support models. Integration of engineering requirements, organizational rules and constraints representative of the environment, and issues that must be considered by
acute care facilities in California are being integrated as proof of concept. As part of this effort, a case study on the State Bill 1953 (SB 1953) in California was completed in year 8. This SB 1953 case study provided a unique opportunity to document the obstacles to the implementation of effective seismic mitigation measures for hospitals and the associated means to overcome those obstacles.

The approaches described above are important toward achieving the objective of developing a methodology to globally consider all critical facilities in an integrated manner.

**Response modification techniques to enhance seismic resilience**

MCEER researchers are investigating the seismic demands on structural and nonstructural systems and components in acute care facilities through two- and three-dimensional numerical modeling of the MCEER West Coast demonstration hospital in a variety of computer platforms. The hospital is an existing facility located in Northridge, California. This acute care facility was constructed in the early 1970’s to meet the seismic requirements of the 1970 Uniform Building Code. One particular building of the facility’s campus, a rectangular four-story steel moment-resisting frame, was selected for in-depth studies. By using these numerical models, MCEER investigators are able to compute demands on nonstructural components and judge the utility and efficiency of different seismic response modification technologies to reduce the vulnerability of structural and nonstructural systems and components. Model verification is on-going across the various computer platforms to ensure consistency of results.
M. Bruneau is investigating the use of metallic displacement-based energy dissipation systems on achieving integrated resilience objectives for structural and nonstructural systems. The concepts developed are valid for a broad range of metallic energy dissipation systems, but two systems are considered for the specific implementation studies in the MCEER West Coast Demonstration Hospital, namely Steel Plate Shear Wall Systems (SPSW) and Buckling Restrained Braces (BRB). These passive displacement-activated damping systems provide significant stiffening and strengthening that can effectively help achieve the structural resilience objectives. They are combined with isolation systems for nonstructural components and floor systems to achieve the nonstructural performance objectives. In year 8, a design procedure for the displacement-activated damping systems formulated for single-degree-of-freedom systems has been expanded to multi-degree-of-freedom (MDOF) systems. Constraints under which steel plate walls and buckling restrained braces can be used to meet the resilience objectives have been preliminarily identified. Research investigated how various metallic displacement-based energy dissipation systems can provide the target structural response control objectives in MDOF systems. Furthermore, analytical models, based on the experimental results obtained on SPSW specimens under the cooperative experimental program with the National Taiwan University (NTU) and the National Center for Research on Earthquake Engineering (NCREE) in year 7, have been developed.

A. Reinhorn is developing a new seismic retrofit procedure aimed at reducing maximum acceleration (and associated forces) and drifts in buildings by reducing their strength (weakening) and adding supplemental damping devices. The method addresses simultaneous reduction of accelerations and deformations in the structure. The effect of the weakening method can be viewed as similar to the base isolation technique, which decreases the global acceleration response of structures while increasing overall movement of the structure. However, the weakening is not sufficient and requires control of deformations through supplemental damping mechanisms. In year 8, the effectiveness of the method and its easy applicability to existing buildings was investigated using the MCEER west coast demonstration hospital. Also, an experimental study of a weakened system was designed. The analysis of the structure for the different steps of the retrofitting procedure (original structure, weakened structure, weakened and damped structure) was done through analysis of highly damped inelastic structures using the software IDARC-3D, which was newly developed at MCEER for this study.

G. Lee is investigating a new seismic response modification system that extends the methodologies proposed in the last decade by MCEER researchers. The control strategy of this innovative “semi-passive” system incorporates two discontinuous damping levels: a normal damping level (smaller damping for regular isolation, larger damping when bearing displacement becomes large) and a critical damping level (when the device is locked). The change in levels is based on preset valve parameters and requires an external power source or integrated computer or controller. All the control actions are achieved by the pressure change inside the hydraulic chamber of the device. Following the theoretical control formulations and numerical response investigations of buildings equipped with the proposed semi-passive system, focus in year 8 is directed at the design and construction of a prototype semi-passive control device.

M. Constantinou is continuing his investigations on the accuracy of methods of analysis of secondary systems in structures with seismic isolation and damping systems. Numerical simulations of the response of secondary systems are being conducted to (a) provide a
comparison of the performance of secondary systems in structures designed with contemporary seismic isolation and damping systems that have a range of design parameters, and (b) provide guidelines on the selection of seismic isolation and damping hardware for achieving specific performance levels. In year 8 a novel Double-Concave Friction Pendulum (DC-FP) isolation system that can be particularly efficient in reducing the seismic forces experienced by nonstructural components and expensive equipment inside acute care facilities has been investigated. Novel features of the DC-FP system are compact size, very large displacement capacity and assumed capability to adjust its behavior for achieving specific objectives such re-centering in weak earthquakes and minimization of impact on secondary systems and equipment. Preliminary shake table testing on a six-story model structure incorporating various designs of the DC-FP in year 8 have demonstrated its capabilities.

A. Filiatrault is investigating the control of both the transient and residual seismic responses of structural and nonstructural components and systems in acute care facilities using the Post-Tensioned Energy Dissipating (PTED) steel frame concept. In this system, the beams and columns of a steel frame are not welded together. Instead, Post-tension (PT) self-centering bars along with energy-dissipating (ED) bars are included at each connection. PTED connections can undergo large transient inelastic deformations with minimal damage to the main structural elements with near zero residual deformations. In year 8, a numerical parametric study on the seismic response of single-degree-of-freedom (SDOF) self-centering systems incorporating flag-shaped hysteretic structural behavior has been completed. This parametric study was conducted using the MCEER ensembles of synthetic earthquake records that correspond to various probability of exceedence at the locations of the MCEER west coast demonstration hospital. The responses of the flag-shaped hysteretic SDOF systems were compared against the responses of similar bilinear elasto-plastic hysteretic SDOF systems, representative of traditional yielding structural systems. The results obtained are plotted as design charts for selecting optimum parameters for multi-story PTED structures.

M. Maragakis is continuing the experimental performance evaluation of pressurized piping distribution systems through shake table experiments. The general layout of the system was designed in collaboration with the Office of Statewide Health Planning and Development (OSHPD) in year 5. In year 8, realistic acceleration levels for braced and unbraced piping systems along with their failure modes were identified. Using the MCEER west coast demonstration hospital, realistic floor accelerations were developed for various hazard levels and will be used to conduct shake table experiments of brazed copper piping systems in year 8.

Year 9 Research Plan and System Integration

The research plan of Thrust Area 2 for year 9 is to continue the research integration strategy initiated in years 6 to 8, per the integration roadmap presented in Fig. 7.

The development of the two decision-support platforms will continue in year 9. The fragility-based decision-support platform, developed by M. Grigoriou and embodied in the Matlab interface RDAT, will be fully integrated into the capital resource allocation software STRATACAP. The evolutionary-based decision-support platform, developed by G. Dargush, will be expanded to spatially-distributed hospital networks. This will involve developing the capability to either assist multi-facility health care organizations faced with resource allocation
decisions or to investigate consequences of regional level policy scenarios. This latter aspect will receive the most attention, particularly now that there is interest in California to find alternative policies to SB1953.

The development of response modification techniques to enhance the seismic resilience of acute care facilities will continue in year 9 with a particular emphasis on moving the various technologies beyond the proof of concept stage by integrating them as viable design or retrofit engineering alternatives within the two decision-support platforms described above.

With the objective of enhancing the knowledge in the seismic performance and fragility of nonstructural components and as a supporting effort of the broader integration framework, MCEER’s Thrust Area 2 will intensify its experimental studies of these components in acute care facilities. Particular emphasis in year 9 will be towards the determination of the seismic fragility of some selected medical equipment critical to the post-disaster operation of acute care facilities. Important medical equipment (e.g., x-ray machines, MRI units, heavy surgical lamps, etc.) are either self-supported, anchored to floor slabs or mounted to ceilings and walls, which make them particularly sensitive to horizontal and vertical accelerations. The results will allow the establishment of the relationship between the various limit (or damage) states of these equipment and the seismic demands imposed on them by structural systems incorporating various response modification technologies being developed within Thrust Area 2 (e.g., dampers, base isolation, etc.). This relationship is vital in order to harmonize the performance of structural systems and nonstructural components in acute care facilities for a target resilience level.

Finally, the thirteen Principal Investigators involved in Thrust Area 2 research have published 53 refereed and other papers, and supervised 32 students, researchers and visitors during 2004–2005, thus contributing significantly to outreach and education. They also worked jointly with or received in-kind support from Armstrong World Industries; Arup Engineering; Degenkolb Engineers; Dynamic Isolation Systems (DIS), Inc.; Earthquake Protection Systems (EPS), Inc.; Enidine Inc.; Kinetics Noise Control; KPFF Consulting Engineers; Office of Statewide Health Planning and Development (OSHPD) of California; Rutherford & Chekene, Taylor Devices, Inc.; Terra Firm Earthquake Preparedness, Inc.; The Thornton-Tomasetti Group; Unison Industrial Co., Ltd; Weidlinger Associates, Inc., York International; all of which are members of MCEER’s Industry Advisory Board (IAB).
Thrust Area 3: Emergency Response and Recovery

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<tr>
<th>Research Team: Years 8 and 9</th>
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<tr>
<td><strong>Task Leader:</strong> Kathleen Tierney, Natural Hazards Research and Applications Information Center, University of Colorado/Boulder</td>
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<tr>
<td>Year 8:</td>
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<tr>
<td>S. Chang, School of Community and Regional Planning, University of British Columbia</td>
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<td>R. Eguchi, ImageCat, Inc.</td>
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<td>B. Houshmand, Jet Propulsion Laboratory, University of California/Los Angeles</td>
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<td>H. Jones II, MLB Company</td>
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<td>M. Shinozuka, Civil Engineering, University of California/Irvine</td>
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<td>Year 9:</td>
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<tr>
<td>S. Chang, School of Community and Regional Planning, University of British Columbia</td>
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<tr>
<td>A. Rose, Geography, Penn State University</td>
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<td>R. Davidson, Civil and Environmental Engineering, Cornell University</td>
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<td>A. Lembo and T. O’Rourke, Civil and Environmental Engineering, Cornell University</td>
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<td>B. Houshmand, Jet Propulsion Laboratory, University of California/Los Angeles</td>
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<tr>
<td>R. Williamson, Science, Technology and Public Policy, George Washington University</td>
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<td>M. Shinozuka, Civil Engineering, University of California/Irvine</td>
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Overview

MCEER defines resilience as the ability of social units (e.g., communities, organizations such as hospitals and lifeline organizations) to mitigate hazards, contain the effects of disasters, and carry out recovery activities in ways that minimize social disruption and contain long-term social and economic losses. Resilience consists of the capacity to reduce the probability of system degradation and damage, cope with physical damage and social and economic disruption when they do occur, and facilitate infrastructure restoration and community recovery as rapidly as possible following disasters. Pre-event loss-reduction measures, such as the seismic design and retrofit measures for lifelines and hospitals that are being studied in Thrust Areas 1 and 2, enhance resilience by reducing the probability of earthquake-induced failures and disruptions to critical infrastructure systems and limiting the damage that does occur. In other words, they contribute to resilience by improving component and system robustness and ensuring that systems and structures continue to perform as intended when an earthquake disaster occurs.

Post-event response and recovery strategies, which are the focus of research in Thrust Area 3, enhance resilience primarily through improving the rapidity with which impacts are identified, resources are mobilized, and critical systems are restored when earthquakes strike, as well as through improving the effectiveness of community recovery strategies that are used following earthquake disasters. Response and recovery activities enable social units to return rapidly to levels of pre-disaster functionality primarily by means of enhancing the resourcefulness
dimension of resilience—that is, the capacity to effectively mobilize appropriate human and material resources to manage the physical, economic, and social dislocation that earthquakes produce—and also through exploiting and, where necessary, creating system redundancies. Sound response and recovery strategies enable social units that have experienced losses and disruption to return as quickly as possible to pre-disaster levels of functioning, as opposed to experiencing prolonged dislocations. Such strategies improve resilience by shortening the time between earthquake impact and physical, social, and economic recovery, while at the same time ensuring that decisions made during the response and recovery period are based on the best available data and information.

While response and recovery activities must be undertaken as rapidly as possible when a major earthquake disaster strikes, it is equally important that the activities that are undertaken are appropriate ones—that is, they employ resources effectively and in ways that contain losses and facilitate optimal recovery. Thus MCEER’s Thrust Area 3 research activities center on two interrelated objectives that are of critical importance to society: improving both the speed with which response, restoration, and recovery activities are undertaken and the quality of the decisions that are made in the immediate and longer-term post-impact period. Such measures will ultimately be judged in terms of the contribution they make to reducing both short and long-term losses and costs associated with earthquakes.

**Previous Years’ Research**

Research activities in past years have addressed the following topics: (1) the extent to which new and emerging remote sensing technologies can enhance resilience by addressing the need for more accurate building inventories for pre-event loss estimation and by providing more accurate and timely data for post-event damage detection and situation assessment; (2) the ways in which MCEER’s advanced loss estimation tools can contribute to resilience by improving response and recovery decision making; (3) the technologies and decision aids currently employed by local government agencies for disaster management and their willingness and ability to utilize more advanced technologies in response and recovery activities; and (4) methods for modeling post-earthquake recovery processes. Additionally, following the events of September 11, research was carried out on the organizational and community response to the World Trade Center attack. That research was supported jointly through a supplementary NSF award to MCEER, MCEER funding, and a grant from the Public Entity Risk Institute. The sections below discuss recent developments in three areas on which Thrust Area 3 activities currently focus: remote sensing, recovery modeling, and community and organizational resilience.

**Remote sensing for loss estimation, response, and recovery**

Tasks associated with this component of Thrust Area 3 seek to determine how remote sensing technologies that have not been previously applied to earthquake hazards and disasters can enhance community resilience. These research activities, which are being undertaken by a multidisciplinary team coordinated by R. Eguchi of ImageCat Inc., have addressed the need for more complete inventories of the built environment and for technologies and tools that can help emergency responders carry out rapid situation assessment in the aftermath of damaging earthquakes. As discussed in more detail in previous annual reports and Research Progress and
Accomplishments volumes, past MCEER research on the use of remote sensing technologies for building inventory development and loss estimation has focused on quantifying important structural and economic parameters associated with different building types, uses, and development patterns. Earlier research on the application of remote sensing technologies for detecting damage following earthquakes has addressed both damage assessment for *entire communities and regions* (Eguchi and collaborators) and the assessment of damage to *individual structures* (Shinozuka). Specific tasks have centered on inventory development for major urban areas such as Los Angeles, as well as on the use of remote sensing technologies to assess damage and recovery in major earthquake disasters, including the Chi-Chi and Marmara earthquakes in 1999 and Bhuj earthquake in 2001, and the Boumerdes and Bam earthquakes in 2003. In earlier years, investigators also conducted a comprehensive review of available remote sensing technologies and their contributions to earthquake loss reduction. That work culminated in year 4 with a 90-page report and companion CD-ROM entitled “Assessment of Advanced Technologies for Loss Estimation.”

Work in subsequent years has increasingly focused on integrating a range of remote sensing technologies, including synthetic aperture radar, high-resolution optical satellite imagery, and GPS-based tools with advanced GIS and improved database management systems. Concurrently, researchers have concentrated on validating data gathered through these techniques against various kinds of “ground-truth” data and on triangulating data collected by means of different remote sensing techniques. Research on the use of remote sensing to detect damage following the 1999 Marmara earthquake illustrates this approach. ERS, SAR, and SPOT optical imagery were used for post-earthquake damage detection, and based on this work, the remote sensing research team developed a series of change detection indices, using measures of intensity difference, correlation, and coherence. These indices were then compared with “ground truth” damage data for two communities, Golcuk and Adapazari. Analytical results indicated that findings based on remotely sensed damage correlated well with on-site observational data. Similarly, displacement and strain field maps derived from GPS measurements were shown to correspond well with maps developed using SAR interferometry.

In related research activity, using supplemental NSF funds, research team members conducted field work to document the use of remote sensing technologies in situation assessment and decision support following the September 11, 2001 terrorist attack on the World Trade Center. That research resulted in an MCEER report entitled “Emergency Response in the Wake of the World Trade Center Attack: A Remote Sensing Perspective” (2002).

In 2003, the MCEER remote sensing team began work on a new post-earthquake reconnaissance tool called VIEWS—Visualizing the Impacts of Earthquakes with Satellites. VIEWS was first deployed for rapid reconnaissance following the 2003 Bam earthquake. At that time, the remote sensing team also began fielding a set of tools called the Virtual Reconnaissance Survey (VRS), which allows researchers to share spatially-referenced disaster impact data online through a web browser. The overall strategy is to employ a two-stage “tiered reconnaissance” approach in which satellite imagery first provides an assessment of damage on a regional basis and identifies severely damaged areas, and other data (e.g., data derived using SAR) are used to assess damage at the level of individual structures.
The remote sensing research carried out in Thrust Area 3 has yielded nearly four dozen conference papers, publications, and workshop presentations since 2002. Examples include a paper on damage detection algorithms using optical and ERS-SAR satellite data, applied to the 1999 Marmara earthquake, which was presented at the 7th National Conference on Earthquake Engineering; a paper on the use of SAR and other remote sensing technologies in the detection of earthquake damage, presented at the International Conference on Earthquake Loss Estimation and Risk Reduction in Bucharest; and a paper presented at the 4th U.S.-Japan-China Trilateral Symposium on Lifeline Earthquake Engineering in China, focusing on the use of remote sensing technologies to detect highway system damage. Other study results have been published in the proceedings of the MCEER workshop on lessons learned from the World Trade Center disaster. Additional findings from recent MCEER research on remote sensing can be found in the 2003 and 2004 “Research Progress and Accomplishments” volume.

The ultimate vision for this element of Thrust Area 3 is to provide risk managers, planners, and emergency managers with better information on exposed assets, more reliable methodologies to project future earthquake losses, and real-time decision support systems that can facilitate rapid response when earthquakes occur. However, before it can be useful in supporting crisis decision-making, techniques must also be developed to provide those data to decision makers as quickly as possible following the occurrence of an earthquake. Thus, investigators are also concentrating on developing more efficient procedures and technologies for rapidly transferring large datasets and files, such as advanced wireless and broadband communications technologies. To move further toward real-time damage assessment capability, MCEER researchers are also developing strategies for obtaining higher-resolution imagery and for acquiring damage data on a very rapid basis following earthquake impact—for example, by utilizing unmanned airborne vehicles (UAVs) that can be quickly deployed over damaged areas.

Agencies that have collaborated with MCEER investigators by providing images and other data include the European Space Agency; NIK Insaat Tikaret (Turkey); Airbornel, which provided LIDAR data for Los Angeles; Japan’s Earthquake Disaster Mitigation Research Center (EDM), which has provided satellite imagery for the 1994 Northridge earthquake and IKONOS satellite coverage for the Bhuj earthquake; the National Center for Research on Earthquake Engineering in Taiwan, which provided IKONOS image data from the 1999 Taiwan earthquake; USGS, which has provided Landsat 7 coverage for Los Angeles; and NOAA, provider of LIDAR data for Southern California. The MCEER team also collaborates closely with university-based remote sensing researchers worldwide, including researchers at Chiba University in Japan, Cambridge University in the UK, and the University of Bologna in Italy.

**MCEER’s comprehensive community recovery model**

The goal of MCEER’s comprehensive community recovery modeling efforts is to develop a decision support system for post-disaster recovery. As indicated in earlier annual reports and “Research Progress and Accomplishments” volumes, initial MCEER research carried out as part of Thrust Area 1 resulted in major advances in earthquake loss estimation methodology. Follow-on investigations undertaken as part of Thrust Area 3 have focused on synthesizing knowledge derived from those modeling efforts with other findings from the literature on community earthquake impacts and earthquake recovery in order to develop a comprehensive model of post-earthquake recovery. The objective of these modeling activities undertaken by S. Chang is to
provide research-based analytic tools that can enhance resilience by enabling decision makers to establish priorities and make better-informed decisions regarding post-earthquake restoration and recovery activities. When fully developed and refined, the recovery model will enable planners and policy makers to forecast the outcomes of a range of pre- and post-disaster choices.

Following disasters, the reconstruction and recovery process typically takes place in a relatively uncoordinated way, often driven by ad hoc decisions. Recovery decision-making is generally confined to particular aspects of the recovery process, such as infrastructure restoration or the provision of redevelopment assistance to commercial districts, without giving consideration to impacts of such decisions on overall community recovery trajectories. The prototype MCEER recovery model, which was initiated in years 3 and 4 and continues to be expanded, validated, and refined, represents the first-ever attempt to model the disaster recovery process comprehensively across various domains (e.g., housing reconstruction, transportation recovery, restoration of employment) and units of analysis (e.g., households, businesses, neighborhoods). When completed, the comprehensive recovery model will make it possible for decision makers and recovery planners to see for the first time how activities undertaken in particular domains affect the progress of recovery in other domains and influence the overall recovery process. The model will allow users to see how particular decisions—e.g., decisions regarding utility or transportation system restoration following an earthquake—affect longer-term recovery outcomes, such as time to recovery and the costs associated with alternative recovery choices. Because the model also includes variables related to pre-event mitigation measures such as building codes, it can be used to show how pre-event mitigation decisions affect post-earthquake recovery outcomes—potentially demonstrating the efficacy of adopting mitigation measures. Ultimately, this important tool will enable users to understand in a much more systematic way than is currently possible how pre- and post-earthquake decisions and policies affect both community vulnerability and community resilience.

Efforts in previous years resulted in the development of a prototype or “first generation” comprehensive model of community recovery, which was implemented in Matlab. Data and variables were added to the model to represent a hypothetical urban area that now includes four neighborhoods with one hundred households and one hundred businesses in each neighborhood. The model was partially validated using data from the 1995 Kobe earthquake. However, testing revealed the need for additional refinements, which were undertaken in years 6 and 7. One such refinement involved moving from a deterministic framework to a probabilistic one.

Additional work on the recovery simulation model in year 7 brought that decision support tool closer to real-world implementation. In 2003, end-users from federal and local government agencies, utilities, and other organizations had an opportunity to review and comment on the first-generation prototype model in focus group discussions, and modifications were made based on those comments. The model was partially validated using data from the 1995 Kobe earthquake, and further refinements to component variables, such as mitigation measures and recovery indicators, are ongoing.

Community and organizational resilience: World Trade Center disaster response

Earlier research on emergency management in Thrust Area 3 centered on local emergency management agencies, their use of various technologies in hazard and disaster management, and their capacity to adopt more advanced technologies. However, following the September 11 attacks, the emphasis in this component of Thrust Area 3 shifted to conducting on-scene quick response field research and more in-depth follow-up studies on the organizational and community response to the World Trade Center (WTC) disaster. Consistent with MCEER’s overall mission and vision, the WTC disaster response study focuses on identifying factors that contributed to New York City’s ability to achieve resilience in the face of an unprecedented crisis event, with a special emphasis on the organizational dimension of resilience and on local emergency management agency operations. Rapid data collection following the WTC attack was made possible through supplemental funds provided by NSF. Additional work was subsequently supported by the Public Entity Risk Institute.

The WTC response study represents an important research opportunity in several respects. First, the emergency response challenges that resulted from the attack on the Twin Towers resemble in many ways what communities can expect to encounter in a major urban earthquake. Research on the WTC disaster can thus yield lessons that can improve the management of large-scale earthquake events. Second, while the September 11 attacks were caused by human action, rather than by natural hazards, many aspects of the public and organizational response were similar to those observed in other large-scale disaster events, suggesting that much of what is known based on decades of research on disasters can be generalized to crises originating from terrorist actions. Along these same lines, the events of September 11 point to the need to explore how engineering and social science insights derived from research on earthquakes and other hazards can be applied to emerging homeland security threats.

Data sources for the WTC study, which is being carried out by the Disaster Research Center at the University of Delaware and the Natural Hazards Center at the University of Colorado, include detailed field notes based on direct field worker observations of ongoing disaster management activities at New York City’s Emergency Operations Center (EOC) and at other emergency response coordination sites around Manhattan following the attack; documentary materials produced by responding agencies; informal interviews conducted in the field during the emergency period; records of public meetings and presentations; systematically-collected newspaper and other media accounts describing various aspects of the emergency response following the WTC attacks; and in-depth interviews with key actors in organizations that played important roles in emergency response activities. These data constitute the largest existing data set on the organizational response to the WTC disaster.

Research in previous years has focused on the development and analysis of network models capable of characterizing the multi-organizational response to the September 11, 2001 attacks. Initial results based on an analysis of the activities of more than 500 organizations that were involved in the post-9-11 response in New York City were presented at the 2004 MCEER annual meeting in Los Angeles and in a paper in MCEER’s 2003-2004 “Research Accomplishments” volume entitled “Networks and Resilience in the World Trade Center Disaster.”
In previous years, MCEER-WTC investigators have produced a number of papers, book chapters, and articles, and approximately a dozen presentations have been made at both professional and practitioner-oriented conferences. A partial list of these meetings includes the 7th National Conference on Earthquake Engineering, MCEER’s 2002 Workshop on Lessons Learned from the WTC Attacks; annual meetings of the American Sociological Association, Emergency Management Australia, the International Emergency Management Society, and the California Emergency Services Association; and a Congressional hearing held in Washington in October 2003, sponsored by the American Sociological Association.

**Year 8 Research and System Integration**

Research tasks in Thrust Area 3 are moving increasingly toward the development of implementable response and recovery decision support tools. In the remote sensing area, research in earlier years focused on proof of concept studies and on validating and ground-truthing remotely-sensed data. Activities are still ongoing in those areas, but in recent years research has turned toward the acquisition of increasingly accurate and timely data from different sources and to fusing those data with GIS platforms and visualization tools. For example, in year 7, the basic damage detection methodology was expanded to include high-resolution QuickBird imagery of the 2003 Bourmerdes and Bam earthquakes.

**Remote sensing**

Year 8 marked a very significant year for MCEER remote sensing research. New methodologies were employed both for damage detection and for infrastructure inventory development. Using a new “object-based” approach to damage detection using data from the Bam earthquake, the remote sensing team devised a semi-automated processing algorithm that compares spectral and textural characteristics of large sets of individual “objects” (in this case buildings) before and after an extreme event. For the development of building inventories for loss estimation, the team developed a new building inventory tool called “MIHEA”—the mono-image height extraction algorithm—that makes it possible to quantify square footage, height, and number of stories for individual buildings. Along with other remote sensing tools MCEER has developed in recent years, MIHEA provides a means for developing more accurate, up-to-date, and complete inventories on building exposures than are available using conventional methods and data.

With respect to the use of remote sensing in post-disaster reconnaissance, teams acquired large amounts of field data following the 2004 Niigata earthquakes, Hurricanes Charley and Ivan, the Parkfield earthquake, and the Indian Ocean Tsunami, as shown in Fig. 10. This work involved the use of both VIEWS and VRS tools. Like earlier research on the World Trade Center disaster, the 2004 studies on non-earthquake disasters have further demonstrated the applicability of MCEER remote-sensing research to other hazards. At the same time, the hurricane and tsunami studies point to the need to expand and refine tools that were originally developed using earthquake-specific data and models. For example, the methodologies that serve as the basis for earthquake damage detection algorithms and for the development of building inventories can be applied to hazards other than earthquakes, but only after further collection and analysis of data on non-earthquake events.
Notable 2004 publications and presentations on remote sensing research and applications include two MCEER quick response reports, “Collection of Satellite Referenced Building Damage Information in the Aftermath of Hurricane Charley,” and “Post-Tsunami Urban Damage Survey in Thailand Using the VIEWS Reconnaissance System;” MCEER technical reports on the use of remote sensing technologies following the Boumerdes, Marmara, and Bam earthquakes; presentations at the 2nd International Workshop on Remote Sensing for Post-Disaster Response, which was held in Newport Beach, CA in October; and a presentation on remote sensing for disaster response for the White House Homeland Security Council. An online catalog of aerial and satellite images from recent disasters, including the 2004 hurricanes, is now available through MCEER’s Users Network.

When MCEER began its research on remote sensing technologies in disaster response, few could have envisioned how quickly the field would develop and how access to high resolution data would improve in only a few short years. MCEER’s goal of integrating technologies and databases into real-time decision support systems now seems increasingly achievable, and even more rapid progress is anticipated in year 9. The work of Thrust Area 3 investigators has put MCEER investigators at the forefront of a rapidly-expanding research area that has applications not only for earthquakes but also for other types of disasters. Recognizing this potential, MCEER management has made remote sensing research for response and recovery an integral element in its year 10 graduation plan.

**Recovery modeling**

In year 8, S. Chang continued work on the development of a “second generation” recovery model that is both more refined and more closely integrated with the Los Angeles lifelines testbed. This integration is achieved by using outputs of the Los Angeles lifeline loss and resilience model as inputs into the recovery model. Several significant technical challenges are being addressed in this “second generation” model, including challenges associated with using the model to analyze a very large urban area and with further refining model variables to take...
into account such factors as variations in the effectiveness of mitigation measures, and also to more accurately measure recovery outcomes. As this work goes forward, additional data are being collected and sensitivity tests are being conducted to improve model accuracy. With the application of the recovery model to the Los Angeles testbed, local government and utility officials in that community will be able to take part in demonstrations that will enable them to have a full picture of the community recovery process—including interactions across time, space, and community sectors—and to see how the decisions they make affect long-term recovery trajectories. S. Chang and S. Miles co-authored a chapter entitled “The Dynamics of Recovery: A Framework,” which appeared in Chang’s co-edited volume “Modeling Spatial Economic Impacts of Natural Disasters” (2004). A related publication by S. Chang and C. Chamberlin in the 2003-2004 Research Accomplishments volume entitled “Assessing the Role of Lifeline Systems in Community Disaster Resilience,” focused on the economic and social impacts of earthquake-induced lifeline disruption and on the manner in which utility infrastructure mitigation can enhance post-disaster resilience. S. Chang also made a presentation on the recovery model at the First International Conference on Urban Disaster Reduction in Kobe, Japan, in January 2005.

**WTC crisis response**

Year 8 research on the World Trade Center crisis response case study has included both qualitative and quantitative analyses. Qualitative research has focused on organizational improvisation following the terrorist attacks. The capacity to improvise has long been recognized as a significant source of organizational resilience in extreme events; organizational effectiveness under conditions of uncertainty and urgency depends upon the ability to both adhere to plans and depart from plans to develop novel approaches to new problems as they appear. Since the WTC disaster created major unanticipated problems for responding organizations, including the loss of virtually the entire upper command structure of the Fire Department, the collapse of the building that housed the city’s Emergency Operations Center (EOC), and a host of other response-related demands, responding effectively required extensive improvisation. Year 8 research has focused on (1) developing a typology of multi-organizational improvisational forms encompassing creative, adaptive, and reproductive improvisation; (2) documenting three large-scale instances of improvisation—the reconstitution of the New York City Emergency Operations Center (reproductive), improvised procedures to maintain site security (adaptive), and improvised debris removal/forensic investigation activities (creative); and (3) identifying conditions that foster improvisation.

Quantitative analyses conducted in year 8 have focused on developing a better understanding of the structure of inter-organizational networks that developed around specific crisis response tasks. The WTC data revealed the existence of forty-four separate task areas in which responding organizations participated, including fire suppression, search and rescue, debris removal, crisis counseling, donations management, infrastructure restoration, crime investigation, and a wide range of other tasks. Initial analyses carried out in years 7 and 8 suggest that these emergent task-specific sub-networks took a variety of forms and that both sub-network forms and organizational positions within networks had an impact on organizational effectiveness.

Year 8 research products include a doctoral dissertation, “Improvising 9-11: Organizational Improvisation Following the World Trade Center Disaster,” by T. Wachtendorf and a M.A.
thesis entitled “Searching for a System: Multi-Organizational Coordination in the September 11th World Trade Center Search and Rescue Response” by J. Trainor. Several presentations on WTC findings were made during this reporting period, including presentations at the 2004 annual meeting of the American Sociological Association, the 2004 Canadian Research on Hazards Network Symposium, the International Conference of the European Crisis Management Academy, and the 4th Workshop for Comparative Study on Urban Earthquake Disaster Management in Kobe, Japan.

Year 9 Research Plan and System Integration

Three significant changes will be made in MCEER’s research activities in Thrust Area 3 in year 9. First, three tasks that formerly had been carried out as part of Thrust Area 1 and overarching Center-wide tasks will be “transferred” to Thrust Area 3 in order to encourage more interaction among investigators and facilitate the development of comprehensive decision support systems. Those tasks focus on the development of web-based GIS for crisis response (A. Lembo); post-event lifeline restoration modeling (R. Davidson); and modeling regional economic resilience using a computable general disequilibrium framework (A. Rose). This reorganization will result in better integration among all MCEER tasks that focus on disaster response and recovery.

Second, in keeping with MCEER’s post-graduation strategic plan, Thrust Area 3 research will continue to expand beyond earthquakes to other types of extreme events. As the discussions above have shown, significant progress has already been made in extending data collection and analysis methods to other types of events, but efforts to generalize beyond earthquakes has now become an explicit goal in year 9 and is reflected in funding decisions for various tasks.

Third, work in Thrust Area 3 will continue to focus on ways of ensuring that the tools that are developed will address user needs. Timeliness is one important end-user concern; particularly with respect to emergency response tools, data and model outputs must be made available rapidly, or they will be of little use to decision makers. MCEER decision tools must also meet user needs with respect to the form and scale at which outputs are presented and the types of questions the tools are able to address. To meet these criteria, task activities will move toward real-time data extraction and processing, and PIs will continue to interact with and seek input from end-users as they continue their research and modeling efforts.

Figure 11, which was taken from the year 8 research of S. Chang and C. Chamberlin, shows the manner in which MCEER models community resilience from the perspective of electric power systems. This same figure can also be seen as providing an overall perspective on how various thrust area activities are being integrated and the manner in which they can be used to guide post-event decision-making. Models of building damage and lifeline disruption can be developed using software tools such as HAZUS, but they can also be generated through the use of remote sensing and rapid post-earthquake GIS products (R. Eguchi, M. Shinozuka, A. Lembo, and others). Empirically-grounded discrete event restoration modeling (R. Davidson), which takes into account emergency response and system restoration activities, helps determine the spatial and temporal dimensions of lifeline outages and also yields information on social and economic losses under different restoration scenarios. Models employing economic and socio-demographic data (A. Rose and S. Chang) are used to estimate the social and economic impacts of earthquakes—and ultimately other extreme events—which are judged in light of MCEER-
developed social and economic resilience factors that have been informed by stakeholder performance criteria. Outputs from such analyses can also be incorporated into recovery models capable of characterizing a range of resilience outcomes (S. Chang). These integrated data collection, analysis, and modeling activities can be used to support decisions regarding response and recovery, but also pre-event decision making with respect to mitigation and preparedness.

**Figure 11: Community Resilience Model.**

**Tools for disaster response: remote sensing and web-based GIS**

Particularly as a consequence of its year 8 activities, the MCEER remote sensing team has collected a large amount of data on diverse disaster events and has formed productive partnerships with data providers and university-based investigators around the world. During years 9 and 10, the team will focus on fully exploiting these data and on making additional progress toward real-time applications. In year 9, the team will continue to refine the tools developed in recent years, including VIEWS, VRS, and MIHEA. M. Shinozuka will work primarily with SAR imagery collected following the Bam earthquake. B. Houshmand, a collaborator from JPL, will focus on the use of spaceborne SAR for rapid damage detection. One of Houshmand’s research goals for year 9 is to develop algorithms capable of automatically generating post-disaster coherence maps for damaged urban regions.

Following his success in making critical data available rapidly following the Niigata earthquakes and the Indian Ocean tsunami, A. Lembo from Cornell University will continue research on advanced Internet-based map server technology for rapid disaster response. A special feature of this work is Lembo’s close collaboration with emergency management organizations, which is geared toward ensuring that the GIS products that are developed meet user needs. Year 8 research focused primarily on technological innovations designed to make crisis relevant GIS data available immediately through the Internet. Year 9 activities will include additional technological refinements but will focus equally on gathering data to better understand the technology and emergency response needs of real-world emergency management organizations.
Year 9 research partners will include LADWP, the Los Angeles Emergency Preparedness Department (both for earthquake planning) and the New York State Office of Cyber Security and Critical Infrastructure Coordination (for homeland security threats).

**Multi-Hazard Considerations.** Recent research activities have demonstrated that with further research and methodological refinements, MCEER’s remote sensing and web-based GIS mapping tools are applicable to natural hazards other than earthquakes, as well as to technological and willful disasters. Year 9 tasks will contain elements that explicitly seek such expansion. In the remote sensing area, for example, R. Eguchi and the ImageCat team will begin using satellite imagery to develop spectral and textural databases for building facades and will validate those data through field work in urban areas, with the objective of better understanding the vulnerability of structures to terrorist attacks. This work will also include analyses of features within urban settings, such as topographical features, that might exacerbate or mitigate the impact of attacks on structures and will be supplemented with data and images from events such as the recent North Korean train explosion, 9-11, and the Oklahoma City bombing. Damage detection and building inventory methodologies will also be extended to hurricanes and tsunamis. Other research will focus on the use of SAR in the assessment of coastal hazards and population vulnerability, as well as the development of more refined damage detection procedures for various types of disasters.

**Tools for disaster recovery: Resilience, restoration, and recovery**

R. Davidson will continue her research on discrete event modeling of the power system restoration process, including work on optimizing the restoration process, using the LADWP testbed. In year 8, Davidson began expanding her research to the Los Angeles water system, beginning with the collection of empirical data on water system restoration processes and the development of a discrete event model for the water system. By the end of year 8 and extending into year 9, she will combine the water system damage model with the water restoration simulation model, thus covering both water and power lifeline systems. Since travel system damage and travel times are key parameters of the lifeline restoration models, model refinements will also take advantage of estimates developed through REDARS, MCEER’s transportation model for earthquakes. A key advantage of this modeling effort is that it explicitly takes into account decisions that lifeline organizations make with respect to restoration and shows how resilience can be enhanced through improved decision making.

**Multi-Hazard Considerations.** As illustrated by events such as the 1906 San Francisco, 1923 Kanto, and 1995 Kobe earthquakes, earthquake-induced fires can produce extensive damage, economic losses, and casualties. In year 9, R. Davidson will address the problem of fire following earthquakes (FFE) in the context of the LA testbed. The ultimate goal of this task is to develop a new model that better characterizes post-earthquake fire ignition, spread, suppression, and damage. The task will first involve the collection of original data on earthquake induced fires and on existing models of fire ignition and spread. Next, discrete event simulation models will be developed that build upon and improve on those models. The Davidson FFE model will take into account issues that have not been adequately addressed, such as the effect of slopes and vegetation on fire spread, exposures associated with different types of occupancies, and ways of characterizing uncertainty. Perhaps most important, the new model will incorporate the water and power restoration simulation models, as well as the REDARS transportation risk model.
Moving on to tools for quantifying economic resilience, A. Rose will further refine conceptual, empirical, and technology transfer aspects of a computable general equilibrium model, which measures business, industry-level, and regional economic resilience to earthquakes. This model, which has matured in previous years, can now estimate direct and indirect business interruption losses from both water and electricity service disruptions and can simulate the regional economic impacts of both mitigation and recovery policies. Important advances that are anticipated in year 9 include continued collaboration with S. Chang and R. Davidson on community-wide economic and social resilience criteria and on criteria for system restoration, as well as new model improvements that will be developed on the basis of data collected from utility customers. S. Chang will continue her research on social and economic resilience, including research on social impacts of lifeline outages, such as household dislocation. For dislocation impacts, resilience is measured in terms of the number of households affected and the duration of displacement. This task will also use focus group methods and exercises to develop a better understanding of performance and resilience objectives that are considered appropriate by different stakeholder groups, including utility officials, emergency managers, elected officials, and representatives of community groups.

**Multi-Hazard Considerations.** A. Rose plans to explore ways in which the computable general equilibrium/disequilibrium methodology can be expanded beyond earthquakes to include hazards such as floods, hurricanes, and terrorist attacks. Rose already has extensive experience conducting similar research on other types of economic “shocks,” including natural hazards rolling electricity blackouts. Similarly, S. Chang will expand her interviews and focus group and exercise activities to take into account hazards other than earthquakes.

Finally, S. Chang’s comprehensive recovery model will increasingly provide a platform for integrating Thrust Area 3 tasks. As discussed above, this model seeks to better understand recovery as a comprehensive process that incorporates disaster impacts at various levels of aggregation (households, neighborhoods, businesses, and regional economies), response, restoration and reconstruction, as well as pre-event decision making with respect to mitigation and planning. This research activity has involved the development of a simulation tool that includes infrastructure, social, economic, and decision variables, their interrelationships, and the dynamics of the recovery process. The model both draws upon and informs other Thrust Area 3 tasks, including, in particular, the work of Davidson and Rose. Task activities in year 9 will focus on the use of the “second generation” recovery model in the analysis of outcomes from different sets of mitigation and recovery policy choices, implemented in different community settings. These simulation runs will make it possible to show how the application of different policies will affect long-term losses and community resilience, and also to explore whether policy strategies work differently across different community settings.

**Multi-Hazard Considerations.** The recovery model has been developed using data from research on earthquakes. However, the basic logic underlying the model can be used for other types of disasters, including those resulting from intentional acts of terrorism. At the same time, it may also be the case that recovery processes and dynamics are influenced more by the social and economic characteristics of affected communities than by disaster agent type. S. Chang plans to explore this question in years 9 and 10.
User Networks for Seismic Assessment and Retrofit of Critical Facilities

| Task Leader: A. Reinhorn, Civil, Structural and Environmental Engineering, University at Buffalo  
  G. Dargush, Civil, Structural and Environmental Engineering, University at Buffalo  
  R. Eguchi, ImageCat, Inc.  
  M. Grigoriu, Civil and Environmental Engineering, Cornell University  
  G. Lee, Civil, Structural and Environmental Engineering, University at Buffalo  
  E. Maragakis, Civil Engineering, University of Nevada/Reno  
  T. O'Rourke, Civil and Environmental Engineering, Cornell University  
  M. Shinozuka, Civil Engineering, University of California/Irvine  
  A. Whittaker, Civil, Structural and Environmental Engineering, University at Buffalo |

The MCEER User Networks activities are developed to enable transfer of information between MCEER investigators and end users. As such, the networking program serves as a catalyst to develop usable tools and databases (from the main research tasks in Thrust Areas 1, 2 and 3) to collect the research products developed by the multiple and geographically distributed MCEER investigators, and to broadly share these products with users in the earthquake engineering community. Among these tools and research results are procedures and computerized platforms, new techniques for experimental and computational evaluation and qualification, and extensive databases related to MCEER’s activities to enhance the seismic resilience of communities.

To achieve the objective of providing an advanced framework for sharing experimental and advanced computational resources and data, through electronic and computerized networks using innovative information technologies, efforts have been invested to establish connectivity and structure accessibility, and to engage MCEER’s investigators in developing web-compatible content.

Due to the complexity and the diversity of hospitals, urban water supply and electric power systems, and due to the distributed location of computational and experimental facilities throughout the MCEER institutions, integration of resources provides a better infrastructure for research and dissemination of information. It also provides the infrastructure for real-time remote observations and interaction during experiments, for distributed data storage and for the development of software platforms available to research teams and industry users. Tasks related to access and technologies are clearly identified, as well as possible interactions between selected components of MCEER’s network with the new NSF-NEES initiative (George E. Brown Jr. Network for Earthquake Engineering Simulation). While the development of new engineering tools and information/data are generated in the research tasks in Thrust Areas 1 to 3, the users networking area of activity develops the infrastructure and toolkits needed for the necessary linkages.
Previous Years’ Research

Several accomplishments in the past several years have been brought to use in year 8. Researchers involved in MCEER User Networks activities have:

- Established a Users Network that links the MCEER experimental and computational facilities: [http://mceer.buffalo.edu/research/](http://mceer.buffalo.edu/research/), as illustrated in Fig. 12.

![MCEER Portals for access to Users Networks.](image)

- Developed and published on the website basic templates for adding new databases and software to the network. Among the examples of implementations are the websites established for the MCEER seismology and ground motion information; website expansion for software platforms such as the 3D-BASIS series, used for the analysis of base isolated structures; and website for experimental databases for collapse of structures. Additional templates were developed for databases resulting from computational evaluations.

- Established a computational network, which includes software platforms for high performance computing (DIANA, ABAQUS) modified by MCEER investigators to perform fragility/sensitivity analysis and design. The website includes advanced software developed by the research tasks for inelastic analysis and design of structures (IDARC2D, IDARC-Bridge, 3D-BASIS, NSPECTRA, EADR, EADS, RDAT, etc.), procedures of evaluation of fragility (PSHA_IDARC) and decision tools (RDAT). The nonlinear analysis software platforms include models of advanced damping devices and control, which have been used by various MCEER investigators to develop new design standards for damping systems (see Constantinou, 2000 in “Research Progress and Accomplishments” volume).
Established an experimental facilities network, which includes benchmark shake table experiments on lifelines (damage limits of piping), on advanced damping devices (toggle brace system), and on a new versatile benchmark model for irregular structures and protection systems.

Established an electronic classroom with web video streaming capabilities and with multicast connections for seminars and student activities. The information is stored electronically for later playback and archiving. Several guest seminar series already tested the capabilities, as illustrated in Fig. 13. Procedures and recommendations for equipment were prepared for the other member institutions of MCEER.

![Seismic Risk Mitigation](image)

**Figure 13: MCEER Webcast Seminar on Nonstructural Components.**

Developed basic tele-operations of laboratory equipment and set-ups. The procedures have already been used for network management, calibration of instruments and troubleshooting of equipment by laboratory specialists. Demonstrations were made to the NEES participants and MCEER site visit teams. The procedures developed for tele-operations are used in the current SEESL (Structural Engineering and Earthquake Simulation Laboratory) facility at the University at Buffalo which hosts MCEER and NEES services.

The MCEER User Networks were also used to disseminate and distribute plans and analytical models for the MCEER East Coast and West Coast demonstration hospitals. Moreover, databases of New York States hospitals were prepared and made available to other researchers.

**Development of Users Network**

The main goal of the research plan of the MCEER User Networks is to develop the network of facilities – experimental, computational and educational – in a web centric system using network-wide distributed information prepared by MCEER investigators in research subtasks. The network provides a common secured access web area (portal) in which benchmark problems, databases, computational tools, experimental tools and facilities information, as well as products (completed or in progress) are shared. The results of the work conducted in the research subtasks are then connected to the MCEER Users Network, a website which is
continuously updated to include new information. Automated update links are developed and maintained for ease of operations.

As such, the research activities of the MCEER User Networks revolve around a central task to (i) coordinate networking activities, (ii) identify and determine the required sub-tasks in the research programs that have mature information that can be shared and integrated, (iii) to prepare tools and databases for integration of products, and (iv) to assist in the development and operation of all participating investigators and institutions. This includes preparation of special infrastructure for web interactive operations and video connectivity. This also includes the development of high-quality internet (IP) based video observation and conferencing with simultaneous video and data transmission; development of technology for education and lab demonstrations through video streaming and recording; development of protocol for tele-participation via application sharing (standardized COTS) procedures; and development of templates for information integration and to assist other investigators in networking their products.

**IT coordination issues**

The MCEER networking task force (led by A. Reinhorn, assisted by E. Maragakis) coordinates and develops templates to organize the information for ease of access and for distributed maintenance. Complementing video with the numerical/graphical data facilitates scientific developments and interpretations by participating investigators. Mixing data and video using dedicated software and designing a MCU-based operation facilitates cooperation and reduces further travel costs. Web-based templates are provided as standards to initiate other participants to use consistent approaches for the manipulation of data and information. The task force also assembles video equipment and IP-based procedures to exchange video and data in real-time (or near real-time) and tests experimental exchange using high speed Internet2.

**Research tools and databases from research tasks**

Research tasks were identified to have potential for products which are being networked according to the flow diagram shown in Fig. 14. The networking diagram is built on the MCEER system approach which includes the conventional excitation-infrastructure-response and a response modification based on feedback including performance survey-evaluation-decision-remediation (simulating post event actions) or feed-forward simulating preventive interventions. The numerals show the tasks and year of accomplishment.

Subtasks in Thrust Areas 1, 2, and 3 have been assigned for networking in year 8. A series of projects complementary to the main research tasks were developed during years 5, 6 and 7 from the work accomplished in Thrust Areas 1 through 3. Accomplishments of year 8 are listed below (names of contributing researchers provided in parentheses):

- **Computational tools for evaluation of structures and lifelines.** This includes software for fragility evaluation of nonstructural systems with cost evaluation (M. Grigoriu, D. von Winterfeldt), development of software framework and tools to automate and integrate fragility sensitivity in global and local structure evaluation (A. Reinhorn, A. Whittaker), software documentation for fragility evaluation of nonstructural systems (A. Whittaker, A. Reinhorn), software for evaluation of lifelines (water and electrical systems) (S. Chang, M
Shinozuka), and software for optimal design of response modification technologies (G. Dargush, A. Reinhorn).

- **Development of databases of information for evaluation of structures and lifelines.** This includes experimental information in separate databases, for fragility of piping systems (E. Maragakis, M. Grigoriu), and for web-based GIS database of water distribution system (T. O’Rourke). In addition, this development includes databases of case studies of structures and analytical models for hospital utility systems and subsystems (G. Lee, A. Whittaker).

- **Development of a database of satellite imaging and software** for interpretation of Virtual Reconnaissance System (VRS) (R. Eguchi); Development of reconnaissance software VIEWS integrating satellite data, with terrestrial information, GPS data and descriptive evaluations (R. Eguchi).

- **Development of information and software** to determine direct losses, social impacts, and community resilience for the Los Angeles lifeline study (S. Chang); software for risk and reliability of lifelines/water supply systems (M. Grigoriu, D. von Winterfeldt); and software for evolutionary methodology for decision support (G. Dargush, D. Alesch and W. Petak).

- **Development of databases of case studies** of structures and analytical models for hospitals utility systems and subsystems (G. Lee, A. Whittaker).

- **Development of software for integrated evaluation of system performance** for transportation and water supply with resilience implications (M. Shinozuka).

![Figure 14: Network Diagram based on MCEER System Approach.](image-url)
Education and information transfer

The Networking Program assists all MCEER activities with connectivity for conferencing, webcast streaming of information, laboratory connectivity, and online tele-operations. New developments were required to allow for links and transfers of video, voice, data and real-time presentations. Hardware and software are linked, in some cases, with readily available software, or newly developed communication platforms have to be connected. This task provided the hardware infrastructure and the organization to enable communications through the Internet (networks or webs), including the development of connectivity with Florida A&M University, CUNY and NJIT (minority-serving institutions) for educational and student activities which started in spring 2003. A demonstration of the technology was completed in summer 2003. The documentation for such development was added to the Users Networks.

The Networking Program is at the base of student connectivity. The program assists the Student Leadership Council (SLC) with conferencing capabilities and organization. Infrastructure was prepared to enable independent use of resources. Manuals and instructions are being prepared for self training. Moreover, the program provides capabilities of recording and streaming of information from special classes to develop a series of instructional modules for training in the laboratory, or developing design skills.

The Networking Program (in cooperation with MCEER Education Director, S. Thevanayagam and Prof. Lee the instructor) supports a multidisciplinary seminar series on integrated engineering and social science aspects. The Networking Program provides the infrastructure for development of such a seminar series using remote speakers and audience. The Networking Program is identifying the infrastructure needed for such distributed courses and will perform tests for connectivity and communications.

Year 9 Research Plan and System Integration

The restructured MCEER Networking Program is intended to integrate products generated by all tasks and approaches specified in MCEER’s new Strategic Plan, as shown in the system diagram in Fig. 14. The main goal of the restructured Networking Program is to develop a joint platform for computational tools and the associated databases resulting from development of analyses and testing performed in the main tasks. This requires development of new innovative database management for experimental and analytical information and development of an Internet-based information technology infrastructure for collaboration by MCEER investigators and associated industry partners. The networking products are developed in separately developed sub-tasks.

The networking infrastructure has grown by integrating matured individual software products and databases developed for evaluation of structures and lifelines and for surveying damage. The products integrated in the network are those that became available from previous research tasks; several issues arise: (i) those products did not cover the overall Center-wide mission as reflected in the system diagram in Fig. 14; (ii) moreover, the products are located at distributed locations, act independently, with manual interaction and activation. The main objective of year 9 is to integrate, automate and activate the distributed computing system. While this is a continuation of the original objectives of the program, in year 9 the integration will start based on new developments in the grid computing, primarily based on the availability of the NEESgrid.
infrastructure, an open architecture, currently missing the computing simulation infrastructure, which can be offered by MCEER through this task. The objective is to implement the developments of MCEER’s integrated multi-Hazard risk Reduction Decision tools (MCEER-iHARD) in a grid environment which simulates the center system diagram.

The work done in this program is generic and although elements of simulations are being developed in NEESgrid (such as the OpenSEES platform developed by the PEER Center) – through its CHEF and GLOBUS components – the suggested task would provide a much broader content for decision making capabilities (as pioneered by MCEER), spanning from engineering (technical) to socio-political (organizational) issues. The proposed task will utilize grid computing capabilities (knowledge available in the IT community), which can be easily integrated into the NEESgrid. Use of the NEESgrid will facilitate and save some parts of the generic developments related to access authorizations.

Year 9 will focus on the development of a prototype example linking several products resulting from research tasks, ground motion generation, network layout (GIS), and damage survey (Satellite), resilience evaluation, decision support, response modification, and integration done within a grid computational system. A series of projects complementary to the main research tasks were developed during year 8 from the work accomplished in Thrust Areas 1 through 3 (names of contributing researchers provided in parentheses) and expanded to be integrated in the developing platform.

In addition, several networking tasks will provide new material for the platform (i) M. Grigoriu’s decision support software (Thrust Area 2); (ii) G. Dargush’s desktop version of evolutionary design method (Thrust Area 2); and (iii) R. Eguchi’s databases and satellite data collection and display including software for reconnaissance (Thrust Area 3). Other products are currently in the integration process: S. Chang’s procedures (Thrust Area 3), A. Filiatrault’s development of MCEER ground motions (Thrust Area 2), and M. Shinozuka’s resilience platform (Thrust Area 1 and Overarching). Also, the networking tasks will integrate the results of the new multi-hazard tasks as they become available in year 9.

Furthermore, work will continue in year 9 to complete the following tasks:

- **Computational tools for evaluation of structures and lifelines.** This includes software for fragility evaluation of nonstructural systems with cost evaluation (M. Grigoriu, D. von Winterfeldt), development of software framework and tools to automate and integrate fragility sensitivity in global and local structure evaluation (A. Reinhorn).
- **Development of databases of information for evaluation of structures and lifelines.** This includes web-based GIS databases of water and electrical distribution systems (T. O’Rourke).
- **Development of information and software** to determine direct losses, social impacts, and community resilience for the Los Angeles lifeline study (S. Chang); software for risk and reliability of lifelines/water supply systems (M. Grigoriu, D. von Winterfeldt); and software for evolutionary methodology for decision support (G. Dargush, D. Alesch).
- **Development of software for integrated evaluation of system performance** for transportation and water supply with resilience implications (M. Shinozuka).
Multi-Hazard Tasks: Mitigation of Infrastructure against Multi-Hazard Extreme Events

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<th>Year 9 Research Team</th>
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| **Task Leader:** M. Bruneau, Civil, Structural and Environmental Engineering, University at Buffalo  
D. Alesch, Public and Environmental Affairs, University of Wisconsin, Green Bay  
G. Dargush, Civil, Structural and Environmental Engineering, University at Buffalo  
R. Eguchi, ImageCat, Inc.  
G. Lee, Civil, Structural and Environmental Engineering, University at Buffalo  
A. Reinhorn, Civil, Structural and Environmental Engineering, University at Buffalo  
M. Ala Saadeghvaziri, Civil and Environmental Engineering, New Jersey Inst. of Technology  
A. Whittaker, Civil, Structural and Environmental Engineering, University at Buffalo |

As part of its strategic plan to transition from an earthquake engineering research center into an extreme event research center beyond 2007, MCEER will invest a significant part of its research effort in strategically significant projects related to multi-hazard mitigation of infrastructure. This is achieved either through an extended scope of work supplementing the current MCEER research tasks that have a potential to be applied to multi-hazard mitigation of infrastructures as well as through the new research tasks described in this section. These new multi-hazard tasks combine strong scientific merit and potential for leading to large Center-wide multi-hazard initiatives in the future, while at the same time fulfilling MCEER’s seismic resilience mission within the current NSF-EERC program. It is proposed to conduct six different multi-hazard tasks in year 9 as described below.

D. Alesh will develop a methodology that will enable a better understanding of the relationship between the extent of losses in a community from an extreme event and recovery prospects and processes. The goal is to develop a comprehensive theory of community recovery and a set of models to evaluate the value of alternative mitigation and recovery strategies. The year 9 research will ascertain the feasibility and desirability of using self-organizing systems concepts to model what happens in communities following extreme events, depending on the amount of damage to artifacts and to social and economic relationships within the community and between the community and other places, pre-event system characteristics, and strategic interventions following the event. This work will build on, complement and support research currently being done by S. Chang at MCEER. It also builds on previous work conducted by D. Alesch and L. Holly under the aegis of the Public Entity Risk Institute.

G. Dargush and A. Reinhorn will advance the development of a computational platform suitable for the analysis of structures subjected to severe multi-hazard environments. While a number of approaches are available for analyzing structural systems under dynamic conditions, none are able to handle the complexities associated with deteriorating response to severe transient loadings; in particular, complexities associated with progressive collapse or sudden changes of geometry and complex stability issues. The proposed approach, based upon a Hamiltonian
formulation developed earlier at the University at Buffalo, has the potential to address these problems in a more systematic way. Consequently, this research is intended to provide MCEER with a unique, advanced computational capability that would be helpful in seeking multi-hazard funding beyond year 10.

R. Eguchi will consider the application of remote sensing technologies in the assessment of human threats to large buildings. This research will build upon methodologies already developed at MCEER for earthquake assessment by 1) refining building height extraction algorithms using high-resolution optical data, 2) creating new methodologies to identify building surface materials and building construction systems using spectral and textural information from satellite imagery, and 3) working with insurance industry officials to implement residual products from this research.

G. Lee will develop a systematic methodology to evaluate the potential multiple hazard (earthquake, fire, and blast) impact of critical facilities (the structural systems together with nonstructural/utility systems). For this purpose, a three-level model will be created for the MCEER east coast (New York State) demonstration hospital: a physical model of the integrated critical facility system, a group of hazard analysis models, and a model of critical failure modes of the physical systems due to hazard acting on them. By analyzing the hazard-based vulnerability of the system and the severity of the failure modes, a quantitative methodology for measuring the hazard impacts of critical facilities will be established.

Ala Saadeghvaziri will evaluate the proof of concept of an innovative water-based protective technology as multi-hazard mitigation measures for civil infrastructure (hospitals, schools, embassies, bridges, etc.). The conceptual design is based on identification of water spray as a possible mitigation system combined with jacketing, which is well established as an effective seismic retrofit measure. Additional benefits include added protection against fire and vehicular collision depending on the application. Year 9 research will be proof of concept activities, which will include i) continuation and expansion of the literature search to fine tune the conceptual design, ii) small scale explosive tests, and iii) development of analytical models for future use to extrapolate explosive tests and plan additional research needs should the concept be proven viable.

A. Whittaker will address the combined seismic and blast protection of safety-related nuclear power plants. The blast tolerance of protected and conventional nuclear power plants subjected to improvised explosive devices will be considered through numerical dynamic analyses. Fragility curves will be developed for critical nonstructural components in nuclear power plant.
3. EDUCATION AND OUTREACH ACTIVITIES

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<th>Year 8 Education and Outreach Team</th>
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<tr>
<td><strong>Task Leader:</strong> S. Thevanayagam, Civil, Structural and Environmental Engineering, University at Buffalo</td>
</tr>
<tr>
<td>M. Abdullah, Civil Engineering, Florida A&amp;M University</td>
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<tr>
<td>A. Agrawal, Civil Engineering, City University of New York</td>
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<td>G. Mylonakis, Civil Engineering, City University of New York</td>
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<tr>
<td>R. Purasinghe, Civil Engineering, California State University, Los Angeles</td>
</tr>
<tr>
<td>B. F. Spencer, Jr., Civil and Environmental Engineering, University of Illinois, Urbana-Champaign</td>
</tr>
<tr>
<td>S. Tangalos, MCEER, University at Buffalo</td>
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A. Overview

MCEER’s education and outreach program focuses on a wide range of audiences who benefit from the discoveries and outcomes of MCEER research. Audiences range from precollege students and teachers to the public at large, from the career academician to the practicing engineering, architecture and planning professional and from decision-shapers (media) to the decision-makers. The mission of the MCEER education and outreach efforts is to increase awareness of the earthquake hazard - particularly in geographic areas of lesser-known exposure, to help others to understand and accept the implications of seismic risk, and to encourage implementation of earthquake loss-reducing programs and engineering technologies. These activities are essential to promoting the Center vision of community disaster resilience. The program has several components: K-12; undergraduate and graduate education; professional education - including workshops, conferences and short courses; and educational outreach: public-at-large, publications and information services. Starting from January 2005, Dr. S. Thevanayagam, Professor in the Department of Civil, Structural and Environmental Engineering at the University at Buffalo, is the overall education program coordinator.

The goals of the program are to achieve several outcomes, which can help to advance MCEER’s mission of enhancing community earthquake resilience, in part by working to dissolve the interface between research and education in order to establish a continuum of knowledge transfer. The following sections review selected accomplishments in the program and describe intended efforts for the future.

B. Education

Undergraduate

MCEER has developed an active program to attract and involve undergraduate students in earthquake engineering research and develop their interest in pursuing advanced study in earthquake engineering. This is accomplished through a variety of Center-wide programs, including:
- Summer REU (Research Experiences for Undergraduates) Programs (since 2001)
- Seismic Design Competition for Undergraduates (since 2004)
- Center-wide informal research experience with MCEER faculty at home institutions
- Course Modules in Earthquake Engineering
- Virtual Laboratory Education Modules

**REU Program:** The REU program has flourished at MCEER since 2001 (Fig. 15). Since 2003, this program is coordinated with MAE and PEER REU programs. It has been offered every year at MCEER since 2001 and will be offered again this summer. The REU program sponsors outstanding junior and senior undergraduate students in civil engineering to spend ten weeks conducting individual research projects exploring new directions in earthquake studies over the summer at the NSF-funded MCEER-affiliated earthquake research universities. At the end of the program, the students present their research results at a tri-center symposium and participate in field trips and other technical activities jointly organized by MCEER, MAE and PEER. The research papers and presentations are published in a proceeding and are made available at [http://www.mceer.buffalo.edu/education/reu/default.asp](http://www.mceer.buffalo.edu/education/reu/default.asp). REU graduates have chosen graduate career paths at EERC affiliated institutions, and have served as mentors to other undergraduates as well as high school students.

![REU Program Participants](image)

**Figure 15: REU Program Participants.**

The REU 2004 program culminated in a *Tri-center Symposium for Undergraduate Researchers* in South Carolina in August 2004. The REU 2005 program at MCEER includes nine undergraduates from across the U.S. It is set to begin on June 1, 2005 and will culminate in a Tri-center Symposium in Reno, Nevada in August 2005.

**Diversity REU Program:** In year 8, MCEER started an effort to develop a Diversity REU Program at UB for under-represented minorities and students from historically black universities under the NSF-supported Louis Stokes Alliances for Minority Partnerships program. Professor Makola Abdullah is coordinating this effort as MCEER’s Diversity Director. This program is also coordinated with MAE and PEER. Joint tri-center recruitment mechanisms have been developed. In year 8, a first group of three students have been recruited for this program at
MCEER and they will join the regular REU students in June 2005. MCEER has received further funding from NSF to continue both REU programs in year 9.

**Seismic Design Competition for Undergraduates:** In year 8, MCEER initiated its first seismic design competition for undergraduates (Fig. 16). Five universities involving a total of 25 undergraduate students participated in this event held at UB in January 2005. This involved design and construction of a 12 story building using balsa wood. The buildings were judged based on several criteria and building performance subjected to shake table testing at UB ([http://www.mceer.buffalo.edu/education/slc/default.asp](http://www.mceer.buffalo.edu/education/slc/default.asp)). The event was organized by the SLC (Student Leadership Council) of MCEER. The winning team participated in the first tri-center seismic design competition and competed with participants from PEER and MAE participants in a tri-center competition held in April 2005 at Berkeley, CA. These competitions are intended to introduce undergraduates to design and construction of earthquake resistant structures using advanced earthquake protective systems, and attract them for graduate studies in earthquake engineering.

![Figure 16: MCEER Seismic Design Competition.](image)

**Minority Serving Institutions:** In year 4, a targeted effort was initiated to reach out to minority serving institutions to promote and engage undergraduate students in earthquake engineering. This included three minority serving institutions, California State University Los Angeles (R. Purasinghe), City College of New York (A. Agrawal and G. Mylonakis) and Florida A & M University (M. Abdullah). These efforts have continued every year with great success and will be continued in year 9. As a result of these efforts, two students have been selected to participate in the summer REU program. Results from undergraduate structural analysis projects at each institution will be molded into the framework for undergraduate classes and stand-alone learning materials. Interaction between undergraduates at these institutions with other MCEER affiliates will be especially encouraged. Plans to offer interactive seminars between UB and the Center's minority serving affiliate institutions are being developed and pilot-tested with assistance from MCEER's networking program. It is hoped that they will be launched in late year 9.

One project at City College of New York has focused on engaging 30 undergraduate students in the study of structural dynamics, using the mini-shake table and a 5-ton shake table facility as learning tools, both in the classroom and as public outreach activities. Five of these students
participated in the first Seismic Design Competition held at UB in January 2005. They also participated in the Building Security symposium in March 2005 in New York City. As a consequence of their involvement, one undergraduate was selected to participate in the summer REU program in June 2005.

**Virtual Laboratory Educational Modules**: In year 7, B.F. Spencer, G.C. Lee, and students have been developing animated PowerPoint presentations describing earthquakes, earthquake engineering and earthquake engineering research (using examples of MCEER research tasks) for the “educated public.” Segments of these presentations may be integrated into various classroom instruction modules from grades 9 - 16. Details of the developments in virtual laboratory education modules are presented in the graduate section of this report.

**Other Center-wide Efforts**: Historically, undergraduates at MCEER affiliated institutions have been able to participate in several classes which have been influenced by the input of MCEER-funded faculty. This continues in year 7 and 8. Among the classes and programs to which students have had access are: Natural Hazards Minor (Penn State University), Economics of Natural Hazards course (Penn State University), Multidisciplinary Aspects of Earthquake Engineering (video-conferences from University at Buffalo), and a Senior Seminar - Hazards, Disasters, and Society (University of Delaware).

In year 6, researcher M. Lew from Mactec Inc. involved undergraduate interns in his studies associated with the MCEER Hospital project, and R. Eguchi of ImageCat hired a former REU student to assist in his project on the use of remote sensing technologies. MCEER is the only one of the three EERCs to fund private firms; it offers an excellent opportunity for undergraduate/graduate student/industry interaction and exchange.

Overall it can be noted that the ratio of undergraduate to graduate students involved in MCEER research has increased.

**Graduate**

**Student Leadership Council**: The primary goal of the graduate education program at MCEER is to attract the best students, nurture them and develop them into leaders in research, academia, engineering practice, and in public policy making. To this effect, since 1997, MCEER has formulated an active Student Leadership Council (SLC). The SLC is a formal group of students involved in performing MCEER research under the supervision of a faculty advisor. Since its inception, MCEER has included and encouraged student efforts throughout its research program and in all of the disciplinary specialties concerned with earthquake hazard mitigation. It also provides students from many different institutions the opportunity to meet with each other and develop/improve interaction. Many former SLC students are now in academia, professional practice or government agencies applying knowledge gained during their exposure to MCEER research. While associated with MCEER, students participate in annual Center Investigator meetings, attend conferences, workshops and seminars, and have the opportunity to make presentations at these events.

MCEER has also promoted the SLC as a vehicle for accomplishing many of its education objectives by engaging the SLC members beyond their formal role as research students. The
SLC has developed a series of activities and has taken leadership roles in many educational tasks promoting earthquake engineering education. Over the past years these tasks included the following:

- Webcast seminars (viewable at [http://civil.eng.buffalo.edu/webcast](http://civil.eng.buffalo.edu/webcast)) (2001 to 2004)
- Annual SLC Retreat (2000 to 2004)
- Organize and participate in Best Student Article Competition (2003, 2004)
- Publication of “Student Research Accomplishments” volume (2001 to 2004)
- Publication of an education column in the “MCEER Bulletin”
- Participation and presentations at MCEER Annual Meeting (2003 to 2005)
- Participation and presentations at Annual NSF Site Visits (2001 to 2004)
- Organization of Tri-center SLC Meetings at EERI Annual Meetings (2002 to 2005)
- Help organize and participate Tri-Center Field Missions (2002-Taiwan, 2003-Italy, 2004-Japan, 2005-Greece)
- Organize Undergraduate Seismic Design Competition at MCEER (2005)
- Mentor seismic design competition participants
- Participate in K-12 Outreach activities, presentations, and organize lab tours

The SLC is continuing these activities in year 9 with a high level of enthusiasm ([http://www.mceer.buffalo.edu/meetings/2005presentations/Saturday/02Pollino.pdf](http://www.mceer.buffalo.edu/meetings/2005presentations/Saturday/02Pollino.pdf)) (Fig. 17).
In year 7, MCEER initiated an award for the Best Student Article, which is selected by a panel of IAB members who review the papers submitted to the “Student Research Accomplishments” volume. The award is presented at the MCEER Annual Meeting. These efforts were successful again in year 8.

SLC students have also served as active mentors of the MCEER undergraduate interns participating in the Research Experiences for Undergraduates program, and have participated in MCEER public outreach activities, such as National Engineers Week. MCEER has been working to increase interaction with industry partners, through webcast seminars and through a closed Student-Industry Partner session at the MCEER Annual Meeting. The webcast audience includes a substantial number of practitioners, particularly internationally. The SLC also works closely with their counterparts at the other two EERCs, through numerous meetings throughout the year.

In year 6, the MCEER SLC coordinated and organized the Annual NSF Student Retreat, which hosts students from all NSF ERCs. In year 5, a new tri-center program was launched which allows advanced Ph.D. students to learn about international earthquake research and post-earthquake reconnaissance in a location recently impacted by a damaging earthquake. In year 6, this Field Mission program was coordinated by MCEER and featured numerous laboratory visits and a reconnaissance tour of the town of San Giuliano di Puglia in the Molise region of Italy, where buildings suffered severe damage during the October 31, 2002 earthquake. Participating students develop papers based on issues they are directed to examine during their visit. These are then mounted on the ERC websites. In 2004, a successful field mission trip to Japan was coordinated by PEER with active participation by students from MCEER’s SLC. MAE is coordinating a tri-center field mission to Greece in July 2005. Four MCEER students have been selected to participate in this event. Additional tri-center educational efforts are described in Volume III of this annual report.

**Virtual Laboratories for Earthquake Engineering (VLEE) Education Modules:** The objective of this MCEER educational task is to develop Java-based Virtual Laboratories for Earthquake Engineering (VLEE) as a tri-center collaborative effort to produce online resources to complement the teaching of graduate level courses in earthquake engineering ([http://cee.uiuc.edu/sstl/java/](http://cee.uiuc.edu/sstl/java/)). This task is a part of a center-wide effort to develop educational modules coordinated by G. Lee and B. F. Spencer and focuses on areas in which MCEER has technical leadership, including expansion of the Java-based structural control and flexible virtual hands-on laboratory modules to allow a wider variety of structural behaviors to be examined. In this task, several modules of Java-Powered Virtual Laboratories (VLs) have been developed to provide a means for online interactive experiments (Fig. 18). They are intended to provide a conceptual understanding of selected topics in the areas where MCEER has made significant advancements in research. In year 9, G. Lee and B.F. Spencer will be continuing the development of stand-alone graduate school modules, which will be shared with the other EERCs and their affiliated institutions.

These VLs are expected to be an effective complement to the teaching of structural dynamics and earthquake engineering analysis at institutions which lack the facilities to conduct dynamic experiments. MCEER believes these tools will also be valuable to undergraduate seniors as well as for industry partners.
Course Module Enhancements: Several course improvements have been made to Structural Dynamics and Earthquake Engineering at Cornell University, complemented by stand-alone decision-making tools being researched at present by M. Grigoriu and others. UB investigators also continue to use remote learning possibilities for advanced degrees. A recent UB MS graduate from the Dominican Republic gained his UB credentials through distance learning (EngiNet) and will soon take a professional position in Puerto Rico.

In year 8, G. Lee and E. Sternberg developed a new course on “Social, Political and Economic Aspects of Extreme Events Engineering.” This course introduces students to the relationships between engineering and non-engineering (social, political, and economic) considerations in the complex task of alleviating disasters caused by earthquakes and other extreme events. The perspectives of disaster planners on mitigation, preparedness, response, and recovery are introduced. Special attention is focused on lifeline infrastructure protection, hospital response to disaster, and emergency response and management. Starting from spring 2005, this course has been offered as a one credit required course for students in the earthquake engineering program co-taught by Sternberg and Lee. This course is also open to students in UB’s CSEE Department and Urban and Regional Planning Department. This course will be developed further to include other extreme events, and made a required 3-credit course in the next few years.

Other MCEER-lead UB-wide Efforts: In year 8, a coordinated effort was made to bring together diverse faculty with distinguished records in the fields of engineering, geosciences, and social sciences at the University at Buffalo to provide an integrated doctoral education and research training program in “Infrastructure Engineering Against Extreme Events.” The proposed curriculum would involve geoscientists, urban and regional planners, and engineers in the formulation, design, and solution of research problems related to complex engineered structures that would better withstand the effects of extreme natural and technological hazards, including those produced by earthquakes, volcanic eruptions, geophysical mass flows (avalanches, landslides and mudflows), fires, blast, and strong winds. The objective of this program is to produce graduates with a unique background in the physical nature of extreme events, the effect of the events on structures, and the problems that the related disasters present to the communities and governments involved. It aims to provide a new direction to the traditional education and research training in infrastructure engineering by placing a focus on extreme events to address the new challenges. This approach will produce versatile infrastructure engineers, planners, and policy makers with broad background and knowledge in each of the above areas, in addition to traditional in-depth knowledge in their respective home discipline,
with an ability to perform across disciplines in diverse teams. The ultimate goals are to: (a) increase awareness of hazards, vulnerabilities, and potential impacts, (b) prevent human and economic losses by early detection, (c) protect and safeguard the infrastructure, society, property, and the economy from the effects of natural disasters by mitigating the impacts, and (d) develop effective plans to enhance preparedness for rapid response and recovery to rebuild communities after an event. Several group meetings were organized and an educational proposal was developed for submission to NSF under its IGERT program.

Precollege

The MCEER precollege programs over the past years involved working extensively with students, teachers, and home-school parents to engage them with earthquake education materials and resources. Earthquake exercises, "frequently asked" earthquake questions (http://www.mceer.buffalo.edu/infoservice/faqs/default.asp) and interactive engineering demonstrations are all available on the MCEER website (http://www.mceer.buffalo.edu/education/k-12/default.asp). MCEER staff has mentored hundreds of students working on earthquake engineering projects in the classroom, at Science Fairs, one-on-one and through the Internet, helping to advance Science/Technology/Engineering/Mathematics (STEM) education in the K-12 classroom. The need to encourage more students to pursue STEM fields is recognized by educators and administrators alike throughout the country and has generated several congressional appropriations to support development of related programs. In recent years, it has been recognized that fundamental education reforms and improvements should be directed at long term systemic changes over what can be considered grades K-16. MCEER needs to be able to respond effectively with educational resources to reflect this evolution.

Starting in year 6, MCEER staff and researchers have actively involved talented high school students in MCEER research projects. One project involved detailing the electric power system of the LADWP system under the supervision of A. M. Saadeghvaziri at the New Jersey Institute of Technology. The second involved the construction of a mini-shaking table by an MCEER Research Experiences for Undergraduates (REU) intern. R. Purasinghe at California State University Los Angeles, a minority-serving institution, has continued his mentorship of a team of students from Alhambra High School in Los Angeles preparing for a JETS (Junior Engineering Technical Society) Competition in Earthquake Engineering. The students were part of the California MESA (Mathematics, Engineering and Science Achievement) program, established in 1970 offering a range of academic support and enrichment to more than 24,000 mostly underrepresented minority students. The MCEER group has received several awards recognizing their contributions, including a 2003 award from the Structural Engineers Association of Southern California for outstanding student effort.

Over the years, MCEER staff, faculty and SLC members have participated in collaborative activities with other organizations and initiatives to further K-12 education and public awareness. This includes participation in real-time monitoring of an Eastern North America seismic activity through an array supported by the Canadian Geological Survey; K-12 curriculum development as part of the USGS Earthscope Initiative, and involvement in proposal development for teacher preparation with the NSF-NEES program. In year 7, partnerships have been built with another national initiative, the U.S. Educational Seismic Network, which is working jointly to develop
curriculum and tools for the precollege classroom. Such activities will complement other MCEER activities involving the use of the mini-shaking tables as part of the UCIST effort (described in greater detail in Volume III of this annual report). Several other educational mentorship activities have been carried out during National Engineers Week, the Buffalo Engineering Awareness for Minorities program (BEAM is a member of the National Association of Precollege Directors – a consortium of universities/industries/government agencies in Western New York dedicated to involving minorities in engineering), Expanding Your Horizons (a nationally funded program reaching hundreds of middle school girls each year), and an annual Engineering Seminar for High School Students. In addition, MCEER is continuing its efforts to support professional development for teachers in year 8 and beyond. As emphasized by the No Child Left Behind legislation (2002), as well as Science and Engineering Indicators (National Science Board, 2002) and FY 2003 legislation for increased NSF funding for Math/Science Partnerships.

MCEER plans to continue to offer a teacher training program in the summer of 2006, which will integrate participation of undergraduates, graduates and faculty members. A year 9 proposal to NSF for RET (Research Experiences in Teaching) will be prepared in order to help supplement this effort. The program exposes teachers to research and resources that can enrich their abilities to thematically convey earthquake concepts in the classroom. In parallel, students and engineering faculty gain an appreciation of the needs of precollege educators. A formative evaluation effort would be incorporated to measure project effectiveness.

**Quake and Shake:** Most recently, in year 8, MCEER introduced a “Quake and Shake” program ([http://www.mceer.buffalo.edu/education/k-12/05QuakeandShake/default.asp](http://www.mceer.buffalo.edu/education/k-12/05QuakeandShake/default.asp)) to introduce hands-on earthquake engineering and reach out to elementary school students (Fig. 19). Students from area schools built popsicle-stick structures according to earthquake design principles and then tested them on the shake table in Ketter Hall. MCEER Deputy Director A. Filiatrault made a presentation to the students on earthquake design and provided pointers on how to build the structures, which were required to support a masonry brick at a height of 12" above a wood base. Each team built a structure using 150 popsicle sticks, a bottle of Elmer's glue and a roll of dental floss that was then subjected to ground motions from historical earthquakes. After the famous “UB Rumble,” all structures were declared “earthquake proof,” and each student received a certificate naming him or her an “honorary structural engineer.” The event was covered by local media, including Channel 4's “Why Guy.” This has created interest among K-12 students from a wider area and has resulted in a number of earthquake laboratory tours.

![Figure 19: Quake and Shake Outreach Program.](image-url)
Professional

In past years, MCEER has offered several formal courses and seminars for the professional engineering community. MCEER investigators have offered a number of independent courses with and for such organizations as the Applied Technology Council, U.S. Army Corps of Engineers, New York State Department of Transportation, LAWDP, and SEAONC. In years 8 and 9, MCEER will continue to take advantage of guidance provided by its Industry Advisory Board (IAB) to create more specialized programs, with continuing education units offered to registered participants.

The MCEER Annual Meeting, held in Sacramento in February 2005, included traditional gathering of MCEER industry partners, students and researchers to review the past year's progress and the next year's promise. A “Practitioners Day” invited participation from the practicing community and public service officials. It included a full-day plenary session with presentations by MCEER investigators and practitioners, student posters, and educational exchanges (http://www.mceer.buffalo.edu/meetings/2005AnnualMeeting/default.asp).

Public-at-large

MCEER participates annually in several events which reach out to the community at large. These include the National Earth Science Week and the National Engineers Week. In year 7, MCEER participated in a full-day program at CalTech on January 17, 2004, marking the 10 year anniversary of the Northridge earthquake. MCEER was one of several exhibitors at the event, co-sponsored by the USGS, Southern California Earthquake Center and others, which featured a full-day of presentations, demonstrations and hands-on activities designed to increase earthquake hazard awareness. Several hundred people attended the event.

Diversity Initiatives

To further expand its efforts to recruit individuals from underrepresented demographic groups, MCEER hosted a working group meeting on diversity and obstacles to involvement in earthquake engineering and other earthquake related areas. The workshop was held in Arlington Virginia. In year 8, MCEER appointed Professor Makola Abdullah as Diversity Director for coordinating a strategic plan aimed at promoting earthquake engineering to students from underrepresented demographic groups. As a part of this effort, a new Diversity REU program and a new Diversity Ph.D. fellowship program has been initiated, with supplemental funding from NSF. These programs have been publicized at several minority conferences and minority serving institutions. A first group of three REU students has been recruited as part of the Diversity REU 2005 program. Abdullah has visited many underrepresented universities and made several presentations on MCEER research and opportunities for students to participate in earthquake engineering. These efforts will continue in year 9.

C. Outreach

Information Services: The MCEER Information Service (IS) has established a professional reputation in the international community for its unique expertise and offerings. Unlike any
other earthquake center, IS provides reference assistance and maintains two unique online resources, QUAKELINE® and EQNet. Additionally, MCEER’s IS continues to develop a comprehensive library collection, and produces a bimonthly newsletter which offers an extensive tables of contents of current discipline-relevant journals. IS provides outreach, education, and reference assistance to more than 2,000 individuals annually, while creating informative exhibits displayed at conferences and meetings worldwide.

The reference component encompasses a broad range of users from elementary students through post-doctoral fellows, researchers, academicians, practicing professionals, government employees at all levels, and the general public. This service is available from the IS website, phone, e-mail, mail, or walk-in. Complementing this service, IS provides literature searches for outreach and educational activities, upon request, and for review on the website. These computerized searches take advantage of the online database, QUAKELINE®, a free, comprehensive database covering literature on earthquakes, earthquake engineering, natural hazard mitigation and related topics. Building on these distinctive services, IS continues to receive funding to maintain the EQNet website (http://www.eqnet.org/), a portal to an array of links to authoritative websites providing earthquake and natural disaster information. EQNet posts current information on significant earthquake activity and impacts (e.g., Northern Sumatra; Kyushu, Japan; central Iran; and the Sumatran earthquake and tsunami, in past months). “ResearchBuzz” and NSF “Sci-Tech Newsletter,” both respected independent web evaluation organizations, consider EQNet a valuable and noteworthy hazard-related resource and have cited the website as an excellent research tool. The Information Service continues to develop an extensive collection, covering diverse formats to include monographs, serials, CD-ROMs, videos, slides, clippings, pamphlets, brochures, and product announcements. IS contributes to the MCEER website (http://mceer.buffalo.edu), which offers access to timely information about MCEER research, education, and outreach. To meet the demands of more sophisticated searchers, QUAKELINE® has begun a major facelift to enhance its search capabilities. Additionally, the behind-the-scenes process of creating and loading new records is being modernized to incorporate a streamlined, web interface. To further achieve a more accessible format, the “Information Service News” will become an online newsletter exclusively in year 9, in an effort to maximize the benefits of a web-based delivery. Because of its critical function in disseminating materials and information, IS continues to receive support from the Department of Homeland Security/Federal Emergency Management Agency to distribute critical mitigation informational materials through the newsletter, the web, conferences, and exhibits. Historically, these efforts have been successful in previous years and will continue in year 9.

This year, Sofia Tangalos has been appointed as the MCEER Senior Program Officer for Education/Outreach Activities and Information Service. In addition to continuing her duties at the MCEER Information Service where she has been Information Specialist since August 2003 and Acting Head since July 2004, Sofia will be the MCEER staff primary contact for education issues. She will work with the MCEER Director, the Education Director, and the Diversity Director to develop and implement MCEER's education and outreach activities.

**Publications:** The MCEER Publications division, overseen by J. Stoyle, continues its efforts to make MCEER research outcomes quickly available to the engineering community. This has been done through technical publications as well as through the widely read “MCEER Bulletin.” As in past years, MCEER reports are printed in paper format, which continues to be a necessity for a
segment of the readership. However, emphasis on electronic versions steadily increases, and report abstracts may be searched and viewed on the MCEER website. MCEER has converted all reports published since 1998 into PDF format, and is selectively converting older reports. These will be available for purchase from the MCEER website. Finally, as part of MCEER’s FHWA-funded Highway Project, the ATC-MCEER Joint Venture has completed a series of publications entitled “Recommended LRFD Guidelines for the Seismic Design of Highway Bridges” (http://mceer.buffalo.edu/research/HighwayPri/NCHRP/default.asp). This set of reports is intended to provide updates to the current AASHTO “LRFD Bridge Design Specification.” The Recommended Guidelines are nationally applicable and contain provisions for all seismic zones, and all bridge construction types and materials.

A particularly notable activity begun in year 6 is the collaborative publication of a new scientific journal, “Earthquake Engineering and Engineering Vibration,” jointly published by MCEER and the Institute of Engineering Mechanics (China State Seismological Bureau) in Harbin, China. The journal is indexed and abstracted in several prominent databases, and since year 7, is included in EI/Compendex. MCEER also works with others in the earthquake community on the production of digitally-available materials, benefiting from other organizations experiences (e.g., EERI) to effectively build an appropriate digital platform for research publications. A detailed bibliography of MCEER reports and publications, as noted throughout this report, may be found in Volume II of this report.

Workshops, Conferences, Short Courses, Seminars: Several major meetings have already been cited in this report. Other events conducted or co-sponsored by MCEER in years 7 and 8 include:

- **ANCER Annual Meeting: Networking of Young Earthquake Engineering Researchers and Professionals**, Honolulu, Hawaii, July 28-30, 2004
- **Second PRC-US Workshop on Seismic Analysis and Design of Special Bridges**, Buffalo, NY, December 3-5, 2003

Reviews of webcast seminars held in years 7 and 8 are available on the MCEER-SLC website at [http://mceer.buffalo.edu/slc](http://mceer.buffalo.edu/slc). Speakers included IAB members, PEER students and other prominent professionals in earthquake hazard mitigation.

Partnerships: MCEER is involved in several important partnerships which allow it to expand its education and outreach activities. Space does not permit description of these activities here, but more information may be found on the MCEER website and in the “MCEER Bulletin.”
4. INDUSTRY/PRACTITIONER COLLABORATION AND TECHNOLOGY TRANSFER

A. Summary

At this mid-point of the current year 8, MCEER’s program of Industry/Practitioner Collaboration and Technology Transfer is continuing to grow, meet its target and fulfill its strategic role in support of the Center’s long-term sustainability and success. Beyond continuing increases in memberships and member support, the program is yielding far greater benefits to MCEER, its researchers, students, and partners alike.

In addition to the Center’s Strategic Partnerships Network (or membership program), a new MCEER initiative – MCEER-Industry Consortia – is attracting still more industry collaboration and support that helps further the Center’s mission with respect to enhancing resilience of electrical power distribution networks and the performance of nonstructural components in acute care facilities – all while enhancing the educational experience of MCEER students. Together, these two Industry/Practitioner programs create a synergy among Center partners, students and researchers that advance the interests of all.

Progress and promise thus far in year 8 include:
- 21 percent increase in member contributions to MCEER’s Strategic Partnerships Network;
- the addition of five new Center members – and the pending addition of others;
- 20 percent growth among Industry Advisory Board (IAB) individual members (from 45 to 54);
- 25 percent growth among IAB member firms (from 28 to 35);
- The addition of three new members to the IAB Executive Committee to ensure wider representation of nonstructural component performance issues of relevance to MCEER’s Thrust Area 2 research on Seismic Retrofit of Acute Care Facilities;
- deeper IAB engagement and involvement in MCEER programs;
- establishment of two new MCEER-Industry Consortia guaranteeing at least $150,000 in support over the next three years;
- the grand openings of four new World-Class Facilities (at Buffalo, Cornell, Nevada/Reno and RPI) thru NSF’s George E. Brown, Jr. NEES awards, that offer a higher level of research and testing benefits to Industry/Practitioner participants.

Consequently, today MCEER is positioned perhaps better than ever before to create the necessary synergies to grow and advance the participation and interests of industry and practitioner communities. Thus, the Center continues its focus to serve these “customers” by:
- strengthening ties with current Center members through still deeper engagement and participation in MCEER programs, and
- continuing to forge new stakeholder relationships that attract new members and research collaborators to the Center, through wider, more personal, and value-added industry outreach.
B. History and Growth

**Strategic Partnerships Network: Center Members**

MCEER’s Strategic Partnerships Network or industry “member” program continues its steady growth, in immeasurable ways beyond simply the number of members and the dollar amount of their collective contributions. Financially, the program’s annual gross revenues (currently measured in membership fees) have increased by nearly 309 percent, from $17,500 in 2001, to a projected $71,500 in 2005 – if MCEER adds no new members for the remainder of the current fiscal year ending September 30, 2005. Further, during the same time period, the number of member firms has increased by 120 percent, from 10 in 2001, to 22 in 2005.

The year end goal is to add at least three more member companies and $13,000 in member contributions in order to stay in step with growth forecasts which will result in 36 members and $157,000 in member contributions by MCEER’s September 30, 2007 “graduation” from NSF’s ERC Program, as shown in Fig. 20.

Despite continuing economic uncertainty, the Center has added five new members since last year’s annual report, International Seismic Application Technology, Rutherford & Chekene Consulting Engineers, Trane - an American Standard Company, WorkSafe Technologies, and York International Corporation. More importantly, new member firms bring a heightened interest and collaborative spirit to the nonstructural components research of MCEER’s Thrust Area 2 studies on Seismic Retrofit of Acute Care Facilities.

**MCEER-Industry Consortia: Center Affiliates**

In year 8, MCEER welcomed it first Industry Consortium: the MCEER Electrical Utility Consortium (EUC), sponsored by the Electric Power Research Institute (EPRI) and various
substation equipment manufacturers. This development subsequently gave birth to a second consortium sponsored by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). Together, these two new Industry Consortia promise an additional $150,000 in sponsored research over the next three years, via five new center affiliates, three of them highly involved during the current year 8 program. This directed research will add substantial value to Thrust Areas 1 and 2 studies, while providing timely research products to the electric power and nonstructural components and equipment markets.

MCEER-EUC studies focus on seismic performance and qualification of electric power substation equipment. The MCEER-ASHRAE Consortium examines performance of seismic restraints and isolation devices for large-institutional HVAC equipment. Still in their infancy, both consortia seek to grow their memberships and their contributions toward long-term collaborations supporting MCEER research.

**MCEER Associated Projects**

In addition to the above, two Center members – Earthquake Protection Systems, Inc., and Taylor Devices, Inc. – have contributed $57,500 to associated projects involving structural control technologies, as they relate to MCEER’s Thrust Area 2 research in Seismic Retrofit of Acute Care Facilities. Earthquake Protection Systems also manufactured and donated seismic isolation bearings for the same studies.

### C. Strategic Plan

**Summary**

MCEER has long recognized that marketplace economics and need for “earthquake resiliency” solutions, lack in urgency and demand. These conditions limit corporate interest and investment in ways not experienced by traditional NSF ERCs, thus serving as significant barriers to large-scale unrestricted contributions by a large number of company members. However, the steady annual growth in membership, financial contributions, and member involvement that MCEER has experienced over the last four years, combined with positive changes in marketplace requirements, climate and demand for the types of earthquake engineering solutions that MCEER is prepared to offer, does yield promise for continued growth in the Center’s “membership fees” revenue stream.

It is believed that these trends in member growth and marketplace promise will have a modest positive impact on MCEER’s self-sufficiency. Based on the program’s historical growth, it is reasonable to forecast that by the year 2007, MCEER’s Strategic Partnerships Network will grow to 36 members contributing annual fees in excess of $157,000. These forecasts fall in line with planned growth resulting from MCEER’s intense focus on enhancing resilience by helping to ensure performance of nonstructural components in acute care facilities following earthquakes.

That stated, MCEER’s strategic plan recognizes that industry support in the form of “memberships” alone, will not sustain the Center beyond its current NSF funding. Rather, it will require a well-planned and well-orchestrated combination of government- and industry-sponsored research, steady growth in industry memberships, well-targeted industry outreach
products and services (industry research consortia and testing, continuing education programs and materials, practical publications, information services and other tools of value to practitioners), all possibly supplemented with modest royalties from licensed technologies.

Thus, MCEER continues – step by strategic step – on its way toward cultivating a culture and climate that fosters the mutually beneficial long-term relationships that will yield short- and long-term mutual benefits – and, which will be so very vital in helping to support the long-term life of the Center.

In addition to these efforts, MCEER has retained the services of Dr. Thomas L. Anderson, as its Strategic Operations Director. Dr. Anderson works closely with MCEER’s Director to secure federal government support for the Center’s earthquake engineering and multi-hazards research initiatives.

Vision

The vision of MCEER’s Industry/Practitioner Collaboration and Technology Transfer Program is to create and foster a “Community” of multi-sector stakeholders gathered around common interests, to exchange and advance knowledge research, education, development, and implementation of tools and technologies that enhance private-sector economic competitiveness and improve earthquake resiliency in communities nationwide.

Goals

MCEER’s goals for Industry/Practitioner Collaboration and Technology Transfer are to:

- Cultivate membership of long-term strategic partners that invest financially in the Center itself, and not just in directed research;
- Actively engage industry partners (and other external stakeholders) in providing valuable input to MCEER research, education and outreach programs, and to collectively play a vital role in building market opportunities by enhancing marketplace awareness, acceptance and demand for Center outcomes, i.e., new knowledge and technologies;
- Ensure continuous process improvement of a flexible and adaptable Center infrastructure to develop and deliver a variety of partnerships, sponsorships, and other revenue-generating products and services that will help shape the marketplace and market demand for desired measures of “earthquake resilience,” in the near-term – and the same market demand for products of the Center’s long-term research endeavors;
- Initiate and entertain development of strategic alliances with key stakeholder groups and organizations, that will generate new revenue streams for the Center, and advance the mutual goals of MCEER, its partners, and involved groups and organizations;
- Help to ensure the Center’s long-term sustainability by aiding MCEER and its strategic partners in meeting mutual goals.
Very simply, MCEER fosters partnerships with the business, industry and government sectors to:

- Engage manufacturing, practitioner and end-user communities related to each of MCEER’s research thrusts;
- Further interaction, research, education, knowledge and technology transfer;
- Increase collaboration and support of Center research, education and outreach endeavors;
- Advance Center and mutual goals.

**Target Sectors and Markets**

MCEER targets participation from critical stakeholders in the business (consultants, owners, and professional and trade associations), industry (technology manufacturers and marketers), and government (federal, state and local regulatory and mission agencies) sectors in markets that are considered stakeholders in the Center’s three thrust areas. MCEER’s emphasis is on vertical markets in the utilities, hospital, and emergency response arenas.

For example, in MCEER’s Research Thrust Area 2: Seismic Retrofit of Acute Care Facilities, this could include targets such as:

- Engineering consulting firms with a specialization in hospital/healthcare facilities;
- Owners of acute care facilities in California and New York State;
- Associations like the American Society for Healthcare Risk Management, the Structural Engineering Association of California, the Vibration Isolation and Seismic Control Manufacturers Association, the American Society of Heating, Refrigerating and Air Conditioning Engineers, and others;
- Manufacturers and marketers of technologies for structural control and protection of nonstructural systems;
- Manufacturers of nonstructural components and hospital equipment;
- Department of Veterans Affairs; and
- California Office of Statewide Health Planning and Development (OSHPD).

In parallel with the above vision and goals, MCEER has focused its industry outreach in a targeted fashion, striving regularly to engage and delight existing members, meeting face-to-face and continually “courting” qualified prospective strategic partners, spearheading discussions of strategic alliances and initiatives with well-positioned stakeholder associations, and enlisting participation from important “non-member” publics in an effort to introduce them to, and engage them in the MCEER research, education and outreach process.

These efforts have included:

- **An MCEER “Family/Alumni” Breakfast** at the 13th World Conference on Earthquake Engineering (August 1-6, 2004 in Vancouver, BC, Canada) re-united 40 members of the Center’s Student Leadership Council, Strategic Partnerships Network, student alumni and investigators, past and present. The event provided an opportunity for renewal of relationships and an update of developments in MCEER’s research, education and outreach programs.
• **13WCEE Technical Tour of Nonstructural Seismic Risk Mitigation at Vancouver General Hospital.** As part of the 13WCEE formal program, MCEER, Terra Firm Earthquake Preparedness (an MCEER member) and the Professional Engineers and Geoscientists of British Columbia hosted a day-long series of technical tours of nonstructural seismic risk mitigation efforts at Vancouver General Hospital. It is believed that as many as 200 conference participants took part in the tours.

• **MCEER’s Nonstructural Components Research Presented at SEAOC 2004 Convention.** A presentation on "MCEER’s Research on the Seismic Response Modification of Structural and Nonstructural Systems and Components in Hospitals," was delivered by Center Director, M. Bruneau, at the *2004 Structural Engineers Association of California Annual Convention*, August 25-28 in Monterrey, CA. The convention was attended by more than 300 practicing engineers in California.

• **MCEER Research Addressed at SMACNA Seminar.** MCEER Deputy Director A. Filiatrault addressed more than 150 attendees at a *Seismic Restraint System Seminar*, sponsored by the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), on November 11, 2004 in Buffalo, NY. Filiatrault teamed up with MCEER IAB member Jay Lewis of Terra Firm Earthquake Preparedness, in preparation of the two-part presentation. Part I focused on “MCEER Research to Protect Nonstructural Components during Earthquakes.” Part II was titled “Seismic Retrofit of Nonstructural Components – A Contractor’s Perspective.”

• **ISAT “Engineers” Quarterly Meeting in Concert with MCEER Annual Meeting.** International Seismic Application Technology (ISAT), one of MCEER’s newest members, held its quarterly meeting in Rancho Cordova, CA, in conjunction with MCEER’s 2005 Annual Meeting, February 25-26. MCEER Deputy Director A. Filiatrault briefed company engineers on the Center’s nonstructural components research, and D. Goralski provided them with an overview of the MCEER’s industry/practitioner collaborations. ISAT is a worldwide supplier of seismic bracing systems for nonstructural components and suspended utilities.

• **Air-Conditioning and Refrigeration Institute Takes Interest in Seismic Protection of Nonstructural Components.** MCEER Deputy Director A. Filiatrault and MCEER Senior Program Officer for Strategic Partnerships D. Goralski met with the Air-Conditioning and Refrigeration Institute Technical Committee on Sound, on March 24, 2005, in Arlington, VA. Filiatrault delivered a presentation titled, “Issues on the Seismic Protection of Nonstructural Components: An Overview of MCEER’s Research.” The invitation was prompted by the committee’s concerns for seismic code requirements involving the installation of nonstructural components. Approximately 20 committee members were in attendance, including representatives of York International Corporation and Trane, two of MCEER’s industry members.

D. Structure

The organizational structure for MCEER’s industry-interaction is illustrated in Fig. 21. MCEER Strategic Partners have a voice in the strategic planning of the Center, through an Industry Advisory Board (IAB). The IAB comprises all members of MCEER’s Strategic Partnerships Network, and strategic federal, state and local government agencies, who for the time being, are offered “no-cost” seats on the IAB. The “no-cost” practice will be phased out as MCEER expects these agencies in time, to sufficiently value membership and become paying partners.
Members of MCEER’s Strategic Partnerships Network (A/E firms, manufacturers, etc.) pay annual dues at one of the following three levels: Flagship Partner ($10,000/yr.), Premier Partner ($3,500/yr.), and Partner ($1,000/yr.). MCEER’s Strategic Partnerships Network currently has 22 members.

The current IAB consists of 54 members from 35 organizations. Members are listed in Table B in the front of this annual report. The IAB operates under a charter, and is steered by an IAB Executive Committee, consisting of a Chair, Vice-Chair, thrust areas representatives, and members at large. Table 2 lists the current members of the IAB Executive Committee.

### Table 2: MCEER Industry Advisory Board Executive Committee.

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Affiliation</th>
<th>Research Thrust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. Ellis Stanley, Chair</td>
<td>General Manager</td>
<td>Earthquake Response and Recovery</td>
</tr>
<tr>
<td></td>
<td>Los Angeles Emergency Preparedness Department</td>
<td></td>
</tr>
<tr>
<td>Dr. Andrew Taylor Vice-Chair</td>
<td>Associate</td>
<td>Seismic Retrofit of Acute Care Facilities</td>
</tr>
<tr>
<td></td>
<td>KPFF Consulting Engineers</td>
<td></td>
</tr>
<tr>
<td>Dr. Sreenivas Alampalli</td>
<td>Director, Bridge Program and Evaluation Services Bureau</td>
<td>Seismic Design and Retrofit of Highways</td>
</tr>
<tr>
<td></td>
<td>New York State Department of Transportation</td>
<td></td>
</tr>
<tr>
<td>Dr. Scott Campbell</td>
<td>Chief Structural Engineer</td>
<td>Seismic Retrofit of Acute Care Facilities</td>
</tr>
<tr>
<td></td>
<td>Kinetics Noise Control, Inc.</td>
<td></td>
</tr>
<tr>
<td>Dr. Jeremy Isenberg</td>
<td>President</td>
<td>Seismic Evaluation and Retrofit of Lifeline Systems</td>
</tr>
<tr>
<td></td>
<td>Weidlinger Associates, Inc.</td>
<td></td>
</tr>
<tr>
<td>Mr. R. Jay Love</td>
<td>Senior Principal</td>
<td>Seismic Retrofit of Acute Care Facilities</td>
</tr>
<tr>
<td></td>
<td>Degenkolb Engineers</td>
<td></td>
</tr>
<tr>
<td>Mr. Glenn Singley</td>
<td>Director, Water Engineering and Technical Services</td>
<td>Seismic Evaluation and Retrofit of Lifeline Systems</td>
</tr>
<tr>
<td></td>
<td>Los Angeles Department of Water and Power</td>
<td></td>
</tr>
<tr>
<td>Mr. Christos Tokas</td>
<td>Senior Structural Engineer</td>
<td>Seismic Retrofit of Acute Care Facilities</td>
</tr>
<tr>
<td></td>
<td>California Office of Statewide Healthcare Planning and Development</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 21: Industry Advisory Board Structure.**
MCEER also engages a variety of contributors that have not joined the program but do provide support for projects that fall under the scope of the Center’s strategic plan (see Database Table 4 for a complete listing of center members, affiliates and contributors). Among others, these include suppliers of utility pipelines, composite manufacturers and contractors, satellite owners, and aerial imagery providers. Efforts are made to convert these valued affiliates to full-fledge members of MCEER through its Strategic Partnerships Network.

E. Engaging Partners in Strategic Planning

The IAB Executive Committee is responsible for convening meetings of the IAB, working with MCEER to develop its strategic plan, soliciting input and comment on MCEER’s strategic plan from the IAB members, and conveying to MCEER decisions, suggestions and concerns of the IAB.

The IAB Executive Committee reports directly to MCEER’s Director and Deputy Director. The IAB Executive Committee Chair (or his/her delegate) is a full-fledged member of the MCEER Executive Committee, providing direct industry insight and guidance at the highest level of MCEER decision-making, ensuring that Strategic Partners are significantly engaged in the strategic planning of the Center, and in the implementation of the research agenda.

The IAB Executive Committee is responsible for organizing the agenda and presentations for the “Industry Session” at MCEER’s Annual Meeting. Taking place at the beginning of the research planning cycle, the purpose of this meeting is to initiate MCEER’s annual review and strategic planning process. The “Industry Session” provides a platform for industry to present its interests, needs, and facilities to faculty members, students, and others, as well as to learn about MCEER research findings from faculty and students.

The 2005 MCEER Annual Meeting, like the 2004 event, again cast a wide net of practitioner involvement with the Center’s second annual “Practitioners Day Forum,” on February 25, in Sacramento, California. Under the theme of “Involving Stakeholders … Igniting Innovation … Securing Resilience,” the event reached out from California’s state capital, and engaged stakeholders from up and down the West Coast. The meeting was held in the Sacramento area at the invitation of the California Office of Statewide Health Planning and Development (OSHPD), a vital MCEER partner. More than 100 participants, including business, industry and government stakeholders, as well as MCEER Industry Advisory Board members, students and investigators, took part in the event. The large “practitioner” turnout made for countless invaluable contributions of insight and perspective to the center’s research, education and outreach programs.
F. Role of IAB in Strategic Planning for Self-Sufficiency

MCEER will require sustained financial support after its “graduation” as an ERC to continue and expand its activities in developing new knowledge, in educating students/working professionals, and in transforming the knowledge developed into practice via the center approach. MCEER’s new business plan, developed by MCEER’s Director, with IAB input, is critical to the strategic planning process.

Over the course of the last two years, IAB members and other external advisors have provided MCEER leadership with significant suggestions and guidance toward strategic planning beyond year 10. In summary, these activities have included:

- June 2003 – A Focused Day of Strategic Business Planning during which select IAB members and Center leadership helped to identify a variety of revenue-generating business activities for the Center;
- November 2003 – MCEER Strategic Visioning Retreat involving a day of “out-of-the-box” exploration of MCEER’s capabilities and future avenues of opportunity, with external strategic advisors;
- January 2004 – MCEER IAB Annual Meeting involving an industry SWOT Analysis, brainstorming and recommendations on MCEER’s future.
- February 2005 – MCEER IAB Annual Meeting, again involving an industry SWOT Analysis, brainstorming and recommendations on MCEER’s future.

IAB members have also provided support in recruitment of new members and in helping to position MCEER for a variety of presentations and outreach opportunities as noted earlier.

G. Membership Agreement and Intellectual Property Policy

A Center-wide membership agreement, which also addresses intellectual property, is included in the Appendices section of this report.
5. INFRASTRUCTURE

A. Institutional Configuration, Leadership, Faculty and Student Teams, Equipment and Space

The Center is led by its Director, Dr. Michel Bruneau, Professor of Structural Engineering at the University at Buffalo, and senior management staff who are responsible for the direction and overall coordination of the research, education, and outreach plans described herein. A list of all MCEER affiliated institutions may be found in Database Table 6. A breakdown of ERC personnel is included in Database Table 7.

To ensure a top-down decision process, all key decisions on the research agenda and resource allocations rest exclusively with MCEER’s Executive Committee, which consists of:

- MCEER’s Director and Deputy Director,
- The research Thrust Area Coordinators, and,
- The Chair of the Industry Advisory Board (IAB) Executive Committee.

Availability of and access to experimental facilities is important to the advancement of earthquake engineering for validation of analytical solutions and reliability testing of new mitigating technologies. MCEER’s consortium approach has allowed its researchers access to a wide range of physical facilities. In this regard, all four major experimental facilities affiliated with MCEER have each received a NEES equipment award, totaling a $19.42 million investment out of a total of $60 million for NEES combined Phases I and II awards. These amounts have also been supplemented by additional infrastructure investments from the recipient universities to house the new equipment. More specifically, these awardees are:

- Rensselaer Polytechnic Institute, $2.38 million, for the Upgrading, Development, and Integration of Next Generation Earthquake Engineering Experimental Capability at Rensselaer’s 100g-ton Geotechnical Centrifuge
- University at Buffalo, $6.16 million, for Versatile High-Performance Shake Tables Facility Towards Real-Time Hybrid Seismic Testing
- University at Buffalo, $4.38 million, for Large-Scale High-Performance Testing Facility Towards Real-Time Hybrid Seismic Testing
- University of Nevada, Reno, $4.40 million, for Development of a Biaxial Multiple Shake Table Research Facility.
- Cornell University $2.1 million, for the Large Displacement Soil-Structure Interaction Facility for Lifeline Systems.

These investments, along with MCEER’s commitment to networked collaboration, will benefit both NEES and MCEER long-term objectives. These facilities have all become fully functional on October 1, 2004 (or before in some cases), and are being used already, in part for MCEER-related research.
B. Broader Outreach and Connectivity with Other Centers

Collaborations among the three NSF-funded Earthquake Engineering Research Centers (MAE, MCEER, and PEER) are most important and required activities. To better describe this extensive connectivity between the centers, a third volume of the Year 8 Annual Reports for the three NSF-sponsored Earthquake Engineering Research Centers has been prepared as a collaborative effort (see Volume III – “Tri-Center Collaboration”). The material presented is identical for each center though the format and cover design conforms to the style of the other volumes of each center’s report. This document has been prepared as a separate document so that it may stand alone to illustrate tri-center collaboration. Furthermore, MCEER is also collaborating with other NSF-funded centers. For example, ground motion data developed by researchers from the Southern California Earthquake Center (SCEC) are being used by MCEER researchers. On the occasion of the 10th anniversary of the 1994 Northridge earthquake in the Los Angeles region, MCEER, and the Business and Industry Council on Emergency Preparedness (BICEPP) hosted a commemorative luncheon that was attended by more than 130 stakeholders in Southern California and featured presentations by representatives of the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), National Science Foundation (NSF), California Department of Conservation, National Center for Crisis and Continuity Coordination (NC4), SCEC and MCEER.

C. Organization, Management Systems and University Support for the ERC Culture

As PI of the NSF center award, MCEER’S Director bears the ultimate responsibility for the success of the center activities, meeting the requirements specified in the cooperative agreement with NSF, securing the annual cash matching commitment from New York State, and leading efforts to ensure that MCEER remains a vibrant and active research center beyond year 10 of the current NSF-funded mandate. He is assisted by a Deputy Director (Andre Filiatrault) primarily responsible for the coordination of research and technical activities, an Education Director (S. Thevanayagam) primarily responsible for the coordination of education activities), and a Diversity Director (Makola Abdullah) primarily responsible for the coordination of activities related to the MCEER diversity strategic plan). George C. Lee is the PI of the FHWA-funded MCEER research activities, helped by a senior program officer for highways dedicated to the management of the FHWA contracts on highway systems, which have tasks that complement NSF-supported research tasks. The Director regularly chairs meetings of the senior staff (individuals responsible for the budget and subcontracting, Education/Outreach and Information Services, Center publications and Industry Partnership Programs) to ensure progress toward strategic goals. These groups deliver all the research services to MCEER investigators and much of the research results to the various users. At MCEER, the Director and the Deputy Director are primarily responsible for interfacing with the University officials and with the Department of Civil, Structural and Environmental Engineering (CSEE) of the University at Buffalo. A Special Tasks Director (George C. Lee) is assigned specific responsibilities on behalf of the Center Director, namely oversight of some international activities (such as the US-PRC collaborative activities) and chairs a committee to pursue education tasks and education-research interface
activities, including the development of a special course to integrate engineering and social sciences. The MCEER Director reports directly to the University at Buffalo’s Dean of Engineering and Applied Sciences, who provides day-to-day Center oversight responsibilities on behalf of the University Provost. The Center’s organizational structure is shown in Fig. 22.

Appointments to Director, Deputy Director and other senior positions are as follows:

Director               Michel Brunreau  
Deputy Director         Andre Filiatrault  
Education Director      S. Thevayanagam  
Diversity Director      M. Abdullah  
Special Task Director   George C. Lee  
Senior Industry/End Users Partnership Officer Donald Goralski  
Business/Contracts Manager Gerald Meyers  
Publications Manager    Jane Stoyle  
Senior Program Officer, Transportation Research Jerry O’Connor  
Senior Program Officer for Education/Outreach and Information Service Sofia Tangalos  

![Figure 22: Center Organization.](image)

For MCEER research management, the Director chairs a five-member Executive Committee composed of the five thrust leaders (two Lifeline networks, Hospitals, Response and Recovery, and User Networks). This Executive Committee considers important policy issues of MCEER, as well as establishes/discontinues plans of research thrusts/tasks of the Center by consensus and by
interfacing with the Executive Committee of the Industry Advisory Board. Once the research plan is shaped, the Center Executive Committee further develops detailed research tasks, and formulates research teams and budgets. Researchers are then invited by MCEER’s Director based on the decision of the Center Executive Committee.

An Educational Committee is appointed by the Director, which provides advice to the Center’s education and research-education interface activities including K-12 outreach, curriculum and educational module development, undergraduate and graduate student and SLC enhancement and networking activities with predominately minority institutions.

As part of the plans to ensure that MCEER remains a vibrant and active research center beyond year 10 of the current NSF-funded mandate, a new confidential MCEER business plan (vision, mission, strategic plan, and operating principles) has been developed. This plan will serve as the beacon leading MCEER’s efforts toward self-sufficiency beyond 2007. Along this road to a successful execution of this plan, MCEER’s internal operating structure has been reorganized into an open management structure that embraces the broad constituency of researchers that identify and align with MCEER’s new vision and mission – full transition to this new operation structure will take place with the addition of new project PIs (at the time of this writing, proposals for approximately $8M in new funding submitted to various granting agencies on behalf of MCEER, from five different project PIs, are being reviewed).

The organizational structure to implement the new MCEER vision and mission is shown in Fig. 23. MCEER management is organized into three layers, each with specific roles and responsibilities.

1) **MCEER Center Management:** MCEER management is led by the Director, assisted by the Deputy Director, and other Special Issue (or special mission) Directors focusing on targeted efforts and special initiatives of various terms in duration. There is no pre-assigned number of Special Issue Directors (two are shown for example purposes in Fig. 23).

2) **Research Project Management:** The Principal Investigators (PIs) of research hosted by MCEER are the project directors for their specific project. They maintain full credit and responsibility for their respective project and benefit from the visibility and recognition of MCEER, from the integrated partnerships and alliances the Center provides, and from various support services that can serve the needs of their project. Each project can elect to have a technical director, an assistant director or project manager, its own research committee and/or advisory committee, or other structures and relationships as dictated by the project size and needs. This project hosting structure is intended to attract a broad constituency of researchers that are active participants in furthering the MCEER vision.

3) **Supporting Activities:** In addition to its strong reputation, expertise, credibility, visibility, and other positive attributes MCEER provides to partnering researchers, it also offers a broad range of services to support the activities of its investigators, and intends to expand the type and sophistication of these services.

There are two important groups identified within the MCEER organization as shown in Fig. 23, namely:

1) **Board of Directors:** The MCEER Center Management and Project Directors (from the Research Project Management) together form a MCEER Board of Directors that periodically
meets to plan resource allocation issues and other Center-wide coordination and promotion activities.

2) MCEER Executive Team: The MCEER Executive Team provides representation for the various core groups that endorse, defend, and advocate the vision and mission of MCEER. It advises management on various matters related to the Center. Members of the Executive Team are appointed by the MCEER Director for selected terms, taking into account recommendations of the various core groups, and to ensure representation from the MCEER Board of Directors.

Research Planning Cycle

Beginning in the early spring of each year, the Executive Committee develops the annual research plan in consultation with the IAB through the IAB Executive Committee, and the other EERC’s through the Council of Center Directors. The planning cycle begins in early January and ends when the Director submits the annual plan to NSF for approval and funding for the subsequent fiscal year (see Fig. 24). Once approved, researchers are invited to participate in the next year’s program by the Director. Requests for proposals are not issued, and unsolicited proposals are considered but not encouraged. However, new research participants may be involved based on recommendations by the IAB, the research community at large or NSF, when the work they can perform can make a significant contribution to the Center's major research thrust areas.
The sequence and purpose of meetings required to develop the annual research plan is explicitly described in Table 3. Important parts of the research decision process rely on the use of a Task Prioritization and PI Performance Matrix that takes a number of important aspects into account. Without going into the quantitative scoring details here, it is important to recognize that prior to year 9, this tool developed by MCEER addressed three major issues related to assessing the relevance, value, and probability of success of each research task (see earlier MCEER annual reports). In year 9, to achieve the goals of the expanded MCEER vision and strategic plan, the Task Prioritization and PI Performance Matrix has been redesigned to further emphasize key criteria to MCEER’s future beyond year 10. The MCEER funding allocation process has also been modeled on the STRATA CAP resource allocation model used as one of the decision making methodologies in Thrust Area 2. The new matrix therefore emphasizes the following:

**MCEER research worthiness/current mission assessment**

The first assessment is based on the following criteria:

1) The task has relevance to advanced technology
2) The task has potential for creating new knowledge on that topic
3) Links to Resilience Measures, expressed in terms of the three resilience measures of “Reduce probability of failure,” “Reduce consequences due to failure,” and “Reduce time to recovery,” recognizing that the ends of robustness and rapidity, as well as the means of resourcefulness and redundancy, link into these three resilience measures.
4) Significance (if successful) of task towards resilience objectives.
5) Implementability to assess whether the research is likely to be implemented if research is successful, and whether many organizational, economical, and societal barriers exist against implementation.

Note that for inclusion in the research program, each research activity undertaken by MCEER must address measures of resilience for critical facilities, i.e., whether the task focuses on reducing probability of failure, reducing consequences, or reducing time to recovery, as well as the means through which resilience is achieved in socio-technical systems – robustness, resourcefulness, rapidity, and redundancy.

**MCEER future plan compatibility assessment**

The second assessment is based on the following criteria:

1) The task has potential to be continued past year 10 of NSF funding
2) Some elements being developed in this task have potential application for the mitigation of hazards other than earthquakes, including natural and man-made hazards
3) This task has potential to attract industry partners to MCEER within and outside of the seismic mitigation field
4) This task has potential to attract researchers to MCEER outside of the seismic mitigation field
5) This task has the potential to lead to a multi-university/industry research project hosted by MCEER

These factors are directly related to the compatibility of a task, which satisfies MCEER mission within the current NSF-ERC program, with the plans for the future of MCEER. Note that in light
of the strategic significance of planning a strong future for MCEER beyond year 10, these factors are given more weight than the other factors as part of the overall scoring equation in the prioritization matrix.

**Past performance assessment**

The third assessment is based on the following criteria:
1) Value to strategic partners
2) Past performance of PI/team (research progress/productivity/publication/knowledge transfer to end-user)
3) Education output of PI/team (students supported, education products developed, center-wide education activities)
4) PI/team contribution to research management, coordination, and support activities
5) PI/team contribution to long-term financial goals of MCEER

These factors are used to promote the funding of tasks and activities that contribute to systems integration, whether they are perceived to be valuable to the IAB, whether they are appropriately staffed, and whether potential investigators have shown that they are able to work in diverse teams focusing on Center-wide goals. Furthermore, the investigators are assessed on their past performance and the value of their contribution to other objectives important to an NSF-funded center, such as publications, students supported or involved in the work, education–related output (new courses, training, participation in education activities, etc.), timely contribution of data to NSF Annual Report, and contribution to long-term financial goals.

**Constraints**

In addition to the above matters, the Center Director may dictate cost and organizational constraints that do not affect the strategic plan objectives but that must nonetheless be taken into account by the Executive Committee. These will vary from time to time, and are tabled at the beginning of the research planning cycle.

Other additional considerations are permanent and understood to be part of the process and recognized as such by the Executive Committee. For example, it is understood and accepted that all basic sciences or social sciences tasks funded by MCEER must contribute to engineering objectives.
Table 3: MCEER Process for Research Task Selection.

**Step 1: IAB Executive Committee and MCEER Executive Committee Joint Meeting**

The purpose of this meeting is to re-assess the state-of-the-art with respect to hazard mitigation policies and standards, the application of advanced technologies for earthquake hazard mitigation and planning, and key findings from recent earthquakes or other related disasters. Based on this assessment, MCEER will identify new research needed to achieve the Center’s strategic objectives.

**Step 2: MCEER Executive Committee meeting to frame research tasks**

Based on the results of Step 1, develop preliminary conceptual statements of new tasks and/or identify tasks that may need to be redesigned or terminated. This meeting may also result in revised and new objectives and goals.

**Step 3: Thrust Area Coordinator* Input**

Based on the results of Step 2, Thrust Area Coordinators gather data and prepare information to support their proposed suite of tasks, including recommendations on new and discontinued research. As part of this process, the Task Prioritization and PI Performance Matrix can be useful to the Thrust Area Coordinators for preliminary assessment purposes.

**Step 4: MCEER Executive Committee meeting to prioritize research tasks**

MCEER Executive Committee meets to discuss and negotiate research programs for the coming year. MCEER Executive Committee then makes preliminary decisions on resource allocation and identification of a small number of potential PI’s for each task. In this process, the MCEER Systems Diagram is a useful tool to guide the decision making process.

**Step 5: PI’s contacted for task statements**

MCEER contacts invited PI’s to have them prepare (or revise) tasks statements and data needed for the evaluation process. Note that the task statement format also collects data on performance measures needed in the Other MCEER Objectives section of the Task Prioritization and PI Performance Matrix.

**Step 6: Thrust Area Coordinator* Review**

Thrust Area Coordinators review task statements, work plans and budgets to ensure conformity to goals and objectives (Step 2).

**Step 7: Final Decision on Funded Research Projects**

MCEER Executive Committee makes final decisions on research for the coming year. A first secret ballot is held to rank each proposed task and investigator per the Task Prioritization and PI Performance Matrix. A second secret ballot is used to assign level of funding to those tasks that survived the first ballot.

* Although MCEER’s research agenda is designed to evolve and progressively transcend thrust area boundaries, Thrust Area Coordinators are still key to provide coordination and management of research priorities. Hence, their role should not be erroneously perceived as narrow and constrained to thrust area boundaries, but should rather be understood in the broader sense of a distributed management and coordination strategy.
Figure 24: Typical Cycle for Development of Annual Research Plan (months for specific events vary slightly from year to year, depending on scheduled date of NSF Site Visit).
D. Financial Support and Budget Allocations

MCEER receives a dollar-for-dollar match for its NSF support from other non-federal sources, plus additional funds totaling approximately $2.0 million per year from the Federal Highway Administration, FEMA, and other sources. Proposed spending for year 9 is outlined in Database Table 8, and in NSF Budget Form 1030. Sources of matching and leveraged support are presented in Database Table 9. Overall expenditure of funds for year 8 and prior years is shown in Database Table 10. Distribution of cash support by industry is explained in Database Table 11.

Mechanism for Internal Audit of EERC Funds

After the research thrust area for the upcoming funding year is defined, the Executive Committee identifies individual tasks and appropriate research personnel. Funding allocations are designated per task, per investigator. The investigators are then invited by the Director to participate in the research thrust area on the tasks defined by the committee, at the level of funding suggested. Investigators evaluate their ability to conduct the work charged with the funding designated. Some adjustments to scope of work or to funding level are usually made to assure that funds are sufficient for the intended work. All task statements and budgets for the tasks that will be subcontracted to other institutions are submitted to NSF as part of the Annual Report. When NSF has indicated its approval, the investigators then prepare a final task statement (scope of work) and a detailed budget for all related funding sources for the effort. These budgets are reviewed at the departmental level and contracts level at investigators’ respective institutions. Institutional approval of budgets must be obtained before materials are submitted to MCEER.

When materials are received by MCEER, budgets are again reviewed to determine that costs budgeted are allowable, indirect cost rates are appropriate, and that the general breakdown of funds is consistent with the work that has been proposed. After MCEER administrative approval, the materials are reviewed by the Research Foundation of the State University of New York at Buffalo. The Foundation assures that all rates being used for fringe, indirect costs, and consultant fees are certifiable. Allowable costs are also reviewed, in accordance with the terms of a master agreement that is established with each institution, and with the Foundation’s Cooperative Agreement with NSF. At that time, the Foundation issues subcontracts to the Research Office at each institution, under a master agreement that defines terms of performance, compensation and payment.

The subcontractor will periodically submit an invoice for the costs incurred, by major budget category. The invoice must be accompanied by a certification by the subcontractor’s authorized representative, which certifies that the costs are allowable as determined by the terms and conditions of the master agreement with the Foundation and that reimbursement for said costs has not been sought elsewhere. Submitted invoices are sent to Sponsored Programs Services, Accounts Payable at the University of Buffalo, which processes payment upon satisfactory review and approval by MCEER. Matching and in-kind contributions are monitored and certified on a year-to-year basis by MCEER and Sponsored Programs Services.


6. REFERENCES CITED


APPENDIX I: DIMENSIONS OF RESILIENCE
<table>
<thead>
<tr>
<th>PERFORMANCE MEASURES</th>
<th>Robustness</th>
<th>Redundancy</th>
<th>Resourcefulness</th>
<th>Rapidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>TECHNICAL</td>
<td>Damage avoidance and continued service provision</td>
<td>Back-up/duplicate systems, equipment and supplies</td>
<td>Diagnostic and damage detection technologies and methodologies</td>
<td>Optimizing time to return to pre-event functional levels</td>
</tr>
<tr>
<td>ORGANIZATIONAL</td>
<td>Continued ability to carry out designated functions</td>
<td>Back-up resources to sustain operations (e.g. alternative sites)</td>
<td>Plans and resources to cope with damage and disruption (e.g. mutual aid, emergency plans, decision support systems)</td>
<td>Minimize time needed to restore services and perform key response tasks</td>
</tr>
<tr>
<td>SOCIAL</td>
<td>Avoidance of casualties and disruption in the community.</td>
<td>Alternative means of providing for community needs</td>
<td>Plans and resources to meet community needs</td>
<td>Optimizing time to return to pre-event functional levels</td>
</tr>
<tr>
<td>ECONOMIC</td>
<td>Avoidance of direct and indirect economic losses.</td>
<td>Untapped or excess economic capacity (e.g. inventories, suppliers).</td>
<td>Stabilizing measures (e.g. capacity enhancement and demand modification, external assistance, optimizing recovery strategies)</td>
<td>Optimizing time to return to pre-event functional levels</td>
</tr>
<tr>
<td>System</td>
<td>Robustness</td>
<td>Redundancy</td>
<td>Resourcefulness</td>
<td>Rapidity</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Global</td>
<td>Damage avoidance and continued service provision</td>
<td>Back-up/duplicate systems, equipment and supplies</td>
<td>Diagnostic and damage detection technologies and methodologies</td>
<td>Optimizing time to return to pre-event functional levels</td>
</tr>
<tr>
<td>Power</td>
<td>Maximize availability of operational power supply (units) after EQ (e.g. #% of pre-earthquake level following small earthquake)*</td>
<td>Replacement inventories (e.g. #% available for small earthquake)</td>
<td>Models to assess network vulnerability and damage (e.g. EPRI model)</td>
<td>Maximize provision target power supply level (e.g. restoration to 95% of pre-earthquake level within 1 day)</td>
</tr>
<tr>
<td>WATER</td>
<td>Maximize availability of operational water supply (units) after EQ (e.g. #% of pre-earthquake level following small earthquake)</td>
<td>Replacement inventories (e.g. #% available for small earthquake)</td>
<td>Models to assess network vulnerability and damage (e.g. SCADA)</td>
<td>Maximize provision of target water supply level (e.g. restoration to #% of pre-earthquake level within 1 day)</td>
</tr>
<tr>
<td>HOSPITAL</td>
<td>Maximize availability of buildings and equipment (units) and #% of functions operational after small earthquake) – (technical unit to be defined)</td>
<td>Back-up/duplicate systems, equipment and supplies (e.g. #% available for small earthquake)</td>
<td>Integrated fragility models to assess system vulnerability and damage</td>
<td>Buildings and equipment are fully functional immediately after EQ</td>
</tr>
<tr>
<td>R&amp;R</td>
<td>Avoid damage and maintain functionality of critical emergency facilities (e.g. EOCs, fire and police stations)</td>
<td>Backup resources exist to provide services in case of loss of functionality</td>
<td>Damage detection technologies and methodologies, other information technologies and decision support systems.</td>
<td>All technology needed for command, control, coordination and critical response tasks is operational</td>
</tr>
</tbody>
</table>
Table A3. Organizational Performance Measures (Illustrative)

<table>
<thead>
<tr>
<th>PERFORMANCE CRITERIA</th>
<th>System</th>
<th>Robustness</th>
<th>Redundancy</th>
<th>Resourcefulness</th>
<th>Rapidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global</td>
<td>Continued ability to carry out designated functions</td>
<td>Back-up resources to sustain operations (e.g., alternative sites)</td>
<td>Plans and resources to cope with damage and disruption (e.g., mutual aid, emergency plans, decision support systems)</td>
<td>Minimize time needed to restore services and perform key response tasks</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>Emergency organization and infrastructure in place; critical functions identified</td>
<td>Replacement inventories for critical equipment (e.g., transformers, bushings)</td>
<td>Plans for mobilizing supplies and personnel (e.g., mutual aid agreements); identification of emergency work-around strategies</td>
<td>Maximum restoration of power supply</td>
</tr>
<tr>
<td></td>
<td>WATER</td>
<td>Emergency organization and infrastructure in place; critical functions identified</td>
<td>Alternative water supplies available (e.g., San Francisco Auxiliary Water Supply System)</td>
<td>Plans for mobilizing supplies and personnel (mutual aid agreements); identification of emergency work-around strategies</td>
<td>Maximum restoration of water supply (potable water, fire-following, industrial usage)</td>
</tr>
<tr>
<td></td>
<td>HOSPITAL</td>
<td>Emergency organization and infrastructure in place; critical functions identified</td>
<td>Alternative sites and procedures identified for providing medical care</td>
<td>Plans and procedures for mutual aid &amp; emergency transfer of patients to undamaged hospitals</td>
<td>Maximize provision of critical medical and health care services; minimize avoidable negative health outcomes</td>
</tr>
<tr>
<td></td>
<td>R&amp;R</td>
<td>Emergency organization and infrastructure in place; critical functions identified</td>
<td>Intergovernmental division of labor for carrying out emergency response activities (e.g., provision of assistance of search and rescue)</td>
<td>Emergency management plans and response strategies effectively implemented</td>
<td>Minimize time needed to initiate and complete critical response tasks (e.g., firefighting, search and rescue, activation of intergovernmental mutual aid)</td>
</tr>
</tbody>
</table>
### Table A4. Social Performance Measures (Illustrative)

<table>
<thead>
<tr>
<th>System</th>
<th>Robustness</th>
<th>Redundancy</th>
<th>Resourcefulness</th>
<th>Rapidity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global</strong></td>
<td>Avoidance of casualties and disruption in the community.</td>
<td>Alternative means of providing for community needs.</td>
<td>Plans and resources to meet community needs</td>
<td>Optimizing time to return to pre-event functional levels</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>At least #% of all households with power immediately after EQ</td>
<td>Alternative power supplies for all critical emergency facilities (e.g., hospitals)</td>
<td>No form of rationing needed to meet minimum power needs</td>
<td>Partial power restored to all households within 1 hour</td>
</tr>
<tr>
<td><strong>WATER</strong></td>
<td>Uninterrupted water supply for fire-fighting</td>
<td>Alternative water supplies for post-event fire-fighting</td>
<td>No form of rationing needed to meet minimum potable water supply needs</td>
<td>Potable water service uninterrupted after event</td>
</tr>
<tr>
<td><strong>HOSPITAL</strong></td>
<td>All injuries treated in first day</td>
<td>Volunteers encouraged to assist at acute care hospitals</td>
<td>Volunteers encouraged to assist at acute care hospitals</td>
<td>All injuries treated in first day</td>
</tr>
<tr>
<td><strong>R&amp;R</strong></td>
<td>All search &amp; rescue incidents identified and rescue teams mobilized within 1 hour</td>
<td>No need to use alternative sources for provision of essential services (medical care, food, water)</td>
<td>Disaster assistance needs estimated within 6 hours</td>
<td>Disaster Assistance Centers (DACs) set up within 1 day of event</td>
</tr>
<tr>
<td></td>
<td>No deaths due to insufficient response capacity</td>
<td>Formal request for disaster declaration submitted within 8 hours</td>
<td></td>
<td>Shelters established for displaced residents within 12 hours</td>
</tr>
<tr>
<td></td>
<td>No deaths or serious injuries due to secondary earthquake effects (e.g., fire following)</td>
<td></td>
<td></td>
<td>Food and water provided for displaced residents within 12 hours</td>
</tr>
</tbody>
</table>
### Table A5. Economic Performance Measures (Illustrative)

<table>
<thead>
<tr>
<th>System</th>
<th>Robustness</th>
<th>Redundancy</th>
<th>Resourcefulness</th>
<th>Rapidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>Avoidance of direct and indirect economic losses.</td>
<td>Untapped or excess economic capacity (e.g., inventories, suppliers).</td>
<td>Stabilizing measures (e.g., capacity enhancement and demand modification, external assistance, optimizing recovery strategies)</td>
<td>Optimizing time to return to pre-event functional levels</td>
</tr>
<tr>
<td>Power</td>
<td>At least #% of all businesses with power immediately after EQ</td>
<td>Alternative power supplies (back-up power) for all key businesses</td>
<td>Voluntary power conservation program implemented</td>
<td>Pre-EQ economic activities re-established in 1 day</td>
</tr>
<tr>
<td>WATER</td>
<td>At least #% of all businesses with water immediately after EQ</td>
<td>Alternative water supplies (back-up power) for all key businesses</td>
<td>Voluntary power conservation program implemented</td>
<td>Pre-EQ economic activities re-established in 1 day</td>
</tr>
<tr>
<td>HOSPITAL</td>
<td>No damage to building or critical emergency equipment</td>
<td>Pre-event arrangements for governmental reimbursement and/or insurance</td>
<td>Pre-event arrangements for governmental reimbursement and/or insurance</td>
<td>Procurement of new/replacement equipment in 1 day</td>
</tr>
<tr>
<td>R&amp;R</td>
<td>Preliminary loss estimate within 1 hour of event</td>
<td>No need for measures to restore economic viability (e.g., transportation rerouting)</td>
<td></td>
<td>Pre-EQ economic activities re-established in 3 days</td>
</tr>
</tbody>
</table>
APPENDIX IV: ABBREVIATIONS AND ACRONYMS
# ABBREVIATIONS AND ACRONYMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>13WCEE</td>
<td>13th World Conference on Earthquake Engineering</td>
</tr>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>ANCER</td>
<td>Asian Pacific Network of Centers for Earthquake Engineering Research</td>
</tr>
<tr>
<td>ASCE</td>
<td>American Society of Civil Engineers</td>
</tr>
<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigerating and Air Conditioning Engineers</td>
</tr>
<tr>
<td>ATC</td>
<td>Applied Technology Council</td>
</tr>
<tr>
<td>AWWARF</td>
<td>American Water Works Association Research Foundation</td>
</tr>
<tr>
<td>BEAM</td>
<td>Buffalo Engineering Awareness for Minorities</td>
</tr>
<tr>
<td>BICEPP</td>
<td>Business and Industry Council on Emergency Preparedness</td>
</tr>
<tr>
<td>BRB</td>
<td>Buckling Restrained Braces</td>
</tr>
<tr>
<td>CGE</td>
<td>Computable General Equilibrium</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial Off-the-Shelf</td>
</tr>
<tr>
<td>CSEE</td>
<td>Civil, Structural and Environmental Engineering (University at Buffalo)</td>
</tr>
<tr>
<td>CUNY</td>
<td>City University of New York</td>
</tr>
<tr>
<td>DC-FP</td>
<td>Double-Concave Friction Pendulum</td>
</tr>
<tr>
<td>DHS</td>
<td>Department of Homeland Security</td>
</tr>
<tr>
<td>DIS</td>
<td>Dynamic Isolation Systems, Inc.</td>
</tr>
<tr>
<td>DOE</td>
<td>U.S. Department of Energy</td>
</tr>
<tr>
<td>EADR</td>
<td>Evolutionary Aseismic Design and Retrofit</td>
</tr>
<tr>
<td>EBMUD</td>
<td>East Bay Municipal Utility District</td>
</tr>
<tr>
<td>EDM</td>
<td>Earthquake Disaster Mitigation Research Center</td>
</tr>
<tr>
<td>EERC</td>
<td>Earthquake Engineering Research Center</td>
</tr>
<tr>
<td>EERI</td>
<td>Earthquake Engineering Research Institute</td>
</tr>
<tr>
<td>EOC</td>
<td>Emergency Operations Center</td>
</tr>
<tr>
<td>EPRI</td>
<td>Electric Power Research Institute</td>
</tr>
<tr>
<td>EPS</td>
<td>Earthquake Protection Systems, Inc.</td>
</tr>
<tr>
<td>EQIP</td>
<td>Earthquake Information Providers Group</td>
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<tr>
<td>EQNET</td>
<td>Earthquake Information Network</td>
</tr>
<tr>
<td>ERC</td>
<td>Earthquake Research Center</td>
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<tr>
<td>ERS</td>
<td>Earth Resource Satellite</td>
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<tr>
<td>EUC</td>
<td>Electrical Utility Consortium</td>
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<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
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<tr>
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</tr>
<tr>
<td>FFE</td>
<td>Fire Following Earthquakes</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>FRP</td>
<td>Fiber Reinforced Polymer</td>
</tr>
<tr>
<td>GIRAFFE</td>
<td>Graphical Iterative Response Analysis for Flow Following Earthquakes</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GRP</td>
<td>Gross Regional Product</td>
</tr>
<tr>
<td>IAB</td>
<td>Industry Advisory Board</td>
</tr>
<tr>
<td>IGERT</td>
<td>Integrative Graduate Education and Research Traineeship</td>
</tr>
<tr>
<td>iHARD</td>
<td>Integrated Multi-Hazard Risk Decision</td>
</tr>
<tr>
<td>IS</td>
<td>(MCEER) Information Service</td>
</tr>
<tr>
<td>ISAT</td>
<td>International Seismic Application Technology</td>
</tr>
<tr>
<td>JETS</td>
<td>Junior Engineering Technical Society</td>
</tr>
<tr>
<td>JICA</td>
<td>Japan International Cooperation Agency</td>
</tr>
<tr>
<td>JPL</td>
<td>Jet Propulsion Laboratory</td>
</tr>
<tr>
<td>JWWA</td>
<td>Japan Water Works Association</td>
</tr>
<tr>
<td>LADWP</td>
<td>Los Angeles Department of Water and Power</td>
</tr>
<tr>
<td>LIDAR</td>
<td>Light Detection and Ranging</td>
</tr>
<tr>
<td>LYS</td>
<td>Low Yield Strength</td>
</tr>
<tr>
<td>MAE</td>
<td>Mid-America Earthquake Center</td>
</tr>
<tr>
<td>MCEER</td>
<td>Multidisciplinary Center for Earthquake Engineering Research</td>
</tr>
<tr>
<td>MCU</td>
<td>Multipoint Control Unit</td>
</tr>
<tr>
<td>MDOF</td>
<td>Multiple Degree of Freedom</td>
</tr>
<tr>
<td>MESA</td>
<td>Mathematics, Engineering and Science Achievement</td>
</tr>
<tr>
<td>MIHEA</td>
<td>Mono-Image Height Extraction Algorithm</td>
</tr>
<tr>
<td>MLGW</td>
<td>Memphis Light, Gas and Water</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NC4</td>
<td>National Center for Crisis and Continuity Coordination</td>
</tr>
<tr>
<td>NCREE</td>
<td>National Center for Research on Earthquake Engineering</td>
</tr>
<tr>
<td>NCS</td>
<td>Nonstructural Components Simulator</td>
</tr>
<tr>
<td>NEES</td>
<td>(George E. Brown, Jr.) Network for Earthquake Engineering Simulation</td>
</tr>
<tr>
<td>NEHRP</td>
<td>National Earthquake Hazards Reduction Program</td>
</tr>
<tr>
<td>NJIT</td>
<td>New Jersey Institute of Technology</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
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</table>
NSF  National Science Foundation
NTU  National Taiwan University
OLE  Orthogonal Limit-space Environment
OSHPD California Office of Statewide Health Planning and Development
PEER Pacific Earthquake Engineering Research Center
PI  Principal Investigator
PSA  Pseudo-Accelerations
PTED Post-Tensioned Energy Dissipating
RDAT Rehabilitation Decision Analysis Toolbox
REDARS Risks from Earthquake Damage to Roadway Systems
RET  Research Experiences in Teaching
REU  Research Experiences for Undergraduates
RPI  Rensselaer Polytechnic Institute
SAR  Synthetic Aperture Radar
SBM  Specific Barrier Model
SCADA Supervisory Control and Data Acquisition
SCE Southern California Edison
SCEC Southern California Earthquake Center
SDOF  Single Degree of Freedom
SEAONC Structural Engineers Association of Northern California
SEESL Structural Engineering and Earthquake Simulation Laboratory
SLC  Student Leadership Council
SMACNA Sheet Metal & Air Conditioning Contractors National Association
SOMBRERO Sliding an Overlaid Multidimensional Bell-Curve of Response for Engineering Resilience Operationalization
SPSW Steel Plate Shear Wall
STEM Science/Technology/Engineering/Mathematics
TOSE Technical, Organizational, Social and Economic
UAV  Unmanned Airborne Vehicles
UB  University at Buffalo
UCIST University Consortium on Instructional Shake Tables
USACE US Army Corps of Engineers
USESN United States Educational Seismographic Network
USGS United States Geological Survey

I-A.55
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIEWS</td>
<td>Visualizing the Impacts of Earthquakes with Satellites</td>
</tr>
<tr>
<td>VL</td>
<td>Virtual Laboratory</td>
</tr>
<tr>
<td>VLEE</td>
<td>Virtual Laboratories for Earthquake Engineering</td>
</tr>
<tr>
<td>VRS</td>
<td>Virtual Reconnaissance Survey</td>
</tr>
<tr>
<td>VTC</td>
<td>Video Tele-Conference</td>
</tr>
<tr>
<td>WECC</td>
<td>Western Electricity Coordination Council</td>
</tr>
<tr>
<td>WTC</td>
<td>World Trade Center</td>
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