

MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

AN ENGINEERING RESEARCH CENTER

Lead Institution: State University of New York at Buffalo

Core Partner Institutions: Cornell University
University of California at Irvine
University of Colorado at Boulder

SUBMITTED BY:

MICHEL BRUNEAU, DIRECTOR

ANDRE FILIATRAULT, DEPUTY DIRECTOR

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4201 Wilson Boulevard, Suite 585
Arlington, VA 22230

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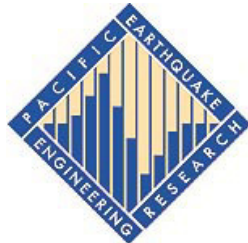
MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

**National Science Foundation
Earthquake Engineering Research Centers**

***Year 7 Annual Report
Volume 3:***

TRI-CENTER COLLABORATION

*Pacific Earthquake Engineering Research Center
Multi-Disciplinary Center for Earthquake Engineering Research
Mid-America Earthquake Center*



Preface

This third volume of the Year 7 Annual Reports for the three NSF-sponsored Earthquake Engineering Research Centers has been prepared as a collaborative effort of the three centers. 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 annual report. This document has been prepared as a separate volume so that it may stand alone to illustrate tri-center collaboration in research, education and outreach.

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Section 1

Introduction

1.1 Background

In October of 1997, soon after establishment of the three earthquake centers, a Council of Center Directors was established. The mission of the Council is to provide a formal channel of communication among the centers for the overall benefit of earthquake engineering research, education and public awareness. The Council identifies mutual areas of technical interest and avoids the duplication of efforts between the earthquake engineering research centers. The Council coordinates and promotes international, educational and outreach activities when mutual involvement is beneficial. The Council has met on numerous occasions since the founding of the centers, particularly over the last two years to develop, implement and assess the strategic plan and collaboration activities presented herein.

Former and current research programs of each of the three centers are complementary because of communication in the initial planning stages. During the first years, advisory boards for each center included representatives from the other centers. Vision, mission and scope of the three research plans were known through these interactions, which avoided duplication in planning of each center's programs. Also, annual research reports for each center have been exchanged after site reviews each year. In particular, benefits of close collaborations on educational activities since the early years of the three centers are well-recognized.

In past reviews of the three centers, panelists found little or no duplication of efforts across the research, education and outreach programs of the three centers. However, reviewers did acknowledge that each center could benefit from increased cooperation. The NSF Blue Ribbon Panel in the Year 4 renewal review stated that significant opportunities existed to create truly robust, complementary, multi-disciplinary, multi-level system solutions. In response to this comment, the Directors, Deputy Directors and other leading researchers of the three centers have discussed at length possibilities for tri-center collaboration. They have met in face-to-face meetings, conference calls and video teleconferences frequently since the Year 6 renewal of the three centers to formulate collaborative ideas. The centers also enlisted a subcontractor to evaluate commonalities in their research programs and identify possibilities for fruitful collaboration. The plan presented with the Year 6 annual reports is currently in the implementation phase. This document presents work done to date to further develop tri-center collaboration that is already contributing to the enhancement and strengthening of the research, education and outreach programs of each center.

1.2 Missions and Thrust-Area Organization for the Three Centers

Because earthquakes broadly cripple multiple engineering, economical and societal systems in their stricken area, the mitigation of earthquake disasters is a complex multifaceted problem that requires the involvement and expertise of structural engineers, systems engineers, geotechnical engineers, seismologists, social scientists, policy- and decision-making experts, and many others. No single government agency or research center can alone tackle all aspects of the problem. A coordinated effort is therefore required. Centers provide the coordination structure needed to conduct the complex holistic work needed to successfully address the earthquake mitigation problem. Furthermore, because each EERC is a consortium of several academic institutions involved in multidisciplinary team research, educational, and outreach activities, in partnership with industry, government, and foreign research organizations, they provide the needed infrastructure and critical mass to attract and train the next generation of professionals that are needed to implement the new technologies and knowledge for seismic risk mitigation and ensure continuing U.S. leadership in the field.

Research thrust areas for each center are organized differently to meet specific goals of its program. The MCEER perspective on lifelines and acute care facilities and on emergency response and recovery are unique to its mission. Thrust areas of PEER are arranged to furnish technologies needed to enable further improvements to performance-based earthquake engineering. The MAE Center core program is organized to develop new tools for synthesizing seismic response of various stakeholder systems on a regional basis, and ways to use these tools to minimize earthquake consequences.

Mission statements and core research thrust areas as reported in each of the three center's Year 6 Annual Reports are summarized in Table 1. Different visions are important to maintain singularity and focus, though further collaboration will be useful for leveraging intellectual talent from each center. Whereas overall goals to enhance seismic resiliency of communities, to minimize consequences across regions or to develop new performance-based seismic design technologies have common attributes, each represents a different perspective that is having a profound impact on earthquake risk reduction in its own right.

1.3 Tri-Center International Collaboration

Common international activities among the three centers have been taking place over the last six years. In 1998, the three EERC's signed an Implementing Arrangement with the European Commission's Joint Research Centre in Ispra, Italy to collaborate with earthquake engineering researchers throughout Europe. In addition, the three US earthquake centers were instrumental in the formation of the present Asian-Pacific Network of Centers in Earthquake Research (ANCER) that has attracted member centers from Taiwan, Korea, China and Japan with many other centers wishing to join at present. With ANCER sponsorship of two significant international earthquake-engineering conferences (in Harbin, PRC and Hong Kong in August of 2002), the world-wide leadership of the three centers in earthquake engineering research continues to grow.

The three centers are poised to take full advantage of the NEES facilities that have been developed at one or more of each center's core institutions. Plans are underway for multi-site, multi-national simulations using NEESgrid. The infra-structure provided by the three centers has

therefore been instrumental in the success of the national NEES program. Many more examples of international collaboration are given in the annual reports of each center.

Table 1 Mission and Research Thrust Areas of Each Earthquake Center

Center	Mission Statement	Year 6 Core Research Thrust Areas
Multi-Disciplinary Center for Earthquake Engineering Research	The overall goal of 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 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.	<ol style="list-style-type: none"> 1. Seismic Evaluation and Retrofit of Lifeline Systems 2. Seismic Retrofit of Acute Care Facilities 3. Emergency Response and Recovery 4. User Networks for Seismic Assessment and Retrofit of Critical Facilities
Pacific Earthquake Engineering Research Center	The PEER mission is to develop, validate and disseminate performance-based seismic design technologies for buildings and infrastructure to meet the diverse economic and safety needs of owners and society.	<ol style="list-style-type: none"> 1. Loss Modeling and Decision Making 2. Hazard Assessment and Geo-Performance 3. Assessment and Design Methodologies 4. Simulation and Information Technologies 5. Structural and Non-Structural Performance
Mid-America Earthquake Center	To develop new engineering approaches necessary to minimize consequences of future earthquakes. Correlated interdisciplinary research synthesizing damage across regions, estimating seismic vulnerability across regional and national networks, and improving current engineering approaches, forms the core research needed to develop such consequence-based approaches and to support stakeholder interests in risk assessment and seismic engineering.	<ol style="list-style-type: none"> 1. Damage Synthesis 2. Consequence Minimization 3. Hazards Definition

1.4 Focus Areas for Tri-Center Collaboration

The three earthquake engineering research centers have developed a strategic plan, articulated in the Year 6 report, to guide future tri-center collaboration. The plan proposes to take advantage of potential synergies among the three centers without detracting from their individual strategic planning processes. The general framework for the plan consists of modules on various topics for which faculty and students are contributing across center boundaries. The following three modules of collaboration continue to form the three-pronged tri-center collaboration efforts:

- collaborative education group
- collaborative forum on social science, economics, public policy and urban planning
- collaborative research on geographically distributed systems

Each of these modules is described in the subsections that follow.

Section 2

Tri-Center Educational Activities

The three Earthquake Engineering Research Centers have historically developed innovative, collaborative education programs and continue to expand upon these accomplishments and to strengthen the education experience. These tri-center activities serve as vehicles delivering knowledge to end-users ranging from elementary and secondary students, undergraduate and graduate students, to the general public. Integrating programs and efforts has provided an opportunity to reach a larger audience, capitalize on diversity, leverage funding available for these activities, and promote a team approach in delivery of exceptional earthquake engineering education activities.

2.1 Tri-Center REU Program

The NSF-funded Research Experience for Undergraduates (REU) program has gained national attention for its work aimed at recruiting promising undergraduates from across disciplines into engineering research. A competitive, multi-center endeavor, the REU program invites outstanding undergraduate students from diverse backgrounds, who are in their junior year, to apply. Candidates must have a minimum GPA of 3.0 and need to be available full-time from June through mid-August. The selected students spend ten weeks conducting a faculty-supervised research project in earthquake engineering or a related field. Each student has an individual project (determined in the selection process) to complete, which contributes to the goals of an existing center project. Appropriate faculty supervision is provided throughout the summer, and the student is encouraged to conduct independent research and is given the opportunity to participate effectively as a member of a research team. Tri-center REU activities commence with student recruitment and conclude with a symposium and a research reports publication. The 2004 program will represent the fifth time this collaboration has taken place.

(i) Student Recruitment - The three centers conduct a coordinated recruiting campaign focusing on the departments at universities and colleges, across the United States, that serve students who have a potential interest in the REU program. Targeted are Earth Science, Social Science, Engineering, and Urban and Regional Planning Departments. National society student chapters, newsletters, and relevant websites are also recruited for program advertising. These announcements have links to the REU home pages of the participating centers, which post the applications to the individual center. Prospective students apply to each center as they chose; some coordination of applications to multiple centers may occur.

To further inform potential participants about the program, a detailed announcement on the three centers' websites is developed to outline the ongoing research projects, stipend, requirements and goals of the REU program, supplemental activities, and housing arrangements. The REU program application is designed to solicit information on the research interests of the applicant,

their background and qualifications, as well as which projects he/she might be interested in. Transcripts and letters of recommendation from faculty members at their institutions are also requested. Qualified applicants are then matched to the center researcher with a similar research interest.

There has been a significant increase in the number of women and underrepresented minority students participating in the REU program. This is attributed to vigorous recruitment. Recruitment of students from underrepresented groups specifically focuses on contacting the office of minority student affairs and the office of disabled student affairs at various institution, as well as, participants in the Tribal Colleges and Universities Program (TCUP). Additionally, regional and national chapters of the National Society of Black Engineers, Society of Women Engineers, National Society for Hispanic Engineers, as well as other institutions with high minority enrollment, receive a REU program notification. At every opportunity, the investigators of the centers are reminded to help us identify women and underrepresented minority candidates for REU positions.

(ii) Earthquake Engineering Symposium for Young Researchers

- At the end of their research internship, all tri-center REU students participate in the Earthquake Engineering Symposium for Young Researchers. The symposium provides a forum for REU participants to present the results of their research projects and to network with other students. Also, at the symposium a program on engineering ethics is included. It is designed to provide the REUs with exposure to and an understanding of ethics, as required and practiced in the engineering field. The participation of an engineering ethics expert is an important component of the symposium. Each student reviews a case study and prepares a paper prior to the symposium. At the symposium the REUs hold small group discussions, facilitated by the expert, on how to solve the ethical dilemma presented to them. Each group then presents its conclusion and supporting arguments in plenary session. The symposium also features keynote speakers and tours of nearby facilities specializing in earthquake studies, if they are convenient.



(iii) REU Research Reports - Each research assistant is required to submit an electronic final report of the results of their project to the REU Coordinator. The scope of this report is agreed upon between the student and the faculty advisor. These final reports are available in print format through a tri-center proceedings volume. The REU participants are also encouraged to publish the results of their projects in either technical journals or conference proceedings. They are particularly encouraged to submit an abstract for the student paper competition at the Earthquake Engineering Research Institute (EERI) Annual Meeting. Several tri-center REU students have participated in the EERI student paper contest.

2.2 Tri-Center Student Leadership Council Activities

The **Tri-Lateral Student Leadership Council (SLC) Workshop** is held yearly at the EERI Annual Meeting. The event is organized to allow for networking, idea sharing, and establishing future collaboration between the three center Student Leadership Councils. By facilitating communication among graduate research assistants, the workshop furthers tri-center group dynamics and underscores the importance of student participation in center activities. Each of the SLC chairpersons presents information about their council, when and how they were formed, where they are today, and the SLC role in center operations. The group reviews issues that concern all three centers. The SLC members also meet periodically throughout the year using videoconferencing.

Based on past suggestions, a new collaborative project will begin in 2004/05. A tri-center undergraduate seismic design competition is being organized that will utilize the small shaking tables which exist at most EERC universities (see 2.5 ii).

2.3 Tri-Center Student Field Missions

A tri-center **Earthquake Field Study** program was initiated in spring 2002. Ideally, four graduate research assistants from each center, plus four non-center graduate students (selected by professional earthquake engineering organizations), compete to spend ten days visiting a recent earthquake site in order to engage in a hands-on field assessment exercise. Each center may send one advisor to accompany the student team. Funds to cover round trip travel, participation in the weeklong field trip, food, and lodging are provided, and industry fellowships are encouraged.

In October 2003, thirteen graduate students plus two professors and staff member traveled to Italy, for a week long study and tour of earthquake laboratories and field sites. The students were sponsored by the three earthquake centers, MCEER, PEER and MAE. The mission was organized by MCEER. The trip began with visits to laboratories in the surrounding area of Milan. Site visits included the Joint Research Centre's European Laboratory for Structural Assessment (ELSA) at Ispra, University of Pavia, University of Rome, La Sapienza, University of L'Aquila, the devastated village of San Giuliano di Puglia, and Naples.



After their return to the U.S., the students have been asked to make at least two presentations during 2003-04 based on information they learned during the trip. One presentation is to be given to groups of students or adults in the U.S. that do not have an academic background in engineering or earthquakes, such as for middle or upper level high school students or lower-division undergraduate students. The second presentation is intended to be a technical seminar for graduate students and interested professors at the earthquake centers. This presentation was delivered at the 2004 MAE Center Annual Meeting and was enthusiastically received.

The three centers have elected to make Japan the next destination for the earthquake field study. PEER will be organizing this trip, scheduled for July, 2004.

2.4 Tri-Center Student Seminars

A **Tri-Center Doctoral Research Seminar Series was initiated in 2003**. EERC supported students who are near the completion of their doctoral degrees are hosted by the other centers. One doctoral student from PEER presented his dissertation work at UIUC and one MAE Center student presented at UCSD. Two other doctoral students from PEER presented their work at MCEER. MCEER students will make the next presentations at PEER and MAE. This exchange between centers allows students to learn more about the centers' respective research programs and to have an in-depth presentation on the student's particular area of study.

2.5 Tri-Center Teaching Modules and Tools

(i) Teaching Modules for Graduate Students – This project has created a series of graduate-level, self-contained, web-based, teaching modules. The modules include materials on various subjects and may be shared by a variety of academic institutions that do not have resident expertise in specialized subjects pertaining to earthquake engineering. The modules consist of written text, specifications for experiments, visual materials and supplementary web information. Modules are being developed for the following areas: *Fluid Structure Interaction, Wave Propagation, Earthquake Engineering Design, Seismic Ground Motion and Hazard, Seismic Upgrading: A PBE Case Study, Seismic Behavior of Timber Structures, Earthquake Resistant Design, Liquefaction, Socioeconomic Aspects of Earthquakes, Putting a Face on Earthquakes: The Human Side of Earthquake Disasters, and Seismic Design of Diaphragms, Chords and Collectors*. In the early phases of this program, each center was to produce at least one module per year on different aspects of earthquake engineering and hazard related studies. An inter-center task force of faculty and professional earthquake engineers selects the module topics in consultation with the other two centers. SLC input has been solicited during the beta-testing of each module. Currently many of the modules are being evaluated and distributed for use.

(ii) Instructional Earthquake Simulators – In an effort to increase students' knowledge of earthquake engineering through hands-on experiments, the three centers have organized a program for deployment of small earthquake simulators specifically designed for use in a classroom setting. Shaking tables have generally been used more as research tools rather than as instructional devices. So, to encourage more interest in structural dynamics and earthquake hazard mitigation at the undergraduate level, 23 institutions drawn from the three national earthquake centers cooperated in the design of a bench-scale shake table. The initial acquisition was partially supported by an NSF grant and other private funding and has grown to a consortium of over 40 institutions know as UCIST. Also, several tables have been purchased by universities outside of the U.S. The equipment is used to integrate earthquake engineering into the undergraduate curriculum. Classroom demonstrations and "hands-on" experiments are conducted at all levels in order to have a significant impact on the curriculum. In addition, the shake tables are displayed and demonstrated at public awareness events, including: state fairs, primary and secondary schools, and local community disaster preparedness programs. Future

activities include plans for developing two nationwide competitions in earthquake resistant design, one for undergraduates and one for elementary school children.

The deliverables from this cooperative effort include drawings of the scale test models, a set of laboratory manuals, various experiments and exercises, video-tapes, and a CD-ROM containing drawings and manuals to allow for the duplication of all of the experiments. These products are available to all participating institutions. Also, a set of Seismic Resistant Design Student Competition Guidelines has been developed for two design competitions. These are offered to any institutions that wish to host such competitions. A second more advanced design competition has been developed for undergraduates. This activity has the potential to generate as much interest as the ASCE Concrete Canoe and AISC Steel Bridge Competitions.

Section 3

Tri-Center Collaboration in the Social, Decision and Policy Sciences

Fostering integrated research on both engineering and societal aspects of earthquakes is a key objective of the EERC program. All three centers have addressed this need by providing support to investigators from a range of social science disciplines, including political science, economics, urban planning and regional science, geography, decision sciences, and sociology. Social scientists affiliated with the centers conduct fundamental research in their own fields in support of center objectives, but also increasingly work closely with engineers on multidisciplinary teams, addressing such topics as decision-making with respect to earthquake mitigation, response, and recovery; societal and economic impacts of earthquake hazards; the acceptability of different levels of risk and earthquake consequences for various stakeholder groups; and earthquake loss-reduction policy design and implementation.

All three centers have a strong commitment to encouraging cross-center collaboration among EERC-affiliated social science researchers on projects that are mutually beneficial for the centers and that yield both scientific advances and societal benefits. Recent years have been marked by various types of cross-center collaborative activity. The sections below briefly discuss these collaborations, which include both center-funded and independently-funded projects. Also included are activities that involve collaboration between investigators from two (rather than all three) centers and jointly funded work.

Social science research activities at the three centers focus on three areas of common interest. The first area concerns decision making for seismic safety. While projects differ in their focus, many social science studies focus in one way or another on generic issues related to acceptable risk and choices made regarding low-probability, high-consequence events under conditions of uncertainty.

Issues related to the adoption and implementation of seismic safety measures constitute a second area of emphasis that is closely related to center-based research on decision making. For example, PEER is considering barriers to the adoption and implementation of performance-based earthquake engineering and issues that PBEE raises for building regulation. MCEER is addressing ways of enhancing the seismic resilience of communities and their critical facilities, with a special emphasis on the adoption of seismic loss reduction measures by hospitals. MAE is considering how to build community support for strengthening infrastructure and critical facilities in the Mid America region. The broader issue is perhaps best stated as one of raising levels of awareness and motivating action to enhance earthquake safety. This is the focus of the FEMA-funded tricenter collaborative project on seismic safety advocacy, which is discussed in more detail in the next section.

A third major research theme centers on the economic evaluation of seismic safety investments. Various projects have been undertaken at the three centers concerning cost-benefit analysis in

assessing seismic investments—particularly mitigation measures—regional economic impacts of earthquakes, and related topics in the fields of economics and regional science. This research thrust is perhaps most advanced with respect to loss modeling for lifeline systems.

3.1 Collaborative Tri-Center Project on Guidance for Earthquake Loss-Reduction Advocates

In 2001, the Federal Emergency Management Agency's earthquake program began providing funding to investigators from the three centers specifically for the purpose of developing research-based guidance for local, state, and regional earthquake risk-reduction advocates - i.e., individuals and groups that are attempting to promote earthquake safety and that are looking for ways to make those efforts more effective. Advocates include people whose jobs involve public safety, engineers and design professionals, political figures who want to make a difference, and citizen-activists working to enhance earthquake safety. The ultimate objective of the project is to strengthen both the knowledge and the skills of these advocates.

The Tri-center project team consists of five members: urban planner Rob Olshansky (lead); political scientist Daniel Alesch; political scientist Peter May; policy and public administration expert William Petak; and sociologist Kathleen Tierney. Over the three-year period since the project began, team members have worked together to produce a series of research-based white papers. The white papers cover a range of topics, including factors that contribute to successful seismic safety advocacy, formulating and implementing sound public policy, and principles of effective risk communication. Once these papers were completed and reviewed, team members then produced a series of very short (usually two-page) guidance documents that distill critical advice from the white papers and incorporate other information advocates need. Topics addressed in the short guidance documents include: how to succeed as a seismic safety advocate; earthquake basics; the ABCs of building codes; policies and legislation; working with experts; appearing before committees; formulating effective policies and legislation; bringing about changes that do not involve legislation; developing partnerships and mobilizing support for seismic safety; communicating risk; and strategies for employing the media in advocacy activities.

The white papers and guidance documents were completed and transferred to FEMA in 2003. The white papers will be published as a Tricenter report. Team members also worked with FEMA to develop an implementation plan that will include both web-based information dissemination and direct contacts with seismic safety advocates, advocacy organizations such as EERI, and other potential end-users. The materials that have been produced are already proving useful. For example, the project team worked with Mark Benthien, Outreach Director of the Southern California Earthquake Center, who was engaged in extensive planning for education and outreach efforts that were timed to coincide with the tenth anniversary of the Northridge earthquake in January 2004. EERI and the "Quake '06" advocacy group in the San Francisco Bay Area constitute other potential end-users. Expanding beyond earthquake hazards, the Tri-Center white paper on risk communication formed the basis for a report that the American Sociological Association provided to the Office of Science and Technology Policy in 2003 in response to OSTP's request for social-science-based guidance on homeland security risk communication and warnings.

3.2 Collaborative Publications and Jointly-Funded Projects

Working collaboratively, social scientists from the three centers contributed four papers that were published in May, 2004 in a special section of the ASCE journal *Natural Hazards Review*. That special section, entitled “Deciding What’s Safe,” features an introductory editorial by MCEER-affiliated researcher Kathleen Tierney and articles by researchers from the three centers, all of which are based on center-sponsored work. Topics addressed in the special section include the decision-making challenges associated with the shift from prescriptive or code-based engineering to PBEE; earthquake loss estimation in Mid America; systems-dynamics approaches to conceptualizing and modeling loss-reduction activities; and the pitfalls that accompanied the implementation of California’s 1994 hospital seismic safety law, SB 1953.

Stephanie Chang (a research investigator for MCEER and PEER) and former MAE graduate student Yasuhide Okuyama (now at the University of West Virginia) have co-edited a book entitled *Modeling Spatial Economic Impacts of Natural Disasters*. That volume contains chapters written by investigators from all three centers and will present findings from center-sponsored research.

Other developments over the past three years have signaled closer center-to-center collaboration on social science research. Psychologist and decision scientist Detlof von Winterfeldt of USC, who was initially funded by PEER to carry out research on retrofit decision making for residential structures, is currently being funded by MCEER to conduct similar studies, with a specific focus on decisions concerning hospital seismic retrofitting. Stephanie Chang from the University of British Columbia is another investigator whose work is co-sponsored by PEER and MCEER. Chang’s PEER-sponsored projects have centered on cost-benefit analyses for performance based earthquake engineering, while her MCEER-funded studies have focused on loss estimation for water and power systems and on post-earthquake recovery modeling. Her 2003 project with PEER, “GIS Modeling of the University Campus,” parallels research she is carrying out on loss estimation for hospitals with support from MCEER.

3.3 Other Collaboration and Contributions

Social scientists who are affiliated with the three centers meet regularly to discuss issues of common interest. At each EERI annual meeting, they take part in meetings under the sponsorship of EERI’s Social Science Forum and make presentations on center-related activities and research findings. The natural hazards workshop held annually at the University of Colorado at Boulder provides another opportunity for discussions and information sharing.

Center-sponsored social scientists are among the most active social science researchers in the fields of hazards and disaster research. In addition to the significant contributions they make to knowledge in their own disciplines, and in addition to their center-sponsored research, they also collaborate closely with physical scientists and engineers on a range of other activities. In many of these activities, center-affiliated researchers are transferring and applying knowledge obtained from their center-funded work, in some cases to hazards other than earthquakes. Examples of such contributions include the following:

- service on the board of directors of the Earthquake Engineering Research Institute
- co-authorship on the EERI research plan, “Securing Society Against Catastrophic Earthquake Losses”

- contributions to other EERI activities, such as the EERI Social Science Forum, EERI Learning from Earthquakes and Social Science Research Committees, and participation in a series of EERI workshops on improving post-earthquake reconnaissance and the collection and archiving of earthquake-related data
- contributions to EERI white papers and other publications on such topics as impediments and incentives to the adoption and implementation of earthquake loss reduction strategies contributions to HAZUS and other loss-estimation methodologies for both earthquakes and other hazards
- contributions to ATC 58 FEMA-funded “Performance-Based Seismic Design Guidelines,” addressing risk performance choices
- leadership in organizing the 7th National Conference on Earthquake Engineering in Boston
- co-authorship on the NEHRP/USGS plan for coordinating post-earthquake investigations
- service on the National Construction Safety Team Advisory Committee, responsible for overseeing NIST’s investigation of the World Trade Center disaster
- co-directorship of the Department of Homeland Security’s newly-funded center on risk-based economic modeling for terrorism
- service on the project management committee and leadership on the research team for the FEMA/NIBS independent study on the benefits accruing to the nation from natural hazard mitigation projects and process activities
- service on the newly-established National Academy of Sciences Committee on Disasters Research in the Social Sciences
- service on the leaders working group of the University of Pittsburgh Medical Center’s Center for Biosecurity

Section 4

Tri-Center Research on Geographically Distributed Systems

4.1 Background

The three EERCs are conducting complementary research related to the seismic performance of geographically distributed systems, including highway and railroad networks, electric power distribution systems, and pipeline distribution systems.

Research in this area includes generation and spatial/temporal distribution of earthquake ground motion; site amplification; ground failure including liquefaction, land sliding, and surface faulting; response of geographically distributed facilities and networks; vulnerability assessment and retrofit of networks' critical components; network flow including effect of post-earthquake demands; direct and indirect loss-assessments; emergency response; and decision-making processes for organizations that operate and/or own lifelines. Solutions of this multi-disciplinary problem may best be accomplished through the development of interlinked modules dealing with aspects of the problem; collaboration in the development of these modules will result in rapid advancement of the field and efficient use of resources of the three centers.

MCEER is conducting research to develop tools and knowledge that can be used for the seismic evaluation of bridge networks, with a particular emphasis on: (i) validation and calibration of a comprehensive highway network Seismic Risk Assessment software developed over the past nine years of FHWA-funded research; and (ii) research to investigate seismic performance and retrofit solutions for types of bridges currently not covered by the existing AASHTO Specifications and FHWA retrofit manuals. MCEER's research on power and pipeline distribution systems focuses on the power and water grid reliabilities as affected by the seismic performance of transformers and pipes, and the impact of seismic retrofits on improving this reliability. In all of its research, MCEER focuses on the use of advanced technologies.

PEER's research on highway networks focuses on: (i) the development of a performance-based engineering methodology and technologies for reinforced concrete bridges of the type commonly found in the Western US (including assessment of post-earthquake capacity and development of bridge fragility functions); (ii) hazard characterization, with emphasis on site effects, ground deformations, and soil-structure interaction; and (iii) functionality of the highway transportation network and the inter-relationship of network and bridge performance (using models for the San Francisco Bay Area highway system). PEER's research on electricity distribution systems addresses similar issues, namely: (i) performance and vulnerability assessment of substation

equipment and buildings; (ii) hazard characterization (including liquefaction); and (iii) electrical system network performance.

MAE's research on geographically distributed systems is concerned mainly with transportation systems and their interaction, with some fundamental developments on networks performance assessment. Two sets of projects are currently underway to synthesize damage and loss across a network, and to re-assess the losses after the application of a wide range of intervention measures, utilizing advanced IT and decision-making. Relationships between level of damage and loss of functionality are also being investigated. Dynamic modeling of traffic flow and effect of disruption of source-destination dynamics on network performance are subjects of Year 6 and 7 investigations. A high-end damage synthesis and visualization software package, MAEVIZ, is the focus of the MAE effort in seismic loss assessment of networks.

It is significant that a large percentage of the research described above is not funded by NSF, but rather by other government agencies (e.g., MCEER's research on highway networks is through a contract with the Federal Highway Administration; PEER's research on electrical networks and some of the research on transportation networks is through contracts with the California Energy Commission, the California Department of Transportation (CALTRANS), Pacific Gas and Electric Company and other industry sponsors; MAE's work on testing of bridge components (complementary to its NSF core research described above) is funded by local state departments of transportation. While this provides an important leverage to the NSF-funded research on such systems, it also means that pre-determined specific tasks must be accomplished to answer the requests of these research sponsors.

The EERCs have had extensive discussions in the past year to investigate how to best develop cross-center research collaboration on the topic of geographically distributed systems (lifelines). Initial meetings took place during the summer of 2002 between PEER, MCEER-FHWA, and Caltrans researchers to assess how PEER and Caltrans can develop modules that could be integrated into REDARS, the comprehensive Seismic Risk Assessment program developed by MCEER as part of its FHWA-funded research. CALTRANS has since initiated a trial study to apply REDARS to a region of the Bay Area Highway Network. During the fall 2002 and continuing through the present, management and researchers representing the three centers have held several meetings and several conference calls to formalize plans for closer research coordination. The outcome of these meetings has led to substantive collaboration in a number of areas, which forms the basis for the tri-center initiative outlined in this report.

4.2 Coordinating Mechanisms and Milestones

A key outcome of the early planning discussions was the creation of a Tri-Center Coordinating Committee on Network Systems (TC³NS) to manage on-going research collaborations between the centers. This committee consists of the Directors from each center (M. Bruneau, J. Moehle, A. Elnashai, Acting Director), the Deputy Directors (G. Deierlein, A. Filiatrault), the Technical Director of the MCEER-FHWA program (I. Buckle), and a representative of the PEER-Lifelines program (C. Roblee).

Apart from funding coordinated projects from each of their respective research programs, each center has committed to providing financial support for initiatives to manage and coordinate the collaborative research. This includes, for example, support for an outside consultant, R. Eguchi

of ImageCat Inc., to review the tri-center activities and provide the TC³NS with a review and planning report that identifies research priorities and opportunities. Other mechanisms to coordinate and review the collaborative research include plans for: (1) an annual meeting of investigators working on projects related to distributed network systems, and (2) co-funding and co-participation in two workshops on bridge performance (relating damage to functionality, repair, and, to some extent, post-earthquake traffic demands) and improved characterization of ground hazards (ground shaking and ground deformation effects).

Two significant milestones of the past year were to organization of the following two events:

Transportation Seismic Risk Assessment Workshop (San Pedro, CA., June 23-25, 2003): This workshop brought together tri-center researchers and transportation officials (representing end users and stakeholders) to discuss the development and application of seismic risk assessment (SRA) technologies for geographically distributed transportation systems. The workshop was attended by about 30 researchers from the three earthquake centers and 25 representatives of state and federal transportation agencies. The first day of the workshop provided an opportunity for tri-center researchers to exchange detailed information on prior and on-going research, and the remainder of the workshop was geared toward presenting research technologies and soliciting feedback from end users (transportation officials). The workshop had a combination of plenary and breakout sessions structured around the following topics: overview of loss estimation methods for transportation systems, bridge performance issues, transportation network analysis, user's perspectives on SRA technologies, performance measures for highway networks and components, and data availability and analysis methods for bridges and highway networks. An important outcome of the workshop was the identification of research needs and priorities, with emphasis towards tri-center collaboration opportunities in the following three areas: (1) development of bridge fragility models, (2) tri-center participation in development of improved modules in REDARS, and (3) coordinated development of multi-scale and variable resolution risk assessment and impact features of REDARS and MAEVIZ.

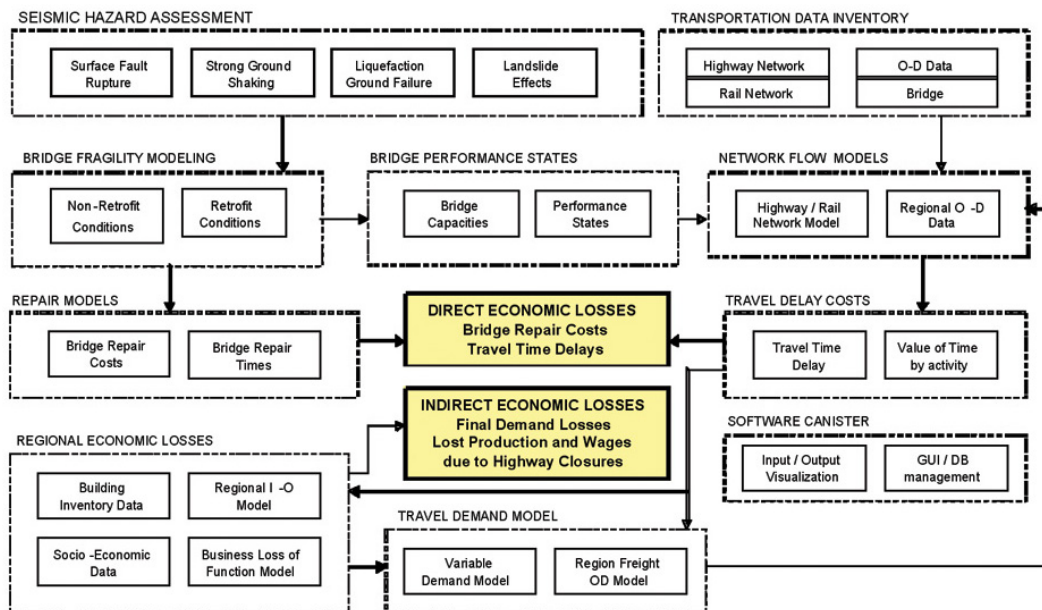
Tri-Center Annual Meeting on Geographically Distributed Systems (Las Vegas, NV, Dec. 11-12, 2003): About 60 investigators, business and industry partners, and representatives of transportation and utility agencies met for an annual tri-centers investigators meeting, which had the following four goals:

- Coordinate research to develop improved fragility relationships for bridges with emphasis on quantifying relationships between engineering demand parameters, damage, and bridge functionality.
- Prioritize research needs on transportation system performance, and identify collaborative activities that will improve the overall assessment of transportation systems and integrate end-user needs into methodologies and software tools.
- Define the current status and user/researcher needs to conduct seismic risk analyses of electric utility components and systems.
- Examine opportunities to dramatically improve seismic risk assessment of geographically distributed systems by tri-center research to improve characterization of seismic hazards (strong ground motions and ground deformations).

The meeting began with plenary presentations on needs and issues related to transportation systems, utility systems, and seismic hazard considerations specific to geographically distributed systems. These were followed up by breakout sessions on: (a) transportation system assessment, (b) electric utility components and systems, (c) bridge fragilities, (d) hazard characterization, (e) social and economic impacts, and (f) cross-cutting issues. Highlights and recommendations from the breakout sessions were reviewed during the meeting and have been incorporated into future research planning, details of which are presented below.

4.3 Transportation Systems

A framework for seismic performance and loss assessment of transportation systems is shown below. This framework was developed through the tri-center collaboration and maps the interrelation among different research areas as well as to identify the accomplishments and foci of each center. The framework encompasses a broad range of considerations from seismic hazard assessment, through bridge and highway performance modeling, to evaluation of metrics that directly relate to economic impacts. The general concepts outlined in this framework represent the underlying architecture of the REDARS software platform, which is envisioned as an important implementation vehicle for seismic risk assessment of highway systems. The MAE Center system MAEVIZ follows the same approach but focuses on regional losses due to transportation network dysfunction, including social and economic consequences. Where appropriate, research conducted through the tri-center’s program will lead to either new or improved modules that can be implemented in REDARS. However, REDARS is not the sole focus of the comprehensive tri-center’s initiative, since much of the transportation-related research in each center is broader in scope. For example, a significant initiative in the MAE center is the above-mentioned high-end visualization platform MAEVIZ for regional loss-modeling, which encompasses a broader range of loss-factors than those considered in REDARS, and which could be used to display results from REDARS and other sources.



Framework for Seismic Performance and Loss Assessment of Transportation Systems

The following is a summary of specific focus areas and research initiative that have been identified for transportation systems.

(i) Bridge Fragility Modeling – MCEER-FHWA, PEER, and MAE all have projects related to bridge fragility modeling; and Caltrans, an important user of these models, is also supporting significant research in this area. MCEER requires these bridge fragility models to improve loss estimates in REDARS and to begin benefit/cost studies related to bridge retrofits. PEER requires better models to perform the same types of analyses and to feed into their post-earthquake highway performance work. MAE is emphasizing work on bridge fragilities within the broader context of fragility curves for regional consequence and loss modeling. From these interests, a common goal for the tri-center’s initiative is the development of standardized fragility functions for retrofitted and non-retrofitted bridges, representative of those in the eastern and central United States as well as California. This is a very broad problem that encompasses many types of structural systems and issues, and to which each center can contribute without overlap. For planning purposes, the research on fragility functions is distinguished into one of the following three categories: (a) generic fragility curve development, (b) standard (“HAZUS-like”) fragility curves for retrofitted bridges, and (c) enhanced fragility curves, whose format incorporates refinements beyond the standard HAZUS-like fragility curves currently used in REDARS and other systems.

Related Projects:

MCEER-FHWA: Shinozuka has a project to develop fragility curves for retrofitted bridges using empirical data on bridges with restrainers and jacketed columns. This is a high priority to develop realistic performance assessments of the California highway network as it currently exists.

PEER: Stojadinovic has an ongoing project to develop a performance-assessment methodology for bridges, which will lead to an enhanced model for developing fragility relationships. In addition, PEER is supporting several related projects on performance data on bridge components (Mahin and Eberhard), testbed studies of two existing bridges (Conte and Kunnath), and evaluation of decision metrics for bridge closure decisions (Porter).

MAE: MAE has supported several projects on fragility curves, which have resulted in a state-of-the-art and recommended methodologies report issued by Wen, Ellingwood and Bracci. The scope of the MAE Project DS-4 is to develop a set of fragility curves for buildings and bridges that utilize the proposed methodologies and the PIs approach to uncertainty modeling. Another project, CM-4, deals with fragility relationships for retrofitted structures. This is currently focusing on a method for including the effect of retrofitting on structural performance in the fragility curve derivation thus reducing the effort of re-deriving fragilities for different retrofitting techniques (Hueste and Elnashai). The third and last issue covered in MAE work on fragility is work undertaken jointly with European colleagues on a refined means of selecting strong-motion records for analysis based on the limit state to which the fragility relationship pertains (Elnashai).

(ii) Bridge Performance States – This topic concerns the development of models to evaluate bridge performance with emphasis on quantifying the relationship of bridge damage to functionality (traffic capacity) and repair. PEER requires this research in order to quantify performance-based standards for bridges; MAE requires this work in order to improve its benefit-cost studies, and MCEER/FHWA requires it for network analysis.

Related Projects: Both PEER (Stojadinovic and Porter) and MAE (Sussman, Wen, DesRoches) have targeted some near-term research on this topic. MAE has an ongoing project to quantify the relationship between level of damage and loss of functionality of RC bridges (DesRoches). The project builds on previous MAE work on relating ground motion intensity to damage (Hwang) and advances towards relating the level of damage to the reduction in the capacity of the network component below the design capacity.

Joint Initiative: Development of specific definitions of bridge performance states was confirmed as a key research need at the San Pedro transportation workshop (June 2003), where efforts were initiated to query transportation officials and bridge engineers on factors affecting bridge closure decisions. Subsequent to the workshop researchers from PEER and MAE (Porter and DeRoches) have developed an on-line survey to solicit input from bridge inspectors and bridge engineers. Follow up to this initiative is being incorporated in future research plans in the tri-centers.

(iii) Modular Platform Development – MCEER-FHWA is committed to developing a public domain version of REDARS. An important aspect of this development is the modular nature of the program. The program is being designed to allow for easy and non-intrusive access to key processing components. The ultimate goal is to have a standardized methodology and tool for the entire U.S. that FHWA can provide to state transportation agencies. The core support for REDARS by FHWA makes this platform an attractive alternative to synthesize and implement research components from the tri-center's initiative.

Related Projects: Caltrans recently initiated a project to evaluate REDARS through trial studies of the SF Bay area. While Caltrans funding for this project is from outside the tri-centers, PEER 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. MAE's current effort on geographically distributed systems is dealing with more global loss modeling, including both highway and railroad systems. Therefore, MAE's interest is to explore 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 Kim and others. Facilities and modules in REDARS that are amenable to implementation within the MAE Center Visualization module MAEVIZ may also be part of the collaboration.

(iv) Seismic Hazard Assessment – The PEER Lifelines program has completed significant research to develop regional seismic hazard methodologies that are directed at distributed systems. Of particular interest are studies that focus on liquefaction and surface fault rupture hazards. MCEER-FHWA has a very keen interest to improve the seismic hazard methodology for liquefaction in REDARS, since the current method requires very detailed data that are not practical for assessing liquefaction hazards regionally. The MAE Center has several projects on characterization of seismic hazard, one of which is concerned with large ground deformations (including liquefaction) effects. There are opportunities to implement the outcomes into REDARS and transfer the PEER work to the MAE Center Visualization module MAEVIZ.

Joint Initiative: Discussions at the tri-center's annual meeting (Dec. 2003) suggested that there are potential areas of fruitful cooperation to pursue research aimed at unique hazard issues for

geographically distributed systems. Three specific topics identified at the meeting include: ground deformations and their effect on bridge performance, geographic correlation effects in probabilistic models for seismic hazards, geographically distributed basin effects. Research to investigate these are being considered in future year research planning, including the PEER-Lifelines project on Next Generation Attenuation functions.

(v) Uncertainty Propagation – The REDARS implementation of the performance/loss assessment framework accounts for uncertainties in all significant aspects of the network simulation. However, a thorough analysis of the impact that the different modules have on the final results has only been addressed superficially. Research opportunities lie in studying the propagation of uncertainties throughout the loss calculation process, including work to identify the most significant sources of uncertainties, insofar as they impact the final outcome. Results of such efforts will be important to identify and target individual modules or models for future research.

***Related Projects:** MAE has several ongoing projects (Wen, Ellingwood, Bracci) dealing with generic issues of uncertainties in system assessment. Issues of how to model and visualize uncertainty in each component of seismic loss assessment and the aggregated uncertainty are of interest to MAE in developing its regional Damage Synthesis module. PEER has a project (Kiremidjian) to look at enhanced methods to propagate and track uncertainties, thereby making it possible to identify the most significant uncertainties. MCEER/FHWA has a related project by Craig Taylor on risk modeling.*

(vi) Development of Network Models – Both MCEER and the MAE Center are examining new (more efficient) methods of constructing network models. Both centers have used GIS methodologies (e.g., dynamic segmentation) to efficiently fuse linear databases with tabular information (e.g., NBI database). In order to ensure that the development of this model does not become the obstacle to implementation, many examples of this development must be completed. An opportunity exists to leverage current work to develop an interoperable methodology to create and validate network models for transportation loss estimation.

***Related Projects:** MAE has a current project (Kim) to examine interoperability between different databases to categorize bridge attributes. MAE has also formulated a Year 7 pilot study to investigate ‘systems interaction’ effects on loss modeling (Goodno) and dynamic traffic flow models (Waller). MCEER-FHWA has a project (Eguchi) to investigate several issues related to transportation systems, including investigations of ways to improve the creation of network models. MCEER and MAE have proposed, as a new initiative, to build a requirement for collaboration on this topic into future project work statements.*

(vii) Post-Earthquake Traffic Demands – Both MCEER and MAE are addressing changes in traffic demand due to congestion and lost production. MCEER has focused most of its activities on measuring the effect of congestion on traffic loads. MCEER has just completed an extensive validation study where these models are now about to be recalibrated. The MAE Center has included in its loss estimation model the impact of lost production (primarily through damage to buildings and facilities) on post-event traffic loads. The significance of this cost or loss is not well understood, particular in a review of past earthquake data. Therefore, the results of this research will be of interest to all three centers, and efforts to share information from these studies will be emphasized, including possible development of a nationwide database.

Related Projects: MCEER/FHWA and Caltrans are supporting a project (Moore) to develop methods and models for incorporating post-EQ traffic demand into REDARS. MAE is working on optimization of dynamic traffic flow (Waller) and taking origin-destination of network- and user-optimum routes into account when estimating pre- and post-event link capacities.

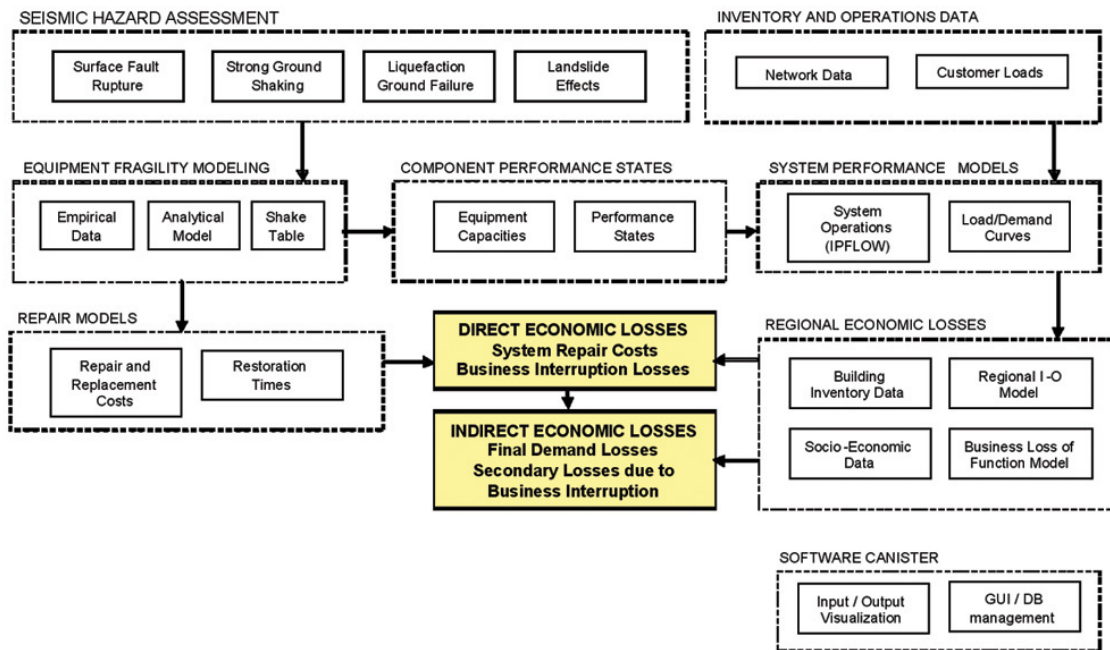
Joint Initiative: As a first step toward sharing and improving information on post-EQ traffic demand, this topic is being incorporated in plans for the Tri-Center workshop on relationship of bridge damage to functionality and repair. MAE and MCEER also intend to share results and methodologies from studies on this topic.

(viii) Link Capacity – Given that most of the transportation system models only represent major roads and highways, there is a need to consider the effect of secondary roads on the global system performance. Since it is not practical to include the full road system in the seismic hazard analysis, a compromise strategy is to create “equivalent link” models for the global system analysis. These “equivalent links” in the global system model are intended to account for redundancy/resiliency to the global network provided by the local road network. This would have applications both towards assessment of post-earthquake emergency routing and general transportation.

Related Projects: MCEER/FHWA has a project by Shinozuka where macro-models of traffic flow and origin-destination formulations are being investigated to improve computational efficiency. In the MAE Center, Kim is pursuing a three-tiered approach to modeling, with the three tiers of highway/roadways at the state, county, and local levels.

4.4 Electric Power Systems

As shown in the figure below, the overall seismic performance and loss assessment methodology for electric power systems shares many common features with that for transportation systems. Currently, only MCEER and the PEER-Lifelines program have research programs on electric power, so collaborative research on this topic is limited to these organizations. MCEER has been focusing on the seismic performance of electric power systems since its inception. Its focus has been on estimating the direct and indirect losses caused by damage and disruption to electric power systems. Much of this research was applied to the Memphis Light, Gas and Water system in Memphis; more recently, the focus has been on the Los Angeles Department of Water and Power system. PEER has had a strong program in assessing the seismic performance of substation equipment. These studies have ranged from the development of experience or performance databases to the development of analytical models for rigid and flexible bus connections. The research at PEER has direct connection to the user community; a major sponsor of this research is PG&E and the California Energy Commission.



Framework for Seismic Performance and Loss Assessment of Electric Utility Systems

(i) Substation Equipment and System Fragility Modeling – Both MCEER and PEER have common interests in the seismic performance assessment of substation equipment and substation systems. Much of the PEER work has been in shake table testing and analytical modeling of electrical equipment (bushings and switches) and data collection of substation components. MCEER’s work has concentrated on the development of fragility models and the performance of transformers through shake table tests. A joint program between the two centers could fuse together important empirical information with testing results and analytical modeling to produce more reliable fragility functions.

Related Projects: Having completed significant research on electrical equipment fragilities, PEER is now focusing on substation modeling, starting first with a small pilot project (Ostrom), subsequently expanding into full substation modeling. MCEER’s studies (Shinozuka) have used generic/empirical fragilities, focusing on transformers primarily because this major substation component has suffered significant damage in past earthquakes, and replacement parts are not readily available following an earthquake for these large pieces of equipment. MCEER has a significant interest in using the PEER studies data on seismic performance of substation components, to develop useful fragility information. Both centers are interested in being able to develop fragility curves for substation equipment components in their installed conditions (i.e., proper boundary conditions), then expanding these models to provide integrated fragility curves that can model entire substations.

Joint Initiative: MCEER and PEER-Lifelines are planning collaboration to development fragility information for substation components using experimental data generated by PEER for these components and MCEER’s experience in fragility modeling. Based on the progress on this first topic, future collaboration opportunities exist to integrate component fragility into substation fragility, and calibration/validation of these data. To facilitate collaboration,

MCEER researchers will be invited to participate in quarterly coordination meetings of the PEER-Lifelines focus area on electric equipment and network performance.

(ii) Lifeline Interaction Studies – There needs to be a comprehensive assessment of how the reliability of each lifeline system depends on other lifelines. Both MCEER and PEER have recognized this need by examining interactions between water, power and transportation. A joint program that leads to a better understanding of the vulnerabilities of all three systems can provide added impetus for lifeline operators to coordinate disaster response plans. Without this quantification, it will be difficult to convince owners to consider these added dependencies or risks. MAE started in Year 7 a project on network interaction that is developing criticality and interaction matrices to aid in decision-making with regard to retrofit strategies for interacting networks.

***Related Projects:** MCEER and PEER share an interest on this topic, but feel that it is too soon to undertake this collaborative activity. MCEER is first currently investigating how to integrate water and power co-dependencies. PEER is more interested in the integration of highway and power systems, and is exploring opportunities to investigate this in conjunction with the Caltrans REDARS demonstration in the SF Bay Area. During the coming year, each center will focus on their respective objectives before contemplating attempts at integration broader in scope.*

(iii) Common Software Platforms – Where the opportunity exists, modular software development should be strongly considered. This would allow deeply needed research funds to focus on those topics and areas that truly require research. Since the different centers are not in the business of selling or licensing software, this seems an excellent opportunity to share the costs of program development.

Joint Initiative (Future): MCEER and PEER envision the integration of SERA and IPFLOW, two packages that handle two parts of the risk assessment methodology with a specific focus on the needs of the power distribution systems. Such a system could also include SHAKEMAP integration. Technically, there should be no difficulty in integrating SERA and IPFLOW, although this would require the development of an interface linking the two programs. With this goal in mind, all of the previously mentioned activities will be conducted in the perspective that an important long term objective of the MCEER/PEER collaboration is the development of a risk assessment methodology that would integrate SERA and IPFLOW (to respectively handle substation fragility and power flow equilibrium) in a single package. The common interests are therefore to improve the quality of the fragility data, and to integrate the steps required for analysis of power systems reliability/fragility. The MAE Center loss assessment system MAEVIZ uses NCSA products that are available free of charge and cooperation in terms of implementation of models from one center into the software systems of another is under consideration.



A National Center of Excellence in Advanced Technology Applications

**The Multidisciplinary Center for
Earthquake Engineering Research**
University at Buffalo
Red Jacket Quadrangle
Buffalo, New York 14261-0052
Tel: 716/645-3391; Fax: 716/645-3399
Email: mceer@buffalo.edu
WWW Site: <http://mceer.buffalo.edu>



Headquartered at the University at Buffalo