Multidisciplinary Center for Earthquake Engineering Research

An Engineering Research Center

Lead Institution: University at Buffalo, State University of New York

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

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Year 8 Annual Report
Volume III:
TRI-CENTER COLLABORATION

Mid-America Earthquake Center
Multidisciplinary Center for Earthquake Engineering Research
Pacific Earthquake Engineering Research Center

PREFACE

This third volume of the Year 8 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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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 to 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, multidisciplinary, multi-level system solutions. In response to this comment, the Directors, Deputy Directors and other leading researchers of the three centers have met in face-to-face meetings, conference calls, and video teleconferences to develop and implement plans to promote tri-center collaboration. In years 6 and 7, the centers also enlisted a subcontractor to evaluate commonalities in their research programs and identify possibilities for fruitful collaboration. This Volume 3 report 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 comprehensive loss assessment tools on a regional basis that include physical, social and economic impact in a consequence-based risk management framework.

Mission statements and core research thrust areas as reported in each of the three center's Year 8 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 seven 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 three significant international earthquake-engineering conferences (in Harbin, PRC, Hong Kong in August of 2002 and Hawaii, 2004), the world-wide leadership of the three centers in earthquake engineering research continues to grow. Emphasis is placed on promoting the role of young researchers in the three centers and new challenges facing the international risk management community.

The three centers are utilizing NEES facilities that have been developed at one or more of each center's core institutions, and the centers have been instrumental in the development of advanced hybrid simulation and networking capabilities. The centers have been instrumental in promoting multi-site, multi-national simulations using NEESgrid, including network validation exercises with NEES sites at RPI and Lehigh, the NCREE in Taiwan, and labs at the Kajima Corporation in Japan. The infrastructure provided by the three centers has therefore been instrumental in the success of the NEES program. Many more examples of national and international collaboration with NEES are given in the annual reports of each center.

Table 1 Mission and Research Thrust Areas of Each Earthquake Center

Center	Mission Statement	Year 8 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.	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.	I. Building Systems II. Bridge and Transportation Systems III. Lifelines Components & Systems IV. Simulation and Information Technologies
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.	1. Engineering Engines 2. Social Sciences 3. Information Technology

1.4 Focus Areas for Tri-Center Collaboration

The three earthquake engineering research centers have developed a strategic plan, articulated in the year 8 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 lifeline systems, nonstructural components, and loss modeling

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

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 in Charleston, S.C. featured presentations by students from the three EERC's as well as Washington University and FAMU-FSU REU programs. The banquet keynote speaker talked about the importance of diversity programs. A tour of one of America's most important new structures, the Cooper River Bridge, was conducted by the South Carolina Dept of Transportation

The 2005 program to be held at Reno, Nevada in August represents the sixth 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). The first event is sponsored by the PEER SLC and took place April 29-30 on the UC Berkeley campus. A total of 8 teams are participating this year, including at least one from each EERC.

2.3 Tri-Center Student Field Missions

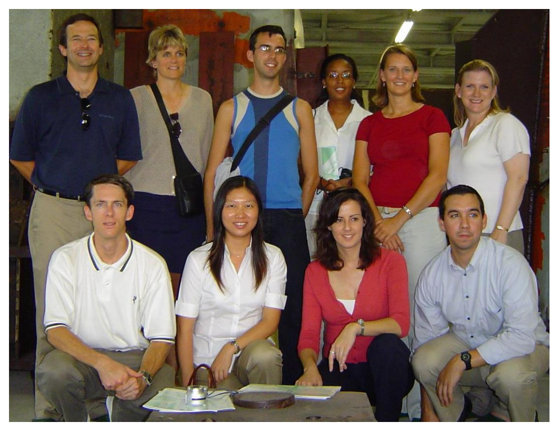
A tri-center **Earthquake Field Study** program was initiated in spring 2002. Ideally, four graduate research assistants from each center, plus four non-center graduate students (selected by professional earthquake engineering organizations), compete to spend ten days visiting a recent earthquake site 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 were asked to make at least two presentations during 2003-04 based on information they learned during the trip. One presentation was 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. This was delivered several times. The second presentation was 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 elected to make Japan the next destination for the earthquake field study. PEER organized this trip in July, 2004. Sixteen students from the three EERC's and SCEC together with faculty and staff from two centers and three middle school earth science teacher visited several laboratories (including the world's largest shake table in Miki), universities and museums and enjoyed a remarkable cultural experience. The students made presentations while in Japan and prepared materials for their presentations at their home institutions. These presentations were on a comparison between the earthquake engineering experimental facilities found in Japan and those available in the US.

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 made 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. A PEER student and a MAE student continued these presentations in 2004. These exchanges usually take place in the spring term, and those for 2005 are currently being planned.

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.

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 Tri-center 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, and the advocacy guidelines were published as a Tri-center report in 2004. (Ordering information can be found on the MCEER web site.) 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 (ASA) 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. Key ideas from the white paper also appeared in an article entitled "How Would Sociologists Design a Homeland Security Alert System?" which appeared in *Footnotes,* the ASA's official newsletter, in April 2003.

In 2003, the National Research Council established the Committee on Disaster Research in the Social Sciences and charged that committee with conducting an assessment of social science contributions in disaster research, with a special emphasis on social science knowledge developed with NEHRP support. Representatives from the three earthquake centers took part in a committee workshop in Washington on August 23, 2004 to provide perspectives on the role of social science research in the three centers and to discuss future research needs.

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.

Researchers affiliated with the EERC’s have also been successful in expanding their research into the homeland security area. Detlof von Winterfeldt is the co-director of USC’s Center for Risk and Economic Analysis of Terrorism Events (CREATE). CREATE, funded in 2003, is the first of four Department of Homeland Security university-based “centers of excellence.” More recently, MCEER investigator Kathleen Tierney teamed with researchers from the University of Maryland and other institutions in a successful DHS “center of excellence” proposal. That new center, the National Center for the Study of Terrorism and Responses to Terrorism (START), will conduct research on the social origins, dynamics, and societal impacts of terrorism.

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
- 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 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
- Participation as senior faculty (May, PEER; Tierney, MCEER) in the

NSF-sponsored project "Enabling the Next Generation of Hazards Researchers" from 2004-2006. This project entailed mentoring of 16 junior faculty about social science and policy issues in hazards research, and included discussion of the EERC activities.

4. TRI-CENTER RESEARCH COLLABORATIONS

4.1 Background

The three EERCs are conducting complementary research in two main areas. One is a continuation of collaboration begun in prior years that relates to the seismic performance of geographically distributed systems, including highway and railroad networks, electric power distribution systems, and pipeline distribution systems. The second area concerns the seismic performance of nonstructural components and equipment and associated activities related to loss assessment.

Research in these areas include characterization of earthquake ground motions (including spatial/temporal effects); ground deformations and failure; response of geographically distributed facilities and networks; vulnerability assessment and retrofit of networks' critical components; network flow including effect of post-earthquake demands; development of fragility and loss models for structural and nonstructural components; direct and indirect loss-assessments; emergency response; and decision-making processes for organizations that operate and/or own lifelines. Solutions of this multidisciplinary 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. MCEER is also significantly invested in research to develop improved knowledge on the seismic performance of nonstructural components and contents as part of its Thrust Area on Acute Care Facilities, leading to the development of fragility curves for nonstructural components and new methodologies and devices for their seismic retrofit and design. 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). Related 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. Finally, characterization of earthquake damage and the associated losses to structural and nonstructural components and building contents is a major emphasis of PEER's research on performance-based engineering of building systems.

MAE's research on geographically distributed systems is concerned mainly with transportation systems, their interaction with other lifeline networks, and the social-economic impact of physical damage, with some fundamental developments on networks performance assessment. Two sets of projects are currently underway to (i) synthesize damage and loss across a network, and (ii) 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. The damage-functionality relationships for bridges are developed as a collaborative activity of the three centers. Dynamic modeling of traffic flow and effect of disruption of source-destination dynamics on network performance were subjects of years 6 and 7 work. In years 8 and 9, investigations are focused on optimized retrofitting of transportation networks using genetic algorithms and also modeling of gas pipeline damage. A high-end damage synthesis and visualization software package, MAEviz, continues to be 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 and through pilot NEES projects. MAE is also engaged in gas pipeline network assessment for Memphis Light, Gas and Water. 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.

4.2 Coordinating Mechanisms and Milestones

The EERCs have had extensive discussions over several years to investigate how to best develop cross-center research collaboration on the topic of geographically distributed systems (lifelines) and, more recently, on nonstructural components and equipment. The outcome of these meetings has led to substantive collaboration in a number of areas, which forms the basis for the tri-center initiatives outlined in this report.

A key outcome of the early planning discussions was the creation of a Tri-Center Coordinating Committee on Network Systems (TC^3NS) to manage on-going research collaborations between the centers. This committee consists of the Directors from each center (M. Bruneau, J. Moehle, A. Elnashai), the Deputy Directors (G. Deierlein, A. Filiatrault), the Technical Director of the MCEER-FHWA program (I. Buckle), and the Associate Director (Y. Borzorgnia) for the PEER-Lifelines program.

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 TC^3NS with a review and planning report that identifies research priorities and opportunities. Other mechanisms to coordinate and review the collaborative research have included special meetings convening investigators working on projects related to distributed network systems, and co-funding and co-participation in workshops (as described elsewhere).

A group of researchers from the three centers is currently planning a Tri-Center Workshop on bridge fragilities to be held in the fall of 2005. The objective of the proposed workshop is to work towards the development of the next generation bridge damage-state fragility models for typical bridges nationwide that can be used for seismic risk assessment. By drawing on the existing strengths in the three centers, it is believed that a consistent approach that will have a major impact on seismic risk assessment of highway systems can be developed.

Significant milestones of past years include organization of the following events:

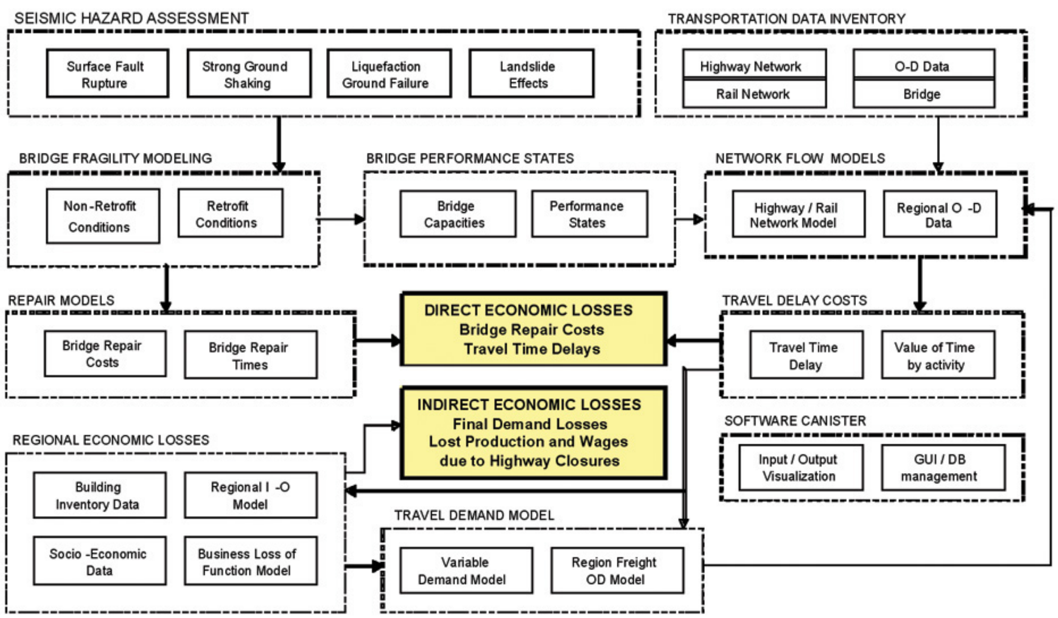
Transportation Seismic Risk Assessment Workshop (San Pedro, CA., June 23-25, 2003): This workshop brought together tri-center researchers and transportation officials (representing end users and stakeholders) to discuss the development and application of seismic risk assessment (SRA) technologies for geographically distributed transportation systems. 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 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 a tri-centers investigators meeting, which had the goals of: (i) coordinating research to develop improved fragility relationships for bridges; (ii) prioritizing research needs on transportation system performance, and identifying collaborative activities that will improve the overall assessment of transportation systems and integrate end-user needs into methodologies and software tools; (iii) defining the current status and user/researcher needs to conduct seismic risk analyses of electric utility components and systems, and; (iv) examining 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). Highlights and recommendations from the breakout sessions at this meeting have served to plan and facilitate continuing collaborations on specific research projects and initiatives as described below.

ATC-58 Workshop on Loading Protocols for Nonstructural Components (San Francisco, November 4, 2004): About 20 investigators from the three centers and other organizations, business and industry partners, and representatives met to develop protocols for experimental development of fragility curves for nonstructural components. This is described in detail in Section 4.5.

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 interrelationship among different research areas as well as identifying 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, and optimal intervention schemes for a given network travel time target. Where appropriate, research conducted through the tri-center's program will lead to either new or improved modules that can be implemented in REDARS and/or MAEviz.



The following sections summarize specific focus areas and research initiatives for collaborations related to 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. The fall 2005 Workshop mentioned above is the mechanism by which cooperation in fragility and damage-functionality will be developed further.

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. Empirical fragility curves have been developed and calibrated for three damage states of a typical Caltrans' bridge. Further work is underway to develop fragility curves that can consider the effect of directionality of earthquake ground motion.

PEER: Stojadinovic has an ongoing project to develop a performance-assessment methodology for bridges, which provides an enhanced framework for developing bridge fragility relationships. His project serves to integrate related PEER research on performance data for simulating RC bridge components (Mahin, Eberhard, Lehman, Kunnath), testbed studies of two existing bridges (Conte and Kunnath), effect of ground deformations and liquefaction on bridges (Boulanger, Ashford, Bray), and evaluation of decision metrics for bridge closure decisions.

MAE: MAE is continuing to fund 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. An increasing effort is dedicated to considerations of soil-structure interaction effects on bridge fragility, due to the nature of sites in the mid-west. Another project, CM-4, deals with fragility relationships for retrofitted structures. Parameterized fragility curves have been derived and a program has been developed with an easy-to-use GUI to derive fragility curves online using a novel technique. Also, fragility curves with intervention devices are being developed (Hueste, Elnashai, Dyke, and DesRoches). The activity in bridge fragility in MAE has covered more than 80% of bridges in the National Bridge Inventory, hence regional losses to transportation networks can be assessed.

(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 modeling in MAEviz, and MCEER/FHWA requires it for network analysis.

Related Projects: *Both PEER (Stojadinovic) and MAE (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). A wide ranging survey was developed and sent to all DOTs for their feedback on the basis for decisions to close or restrict traffic on bridges given a reported level of damage. The surveys were a collaborative effort of the three Centers and have yielded pioneering damage-functionality relationships that are already implemented in MAEviz.*

(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. General facilities and modules in REDARS that are amenable to implementation within the MAE Center Visualization module MAEviz are also 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. Werner is integrating the Tokimatsu-Seed model for liquefaction-induced ground settlement into REDARS, as well as a Bardet-Tobita-Mace-Hu model for estimation of liquefaction-induced lateral spread displacements. 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 MAEviz.

Joint Initiative*: Discussions at the December 2003 tri-center's meeting identified 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 and under a future FHWA contract with MCEER.*

(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 projects (Kiremidjian, Kramer, and Stojadinovic) to look at enhanced methods to propagate and track uncertainties for assessment of individual bridges and transportation systems, thereby making it possible to identify the most significant uncertainties. MCEER/FHWA has a related project by Craig Taylor on risk modeling that includes a variance-reduction procedure, which will enable users to periodically estimate confidence levels and limits for mean values of losses estimated during probabilistic Seismic Risk Assessments (SRA) for successively increasing numbers of simulations. This will enable a user to stop the probabilistic SRA when a sufficient number of simulations have been considered that, in the opinion of the user, lead to acceptable confidence levels and limits.*

(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. The MAE Center has adopted a highly efficient data management system as its permanent tool box within MAEviz; this is D2K (Data-to-Knowledge) developed by NCSA.

Related Projects: *The year 7 pilot study in the MAE Center on network systems interaction (Goodno) has been exceptionally successful and the outcomes are being implemented in MAEviz. The dynamic traffic model (Wallre) has been developed and is undergoing testing. Static models have also been implemented in MAEviz alongside intervention optimization techniques. MCEER-FHWA has a project (Eguchi) to investigate several issues related to transportation systems, including investigations of ways to improve the creation of a network model. Using tested, and verified methods to combine and subset topological networks, while simultaneously integrating additional geospatial data such as soils, bridges, and origin/destination matrices, work is now focused on fine-tuning algorithms, and coding into a data Import Wizard that will enable the creation of a baseline REDARS study region with minimal user processing. MCEER and MAE have proposed, as a new initiative, to build a requirement for collaboration on this topic into future project work statements.*

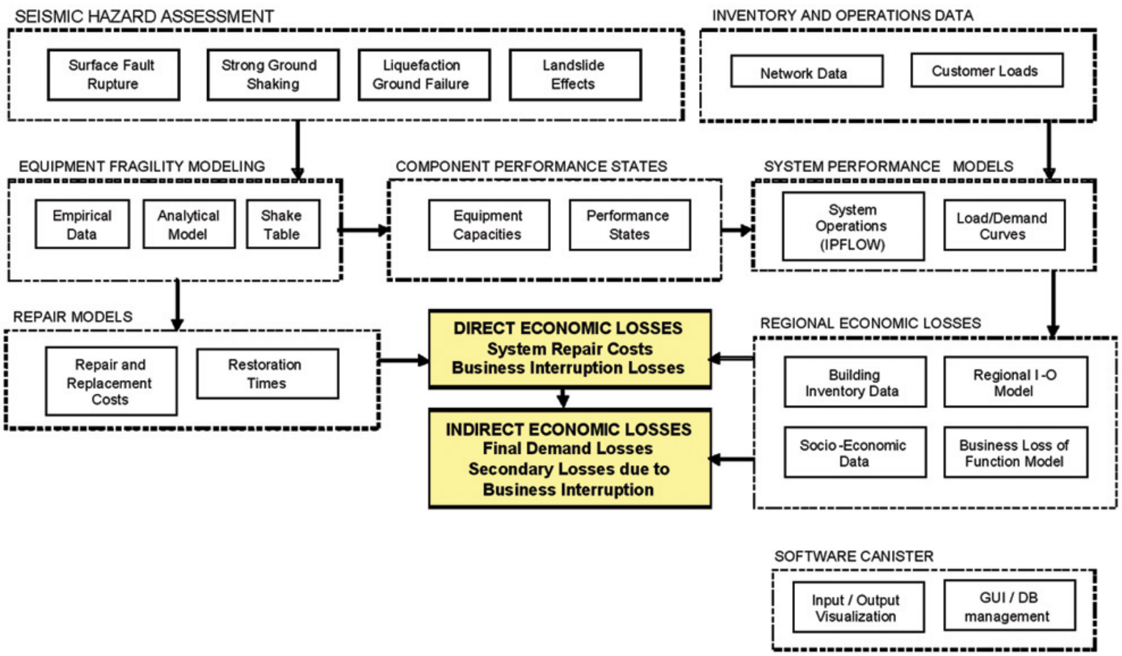
(vii) Post-Earthquake Traffic Demands and Network Performance – All three centers have done research to address changes in traffic demand due to congestion and lost production. MCEER has focused most of its activities on measuring the effect of congestion on traffic loads, including an extensive validation 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. PEER research has contributed to developing models for simulating post-earthquake traffic demands, with future plans to emphasize more complete representations of post-earthquake network performance as related to route-planning for emergency response and recovery efforts.

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 capacitates. PEER's transportation research has a new initiative (Moore, Fan) to develop improved models to characterize post-earthquake network performance for emergency response and recovery, with the ultimate goal toward pre-event network design and retrofit priorities.*

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

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), and then expanding these models to provide integrated fragility curves that can model entire substations.*

Joint Initiative: *MCEER and PEER-Lifelines are planning collaboration for the 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. In year 8, MCEER has increased its testing of various types of lifeline equipments from which fragility curves will be developed. 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. The MAE Center project on the subject has lead to the development of a framework for network interaction and joint fragility, and is leading to significant changes in the loss assessment platform MAEviz.

Related Projects: *All three centers' 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. MAE has continuing interest in integrating network loss models in MAEviz. During the coming year, each center will focus on their respective objectives before contemplating attempts at integration broader in scope.*

4.5 Nonstructural Components

All three EERCs share a common interest on the seismic performance of building nonstructural components. The implementation of PEER's Performance Based Earthquake Engineering (PBEE) approach requires the harmonization of the performance levels between structural and nonstructural components. Even if the structural components of a building achieve an immediate occupancy performance level during a seismic event, failure of nonstructural components inside the building can lower the performance level of the entire building. Similarly, MCEER's resilience concept for acute care facilities requires adequate performance of critical medical equipment in an acute care facility during a major earthquake. Several recent earthquakes have shown that damage to nonstructural components in hospitals, including medical equipment, is by far the largest contributor to direct economic losses resulting from earthquakes and often leads to the loss of functionality of these facilities for extended periods of time. A component of MAE's research focuses on response modification of essential facilities that are at-risk, such as unreinforced masonry (URM) construction of low-rise firehouses and school buildings – both of which are important because of their vulnerability and role in post-earthquake emergency response and recovery. Use of cost effective rehabilitation devices, such as tapered metallic yielding devices, were examined to guard against overall collapse and failure of brittle nonstructural components; aid in protection of occupants and contents; and to ensure continued operation. Most recently, MAE has been incorporating improved models for nonstructural damage and resulting economic losses into MAEviz and has initiated an industrially-funded project for nonstructural damage modeling and economic impact in the Memphis area.

Based on their common interests and activities, MCEER, PEER and MAE have begun to formalize their collaboration on the seismic behavior of nonstructural components in year 8 with the intent of continuing this in the future. The following are some highlights of the previous joint activities and future plans:

Joint Seminar: MCEER and PEER co-sponsored (with participants from all three centers) the ATC-29-2 seminar entitled *Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities* that was held on October 23-24, 2003 in Los Angeles. The ATC-29-2 seminar provided an opportunity to review current research, practice, and informed thinking pertinent to the seismic design, retrofit, and performance of nonstructural components in buildings. Components and systems that were discussed during the seminar included: supports and bracing for elevator systems, ceilings, partitions, cladding, glazing, contents, water piping systems, and mechanical and electrical equipment. Nonstructural components or systems in facilities with critical functions (e.g., computer centers, hospitals, manufacturing plants with especially hazardous materials, museums with fragile/valuable collection items) were particularly addressed.

Loading Protocol for Nonstructural Components: In year 8, MCEER, PEER and MAE supported the development of three interim test protocols for nonstructural building components as part of the on-going ATC-58 project. Several investigators from PEER, MCEER and MAE participated actively in the project. MCEER Deputy Director Andre Filiatrault served as the team leader for the development of a shake table testing protocol. He was supported by a team of eight individuals including MCEER investigator Andrei Reinhorn and PEER investigators Tara Hutchinson, Eduardo Miranda and Jose Restrepo. PEER Thrust Area I Leader Helmut Krawinkler served as the leader of the team developing a racking protocol. He was supported by a team of seven individuals including PEER investigator Jose Restrepo and MAE investigator Barry Goodno. MCEER investigator Manos Maragakis served as the team leader for the third team responsible for the development of protocols for the cyclic testing of distributed systems. He was supported by a team of six individuals including MCEER Industry Advisory Board Member Scott Campbell. MCEER and PEER supported the travel costs of their investigators and co-sponsored the project's workshop that was held in San Francisco on November 4, 2004.

Collaboration on Component Testing: Several joint experimental investigations on the seismic performance of building components were conducted in year 8 at MCEER and PEER. The seismic fragility of gypsum light gage metal stud partition walls that are common to modern office, hotel, and laboratory buildings were investigated by PEER investigator Jose Restrepo (see figure). MCEER Deputy Director Andre Filiatrault served on the External Advisory Panel that provided guidance to the project. Also in year 8, Andre Filiatrault conducted shake table fragility testing on a centrifugal liquid chiller (see figure). In the first phase of the project, seismic fragility tests were conducted using floor acceleration time-histories generated from numerical studies on one of MCEER's demonstration hospitals. In the second part of the project, the seismic behavior and fragility of various equipment isolators/restraints will be investigated using the same chiller unit. The results of these tests will be distributed to PEER investigators involved in nonstructural components and building contents research.

Seismic Fragility Testing of Gypsum Light Gage Metal Stud Partition Walls at PEER

Seismic Fragility Testing of Centrifugal Chiller at MCEER

Other Collaborations:

- PEER investigator Keith Porter is developing a taxonomy of nonstructural components; MCEER Deputy Director Andre Filiatrault is serving on an Oversight Committee for the project.

- On December 3, 2004 PEER Investigator Eduardo Miranda visited the University at Buffalo and delivered a seminar entitled *Estimation of Seismic Acceleration Demands on Nonstructural Components for Performance-Based Design* as part of MCEER's web cast seminar series (*http://mceer.buffalo.edu/archives/pr/2004/1203-2004-mirandasem.asp*). This presentation to MCEER investigators and graduate students summarized recent PEER research aimed at improving the estimation of acceleration demands in buildings. The presentation emphasized the understanding of the main variables controlling the amplitude and characteristic of seismic demands on building nonstructural components through simplified methods. The presentation concluded with some comments on current code provisions and possible improvements.

- In year 8, MAE initiated a project on nonstructural damage and resulting economic losses in buildings. The MAE investigators (Goodno, Craig) have contributed to the various discussions and workshops mentioned above and are involved in an industrially-funded project for nonstructural damage modeling and economic impact in the Memphis area. They are exploring opportunities for closer collaboration with key researchers at PEER (Miranda) and MCEER (Filiatrault).

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