# Table of Contents

## Section A: Project Descriptions

### 1. Year 7

- Project Descriptions II.A-1.1
- Overarching Center-wide Cross Program Research Activities II.A-1.3
- Thrust Area 1: Seismic Evaluation and Retrofit of Lifeline Facilities II.A-1.7
- Thrust Area 2: Seismic Retrofit of Acute Care Facilities II.A-1.39
- Thrust Area 3: Earthquake Response and Recovery II.A-1.71
- User Networks for Seismic Assessment and Rehabilitation of Critical Networking II.A-1.131
- Education and Outreach Activities II.A-1.165

### 2. Year 6

- Project Descriptions II.A-2.1
- Overarching Center-wide Cross Program Research Activities II.A-2.3
- Thrust Area 1: Seismic Evaluation and Retrofit of Lifeline Systems II.A-2.7
- Thrust Area 2: Seismic Retrofit of Acute Care Facilities II.A-2.35
- Thrust Area 3: Earthquake Response and Recovery II.A-2.69
- User Networks for Seismic Assessment and Retrofit of Critical Care Facilities II.A-2.131
- Education II.A-2.145

## Section B: Bibliography of Publications

II.B-1

## Section C: Biographical Sketches

II.C-1
Section A:

Project Descriptions
Year 7 Project Descriptions
OVERARCHING TASKS

Overarching Center-wide cross program research activities are those whose outcomes are most closely linked to the overall Center vision, while at the same time providing both focus and integration for Thrust Area tasks.

To this end, studies on how to aggregate the resilience performance evaluation of water and power systems (see Thrust Area 1) will be used as a model to later aggregate the evaluation of resilience for the support subsystems of hospitals. Subsequently, the hospital systems will be integrated with water and power support systems into overall community resilience evaluation and decision support systems that aim to facilitate rapid organizational response and improve recovery management and mitigation planning. Although developed for earthquakes, the hope is that these methodologies and tools can ultimately be extended to other hazards. Finally, it should be emphasized that research on the development of earthquake simulation tools is also needed for implementation in integrated methodologies, and this research task is therefore included in this section.

A description of the integration between tasks is presented in Volume I.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Project Number:** 040001

**Task Title:** “Earthquake Simulation for Integrated Research”

**Investigator:** Apostolos S. Papageorgiou  
**Institution:** University at Buffalo

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

Modeling and prediction of earthquake ground motion in continental United States. Originally our goal was to focus our prediction capabilities to Eastern North America (ENA). However, responding to the growing needs of MCEER researchers, we expand the scope of our work to include the entire continental United States. Specifically, our goal is to provide earthquake ground motion modeling and prediction capability for three types of tectonic regimes that characterize continental United States:  
(1) active tectonic regime (e.g., California),  
(2) extensional tectonic regime (e.g., Nevada), and  
(3) low seismicity tectonic regime (ENA).  
Regarding our work on earthquake ground motion modeling and prediction in California, we will exploit to the fullest the accomplishments of the **Southern California Earthquake Center (SCEC)** (Phase II & III results).

Our task is the synthesis/simulation of strong ground motion input over the entire frequency range of engineering interest as well as the prediction of various measures of strong ground motion (e.g., $a_{max}$, $v_{max}$, $d_{max}$, $SA$, $PSV$ etc). The synthesis/simulation and prediction techniques of strong ground motion should account properly for site effects and should be valid for sites both near an extended fault/source as well as at far-field.

**Problem Description and Research Approach of Proposed Work for Year 7:** *(Detailed description of research to be conducted and methodology to be used.)*

Our task is the synthesis/simulation of strong ground motion input over the entire frequency range of engineering interest. For this task we have adopted two different approaches:

1. **The Stochastic (Engineering) Approach**
2. **The Kinematic Modeling Approach**

We started our work with the Stochastic (Engineering) Approach because it is very expedient and, for most engineering applications, adequate enough. The computer codes that we have produced may be used for providing earthquake input representative of earthquakes in ENA. These computer codes may be accessed by MCEER investigators through a website [http://civil.eng.buffalo.edu/engseislab/index.htm](http://civil.eng.buffalo.edu/engseislab/index.htm) that we have created and that is part of the MCEER User’s Network.

Responding to the growing needs of MCEER researchers, we propose to expand the above capability in order to cover the entire continental US. Specifically, addressing the need to predict and synthesize earthquake ground motion in Southern California (Los Angeles region) for projects related to seismic evaluation of lifeline networks (i.e., electric power and water supply systems), we have initiated work aimed at calibrating the source model that we use (i.e., the “specific barrier model”).

II.A-1.9
(1) Synthesis of earthquake ground motion input for seismic evaluation of lifeline networks

This effort involves the following steps:

a. *Calibration of the “Specific Barrier Model”*: Calibration of the source model entails a database of carefully selected strong motion data. We are in the process of compiling such a database for active tectonic regions by fusing the USGS database (Boore, et al., 1997, *Seism.Res.Lett.*) with the SCEC Phase III Strong Motion Database (Steidl and Lee, 2000, *BSSA*).

b. *Disaggregation of the Seismic Hazard at a grid of sites covering the lifeline networks under investigation*: A set of sites covering the two lifeline networks under investigation (i.e., the electric power and water supply systems) will be selected, and the seismic hazard at these sites will be estimated and disaggregated using the results of the National Hazard Mapping Project (Frankel et al. 1996, *USGS Open-File Report*). The minimum number of points necessary to cover the two networks is estimated to be ~50. Selection of the events, for which an ensemble of synthetic earthquake ground motions will be generated, will be based also on the SCEC Phase II report (Working Group on California Earthquake Probabilities [WGCEP] 1995, *BSSA*).

c. *Simulation of Earthquake Ground Motions*: It has been estimated that, for a profile of sites crossing the LA Basin, the 10%-in-50 yr exceedance level (which is typically used in design) is generally dominated by $M_W \geq 6.75$ events within ~20 km of the site. In view of this fact, it becomes evident that the synthetic ground motions must realistically represent near-fault effects. We have developed a simple, yet very effective, model to represent near-fault effects (Mavroeidis and Papageorgiou, 2003, *BSSA*) and we will use it in the simulation of the earthquake ground motion realizations. Finally, the synthetic motions at a site should reflect the amplifying effects of the sedimentary deposits of the site. For this site effect we will rely on the site-category map of Southern California developed by SCEC (Wills et al. 2000, *BSSA*) based on the average shear-wave velocity to 30 m ($V_s^{30}$). For each site-category we will associate an amplification function that Abrahamson and Silva (1997, *Seism.Res.Lett.*) have proposed that incorporates intensity-dependent sediment nonlinearity. All the above steps are tailored so as to guarantee that the simulated motions are consistent with the existing database of recorded motions in Southern California.

(2) Incorporation of basin-edge-generated surface waves in the stochastic simulations of earthquake ground motions

The simulation techniques that we have developed so far do not account for the long period surface waves (usually T ~ 3sec and longer) that are generated in a sedimentary basin, (i) from the conversion of body waves at the edges of the basin, if the seismic source is located outside the basin (e.g., 1952 Kern County; 1971 San Fernando; 1990 Upland; 1992 Landers; 1994 Northridge; 1999 Hector Mine), or (ii) from channeling of seismic energy in the waveguide of the sediments in the form of surface waves, if the source is located in the basin (e.g., 1979 Imperial Valley earthquake). Such waves affect the long-period structures, such as long-span bridges, and high-rise buildings (~30 stories and higher). From the above list of earthquakes, it is evident that basin-edge-generated surface waves are an important consideration for long-period structures located in the LA Basin.

We would like to expand the capability of our simulation techniques and incorporate such waves in the synthetic motions for sites where the conditions warrant the presence of such waves. The technique that we propose to use is based on the physics of surface wave propagation and incorporates the dispersion characteristics of the sedimentary deposit (i.e., group and phase velocities). Incorporation of such waves, with the appropriate arrival time, in the synthetic motions will render the simulated time-series non-stationary with respect to their frequency content. In the past, earthquake engineers proposed simulation techniques of non-stationary processes (e.g., Grigoriu et al., 1988, *Earthquake Spectra*). We would like to
explore how our physically based technique relates to the abovementioned phenomenological techniques.

(3) **Causative relationship between near-fault pulses (“killer pulses”) and stress drop on the fault plane**

We have proposed a simple, yet very effective, mathematical expression to describe near-fault pulses (Mavroeidis and Papageorgiou, 2003). We have used this mathematical expression to successfully model all (i.e., worldwide) existing near-source records. Furthermore, this is the model we plan to use in the simulations of earthquake input for the seismic evaluation of lifeline networks, as we described above.

We propose to have a closer look at the causative relationship between near-fault pulses and stress-drop on the fault plane. Stating this differently, we would like to investigate if there are any particular locations in the vicinity of the fault that are more susceptible to very intense near-fault pulses than other locations. To accomplish this, we plan to use the kinematic modeling technique (we have already developed the necessary computer code) in connection with the concept of “isochrones” so as to be able to link specific phases (i.e., pulses) on the seismogram with the locations on the fault plane that generate them. We plan to analyze several (~5) earthquake events for which the slip on the fault plane is available to us. As a by-product of the above analyses will be the displacement and strain field in the vicinity (say within 20 km) of the fault.

(4) **Site effects**

This research task is feasible because of the unprecedented recorded database generated by the 1999 Chi-Chi, Taiwan, earthquake and its aftershocks. Specifically we propose to infer site Amplification Factor \((AF)\) from the analysis of coda waves (i.e., scattered waves that can be found at the tail of a seismogram following the major phases such as body and surface waves; *coda* in Latin means *tail*) and compare it with the \((AF)\) inferred from strong motion data recorded by accelerometers *co-located* with the seismometers that recorded the coda waves. We anticipate that the \((AF)\) inferred from coda waves, \((AF)_c\), (which represents the truly linear response of sediments) will be larger than the \((AF)\) inferred from strong motion data, \((AF)_S\). In fact we anticipate that \((AF)_S\) will be a function of the intensity of ground motion (traditionally in geotechnical earthquake engineering, earthquake intensity for site amplification purposes has been quantified in terms of peak acceleration). We propose to investigate/quantify the dependence of \((AF)_S\) on ground motion intensity. The result of such an investigation will provide the necessary correction factors that need to be applied to \((AF)_c\) to provide estimates of site amplification for strong ground motion. Estimation of site amplification from coda waves can be very useful from a practical point of view, given that coda waves are recorded by existing networks of seismometers that routinely record small earthquakes. Thus, there is an abundance of such data available for many regions of the world, including ENA. We inform the reader that a preliminary classification (in terms of site classes A, B, C, D, and E) has been done for the sites/stations of the 1999 Chi-Chi dataset that we propose to analyze, a fact that will facilitate our work considerably.

We have made progress in this research thrust that we formally initiated in Year 6. We are currently obtaining estimates of the \((AF)\) using three different techniques: (i) direct spectral ratio, (ii) horizontal-over-vertical (H/V) component ratio, and (iii) generalized inversion. Preliminary results indicate that there is great station-to-station variability in site response, a fact that confirms the conclusion of other researchers (Chen and Tsai, 2002, *BSSA*) who studied the attenuation characteristics of \(a_{max}\) in the island of Taiwan.
(5) **Sub-event models**

We are about to complete our study regarding the development of a new class of sub-event models by studying the effects of “healing” of rupture. We are in the process of deriving exact mathematical expressions for the far-field radiation of cracks taking into account the effects of “healing”.

(6) **Miscellaneous**

*Scattering effects of the lithosphere*: This is a research thrust that we started early on in our investigations and we would like to continue because scattering effects are a very important consideration in the synthesis of ground motion in ENA. We have initiated the collection of seismograms of small events that have been recorded in ENA (US and Canada) by various networks (including broadband, short period and strong motion networks) with the intention of performing analysis that will provide values of important parameters (e.g., quality factor $Q$ and scattering coefficient $g$) of the scattering characteristics of the lithosphere in ENA. Our objective is to synthesize results developed in the field of *Stochastic Seismology* with techniques for the generation of *evolutionary* stochastic processes developed in the field of *Probability Theory* (such as the *Spectral Representation* developed by Prof. M. Shinozuka; see also “*Applied Non-Gaussian Processes*” by Prof. M. Grigoriu). We expect the outcome of the “marriage” of the above two fields to be the development of a simulation methodology of realistic Green’s functions that reflect the characteristics of a particular tectonic region. We remind the reader that the Green’s function is one of the two elements (the other being the slip on the fault plane) required by the Kinematic Modeling Approach for the simulation of strong ground motion.

*Variable size sub-events*: We have completed our investigation on the effect of variable size sub-events on the prediction of ground motion and we preparing a manuscript.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

Regarding goal #2 (i.e., “*Incorporation of basin-edge-generated surface waves in the stochastic simulations of earthquake ground motions*”) described above, no work has been done before. In fact, Boore (2003, *Pure and Applied Geophysics*), in his most recent review paper in honor of Prof. Kei Aki, points to this problem as a necessary improvement to the stochastic simulation techniques of earthquake ground motion. Our work will benefit also from the work of Joyner (2000, *BSSA*) (part of SCEC Phase III) who studied the attenuation characteristics of the basin-edge-generated surface waves.

Goal #3 (i.e., “*Causative relationship between near-fault pulses and stress drop on the fault plane*”): No such investigation has been reported in either the earthquake engineering or seismological literature. Bouchon (1997, *J.Geophys.Res.*) has computed the state of stress on some faults of the San Andreas Fault system, but his focus was not the causative link between near-fault pulses and stress drop on the fault plane.

Goal #4 (i.e., “*Site Effects*”) is considered by earthquake engineers, as well as seismologists, a very important one because of the unprecedented availability of high quality data recorded by the same network (Taiwan Strong Motion Network). Results of such an investigation will have important implications for attenuation relations that are routinely used for engineering design.

Goal #5 (i.e., “*Sub-event Models*”) is a very original research work.

Finally, goal #1 (i.e., “*Synthesis of earthquake ground motion input for seismic evaluation of lifeline...*”)
networks”), even though it may be considered as just a service provided to the community of MCEER researchers, has not been attempted before. It is the synthesis of all the elements of a regional seismic hazard study (i.e., estimation of the aggregate seismic hazard, disaggregation of the seismic hazard, synthesis of ground motion realizations incorporating near-fault effects, over an extended region such as the LA Basin).

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

(1) We have fully developed and implemented the Stochastic (Engineering) Approach and we have developed computer codes that may be used for the following three purposes:
   (i) Simulation of strong ground motion time histories for given Magnitude, Source-to-Station Distance and Site Conditions (as specified by Site Classes defined in the NEHRP Provisions).
   (ii) Prediction various measures of strong ground motion (e.g., $a_{max}$, $v_{max}$, $d_{max}$, $SA$, $PSV$ etc) using Random Vibration Theory (i.e. without having to resort to the generation of numerous realizations and subsequently to average the results).
   (iii) Simulation of spectrum compatible time histories.

(2) We have created a website [http://civil.eng.buffalo.edu/engseislab/index.htm] which, among other things, provides access to the above codes to any one that may want to use them. Furthermore, sample time histories representative of the seismic hazard for five ENA cities (Buffalo, NY; New York City; Boston, MA; Memphis, TN; Charleston SC) have been posted on the website for the immediate use by the Users/MCEER researchers. We have also generated (upon the request of Prof. G. Lee) the necessary seismic input for the analysis of critical facilities/hospitals that are used as demonstration cases.

(3) We have a first draft of a comprehensive Technical Report/Monograph documenting in detail the Stochastic (Engineering) Approach used for the simulation of time histories. This Technical Report/Monograph, after being subjected to the standard MCEER review process, will be posted on the website. Thus it will be readily accessible by all the Users/MCEER researchers who can form their own opinion as to the assumptions and uncertainties involved in simulating the time histories that they use in their analyses. Posting of the Technical Report/Monograph on the website will be done in coordination with Prof. A. Reinhorn (MCEER’s Users Network) so that its access will be user friendly.

(4) We have made substantial progress in our efforts in synthesizing ground motion using the Kinematic Modeling Approach. Specifically, we have derived closed form solutions for the seismic radiation of a new class of kinematic models (asymmetrical circular and elliptical crack models) that will be used to simulate sub-events in the synthesis of strong ground motion generated by large earthquake events. These results have been presented in a forum consisting primarily of seismologists ("International Workshop on the Quantitative Prediction of Strong-Motion and the Physics of Earthquake Sources” held in Tsukuba, Japan, from Oct. 23 to 25, 2000) and were very well received. We present these results in three (3) journal papers, two of which have appeared in the Bulletin of the Seismological Society of America, and one has appeared in Physics Of Earth and Planetary Science. As stated above, our work on the effects of “Variable Size Sub-events” has been completed and we are preparing a manuscript to submit for publication. Some of the results that we have obtained so far related to “Near-source Ground Motions” have been presented in a journal paper that has been accepted for publication and will appear in the Bulletin of the Seismological Society of America.

II.A-1.13
**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

Our Task is a Center-wide overarching MCEER activity that supports multiple Thrust Areas, namely in this case Thrust Area 1 “Seismic Evaluation and Retrofit of Lifelines Networks” and Thrust Area 2 “Seismic Retrofit of Emergency Care Facilities”.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

Our Task is a Center-wide overarching MCEER activity that supports multiple Thrust Areas, namely in this case Thrust Area 1 “Seismic Evaluation and Retrofit of Lifelines Networks” and Thrust Area 2 “Seismic Retrofit of Emergency Care Facilities”.

**Possible Technical Challenges:**

1. Disaggregation of the seismic hazard and selection of the dominant events is a delicate process that will require substantial effort.

2. Derivation of closed form mathematical expressions for the seismic radiation of *crack models* accounting for “healing” is definitely a challenging task.

3. Synthesis of results developed in the field of *Stochastic Seismology* with techniques for the generation of *evolutionary* stochastic processes developed in the field of *Probability Theory* is also a technically challenging task.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

- Extension of the applicability of the computer codes so that they can be used for any location in the continental United States (including Southern California / LA Basin).

- Completion and posting on the website of the comprehensive Technical Report/Monograph documenting the Stochastic (Engineering) Approach for earthquake motion simulation.

- Development of a simple engineering approach to synthesize realistic ground motions incorporating long period basin-edge-generated surface waves.

**Potential end-users beyond academic community:** *(IAB members and others.)*

- Seismic Evaluation and Retrofit of Lifelines Networks
- Seismic Retrofit of Emergency Care Facilities
- Loss Estimation
- Fragility Curves
## Educational outcomes and deliverables, and intended audience:

The **Technical Report/Monograph**, documenting in detail the Stochastic (Engineering) Approach used for the simulation of time histories, is prepared in a tutorial style so as to educate engineers as to how we synthesize/simulate earthquake ground motions.

## Project Schedule and Expected Milestones for the Project: *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

Extension of the applicability of the computer codes so that they can be used for any location in the continental United States (including Southern California / LA Basin):  
We will give priority to this research effort. We expect to be able to start posting synthetic ground motions for the selected sites as soon as June 2003.

Posting on the website of the final version of the comprehensive Technical Report/Monograph documenting the Stochastic (Engineering) Approach for earthquake motion simulation:  
By the end of Fall 2003.

Causative relationship between near-fault pulses (“killer pulses”) and stress drop on the fault plane:  
By the end of Spring 2004.

Site Effects:  
By the end Year 7.

## Team Members: *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

- Dr. Gang Dong (Sr. Research Scientist)
- Mr. Benedikt Halldorsson (Graduate Research Assistant; Ph.D. candidate)
- Mr. George Mavroeidis (Graduate Research Assistant; Ph.D. candidate)
- Mr. Fangyin Zhang (Graduate Research Assistant; Ph.D. candidate)

## Possible Direction of Work in Subsequent Years:

There is substantial research work that needs to be done regarding:

- The development and implementation of the Kinematic Modeling Approach (accounting properly for scattering effects in synthesizing Green functions).

The above research effort will spill over beyond Year 7.
## MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 040002</th>
</tr>
</thead>
</table>

### Task Title:
Operationalization of the Broader Resilience Concept and Measures for Specific Critical Facilities.

### Investigator/
Institution:
- M. Shinozuka*, University of California at Irvine
- Michel Bruneau, University at Buffalo
- Andrei Reinhorn, University at Buffalo
- Kathleen Tierney, University of Delaware ***
- Detlof von Winterfeldt, University of Southern California ***
- Stephanie Chang, University of Washington ***
- Adam Rose, Pennsylvania State University ***
- Rachel Davidson, Cornell University ***

* Indicates task leader
*** Tierney, Chang, Rose and Davidson task and funding described in separate task statement

### Statement of Project Goals:
(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The objective of this overarching task is to take the previously developed center-wide definition and quantification of resilience, and operationalize these measures in a manner compatible and appropriate for the specific critical facilities within the MCEER Strategic Plan.

### Problem Description and Research Approach of Proposed Work for Year 7:
(Detailed description of research to be conducted and methodology to be used.)

MCEER’s current mission statement states:

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.

This framework must be further developed and refined for the specific MCEER testbeds. The objective is to preserve the center-wide conceptual approach to resilience quantification, but further develop the framework to allow it to embrace the intricacies germane to each type of critical infrastructure system. Research will be conducted to implement the resiliency definitions and measures to the problem of integrated water and power lifelines, as well as, in a preliminary way in Year 7, to acute care facilities.
**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

To the best of the investigators’ knowledge, no similar work is currently being conducted elsewhere at this time. Seismic resilience has never been quantified in the past, and the approaches proposed by MCEER are providing leadership in this endeavor.

**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

The basic framework for the definition of resilience and approaches to quantify and measure this resilience was proposed for the first time by MCEER in Fall 2001. Development since have been summarized and published in:


Since then, a pilot study that provides a good analytical and numerical insight has been in completed with respect to the LADWP’s power network for its performance encompassing technical and economical dimension.

Work on resilience of hospitals has also been presented to an ATC-58 Workshop “Seismic Design Guidelines for Performance Based Design (a FEMA-funded initiative). The proposed MCEER resilience framework was well received, and will be considered in future ATC-58 development work.

**Role of Proposed Task in Support of Strategic Plan:** (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

Enhancing seismic resilience at the community level is at the core of MCEER’s strategic plan, and development of the general framework of resilience measures is required to achieve MCEER’s mission objective.

**Task Integration:** (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The definition and measures of resilience proposed by MCEER in November 2001 provided a clear target for center-wide research integration and as such already have a direct impact on all researchers funded by MCEER. The further development to be accomplished as described in this task statement will continue to have such an impact, and updates on progress will therefore be periodically provided to all researchers.
**Possible Technical Challenges:**

To quantify seismic resilience in the specific terms and at a level of details required for the systems studied by MCEER is by itself a major challenge. Developing the proposed resiliency framework from its conceptual basis to a workable level for each of the systems considered, without straying from center-wide broadly applicable measures is a difficult yet important balance to maintain. Another balance to maintain is the level of details of database for technical, organizational, economical and societal dimensions. Particularly, restoration-related experience data are not easy to get for all these dimensions, and certainly not available to a similar level of detail, accuracy and significance to resilience issues.

<table>
<thead>
<tr>
<th><strong>Anticipated Outcomes and deliverables:</strong></th>
<th><strong>Potential end-users beyond academic community:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Also indicate those of particular benefit to IAB members and other end users.)</td>
<td>(IAB members and others.)</td>
</tr>
</tbody>
</table>

Practical definitions and measures of seismic resilience will be introduced that can be used to evaluate, compare and verify the enhancement of the resilience resulting from MCEER’s research in a rational and comprehensive manner.

Utility companies (lifelines), owners of acute care facilities and the practicing engineers they hire, emergency response agencies, and all agencies or groups who can benefit from a rational approach to enhancing seismic resilience, for example to establish seismic risk reduction policies or gage the consequences and benefits from various actions.

<table>
<thead>
<tr>
<th><strong>Educational outcomes and deliverables, and intended audience:</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The MCEER’s definitions and measures of resilience, and applications demonstrated by MCEER, could impact all earthquake engineering courses focusing on how to reduce the seismic risk.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Project Schedule and Expected Milestones for the Project:</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)</td>
<td></td>
</tr>
</tbody>
</table>

Preliminary operationalized measures of resilience for MCEER’s critical facilities – March 2004  
First iteration on revised definitions – September 2004

<table>
<thead>
<tr>
<th><strong>Team Members:</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)</td>
<td></td>
</tr>
</tbody>
</table>

Students will conduct research with Rose, Chang and Davidson to accomplish the specific tasks described in their task statement. The other members of this overarching center-wide integrated task will contribute the experience, vision, and expertise that they possess as senior research managers with MCEER (Shinozuka, Tierney, Reinhorn and Bruneau) and continuity with the original work of the MCEER Task Force that led to the original definition and proposed measures of resilience (Winterfeldt, Chang, Shinozuka, Tierney, Reinhorn, Bruneau and Eguchi).
Possible Direction of Work in Subsequent Years:

In Year 7, overarching effort will be directed to ensure a seamless research coordination for the MCEER investigators in economic and technical dimensions emphasizing the system interaction and possible simultaneous service interruptions of these systems under severe earthquakes. This effort will be further extended to focus more strongly on the organizational and societal arena in Year 8. Throughout these years, the overarching direction of MCEER research will be mindful for applications of the research result in the integrated test-bed systems in Los Angeles. In Years 9, using Los Angeles as a testbed, focus will be on demonstrating and verifying the how the MCEER research products can be used to achieve a more resilient city/community. In addition, the MCEER investigators involved in this task will contribute to identify opportunities to ensure the viability of MCEER as a financially independent Research Center beyond Year 10.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>040003</td>
</tr>
</tbody>
</table>

**Task Title:** Measures of Organizational and Community Resilience: Collaboration on Overarching Center Research on Lifeline Systems

**Investigator/Institution:** Kathleen Tierney, University of Delaware

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This task has three primary objectives: (1) to contribute to the further refinement of MCEER’s measures of organizational and community resilience by synthesizing findings from the research literature on resilience and the results of earlier empirical work; (2) to provide survey-based data on business impacts and resilience following earthquakes and other disaster events for incorporation into the economic loss models that will be developed for the Los Angeles integrated water and power demonstration project; and (3) to assist other investigators with the development of research instruments and fieldwork strategies for the Los Angeles lifelines study. This task is one element in an overarching centerwide task that encompasses all of MCEER’s research thrust areas, but is most closely linked to research on lifeline-related loss estimation.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

In collaboration with other MCEER investigators involved with the centerwide resilience task, the PI will continue work in Year 7 to develop conceptually sound and empirically grounded measures of resilience, with a particular emphasis on organizational and social resilience. Contributions to the overarching resilience measurement task will draw upon earlier social scientific research on resilience, as well as on relevant MCEER-funded work.

MCEER has identified the City of Los Angeles and its key lifeline organization, the Department of Water and Power, as testbeds for demonstrating state-of-the-art loss estimation methodologies for integrated (power and water) systems, as well as for conducting research on resilience-enhancing strategies for lifelines, such as lifeline retrofitting using advanced materials, the prioritization of lifeline service restoration, and the emergency mobilization of personnel and resources to repair lifeline damage following earthquakes. The ultimate objective of this work is to improve community and organizational decision making so as to minimize social disruption and shorten the time required to achieve desired levels of service delivery following earthquakes. To support these research activities, the PI will do the following:

1) continue collaborative multidisciplinary work on the conceptualization and measurement of organizational resilience that was initiated in Year 5;

2) provide MCEER investigators Chang and Rose with survey datasets on disaster-affected businesses that include variables that are relevant to direct and indirect loss estimation.

II.A-1.20
and the measurement of resilience. Such variables include information on post-disaster lifeline service losses, disruptiveness of those losses, business interruption, dollar losses due to earthquake damage and business interruption, and related topics. The disasters for which these data are available are the 1989 Loma Prieta earthquake; the 1993 Midwest floods; Hurricane Andrew; and the 1994 Northridge earthquake. Although some of these data have been used in a number of other studies, and some survey results have already been incorporated into MCEER’s “seamless” loss estimation models, their potential with respect to the overarching resilience task has yet to be thoroughly explored.

3) assist investigator Rose with the development of the Los Angeles business survey instrument discussed in his Year 7 work plan.

4) provide other assistance with the Los Angeles demonstration project as needed, e.g., by attending coordinating meetings

Assessment of State-of-the-Art:  (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Although the concept of resilience and related terms, such as disaster resistance and sustainability, are used frequently in writings on community vulnerability to hazards and disasters, no methodology currently exists to measure either resilience or the relative contributions made by alternative resilience-enhancing strategies, such as pre-disaster mitigation and post-disaster response and recovery. MCEER’s research activities in this area constitute a pioneering approach to conceptualizing and measuring resilience for both physical and social systems. Over the past two years, MCEER investigators have made considerable progress in conceptualizing and developing quantitative measures of resilience. However, more work is needed to further specify performance criteria on all resilience dimensions, assess the relative contributions to resilience made by different loss-reduction strategies, collect additional data to improve modeling capability and resilience estimates, and demonstrate the efficacy of these models by applying them in community testbeds. This is the objective of the Los Angeles lifelines demonstration project. MCEER is uniquely suited to carry out this work because of its ability to foster collaboration among investigators from the earth sciences and from various engineering and social science disciplines. This task is intended to support and complement other engineering and social science activities that are being carried out as part of this overarching task.

Progress to date:  (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

Along with eight other MCEER investigators and one MCEER consultant, the PI participated in the preparation of a manuscript entitled “A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities,” which has been submitted for review to *Earthquake Spectra*. This manuscript defines constituent elements (robustness, redundancy, resourcefulness, and rapidity) and dimensions (technical, organizational, social, and economic) of resilience and provides a framework for interlinking various resilience-focused MCEER research activities. Measures of resilience are defined as (1) reduced failure probabilities; (2) reduced consequences
from failures; and (3) reduced time to recovery. Work has also focused on developing empirical indicators of specific performance measures, e.g., indicators associated with organizational, economic, and social resilience. At the MCEER workshop on “Lessons from the World Trade Center,” which was held in New York City in June, 2002, the PI made a presentation entitled “Conceptualizing and Measuring Resilience for Physical and Organizational Systems,” which outlined MCEER’s definition of resilience and presented illustrative measures of technical and organizational resilience for emergency operations centers and emergency management organizations (EROs). The PI and other Disaster Research Center staff members have written a number of papers that are either in print or in press; presented papers or made presentations at professional meetings, including the 7th U. S. Conference on Earthquake Engineering, the annual meeting of the American Sociological Association, and the Natural Hazards Workshop; and made presentations based on MCEER research at meetings and workshops attended by policymakers and members of the emergency management community (see “Contribution to MCEER Objectives” for listing of publications and outreach activities).

Field work is continuing in DRC’s study on the organizational and community response to the World Trade Center disaster, which is also supported by a grant from the Public Entity Risk Institute and a post September 11 NSF supplement to the MCEER grant. Since the intensive interview phase of this work was initiated in October, 2002, 52 in-depth interviews have been conducted with key decisionmakers and departmental personnel who were directly involved with the 9-11 response in New York. All interviews have been tape-recorded, and most have been transcribed. Related analytic work focuses on characterizing the multi-organizational network that emerged in New York during the ten days following the Trade Center attack. Data on organizational activities and relationships are being systematically coded from sources that include field notes based on direct observations by DRC staff following the 9-11 attacks, organizational documents, meeting minutes, print media accounts, situation and after-action reports, and other materials. One line of conceptual and analytic work associated with these activities consists of explorations of the role of improvisation and creativity in organizational resilience. Another centers on the distinctive strengths of the “network form of organization” and its contributions to resilience in the Trade Center attack.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

Enhancing community seismic resilience is central to MCEER’s mission. MCEER seeks to achieve this goal by developing fundamental knowledge, techniques, and tools that can be used to improve the resilience of critical facilities, the organizations that manage them, communities, and economic systems. This and other tasks associated with centerwide overarching tasks are thus critical for MCEER’s strategic vision. With respect to MCEER’s strategic framework and three-level chart, this task contributes to “Fundamental Studies on Resilience,” “Loss Modeling,” “Resilience Criteria and Measures,” and “System-Integrated Loss Reduction Strategies.” In the context of the Los Angeles case study and demonstration project, this task makes available relevant data on more than 4,000 businesses affected by four different disasters—the largest datasets available on the experiences of randomly-selected, representative samples of businesses in disaster-stricken communities. Those data will be useful for fundamental research on business resilience in disasters, for improving MCEER loss models,
and for the comprehensive community recovery model being developed by PI Stephanie Chang as part of her Program 3 activities. The PI will also assist PI Adam Rose with the development of the improved survey instrument that is being planned as part of the Los Angeles integrated lifelines demonstration project.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The PI will collaborate closely with other investigators who are working on the overarching resilience task and on the Los Angeles lifelines study: PI’s Shinozuka, Reinhorn, Bruneau, Eguchi, von Winterfeldt, Rose, Chang, and Davidson. A meeting will be held with Rose and Chang to discuss ways of better utilizing business survey datasets in MCEER research activities.

**Possible Technical Challenges:**

MCEER investigators have been making considerable progress in addressing the technical challenges associated with the measurement of resilience, such as coming to consensus on measures that adequately operationalize various dimensions of resilience, developing performance measures that are consistent across systems, dimensions of resilience, and units of analysis, and refining MCEER’s state-of-the-art loss models to incorporate resilience-related measures. However, these challenges remain. With respect to the Los Angeles community study, technical challenges involve dealing with very large systems and data requirements, achieving consensus on engineering and social science models, measures, and spatial data, and addressing uncertainty.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

- Contributions to papers, reports, conferences, and workshops on resilience definition, measurement, and enhancement
- Contributions to papers, reports, conferences, and workshops on the World Trade Center disaster
- Collaboration with other MCEER investigators on the analysis of business resilience following earthquakes and other disasters

**Potential end-users beyond academic community:** *(IAB members and others.)*

- Emergency management agencies at various governmental levels
- Corporate risk managers and emergency managers

II.A-1.23
### Educational outcomes and deliverables, and intended audience:

Training experiences for graduate and undergraduate students. One dissertation will be produced during 2003.

### Project Schedule and Expected Milestones for the Project: *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

Since this task involves extensive collaboration with other PIs, the task activities described here will be adapted to their schedules. The overarching resilience task and its related demonstration project are multi-year studies.

### Team Members: *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

MCEER Collaborators:

On Resilience Measurement: Shinozuka, Reinhorn, Bruneau, von Winterfeldt, Eguchi, Chang
On the Los Angeles Lifelines Project: O’Rourke, Shinozuka, Chang, Rose, Davidson

### Possible Direction of Work in Subsequent Years:

Collaboration with other MCEER investigators to develop resilience-enhancing decision support tools for critical facilities and infrastructure systems.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 040004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Direct Losses, Social Impacts, and Community Resilience: L.A. Lifeline Study</td>
<td></td>
</tr>
<tr>
<td>Investigator/ Institution:</td>
<td>Stephanie Chang / University of Washington</td>
<td></td>
</tr>
</tbody>
</table>

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This project aims to develop a loss model and related measures of community resilience for the Los Angeles lifeline study. It focuses on modeling social and economic dimensions of resilience. In Year 6, the Memphis loss model will be adapted to the Los Angeles water system case. In Year 7, the L.A. model will be refined by (1) revising performance objectives, which are needed to quantify resilience; (2) expanding the model to include impacts on hospitals; and (3) integrating with other MCEER work on a decision support platform for critical lifelines.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

The overall goal of MCEER research in lifelines is to improve the seismic resilience of communities through substantial improvements in the earthquake reliability of critical lifeline systems. In contributing to this goal, this project will develop a model of direct economic and social losses associated with lifeline disruption in earthquakes. The model can be used to evaluate the community resilience improvements that would be afforded by applying advanced technologies, as demonstrated in MCEER’s Los Angeles study.

Efforts in Year 7 will build on Year 6 work on the L.A. lifeline loss model and related community resilience measures. The objective in Year 6 is to transfer the Memphis lifeline loss model framework to L.A. and expand it in the direction of social losses. Efforts in Year 7 will focus on three subtasks: (1) revising performance objectives, (2) modeling hospital impacts, and (3) integrating with other MCEER work on creating a decision support platform for critical lifelines.

Defining performance objectives is an important step in developing and implementing measures of resilience. Previous work in the Memphis lifelines study demonstrated resilience measurement on the basis of arbitrarily-defined performance objectives (e.g., “less than one week until regional economic output return to 99% of ‘normal’ levels”). Here, refined performance objectives will be developed based on consultation with lifeline management practitioners, particularly those at LADWP, as well as other MCEER researchers.

The modeling of the social dimension of resilience will be expanded in scope to include impacts of lifeline outage on hospitals. This will first entail collecting general facility data on
the L.A. regional hospital system and integrating this data into the loss model. Interviews will then be conducted with representatives of major hospitals in L.A. and, potentially, in Seattle. These interviews will yield information on how lifeline outages could potentially affect hospital functionality and patient care. The lifeline loss model will then be expanded to include hospital impacts as a component of the social dimension of community resilience.

(The interviews will be coordinated with other MCEER researchers, especially W. Petak and D. Alesch, who are also conducting interviews with L.A. area hospital managers. Although Petak and Alesch are focusing on a very different set of questions, i.e., mitigation decision-making in relation to California legislation SB 1953, coordination will be pursued to the extent possible and beneficial. For example, the interviews here will begin with a subset of the Petak/Alesch hospitals, for which background information will be available and contacts will already have been made. Data collection instruments will be shared. Opportunities for gathering supplementary data for the Petak/Alesch study, e.g., through coordinated Seattle area hospital interviews or follow-up questions for the L.A. hospitals, will be pursued.)

The loss model will be integrated with work by other MCEER researchers on a decision support platform for critical lifelines that addresses seismic resilience in its technical, organizational, societal, and economic dimensions. The P.I. will work with Cornell researchers (T. O’Rourke, M. Grigoriu, R. Davidson) on this integration.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

To the P.I.’s knowledge, MCEER researchers have developed the only existing models that evaluate the economic disruption impacts of electric power and/or water outage in earthquakes. No current loss models consider the interaction between lifeline performance and critical facilities such as hospitals. Also, this work is innovative in modeling earthquake risk in terms of community resilience, rather than simply in terms of expected loss.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

Efforts in previous years, under the Memphis Lifelines and the Loss Estimation tasks, produced an integrated engineering-economic model of losses due to water outage. This model is innovative in its treatment of uncertainty, use of GIS, incorporation of empirical data, and application to comparing pre- and post-disaster loss reduction strategies. Results have been presented and published in various venues, including MCEER’s Research Accomplishments series and, within the past year, in the journal Environment and Planning B and proceedings of the 7th National Conference on Earthquake Engineering. Most recently, the Memphis model has been refined to evaluate outcomes in terms of community resilience. These results are documented in a discussion paper prepared for the 2003 annual meeting. Currently, work on the Memphis model is being completed by evaluating the resilience improvements of pump station retrofits that were actually undertaken by MLGW. Work on transferring the model to Los Angeles has been initiated.
Role of Proposed Task in Support of Strategic Plan:  *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The proposed research will support MCEER’s strategic plan by contributing toward a systems model that promotes a comprehensive assessment of lifeline disruption risk in earthquakes. It develops a model for evaluating social and economic resilience impacts of loss reduction strategies, including engineering technologies, that MCEER is developing for water and power systems. This model will help water authorities and the communities they serve to make rational decisions about the allocation of resources necessary to achieve community goals in earthquake resilience.

Task Integration:  *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The socio-economic loss model developed here will eventually be integrated with engineering models of water outage that T. O’Rourke and M. Grigoriu are developing for Los Angeles, similar models of electric power outage by M. Shinozuka, lifeline restoration models by R. Davidson, and indirect economic loss models by A. Rose. Potentially, the work on hospital impacts from lifeline outage could serve as a bridge from MCEER’s Lifelines program to its Hospitals program. Data collection from the hospital interviews will be coordinated with W. Petak and D. Alesch (and potentially others, such as D. von Winterfeldt), as described above.

Possible Technical Challenges:

Los Angeles is a much larger and more complex urban area than Memphis. It encompasses dozens of cities and involves several major lifeline providers. Challenges may include issues of data consistency and completeness, as well as computational efficiency.

In addition, hospital managers may be reluctant to share data on potential impacts of lifeline disruptions due to security concerns.

Anticipated Outcomes and deliverables:  *(Also indicate those of particular benefit to IAB members and other end users.)*

| Potential end-users beyond academic community:  *(IAB members and others.)* |
| City of Los Angeles |
| LADWP |
| Emergency managers and planners |
| Utility agencies |

Improved definitions of lifeline performance objectives.

Model of hospital impacts from lifeline disruptions.

Refined Los Angeles loss model that evaluates social and economic resilience.
Educational outcomes and deliverables, and intended audience:

Training of 2 graduate students.

In addition, the loss model itself can serve as an educational tool for lifeline agencies, engineers, and emergency managers and planners.

Project Schedule and Expected Milestones for the Project:  *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

- **Fall 2003:** Obtain input on lifeline performance measures. Develop revised measures. Incorporate into L.A. lifeline loss model.
- **Spring 2004:** Conduct hospital interviews. Develop hospital impact model. Incorporate into L.A. lifeline loss model (measures of social resilience).
- **Summer 2004:** Integrate with engineering work on water system modeling at Cornell. Write up for publication.

Team Members:  *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

S.E. Chang, Principal Investigator
C. Chamberlin, graduate research assistant (GRA)
another GRA, to be determined

Possible Direction of Work in Subsequent Years:

Further integration with lifeline engineering models for L.A. study. Contribution to combined water and electric power systems model. Development of links between social and economic loss, e.g., loss of labor productivity due to earthquake disruption at the home. Contribution toward decision support tools for lifeline managers and engineers. Assessment of social and economic resilience impacts of implementing advanced technologies.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
<th>040005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Modeling Regional Economic Losses from Earthquakes—LA Lifeline Study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigator/ Institution:</td>
<td>Adam Rose / The Pennsylvania State University</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The goal is to refine and apply a computable general equilibrium (CGE) model of the Los Angeles economy to: a) estimate regional economic losses from utility lifeline disruptions and b) measure individual business and community resilience. The analysis will be linked to the LA Demonstration Project on water and electricity lifelines headed by Tom O’Rourke and Masanobu Shinozuka. The CGE model will be integrated into the work of other researchers in the engineering, vulnerability assessment, GIS, mitigation technology and adoption and policy areas.

Problem Description and Research Approach of Proposed Work for Year 6: (Detailed description of research to be conducted and methodology to be used.)

Computable General Equilibrium (CGE) refers to a model of the entire economy based on decisions by individual producers and consumers in response to prices and markets within the limits of available capital, labor, and natural resources.

CGE is the state-of-the-art methodology for impact analysis at the national level, and is being more frequently used at the regional level, the appropriate geographic scope of most natural hazards. It represents a significant advance over input-output modeling, which has dominated the hazards impact literature, through the incorporation of nonlinearities and behavioral responses (including bounded rationality) to price signals, resource limitations, and private and public sector policy decisions.

The project will capitalize on the investigator’s recent refinements of CGE analysis, such as the incorporation of new empirical data, the modeling of disequilibria, and decomposition of direct and indirect impacts.

The following tasks will be undertaken:

1. Validate and refine a computable general equilibrium model of the LA County economy constructed during Year 6 (by-products of this will be an input-output table for economic structural analysis and a social accounting matrix for distributional analysis).
2. Adjust production function parameters for water use on the basis of data obtained from LADWP and other MCEER researchers.
3. Further incorporate behavioral considerations into the model from the work of MCEER decision scientists.
4. Design a questionnaire to assess resiliency in individual businesses, primarily water customers.
5. Apply the model to a water system disruption in the LADWP system of LA County.
Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

I am the only economist affiliated with MCEER. No other MCEER researchers are involved in regional economic analysis in general (except for Stephanie Chang’s work on direct impacts and economic recovery) and on CGE modeling in particular. Economists and regional scientists at other earthquake centers are not working on CGE analysis (Peter Gordon of PEER continues to work on multiregional input-output analysis, and Geoff Hewings at MAE on conjoined econometric/I-O models).

Earlier attempts at adapting CGE models to natural hazards by David Brookshire at New Mexico and Dick Boisvert at Cornell have not followed through. My work has advanced on theirs by: 1) using more sophisticated production functions, 2) testing the sensitivity of key parameters, 3) including individual business and community resilience, 4) incorporating real world data for parameter estimation, 5) being able to model adjustments when utility service prices are fixed, and 6) measuring resiliency at the community level.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

Major accomplishments in the past include:

1. Advanced the state of the art of input-output and linear programming models of indirect loss estimation for earthquakes.

2. Identified and measured capabilities of nonstructural post-event recovery measures to reduce business interruption losses from earthquakes (e.g., restructuring of suppliers and customers, rationing of scarce lifeline services, interruptible service contracts).


4. Advanced the state of the art of CGE modeling for natural hazard loss estimation including: a way to incorporate real world data into the estimation of input parameters for lifeline services using numerical methods, criteria for validating CGE models applied to natural hazard loss estimation, and advances in modeling sectoral and community resiliency.

5. Demonstrated model capabilities in the Portland Water System Study funded by a related NSF grant.

6. During the reporting period, I made the following progress including:
   a. developed a way to incorporate real world data into the estimation of input parameters using analytical methods.
   b. advances in specifying business and community resiliency.
   c. advances in incorporating adaptive nonlinear considerations, such as learning, into responses to utility service disruptions.
   d. constructed basic LA CGE model.
   e. demonstrated model capabilities in study of sectoral and regional economic impacts of summer
2001 rolling blackouts in SCE service territory.

f. Graduated two Ph.D. students whose dissertations focused on natural hazards, and provided post-doc experience to another.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This task will uniquely contribute to the MCEER objective of analyzing regional economic impacts of and enhancing community resiliency to earthquakes. It calls for conceptual and empirical advances in a regional economic model, which explicitly incorporates resiliency at the individual consumer and producer levels and assesses the impacts of their decisions, together with underlying engineering system features, on the community as a whole. It focuses on the economic impacts, but can be integrated with other dimensions. It is the only community-wide model at an advanced stage at MCEER. The model is operational and can play a key role in the LA Demonstration Project in estimating direct and indirect business interruption losses from both water and electricity service disruptions.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

My proposed research builds on the work of other MCEER researchers and will be part of an integrated, interdisciplinary loss estimation system. It will essentially yield bottom line economic loss estimates for the LA economy as a whole.

1. T. O’Rourke — modeling LA lifeline networks
2. M. Shinozuka — modeling network vulnerability/reliability
3. D. von Winterfeldt — modeling decisions
4. K. Tierney — measuring resiliency
5. S. Chang — measuring direct economic losses and recovery

**Possible Technical Challenges:**

Major challenges include:
- reconciling spatial engineering data with spatial economic data through GIS
- matching theoretical properties of the model to real world needs
- collecting data on decision-making to calibrate the model
- streamlining the model so that it can be incorporated into a computerized integrated assessment framework with other MCEER researchers

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

1a. Validate LA I-O & SAM Models
1b. Validate LA CGE Model
2. Design questionnaire on resiliency behavior
3. Incorporate data from other MCEER researchers and LADWP
4. Further incorporate behavioral considerations
5. Run regional economic impact simulations

**Potential end-users beyond academic community:** *(IAB members and others.)*

1. LA public officials, utility managers, other researchers, & policy-makers
2. Utility managers
3. Utility managers
4. MCEER researchers
5. All
**Educational outcomes and deliverables, and intended audience:**

Completion of the following theses in the natural hazards area:

- Hubert Huang (M.S.) — Fall 2003
- Bo Yang (Ph.D.) — Summer 2004

Further development of an undergraduate Natural Hazards Minor

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

<table>
<thead>
<tr>
<th>Outcome 1a</th>
<th>January 2004</th>
<th>Revised visual representation of LA economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcome 1b</td>
<td>March 2004</td>
<td>More fully documented model</td>
</tr>
<tr>
<td>Outcome 2</td>
<td>May 2004</td>
<td>Complete survey instrument</td>
</tr>
<tr>
<td>Outcome 3</td>
<td>August 2004</td>
<td>Revised model</td>
</tr>
<tr>
<td>Outcome 4</td>
<td>September 2004</td>
<td>Refereed journal article &amp; chapters of MCEER monograph</td>
</tr>
</tbody>
</table>

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

- Tom O’Rourke (Team Leader)
- Masanobu Shinozuka (Co-leader)
- Kathleen Tierney
- Ron Eguchi
- Stephanie Chang
- Rachel Davidson
- Bo Yang (Penn State graduate student)

**Possible Direction of Work in Subsequent Years:**

1. Circulation of questionnaire to incorporate more behavioral considerations of responses by producers, consumers, and policy-makers in conjunction with MCEER decision scientists.
2. Improved conceptual and empirical modeling of individual and business resiliency.
3. Exploration of tangible policy advances to enhance regional community resiliency, such as the establishment of an information clearinghouse to match customers without suppliers and suppliers without customers.
MCEER RESEARCH TASK STATEMENT

Task No. | Budget: | Yr 7 Assigned
---|---|---
| | Project Number: 040006

**Task Title:** Restoration analysis for lifelines

**Investigator/Institution:** Rachel Davidson / Cornell University

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The objective of this task is to develop an improved model of the post-earthquake restoration processes of the electric power and water supply systems. The model will use estimates of physical damage to the systems and an understanding of the repair and recovery operations to estimate expected restoration times for each system, as well as the uncertainty surrounding those estimates. This task will be undertaken in conjunction with other work on the Los Angeles Department of Water and Power (LADWP) demonstration project.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

The rapidity dimension of electric power and water supply system resilience is a critical determinant of a community’s economic resilience. Assessment of lifeline rapidity requires quantitative measurement of expected post-earthquake restoration times. The objective of this task is to develop a model of the post-earthquake restoration processes of the electric power and water supply systems. The model will output quantitative estimates of system restoration times, which will directly support efforts to assess economic community resilience.

In Year 7, the work will include three main phases. First, additional background information will be collected and interviews conducted as necessary to fill in knowledge gaps. A one-week visit to LADWP and EBMUD is planned for May or June to see the water and electric power systems and facilities first hand, and to meet with the personnel involved in post-earthquake restoration.

Second, two restoration models, one for the electric power system and one for the water system, will be developed. These models will be developed using an object-oriented, discrete event simulation to capture the dynamic nature of the restoration process while offering maximum flexibility. The models may be implemented in a Geographic Information System (GIS) to capture the spatial nature of the networks and the restoration process. Probabilistic duration estimates of the tasks involved in restoration will be used so that the uncertainty in the final restoration time can be estimated. The models will address the temporal and spatial variability within the restoration process, and the effects of organizational factors on the processes (e.g., repair prioritization plans, mutual aid agreements).

Third, the models will be applied in Los Angeles as part of the LADWP demonstration project. Model results will be compared to observed system performance in the 1994 Northridge and 1971 San Fernando earthquakes, and the models will be refined as necessary.
Assessment of State-of-the-Art:  
(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

ATC (1992) provided an early restoration model for the U.S. water supply system based on ground shaking intensity, facility type, and region of the U.S. Ballantyne (1990) models the Seattle water supply system restoration process using several assumptions about the repair process, resources required for repairs, and availability of resources. HAZUS employs a similar approach to water system restoration (NIBS 1997). In previous MCEER work, Shinozuka et al. (1998) assume a nonlinear functional form for restoration curves for the electric power system. Chang et al. (2000) uses a resource constraint approach in which the number of repairs completed in a time period is estimated based on repair personnel availability, and the sequence of repairs is specified based on observations from the Kobe and Northridge earthquakes.

Previous studies such as these suggest that future restoration models should incorporate both the spatial and temporal variability inherent in the restoration process, the effect of mutual aid agreements and other organizational issues, and the effect of interdependencies among lifelines. They also suggest that some assumptions required by models that simulate the actual repair process have not been supported by empirical evidence from recent earthquakes. A well-designed restoration model will allow assessment of the effectiveness of strategies that aim to reduce losses by shortening restoration times through mutual aid agreements, or by prioritizing the sequencing of component repairs based, for example, on their damage level, their geographic location, their function within the system, or the characteristics of the customers they serve.

Davidson et al. (2003) describes the performance of the electric power distribution system in the Carolinas in recent hurricanes, and Liu et al. (2003) describes a negative binomial regression model developed to predict power outages in hurricanes. Although hurricanes and earthquakes cause very different damage patterns, the investigator’s previous research experience modeling hurricane damage to electric power systems serves as a helpful foundation for the proposed task.


### Progress to date:
*(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

The investigator began work with MCEER in October 2002. Since then, three main tasks have been accomplished. First, literature surveys have been conducted to better understand (1) lifeline restoration modeling approaches used in the past, (2) how water and electric power systems work and observed earthquake damage patterns for them, and (3) simulation modeling approaches and available software packages. Second, many interviews have been conducted to gain necessary background for the project. The PI talked with other MCEER investigators’ to learn more about the tasks that directly interface with this one—tasks that aim to estimate damage to the systems (Shinozuka and O’Rourke) will offer input for the restoration model, and tasks that aim to measure economic resilience (Chang and Rose) will use the output of the restoration model. The investigators have also had a series of interviews with electric and water system emergency response personnel to gather information about how the restoration process actually works for water and power systems. They have had lengthy phone interviews with Glenn Singley (LADWP Director Water Engineering and Technical Services), Martin Adams (LADWP Water Emergency Coordinator), Ron Tognazzini (LADWP Electric Power Disaster Coordinator), and David Lee (EBMUD Senior Engineer, Seismic Improvement Program). Third, a very simple object-oriented simulation-based restoration model was developed in ProModel to get an idea of how the modeling approach might be applied to this problem.

### Role of Proposed Task in Support of Strategic Plan:
*(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This task will provide a methodology to help measure the rapidity dimension of resilience for electric power and water supply systems. It will offer a direct contribution to measurement of the technical and organizational aspects of resilience, which in turn will support efforts to assess the economic and societal resilience of a community. In terms of the MCEER three-level strategic framework chart, the development of a restoration model fits in with the modeling and simulation associated with loss estimation methodologies that are part of the middle level.

### Task Integration:
*(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The proposed work will form a critical link between the tasks that involve estimating damage to electric power systems (Shinozuka) and water supply systems (O’Rourke), and the tasks that involve measuring the economic and societal aspects of community resilience (Chang and Rose). The restoration models will be designed to take full advantage of the estimates of physical system damage provided as input from Shinozuka and O’Rourke, and to provide as output the information required by Chang and Rose to assess the economic and societal aspects of community resilience.

### Possible Technical Challenges:
- Even though there exist well-established earthquake response plans that dictate how a restoration is expected to proceed, the restoration process is heavily influenced by decisions made post-earthquake in reaction to the actual circumstances. It will be difficult to anticipate the way that repair personnel and others interact with the restoration process and to incorporate the effect of those human interactions.
- Data required by the model (e.g., availability of repair personnel and materials; and time required for post-earthquake inspections, component repair work, and replacement of components that cannot be repaired) may be difficult to obtain.

- Restoration of the electric power and water supply systems are not independent of each other or the performance of other lifeline systems. For example, the repair of water supply pipes may be impeded by damage to the transportation network or debris in the roads if repair crews cannot gain access to the damaged area, or it may be delayed by damage to the electric power system if the electricity required to operate pumps is not available. It may be difficult to incorporate the effects of those infrastructure interdependencies.

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Models for assessing expected post-earthquake restoration times for electric power and water supply systems.</td>
<td>LADWP</td>
</tr>
<tr>
<td>2. Estimates of restoration times for LADWP demonstration project.</td>
<td>Other electric power and water supply companies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Educational outcomes and deliverables, and intended audience:</th>
</tr>
</thead>
<tbody>
<tr>
<td>This task will provide a multidisciplinary educational experience for a graduate research assistant and an undergraduate research assistant who will work on the project. It will also possibly serve as a case study for discussion in a course entitled Civil Infrastructure Systems (CEE 506). The course aims to introduce structural engineering students to the concepts and methods of the systems engineering approach through case studies relating to infrastructure systems.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Complete background information gathering, including visit to LADWP and EBMUD (Spring 2003).</td>
</tr>
<tr>
<td>2. Water system restoration model development (Summer 2003 to Spring 2004)</td>
</tr>
<tr>
<td>3. Electric power system restoration model development (Summer 2003 to Spring 2004)</td>
</tr>
<tr>
<td>4. Comparison of model results for Los Angeles with observed performance in recent earthquakes (Summer 2004)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professor Rachel Davidson, Cornell (Project leader)</td>
</tr>
<tr>
<td>Ms. Zehra Çağnan, Cornell (Graduate research assistant)</td>
</tr>
<tr>
<td>Ms. Shideh Dashti, Cornell (Undergraduate research assistant)</td>
</tr>
</tbody>
</table>
Possible Direction of Work in Subsequent Years:

Integrate the electric power and water supply restoration models into a single multi-lifeline restoration model that accounts for the interdependencies between the systems.

While the initial work involves developing descriptive models that capture the way the restoration process works today, future work could develop prescriptive optimization models to help determine the best way to run the restoration.

The restoration models developed in this research will be consistent with the type of approach needed for the restoration of acute care facilities and hospitals. The research products developed here for lifelines, therefore, will form the basis for hospital restoration assessment, and can be further developed for these facilities in the future.
THRUST AREA 1:
Seismic Evaluation and Retrofit of Lifeline Facilities

This thrust area closely supports the Center-wide effort to construct an overarching strategic framework for the measures of resilience and associated decision support tools. Specifically, the thrust area focuses on the development of GIS-based analytical, experimental and empirical procedures to evaluate and enhance the seismic resilience of lifeline systems. Seismic resilience of lifeline systems involves their robustness, or resistance to seismic loads, as well as the rapidity with which repair/restoration can be implemented after an earthquake.

To further the objective of system integration, MCEER has combined the electric power and water distribution systems in the same GIS, and is investigating the integrated performance of water and electric power distribution. Complex network simulations are performed for each system and interrelated to account for interdependencies (e.g., electric power loss effects on pump stations for water, flow interruptions effects on hydroelectric capacity, etc.) in their combined performance. Through the involvement of economists and social scientists, MCEER is developing ways to quantify reliably the direct and indirect economic consequences of seismic damage. The development and demonstration of integrated models that account for combined systems performance are important and enduring contributions of MCEER because such models establish a platform for future interagency and regional community work.

A description of the integration between tasks is presented in Volume I.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 041001</th>
</tr>
</thead>
</table>

**Task Title:** Comprehensive Model for Integrated Electric Power Systems

**Investigator/ Institution:** Masanobu Shinozuka, University of California, Irvine

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The goal of this project is to integrate the technologies developed by MCEER and elsewhere for the purpose of establishing analytical procedures that permit the evaluation of seismic resilience of a community as it pertains to the seismic performance of a joint system consisting of water delivery and electric power networks accounting for their interactions, not just through their physically sharing some components but also from their inter dependent functions. In particular, the initial version of performance criteria definition and the probabilistic analytical procedures developed in Y6 for electric transmission systems will be further extended to evaluate the joint performance of power and water systems and consequence aggravated by simultaneous interruptions under each earthquake as common cause. We will consider the community seismic resilience under these two and transportation and hospital systems combined.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

The proposed work intends to integrate the technologies developed by MCEER including GIS inventory data of the LADWP’s database and electric transmission systems, multiple scenario earthquakes representing the LA area seismic hazard, fragility analysis of systems, sub-systems and equipment, base-isolation techniques for transformers, systems analysis on the basis of WSCC’s (Western Systems’ Coordinating Council’s) database and EPRI’s (Electric Power Research Institute’s) IPFLOW computer code, direct and indirect loss estimation methods, the initial version of performance criteria definition, and the probabilistic procedure developed in Y6. The purpose of this integration is to evaluate the joint performance of power and water systems and the consequence of their system interruptions under each earthquake as common cause. The second component of this project is to further establish the performance criteria that can be quantitatively mapped into the response space, not only in technological, and economic, but also organizational, and social dimensions. Finally, the third element is to develop probabilistic procedures to estimate the reliability of the seismic resilience of the community, for example, in terms of annual probability of the combined response being within an acceptable domain in the response system space (acceptable performance), which can serve as a backbone of the analytical framework for community resilience evaluation.
Assessment of State-of-the-Art:  (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

MCEER’s lifeline research has now been expanded to evaluate the joint performance of lifeline systems network as opposed to that of individual systems independently. This is the only way, for example, in which interaction among the systems can be assessed quantitatively for the purpose of evaluation of the seismic resilience of the community in various dimensions such as technical, organizational, economical and societal. In all these respects, we uniquely represent the state-of-the-art.

Progress to date:  (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Years 1 through 5

Engineering Seismology and Geotechnical:  Seismologically consistent scenario earthquakes were identified to represent seismic hazards of the Los Angeles and the Memphis regions. The system analysis is then performed making use of Monte Carlo simulation techniques under these scenario earthquakes and taking the fragility curves of transformers and other equipment into consideration. The systems analysis for both LADWP and MLGW power transmission networks evaluates the average reduction in the output power in each service area, reflecting the average effect of the degradation of the system performance due to the seismic damage.

Systems Analysis:  The systems analysis utilized the Western Systems Coordination Committee’s and MLGW’s database, and EPRI’s IPFLOW computer code for transmission systems. For the seismic performance of substation equipment, fragility information was developed from various sources and used in the IPFLOW code. The difference in the resulting fragility curves is studied from the viewpoint of the uncertainty involved in the evaluation of ground motion intensity index such as PGA. Of equal importance is the study to determine the extent of fragility curve enhancement by rehabilitation of the bushing-transformer systems by base isolation. This was studied on the basis of the shaking table test performed at Taiwan's National Center for Research on Earthquake Engineering (NCREE) in Taipei under the MCEER-NCREE Cooperative Research Program by Feng and Saadeghvaziri. These test results showed that the reduction of the acceleration at the bushing-transformer interface is in the range of 50% (measured in terms of median value increase of up to 100%) in the earlier systems analysis.

Year 6

We developed the performance criteria that can be quantitatively mapped into the response space, particularly in technological dimension and are working on the performance criteria in organizational, economic and social dimensions. In addition, we developed probabilistic procedures to estimate the reliability of the seismic resilience of the community, for example, in terms of annual probability of the combined response being within an acceptable domain in the response system space (acceptable performance). These were all done by integrating the
technologies developed by MCEER including GIS inventory data of the LADWP’s database and electric transmission systems, multiple scenario earthquakes representing the LA area seismic hazard, fragility analysis of systems, sub-systems and equipment, base-isolation techniques for transformers, systems analysis on the basis of WSCC’s (Western Systems’ Coordinating Council’s) database and EPRI’s (Electric Power Research Institute’s) IPFLOW computer code, direct and indirect loss estimation methods, the initial version of performance criteria definition, and the probabilistic procedure introduced in Ys 5 and 6. The purpose of this integration is to evaluate performance-based resilience of the combined power and water system under each earthquake as common cause.

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

This work plays a major role in MCEER’s Strategic Plan to develop methods and tools to enhance seismic resilience of the community. Indeed, this work formulates such a process of evaluation for the resilience of a combined system consisting of water and power networks. The process is actually implemented utilizing the knowledge acquired for our testbeds, LADWP’s water and power system. This will pave the way to integrate other systems supporting the seismic resilience of the community.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

This work will be tightly integrated with the effort by Grigoriu and T. O’Rourke on the systems analysis of water network. The interaction of these systems from technical point of view is being investigated. The effect of rehabilitation of water network by the use of FRC and electric power network by base-isolation is evaluated for a combined system consisting of these two networks working with O’Rouke, Saadeghvazini and Feng. The seismic resilience of this combined system in economic and social dimensions will also be attempted together with S. Chang, Rose, Tierney and Von Winterfield. Organizational dimension of the resilience will be studied by Davidson with the LADWP engineers and management. This last work continues to concentrate on repair and repair schedule of damaged substations.

Possible Technical Challenges:

Quantitative evaluation of seismic resilience of the community (even of the combined water and power network) in organizational and social dimensions appears to require substantial and sustained effort in collecting necessary information. In addition, the specific and detailed GIS information of water, power and other lifeline systems has become very sensitive from the viewpoint of security since the September 11th event.
**Anticipated outcomes and deliverables:**
(Also indicate those of particular benefit to IAB members and other end users.)

Development of software that allows estimation of resilience of a combined water and power network in technical and economical dimensions.

**Potential end-users beyond academic community:** (IAB members and others.)

- LADWP
- Southern California Edison
- Utility companies
- California OES
- Emergency Response Community

**Educational outcomes and deliverables, and intended audience:**

The subject of this task will be integrated into one of the PI’s graduate courses dealing with risk assessment of infrastructure systems. Also, give seminars and lectures at electrical engineering department on the subject. All post-doctoral researchers and graduate and undergraduate students will be trained in systems analysis involving real-life large scale network, submitting reports to PI on their research. They are also required to make presentations at appropriate seminars and conferences.

**Project Schedule and Expected Milestones for the Project:** (Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)

Performance criteria will be examined to see if parameters in economic and other dimensions must be included upon completing this study, quantitative performance criteria will be redeveloped in technical and economic dimensions in Winter and Spring. Preliminary development of the performance criteria in organizational and social dimensions together with probabilistic systems analysis will be attempted.

**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- Masanobu Shinozuka, Principal Investigator, UCI
- T.C. Cheng, Professor of Electrical Engineering, USC
- Chin-Hsiung Loh, Professor of Civil Engineering, Director of National Center for Research on Earthquake Engineering, Taiwan
- Hung-Chi Chung, Research Associate, UCI
- Hung Seok Park, Visiting Research Scholar, UCI
- Jin Hak Yi, Visiting Research Associate, UCI
Possible Direction of Work in Subsequent Years:

Building on the research carried out in Y6, we will study in more detail the performance of combined water and power systems in organizational and social dimensions in Y7 and beyond. Also, the integration of other systems such as systems of lifelines (water, power and gas), emergency response organizations, and medical care systems (a regionally designated network of acute care hospitals) will be carried out to evaluate the community resilience.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>041002</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Title:</th>
<th>Electric Power Systems Network Modeling</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Investigator/</th>
<th>Tsen-Chung Cheng*, Xianhe Jin</th>
</tr>
</thead>
</table>

* indicates task leader

<table>
<thead>
<tr>
<th>Institution:</th>
<th>University of Southern California</th>
</tr>
</thead>
</table>

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This project focuses on electric power network analysis for WECC (Western Electricity Coordinating Council) electric power systems under emergency scenarios, including earthquake strikes and terrorist attacks; internal insulation degradation and electromechanical effects of a high voltage power transformer during and after an earthquake; correlation analysis between water and power systems under ground motions; power system recovery modeling and power system retrofit strategies for hospital life line systems.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

To address the research objectives, we will concentrate on the WECC electric power system analysis under various scenarios, the internal insulation degradation and electromechanical behaviors of a high voltage power transformer, correlation investigation between water and power systems, power system recovery modeling and emergency response of a power supply system in a hospital. For the WECC electric power system analysis, we will explore the impacts from disabled 500kV AC transmission lines, disabled 500kV DC lines, and some 230kV lines disabled based on importance from network perspective. We will also focus on the impacts on the WECC service areas from disabling critical power equipment, such as power transformers, circuit breakers, disconnect switches, and capacitor-banks etc. Internal insulation degradation and electromechanical behaviors of a high voltage power transformer and internal partial discharge patterns will be investigated in detail using different neural network paradigms and algorithms. Exploration of detecting sensors and monitoring system for potential failures of a high voltage power transformer will be conducted. In addition to the power system analysis to the WECC power networks, we will be investigating the correlation between water and power systems within LADWP. Electric power is a major source to energize water treatment facilities and pumping stations. Conversely pump storage reservoir, acting as electric energy storage, will influence a power system’s stability and reliability. To reach our research objectives, the impact on water systems will be evaluated with electric power outages in various supply lines.

Preliminary research on power emergency supply system in a hospital will start in year 7. It is well known that an electric power emergency supply will play a critical role in a hospital retrofit system. We will examine existing power systems in a hospital and study the state-of-the-art electric power emergency response system for hospitals. This research task is in support of Dr. G. Lee’s research group. We will also assist Dr. Rachel Davidson in her efforts to model the recovery of a power system after an earthquake, using the experiences of LADWP as a start point.
Assessment of State-of-the-Art:  (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The Seismic Retrofit of Lifeline Systems, Trust Area I in MCEER, is a unique research area. Our project under Trust Area I, Electric Power Systems Network Modeling, is one research project within MCEER. Electric power system is one of the critical lifeline systems and obviously vital to a society’s continued well-being and survival.

Progress to date:  (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

We have evaluated seismic behaviors for LADWP’s power system under 47 earthquake scenarios with various assumed magnitudes of earthquakes. The condition, under which LADWP’s power system may experience voltage drop or rise under an earthquake strike, has been categorized. The fragility curve of high voltage power transformers has been developed based on the seismic data in the 1994 Northridge Earthquake. Preliminary research of lifetime reduction of a power transformer due to an earthquake has been investigated. The major mechanisms for this reduction have been identified, which are partial discharges in the insulation system of a high voltage power transformer.

In the past year, we expanded our experience and methodologies accumulated during the past five years research to the WECC power system, which is much larger and much more complicated than LADWP’s power system. The major focus of this study is that if any major 500kV transmission line were disabled for whatever reason (an earthquake strike or terrorist attack) in the WECC grid ever far away the Los Angeles area, what would be the impact to the service areas of the Los Angeles Department Water and Power (LADWP) from a power supply standpoint. Conversely what would be the impact on the rest of WECC if Los Angeles were struck? We employed four scenarios, involving four 500kV transmission lines being disabled between Washington and Idaho, between Washington and Oregon, between Oregon and California as presented in the MCEER 2003 Annual Meeting in Florida. The impact to the Los Angeles service areas has been evaluated using the IPFLOW (professional version), which is a power flow calculation software developed by the Electric Power Research Institute (EPRI). Based on the above four scenarios, the 500kV transmission line’s blackout between Washington and Oregon deliver the most severe impact to Los Angeles’ service areas.

The major reason initiating a high voltage power transformer failure after an earthquake is internal partial discharges occurring on pressboards or in oil, which substantially reduce the life expectancy of a power transformer. Pattern recognitions of partial discharges within a power transformer have been carried out, which are strongly correlated to the location of partial discharges, their severities, and voltage level of the power transformer. With Artificial Neural Networks (ANNs) analysis and MATLAB data preprocessing, partial discharges, a driving force behind power transformer failure, can be recognized and classified.

Role of Proposed Task in Support of Strategic Plan:  (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

Electric Power System Network Modeling is a unique research project in MCEER. The effort from this project will make tremendous contributions to the MCEER strategic plan through cooperation with other MCEER investigators, who are currently working on the water system, hospital emergency retrofit and power system recovery after an earthquake.
### Task Integration:
*(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The tasks of this project are closely coordinated with other MCEER researchers, in particular with Dr. Shinozuka (electric power system modeling and analysis), Dr. O’Rourke (correlation analysis between water system and power system), Dr. Feng and Dr. Saadeghvaziri (internal electromagnetic and electromechanical effects of a high voltage power transformer) and Dr. G. Lee (electric power system in hospital) Dr. R. Davidson (power system recovery) and other MCEER investigators. The outcomes from this project will substantially contribute to the project goals of the investigators mentioned above.

### Possible Technical Challenges:

Fully understanding seismic behaviors of WECC power systems during an earthquake or terrorist attack, internal insulation degradation and electromechanical behavior of a high voltage power transformer induced from ground motion, correlation between water and power systems, power system recovery, emergency response of a power system in hospitals, are all considered as major technical challenges.

### Anticipated Outcomes and deliverables:
*(Also indicate those of particular benefit to IAB members and other end users.)*

<table>
<thead>
<tr>
<th>Potential end-users beyond academic community: <em>(IAB members and others.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct end users for an optimal rehabilitation strategy for power systems are utilities in California and other quake prone states. In particular, LADWP, SCE, SDG&amp;E, and their customers will benefit. Other major users such as hospital, telecommunication concerns, internet, financial, manufacturing industries, etc. and national security agencies will also benefit.</td>
</tr>
</tbody>
</table>

| System behaviors of WECC power systems during an earthquake and a terrorist attack will be evaluated. Connections between water and power systems will be investigated. The internal insulation degradation of a high voltage power transformer will be delineated. And a power system in hospitals used for emergency response will be studied. |

### Educational outcomes and deliverables, and intended audience:

The electrical blackout study within WECC power systems during an earthquake is one of the most interesting topics for both undergraduate and graduate students. Power system modeling and retrofit in hospital is a new topic to power students. Technical challenges may simulate students to get involved in different aspects. Introducing state-of-the-art technology to students will enhance their prospective academic and professional careers.

### Project Schedule and Expected Milestones for the Project:
*(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

To reach our research goals, the estimated milestones of our research project are as follows. Power flow computations in the WECC power systems with proposed various scenarios would be undertaken and scheduled in Fall, 2003 through Spring, 2004. Internal insulation degradation and electromechanical behaviors of a high voltage power transformer will be explored with the help of Dr. Feng and Dr. Saadeghvaziri. The scheduled time duration for this task is Fall, 2003 and Spring, 2004. The correlation study between a water system and a power system will be conducted in Fall, 2003. The power emergency supply system in a hospital will be investigated in the Fall, 2003 and Spring, 2004. The power recovery modeling will be conducted in Fall, 2003 and Spring, 2004.
**Team Members:**  *If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.*

Dr. Ten-Chung Cheng, Dr. Xianhe Jin, Prof. Changchang Wang. Possibly undergraduate students and graduate students. We will consult with engineers from the Los Angeles Department Water and Power (LADWP) and Southern California Edison (SCE), such as Mr. Gerald Paiva (SCE) for a power transformer failure analysis, Mr. Don Penn (SCE) for emergency response, and Mr. John Mochizuki (LADWP) for earthquake-related engineering.

**Possible Direction of Work in Subsequent Years:**

After year 7 of MCEER project, we will still focus on electric power network analysis for the WECC power systems and emphasis on systems rehabilitations from a network and systems perspective. The further impacts including social and economic aspects on the WECC service area will be delineated. This is extremely important to national economy and homeland security. Internal insulation degradation and electromechanical behaviors of a high voltage power transformer will be emphasized on partial discharges detecting sensors and monitoring systems to detect and prevent high voltage power transformer failure. Possible correlation study between a satellite image system and SCADA control system for monitoring high voltage substations within the SCE power system for emergency preparedness will be initiated.
### MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Project Number: | 041003 |

<table>
<thead>
<tr>
<th>Task Title:</th>
<th>Rehabilitation Strategies for LADWP’s Power System</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Investigator/</th>
<th>Maria Q. Feng</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Institution:</th>
<th>University of California, Irvine</th>
</tr>
</thead>
</table>

* indicates task leader

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

To experimentally and analytically investigate the applicability of base isolation and energy dissipation technologies for seismic protection of electrical power transformers and other facilities in power networks, and to further develop these technologies and associated design guideline for practical use.

**Problem Description and Research Approach of Proposed Work for Year 7:** *(Detailed description of research to be conducted and methodology to be used.)*

Damage and failure of electric power substations in recent destructive earthquakes highlighted the urgent needs for seismic upgrade and retrofit of electric transformers and other equipment. Electrical power transformer is one the most critical equipment in the power delivery network. Due to its complexity, it may take years to repair a transformer damaged by an earthquake. Post 1994 Northridge earthquake data show that earthquake shaking can significantly reduce the longevity of a transformer. Therefore, base isolation of the entire transformer/bushing system appears to be an effective measure to protect the transformer/bushing system. However, the application of the base isolation technology has not been thoroughly studied.

The primary objectives of this study are to experimentally and analytically investigate the applicability of base isolation and energy dissipation technologies for seismic protection of electrical power transformers and other equipment and facilities, and to further develop these technologies and design guidelines for their applications in facilities of electrical power networks.

In previous years, different types of base isolation systems have been analytically, numerically, and experimentally investigated to assess their applicability to electrical power facilities, and a simplified design procedure based on seismic design spectra is being developed. In Year 7 and beyond, focus will be placed on field implementation of the base isolation technology for seismic retrofit of electric power facilities. In Year 7, this PI will work closely with LADWP to select a typical seismically vulnerable electrical power facility, either a power transformer or a switch. Then important issues related to implementation of the base isolation technology will be studied. For example, will the connecting pipes and wires be able to accommodate the...
seismically induced base displacement of the base-isolated facility? If not, what measures must be undertaken to solve this problem? Will adding more damping to the base isolation system or making the connections and wires flexible help? Will the base of the power facility need to be further stiffened in order to place the facility on the base isolator? Cost-effectiveness will be analyzed to make decisions. Finally, a base isolation system will be designed using the simplified approach developed in this project, and seismic time history analysis will be performed to verify the design.

### Assessment of State-of-the-Art:  
(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Electrical power transformer is one the most critical equipment in a power delivery network. Due to its complexity, it may take years to repair a transformer damaged by an earthquake. Post 1994 Northridge earthquake data show that earthquake shaking can significantly reduce the longevity of a transformer. Therefore, base isolation of the entire transformer/bushing system appears to be an effective measure to protect the transformer/bushing system. Although the base isolation technology has been extensively studied for the applications in buildings and bridges, their applications to the electrical power transformers and other substation facilities have not been thoroughly studied. Dynamic characteristics of a transformer/bushing system are quite different from a building or a bridge, such as the light-weight nature.

Replacement of bushings with fiber reinforced polymer composite materials is being studied outside of MCEER. However, seismic protection of the transformer itself is not being addressed.

Therefore, this project will make a unique contribution toward the implementation of the base isolation technology for seismic protection of transformers (including bushings), and other seismically vulnerable electrical power facilities.

### Progress to date:  
(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

In Year 3, a base isolation system for electric transformers was designed and 3-D shaking table testing was performed at NCREE, Taiwan, using a large-scale transformer model equipped with a bushing. The base isolation system consists of sliding bearing to support the transformer and rubber bearings to provide restoring forces. The results verified the effectiveness of the base isolation system in reducing seismic response of the transformer and its bushing. However, some of the results indicated that effectiveness could be significantly influenced by the dynamic characteristics of the mounted bushing under 3-D ground motion.

In Year 4, the problem associated with the isolation system under 3-D ground shaking was investigated through simulation analysis. It was found that the change of the friction forces in the sliding bearing due to the vertical ground motion excited the vibration mode of the bushing, causing excessive response of the bushing. Based on this analysis, the design of the base isolation system was improved by replacing the sliding bearing layers with high-damping rubber
bearings.

In Year 5, a prototype base-isolation system was fabricated based on the improved design using high-damping rubber bearings. The challenge in design is to achieve a long isolation period without buckling of the bearing, due to the light-weight nature of a transformer/bushing system. A multi-level structure of the bearings was designed to meet this challenge. Then, 3-D shaking table tests were performed using the same shaking table and transformer/bushing models in NCREE, Taiwan. A variety of ground motions including an artificial ground motion generated based on the IEEE design spectrum were used in the shaking table tests, in order to investigate the seismic performance of the base-isolated transformer/bushing system under ground motions with different frequency contents and intensities. As designed, the base isolation performance under 3-D shaking was dramatically improved.

In Year 6, the focus was placed on development of a simplified design procedure based on seismic design spectra for practitioners to design seismic protective systems for electrical power facilities. To be more specific, the data collected in the shaking table tests in Year 5 were first analyzed. An analytical model for the base-isolated transformer/bushing system was then developed and calibrated by the shaking table test data. Based on this analytical model, a simplified model for the design purposes will be derived. In addition, shaking table tests were performed to demonstrate the effectiveness of damping placed at the bushing/transformer joint on reducing the bushing response.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This task plays an important role in improving seismic performance of transformers and other substation facilities in LADWP’s electrical power network. LADWP’s electrical power network is one of the testbeds of MCEER’s demonstration projects. This task uniquely contributes to the enhancement of the seismic resilience of the electrical power network, and ultimately the resilience of the community.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This PI is focusing on the development and implementation of rehabilitation technologies (including base isolation and energy dissipation) suitable for seismic protection of electric power transformers. The results of this study will be used to assess seismic fragility of the electric power system with and without the seismic rehabilitation measures. Comparison of the cost-effectiveness of this with Saadeghvaziri’s PFS will be examined.

**Possible Technical Challenges:**
Base isolation of a substation facility, such as a transformer or a switch, presents a unique technical challenge, due to the fact that the mass of the system is much lighter compared to a building, making it difficult to elongate the isolation period without buckling the bearings. For successfully field implementation, additional technical difficulties associated with the excessive base displacement and the requirement for base rigidity must be overcome.
## Anticipated Outcomes and deliverables:
(Also indicate those of particular benefit to IAB members and other end users.)

- Design of a base isolation system for a selected substation facility for field implementation
- MCEER technical report
- Journal and conference papers

## Potential end-users beyond academic community: (IAB members and others.)
- Utility industry
- Transformer manufacturers
- Base isolator manufacturers

## Educational outcomes and deliverables, and intended audience:

Currently, a Ph.D. student and a few undergraduate students and MS students are working on the project. Two MS thesis have been produced under the support of this project. A Ph.D. dissertation will be completed in the end of this project. The results of this research has been incorporated into a graduate course on “Seismic Resistant Design of Structures” which this PI is teaching.

## Project Schedule and Expected Milestones for the Project:
(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)

<table>
<thead>
<tr>
<th>Milestone Description</th>
<th>Estimated Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection of a typical substation power facility</td>
<td>May 31, 2003</td>
</tr>
<tr>
<td>Study of issues related to field implementation</td>
<td>October 31, 2003</td>
</tr>
<tr>
<td>Design of a base isolation system</td>
<td>December 31, 2003</td>
</tr>
<tr>
<td>MCEER technical report</td>
<td>December 31, 2003</td>
</tr>
<tr>
<td>Simulation analysis of the base-isolated power facility</td>
<td>March 31, 2004</td>
</tr>
<tr>
<td>Cost-effective analysis</td>
<td>Summer, 2004</td>
</tr>
</tbody>
</table>

## Team Members:
(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- Nobuo Murota, PhD Student
- Yasser Salem, PhD student
- John Sun, Undergraduate student

## Possible Direction of Work in Subsequent Years:
Installation of the base isolation system designed in Year 7 to the selected LADWP substation power facility.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 041004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Analytical Study on Rehabilitation of Critical Electric Power System Components</td>
<td></td>
</tr>
<tr>
<td>Investigator/ Institution:</td>
<td>M. Ala Saadeghvaziri, New Jersey Institute of Technology</td>
<td></td>
</tr>
</tbody>
</table>

* indicates task leader

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

Substations, key components of electric power systems, are susceptible to significant damage under seismic events. Rehabilitation of existing substations using advanced technologies and proper design of new systems will reduce the likelihood of failure and/or will enhance the probability of post-earthquake system functionality in a timely manner. Furthermore, it will ensure long-term reliability and longevity of critical equipment, which is essential in light of ever increasing dependence of modern societies on electrical power. Under this task a system approach is employed in order to evaluate the interaction among transformers, bushings and interconnecting electrical equipment. Results will contribute to the larger tasks within Program 1 that develop fragility curves. Furthermore, efforts are being made to implement the research results and findings through collaboration with LADWP.

**Problem Description and Research Approach of Proposed Work for Year 7:** *(Detailed description of research to be conducted and methodology to be used.)*

Substations sustained significant damage and failure during past earthquakes. Substation equipment are designed and qualified for a specified level of base excitation. If the design level is exceeded or if their interaction aggravates the seismic response, as in the case of recent strong earthquakes in California and abroad, damage of the equipment is almost certain. This would result in direct and indirect loss and significantly impact the regional economy. Raising the design level is not practical, neither technologically nor economically. Furthermore, we do not understand the complicated interaction among various electrical components during the dynamic response of the entire system to an event. Therefore, raising the design level by itself might not remedy the situation even if it was feasible to do so. Thus, research is needed to (1) identify critical components in the power system, (2) develop the tools and a framework to evaluate and assess seismic performance of various components as well as their interaction in light of the system response (3) develop advanced but practical and cost-effective strategies for rehabilitation of the most critical elements, (4) design and implement practical strategies on a pilot scale, (5) monitor the performance of rehabilitated system, and (6) disseminate successful results for wider applications including improvements and expansion to IEEE 693-1997.

In light of the above objectives, this research have included both analytical and experimental studies on critical substation components to better understand their dynamic characteristics and to evaluate their seismic response in order to develop effective rehabilitation strategies. Accomplishments are listed under “Progress to date” section. For year 7 the following objectives will be pursued:

1. Complete and submit a report on effect of base-isolation of primary systems on the response of secondary systems with emphasis on its implications for response of transformer-supported
2. Investigate and address possibility of uplift in base-isolated transformers.
3. Quantify/identify, to the extend possible, the effect of earthquakes on electro-magnetic performance of transformers and their longevity.
4. Continue work on cost benefit analysis, integration and dissemination of results, and possibility of manufacturing new flange design.

During year 5/6 a nonlinear finite element for friction pendulum system (FPS) was developed and implemented into ADINA. Parametric study is ongoing. These results will be finalized and submitted in the form of a complete report. In addition to its immediate application to rehab of transformers, these results will be of great importance in application of base-isolation technology to buildings and bridges. Furthermore, uplift could be an issue in a base-isolated transformer if a limited number of bearings are used. Using the FPS element, this factor will be investigated using spatial FE models. Recent improvements made to FPS bearing by the manufacturer to prevent uplift will be evaluated and its impact on system response will be assessed. An important objective of year 7 is to identify the effect of seismic forces on stability of internal components such as core and coil. Stability of winds is critical to proper distribution of electro-magnetic (short-circuit) forces. Similarly, effect of seismic forces on the design of anchorage between the core-coil assembly and the tank floor, if any, will be assessed. A challenge to successful achievement of this objective is collecting accurate data on internal packaging. Finally, work on several other issues related to implementation will be continued. To facilitate achievements of some of these objectives, it is planned to involve technical staff of Bonneville Power Administration (BPA) during the next phase of this task.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Experimental investigation conducted at PEER on electrical equipment relates to this task. However, they differ in that PEER has conducted experimental tests of individual bushings while here a system approach is used and it includes both analytical and experimental studies. 3-D finite element results indicate that interaction between the transformer and the bushing is important to accurately assess the seismic response of the system. PEER results also support this finding and have always pointed to the need for analytical work of the type conducted under this study. There has not been any work on effects of earthquake on packaging and internal components of transformers. Furthermore, the system approach used under this task considers the interaction among transformer-bushing and interconnecting equipment as well as problems/issues related to seismic design of anchorage and foundation. The research team has initiated, and will continue, efforts to develop inter-center exchange of research results with PEER and to integrate results by both centers (e.g., see last item under Progress to Date).

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.) Note: * symbol for the bullet indicates past year progress

- Substation transformers (and bushings) have been identified as the most critical component in a complex power system.
- 3-D finite element analyses of three (small/medium/large) actual transformers have been completed. It has been determined that flexibility of the transformer body has a significant effect on the bushing response and its frequency content. Translational modes of the transformers have the highest effect on the response of the bushing. Hence, seismic design and rehab procedures must recognize this important effect.
- A nonlinear element for FPS bearing formulated and implemented into ADINA.
* Effect of normal force variations and vertical acceleration on total response of base-isolated primary system and secondary system are investigated and continues.
* Site visit to Southern Edison Company conducted to collect data on internal packaging of transformers. Literature search also conducted.
* Limited cost analysis performed that indicate competitiveness of base-isolation on even initial cost basis. Should be expanded to validate. However, it is challenging to gather accurate construction costs information.
* Parametric study on transformer-bushing interaction with interconnecting equipment using simplified model is completed.
* To apply knowledge created to other systems a summary proposal was submitted to AT&T Research Lab entitled: Enhancing Resiliency of Telecommunication Network (Jan. 2003).
  - It is recommended that current qualification procedures (IEEE 693-1997) be modified to reflect the transformer-bushing interaction. For example, bushings tests should be performed on a semi-rigid stand with a frequency equal to that of the translational mode of the transformer.
  - A simplified model has been developed to study transformer-bushing interaction with interconnecting electrical equipment and to address the issue of large displacement associated with the use of base-isolation. The model will be used to determine slack design and to investigate effect of modification to bushing flange design on system response.
  - Fixed-based transformers require large amount of anchorage capacity to transfer the inertia forces to the foundation. It is usually difficult or impractical to provide strong and stiff anchorage system. The need for mobility for maintenance purposes further compounds development of an optimal anchorage design. Furthermore, the level of inertia forces point to high vulnerability of current foundation designs, especially footing foundation. This is consistent with observations made during past earthquakes including those made in Sylmar Converter Station during the events of 1971 and 1994.
  - Base isolation has been identified as the most practical and effective technology for rehabilitation of transformers. In addition to alleviating problems associated with bushing response and foundation design, base-isolation will also reduce the possibility of damage to internal elements (such as core and coil). Thus, enhancing post-earthquake reliability and longevity of the system too.
  - Large displacements associated with the use of base-isolation require special consideration, which could probably be accommodated through proper design of the conductor cables.
  - Friction pendulum System (FPS) was targeted for detailed study.
  - Building upon research and practical experience gained over the past decade or so, an extensive analytical study on response of FPS bearings using SDOF models were performed. Among parameters considered are ground motion characteristics, peak ground acceleration, bi-directional motions, effect of vertical motion, and bearing radius. Results were evaluated in light of level of inertia reduction and the maximum displacement. FPS bearings are very effective for isolating transformers. They can provide as much as 60% inertia reduction compared to input PGA, and significantly more compared to fixed base situation.
  - Preliminary design charts for FPS have been developed and appropriate response combination rule(s), for design purposes, have been identified.
  - Close to 100 tests were conducted at NCEER in Taiwan on a transformer model supporting a bushing. Results have been processed and are in agreement with analytical results. However, they suggest the need for more detailed evaluation of the effect of vertical ground acceleration, probably due to its effect on normal force variations, which in turn affects frictional force.
  - Several substations, including the Sylmar HVDC Converter Station, have been visited. Various meetings with possible end-users and industry representatives have been held and will continue.
- A Ph.D. thesis entitled “Seismic Response of Transformer Bushing Systems and Their Rehabilitation Using Friction Pendulum System,” is completed. Six journal and conference papers have been published or are in press. An undergraduate student was also involved with the project for one semester (S00). Currently, an M.S. student is supported.
- A session entitled “Seismic Design and Rehabilitation Strategies for Power Systems,” was organized and chaired by the PI during the 2001 Structures Congress, ASCE, Washington, DC, May 21-23, 2001. (Participants: MCEER, PEER, Bonneville Power Administration)

### Role of Proposed Task in Support of Strategic Plan:
(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

This task will contribute to MCEER overall goal of enhancing the seismic resiliency of communities by increasing seismic resiliency of substations within electric power system. This objective is achieved through application of enabling technologies to improve seismic performance of substation equipment and by performing fundamental research. The former activity builds upon vast research results available on buildings and bridges and the latter activity addresses structural and functional problems unique to a substation facility.

### Task Integration:
(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The work conducted will be integrated into the overall loss estimation model for an entire power system under Program 1. It contributes to development and accuracy of such model by providing the knowledge base and the analytical tool for time history analysis of substations under various earthquake scenarios in order to develop fragility curves for substations (Shinozuka/Saadeghvaziri).

The work is also integrated with research conducted by Prof. Feng (working with Bridgestone) by making a recommendation on the most suitable base-isolation technique (device) for transformers considering transformer seismic response and the response of the supported bushings and interconnecting elements, as well as level of forces that need to be resisted by the foundation (Feng/Bridgestone/EPS/Saadeghvaziri).

Results will also be integrated with the work of other MCEER researchers in light of electrical design considerations to improve the reliability and longevity of transformers (Cheng/Saadeghvaziri).

Furthermore, efforts are being made to implement the research results and findings in the rebuilding of Sylmar Converter Station by LADWP (Shinozuka/Cheng/Penn/Saadeghvaziri).

### Possible Technical Challenges:

This study will attempt to evaluate the effect of seismic forces on the electro-magnetic performance of transformers. This is the first of such study and important to development of suitable rehabilitation strategies. A challenge in achieving this objective is access to design of transformers, which is proprietary. Another challenge is cost-benefit analysis on the use of advance technologies, especially in quantifying their life-cycle benefit as they enhance long-term reliability and longevity of transformers by minimizing or even eliminating damage to internal components during an event.
**Anticipated Outcomes and deliverables:**  
(Also indicate those of particular benefit to IAB members and other end users.)

- Seismic evaluation of, and rehabilitation strategies for critical substation equipment such as bushings and transformers.
- Quantify the effect of transformer-bushing interaction with interconnecting equipment such as disconnect switches, circuit breakers, etc. on their seismic response for both fixed and base-isolated transformers.
- Cost-benefit analysis on the use of advanced technologies in light of initial cost as well as reduced probability of failure and longevity (life-cycle basis).
- Develop resources and design guidelines for application of base-isolation to transformers.
- Modify current structural design of electrical equipment, internal packaging, and connections to increase robustness, resiliency, and redundancy.
- Collaborate with utility companies and manufacturers to better interpret and implement IEEE 693-1997, and to develop the knowledge base to improve and expand IEEE 693-1997 and other relevant codes.

**Potential end-users beyond academic community:**  
(IAB members and others.)

- LADWP & other utility companies,
- Manufacturers of substation transformers and equipment,
- Manufacturers of base-isolation systems,
- Structural and Electrical engineers.

---

**Educational outcomes and deliverables, and intended audience:**

- Availability of resources, methodologies, and tools for seismic analysis of substations and application of advanced technologies for their rehabilitation.
- Presentation of results and teaching of knowledge created within the context of: i) a new graduate course at NJIT (Topics in Structural Engineering) targeted towards practitioners, and ii) existing courses (such as Earthquake Engineering).
- Undergraduate students may also benefit from the research by directly participating in its execution or by learning about the problem and solution within the independent study course.

**Project Schedule and Expected Milestones for the Project:**  
(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)

- Complete work on effect of base-isolation on secondary systems with emphasis on transformer-supported bushings (Fall).
- Investigate possibility of uplift and provide remedy if important (Fall/Spring).
- Effect of seismic forces on the internal design of transformers – core and coil stability, anchorage of core/coil assembly to tank floor, etc. (Spring).
- Cost benefit analysis, implementation/dissemination, and new bushing flange (Fall/Spring).
**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

M. Ala Saadeghvaziri, Professor, Dept. of Civil and Environ. Engrg., NJIT, PI.

Seyed Ali H N Ashrafi, Graduate Student, Dept. of Civil and Environ. Engrg., NJIT, RA.

Leon Kempner Jr., Bonneville Power Administration as consultant.

**Possible Direction of Work in Subsequent Years:**

- Complete work on internal components and packaging of transformers.
- Design example(s) on application of base-isolation and comparison to current options for both rehabilitation and new transformers.
- Integrate with results of research conducted at PEER and develop design recommendations for possible adoption by relevant codes.
- Identify industry partners to manufacture and test bushings with modified flange.
- Identify testbed project(s) (assessment, rehab using two alternatives, new design, and integration with other tasks – hazard, site effects, system response, etc.).
MCEER RESEARCH TASK STATEMENT

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The project goals are to 1) develop a hydraulic network model for the Los Angeles water distribution system that allows for a comprehensive evaluation of its earthquake performance, 2) develop an integrated systems reliability model for the LADWP water and electric power networks that is approved and supported by LADWP management, and 3) use the results of 1) and 2) to create a decision support platform for critical lifelines that addresses seismic resilience in its technical, organizational, societal, and economic dimensions. The third project goal involves integrating research performed by MCEER social science and engineering researchers in the evaluation of earthquake damage effects on the regional economy and the ability of communities to perform emergency services and undertake restoration activities. Specifically, the project will use a state-of-the-art hydraulic network model of the LADWP water distribution network for earthquake reliability analysis and as a test bed for defining and evaluating community resilience, predicting regional economic impact, and developing restoration models to optimize emergency operations and system recovery.

Problem Description and Research Approach of Proposed Work for Year 7: (Detailed description of research to be conducted and methodology to be used.)

The overall goals of MCEER research in lifelines is to improve the seismic resilience of communities through substantial improvements in the earthquake reliability of critical lifeline systems. The goal includes the development and demonstration of the next generation of lifelines that benefits from advanced geospatial analyses; high performance materials and manufacturing; improved loss estimation; intelligent monitoring; and advanced systems and socioeconomic modeling to assess the regional impact of lifeline operations.

The Los Angeles water and electric power distribution networks are the test beds within which advanced technologies and systems modeling are applied. Los Angeles is sufficiently complex that the products and procedures developed and proven for this community will have relevance and applicability throughout the U.S.

The approach taken for the proposed Year 7 work is a direct extension of Year 6 work and is derived from the project goals, as follows:
1. Hydraulic Network Model

Year 7 research will build on accomplishments in Year 6. In Year 6, a comprehensive hydraulic network model for the LADWP water distribution network will be developed. Cornell researchers will adapt the hydraulic network model for earthquake simulation and performance under various damage states. An important part of this process will be to link the network analysis with special algorithms developed originally at Cornell that account accurately for water flow and pressure conditions in heavily damaged pipeline networks. The algorithms for the hydraulic network analysis of heavily damaged systems were embodied in the code GISALLE, written originally for the San Francisco water supply. The hydraulic network model will be validated and calibrated with respect to the observed systems performance during the 1994 Northridge earthquake. Where appropriate, the hydraulic network analysis will be calibrated with respect to special flow tests performed by LADWP.

In Year 7, the hydraulic network model developed in Year 6 will be calibrated with special fire flow tests and operational data available from LADWP. Validation of the hydraulic network model will be important to ensure that the model is robust and is able to represent conditions of high demand typical of emergency operations.

2. System Reliability Model

A system-wide reliability model will be created in Year 7 with strong motion input representative of the regional seismic sources that can affect Los Angeles and incorporating fragility characterization of system components and soil-structure interaction models to account for both the transient and permanent ground deformation effects of earthquakes.

The system reliability model that will incorporate fragility curves and characterizations performed in collaboration with M. Grigoriu under the MCEER program, entitled System Risk and Reliability for Water Supply. Experimental work and laboratory testing results obtained at Cornell and the University of Nevada at Reno will be used in the fragility characterization. The results of large-scale experiments performed by MCEER during Years 3 – 6 on the response of welded slip joints and the effects of seismic strengthening with fiber-reinforced polymers (FRPs) will be integrated into the fragility characterization.

Hydraulic network analyses will be performed for various earthquake scenarios determined in cooperation with A. Papageorgiou, who is working on seismic hazards characterization for MCEER. In Year 6, Papageorgiou will provide strong motion records for various causative faults at various locations within the area of the water and electric power distribution systems.

3. Decision Support Platform

As stated previously, the hydraulic network model and reliability analyses will be a test bed for defining and evaluating community resilience, predicting regional economic impact, and developing restoration models to optimize emergency operations and system recovery.

II.A-1.61
Loss models developed for Memphis lifelines will be transferred in Year 7 by S. Chang to the LADWP water supply. Chang will work with Cornell researchers and LADWP to establish the appropriate performance objectives so that earthquake resiliency of the water distribution system can be quantified and the process of defining resiliency measures documented for use in other systems.

Regional economic models will be developed by A. Rose and applied through the water system hydraulic network model and reliability analyses to evaluate the impact of earthquake losses on local businesses and local economic stability. Rose will work with Cornell researchers and LADWP to upgrade and apply economic modeling that is calibrated through questionnaires and social science investigations performed by MCEER researchers after the Northridge earthquake.

An improved model for post-earthquake restoration will be developed by R. Davidson and implemented for the LADWP water supply. Davidson will work with the PI and LADWP to model repair and recovery operations, quantify the uncertainty associated with these activities, and estimate the expected restoration time for the system under various earthquake scenarios.

The PI and graduate students working on this project will help coordinate the multidisciplinary research. They will work with LADWP managers and engineers to develop a decision support system. It is anticipated that the decision support system will be exercised on a preliminary basis in Year 7 and that the feedback gained from this activity will serve as the basis for expanded applications and community involvements in Year 8.

Work on the water supply will proceed in collaboration with similar work on the electric power system that is supervised by M. Shinozuka. The work will demonstrate that the combined systems can be evaluated within a framework of common seismic hazards and spatial variations of strong motion. Definitions of and procedures for evaluating systems risk and reliability will be developed that are consistent for both the water and electric power networks.

The overarching goal of MCEER is to create earthquake resilient communities, and one of the most important programs of MCEER is focused on defining and quantifying this resilience. The research will support MCEER efforts to define and develop performance measures for resilience. The systems model for combined water and electric power will be used to explore and quantify the technical measures of resilience. Moreover, LADWP engineers and managers will be engaged to help define the organizational issues that affect their operations and influence their planning and allocation of resources for earthquake hazards.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Network modeling and reliability assessments for water supply and electric power systems have been subjects of research and development primarily in the U.S. and Japan. Research developments in lifeline systems performance and modeling have been summarized in two recent state-of-the-art reviews (O’Rourke, 1996; O’Rourke and Jeon, 2000). The principal investigator has been in communication with leading researchers in Japan and the U.S., including researchers at PEER and MAE.
The proposed research differs from work currently being performed with respect to the comprehensive nature of the component and geotechnical modeling that will be performed, advanced loss estimation that will be incorporated, and socioeconomic modeling that will become an integral part of the product package. Specifically, the systems modeling and reliability assessments will build on the state-of-the-art MCEER accomplishments that have used Input / Output and Computable General Equilibrium models and analytical methods for spatially distributed systems to assess the indirect economic effects of damage caused by earthquakes (Chang et al., 2000a; Chang et al., 200b; and Shinozuka, et al., 1998).

References


Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

Research accomplishments during the past year include the successful execution of full-scale tests on water trunk lines fabricated by LADWP. The tests have conclusively demonstrated that the application of FRP wrap can increase the compressive capacity of welded slip joints by as much as 80 to 100%. The research has also resulted in advanced analytical models that are able to simulate the buckling and wrinkling behavior of straight pipelines and pipelines with welded slip joints in both their as-built and FRP-reinforced conditions. Research results provide guidance not only for FRP products, but for fabrication of the joints, alternate reinforcement procedures, internal vs. external welding, and the contribution of both the external and internal mortar linings of the pipelines.
An agreement was reached between MCEER researchers, represented by Cornell, and LADWP for full cooperation and joint development of a decision support system in August 2002. As part of the agreement, LADWP has provided its hydraulic system database and software to Cornell researchers. Training and preliminary modeling with the LADWP database was accomplished by December, 2002. By January, 2003 Cornell researchers created a common GIS database for both the water and electric power systems. Additional training under the direction of LADWP engineers and detailed system modeling by Cornell graduate students took place in February and March, 2003. During the same time period Cornell researchers developed a common framework for both the GIS database, compiled during previous MCEER-supported research, and the LADWP hydraulic network model.

**Role of Proposed Task in Support of Strategic Plan:** (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The proposed research will support the MCEER strategic plan by developing the next generation lifeline system, which is critical for earthquake resilient communities. Specifically, the research will develop a systems model that will promote a comprehensive assessment of earthquake risk. The model will quantify the reduction of damage, including direct and indirect losses, so that water authorities and the communities they serve will be able to make rational decisions about the allocation of resources necessary to achieve community goals in earthquake resilience.

**Task Integration:** (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The work performed interfaces directly with research performed by M. Grigoriu and R. Davidson under the tasks entitled Systems Risk and Reliability for Water Supply and Restoration Analysis for Lifelines, respectively. In addition, the task interfaces with research performed for electric power systems led by M. Shinozuka. Developing a model for the combined water and electric power systems is an integrating effort essential for evaluating the interdependencies between different lifeline systems. Moreover, the research will make direct use of models for the regional socioeconomic effects of lifeline losses that have been developed and tested by MCEER in the Memphis area. As explained under Project Description and Research Approach above, the work in this project is integrated with the research on loss models and performance objectives by S. Chang and the research on regional economic impacts by A. Rose.

**Possible Technical Challenges:**

The technical and institutional challenges include:

1. Development of a fully operational hydraulic network model that covers accurately a variety of damage states, and the validation thereof by comparison with prior earthquake performance and special flow tests.

2. Development of reliability assessments that are consistent for both water and electric power and compatible with reliability procedures and resilience definition that apply to hospitals.

II.A-1.64
3. Obtaining the appropriate security clearances and cooperation of LADWP management and engineering to ensure detailed characterization of the water supply system.

4. Obtaining the appropriate security clearances and cooperation of LADWP management and engineering to develop an accurate model for combined water and electric power.

5. Creation of systems models and decision support tools that are sufficiently transparent and accessible to communities for effective planning and engagement of support from both the public and private sectors.

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Successful demonstration of FRP strengthening of critical water trunk lines in Los Angeles and adoption of the technology in other systems, such as EBMUD.</td>
<td>- Water distribution companies, such as LADWP and EBMUD.</td>
</tr>
<tr>
<td>- Advanced analytical models for pipeline and facilities behavior under earthquake loads.</td>
<td>- Engineering design and consulting companies.</td>
</tr>
<tr>
<td>- Improved fabrication and welding procedures for slip joints and alternate reinforcement procedures.</td>
<td>- Electric power and gas distribution companies.</td>
</tr>
<tr>
<td>- Advanced hydraulic network model for LADWP.</td>
<td>- City and regional planners.</td>
</tr>
<tr>
<td>- Combined systems model for the Los Angeles water and electric power networks.</td>
<td>- Emergency response agencies.</td>
</tr>
<tr>
<td>- Decision support tools for lifeline system improvements and operations that incorporate estimates of regional socioeconomic impacts.</td>
<td></td>
</tr>
</tbody>
</table>
- Improved specifications and design procedures for water trunk lines.

- Systems model for earthquake effects on water distribution systems suitable for management decisions about operations and the implementation of advanced technologies to reduce earthquake losses.

- Use of the project to support graduate students and undergraduate research experiences.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

Fall 03: Operational hydraulic network model and system reliability assessment for the LADWP water distribution system that is tested against observed performance during and after the Northridge earthquake.

Winter 03: Calibration of hydraulic network model with LADWP operational data and special fire flow tests.

Spring 03: Incorporation of fragility curves, soil-structure interaction models, and advanced loss estimation algorithms in collaboration with M. Grigoriu.

Summer/Fall 03: Application of resiliency models, regional economic impact assessment, and lifeline restoration models by S. Chang, A. Rose, and R. Davidson, respectively.

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

T.D. O’Rourke, Principal Investigator
A. Lembo, Senior Research Associate
J. Mason, Graduate Research Assistant (GRA)
Y. Wang, GRA
P. Shi, GRA
S. Mori, Visiting Scientist

Undergraduate students will be engaged to assist with the hydraulic network modeling and analysis.

**Possible Direction of Work in Subsequent Years:**

In subsequent years, a combined water and electric power systems model will be developed that is capable of assessing both direct and indirect economic losses and of discerning the social impact of lifeline losses on the communities they serve. Decision support tools will be developed and demonstrated that will allow lifeline managers and engineers to create earthquake resilient systems consistent with community goals and resources.
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>041006</td>
</tr>
</tbody>
</table>

| Task Title: | System Risk and Reliability for Water Supply |

| Investigator/ Institution: | Mircea Grigoriu, Cornell University |

* indicates task leader

## Statement of Project Goals:
(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

It is proposed to develop (i) a methodology for fragility analysis of components of water supply systems and (ii) a computer code for generating seismic hazard scenarios for these systems. The seismic hazard scenarios will consider both the seismic waves and the permanent ground displacements. The proposed research is essential to the development of a procedure for assessing the seismic performance of water supply systems and, therefore, will contribute to the overall MCEER goal of enhancing the seismic resilience of communities.

The work at Cornell University by T.D. O’Rourke’s team and University of Nevada at Reno by E. Manos Maragakis’ team will be combined to provide a comprehensive database for fragility characterization for selected critical components of water supply systems.

## Problem Description and Research Approach of Proposed Work for Year 7:
(Detailed description of research to be conducted and methodology to be used.)

The functionality of water supply systems depends on the seismic performance of its critical components, for example, joints, pipelines, elbows, hydrants and pumping stations. A methodology will be developed for calculating the fragility surfaces for selected critical components of the water supply systems, giving the probability that these components reach a damage state if subjected to an earthquake with specified magnitude and source to site distance. The initial conditions (initial damage states) of the selected components at the time of earthquake will be accounted for in the analysis. The proposed research involves:

- Refinement of the methodology for identifying critical components of water supply systems with focus on the Los Angeles Department of Water and Power (LADWP).

- Development of a methodology for calculating fragility surfaces for selected critical components of water supply systems, such as pipelines, tanks, pump stations, and treatment plants. Donald Ballantyne from ABS Consulting and David Lee from East Bay Municipal Utility District (EBMUD) will be contacted to define the damage states needed for developing the fragility surfaces as well as fragility curves for some of the selected critical components.
- Completion of the seismic hazard scenario models for the selected critical components of water supply systems, with consideration of both the seismic waves and the permanent ground displacements.

The fragility analysis will be based on mathematical models and the extensive database generated for MCEER at Cornell University by T.D. O'Rourke's team and the University of Nevada at Reno by E. Manos Maragakis’ team. The database and fragility characterization will cover both external and internal Fiber Reinforced Composites (FRC) strengthening as well as seismically reinforced joints. The methodology will apply to virtually all types of pipelines in water supply systems, including steel, cast iron, ductile iron, and plastic.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Current computer frameworks on component seismic performance are based on simplified models for soil conditions, seismic hazard and component properties. The proposed methodology will take into account more realistic models for soil, earthquakes, and selected critical components of water supply systems to generate fragility surfaces for these components.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

- Preliminary developments on a methodology for fragility analysis of water supply systems. The analysis will consider the effect of both seismic waves and permanent ground displacements and will be applied to selected critical components.

- A methodology to generate seismic hazard scenarios associated with seismic waves is nearly completed.

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The task will contribute in an essential way to the MCEER objective of developing a quantitative measure for the seismic resilience of communities by providing a computational tool for assessing the seismic performance of water supply systems. The proposed task will deliver (i) a methodology for calculating fragility surfaces of selected critical components of water supply systems based on realistic seismic, soil, and components models, and (ii) a computer framework for generating seismic hazard scenarios with consideration of both seismic waves and permanent ground displacements.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The success of the proposed research will require extensive interaction with other MCEER researchers from various disciplines of engineering field. For example,
- The selection of the critical components of a water supply system will be based on consultations with T.D. O’Rourke and M. Shinozuka.

- The characterization of the soil conditions relevant to a water supply system will be provided by T.D. O’Rourke and other experts in geotechnical engineering.

- The components’ failure modes will be obtained from previous work by T.D. O’Rourke funded by MCEER.

- The definition of damage states for fragility surfaces analysis for the selected critical components of water supply systems will be based on extensive interaction with Donald Ballantyne from ABS Consulting and David Lee from East Bay Municipal Utility District (EBMUD).

### Possible Technical Challenges:

- Identification of critical components of water supply systems is an essential and necessary step in assessing the performance of water supply systems.

- The modeling and validation of interaction between soil and components of water supply systems needed for fragility analysis.

- Water supply systems extend over relatively large areas and their components are generally subjected to different seismic actions (axial/bending/combination of both). Therefore, it is necessary and essential to develop an accurate spatial characterization of the seismic input.

### Anticipated Outcomes and deliverables:

(Also indicate those of particular benefit to IAB members and other end users.)

- Methodology for characterizing soil conditions that are consistent with available bore hole measurements.

- Methodology for fragility analysis of selected critical components of water supplies systems based on both seismic waves and permanent ground displacements.

- Methodology for the generation of coherent seismic ground acceleration time histories at a collective of sites.

### Potential end-users beyond academic community: (IAB members and others.)

- Planning agencies that will need to do assessment on seismic performance.

- Water supplies companies and engineering designers.
**Educational outcomes and deliverables, and intended audience:**

It is anticipated that a computer algorithm for generating fragility surfaces for selected critical components of water supply systems with spatial variation of soil condition will be made available to the users network at MCEER. (Can be used in CEE 678 : Structural Dynamics and Earthquake Engineering at Cornell University)

---

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

- Fall 2003: Identification of critical components of water supply systems and selection of these components for the Los Angeles Department of Water and Power (LADWP).
- Spring 2004: Methodology for fragility analysis of selected critical components of water supply systems.
- Summer 2004: Methodology for generating seismic hazard scenarios with consideration of both the seismic waves and the permanent ground displacements.

---

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

Anita Jacobson, MSc. Student

---

**Possible Direction of Work in Subsequent Years:**

The component fragility information in this Task together with the flow analysis algorithm developed by T.D. O’Rourke in year 7 will be used to develop a methodology for evaluating the overall performance of water supply systems. These future developments will be based on the system reliability theory and will provide the framework for (1) evaluating the joint seismic performance of water, electric, and other systems and (2) developing rational strategies for enhancing the seismic resilience of communities.
THRUST AREA 2:
Seismic Retrofit of Acute Care Facilities

Thrust Area 2 research is structured such that efforts aimed at the development of seismic retrofit technologies and response modification methods provide data that can be used in integrated decision engines. Thrust Area 2 therefore addresses research needs for seismic retrofit technologies (using advanced technologies per the MCEER mandate) that can provide effective solutions for acute care facilities, and research needed to formulate the integrated decision systems that would be required to identify the most appropriate seismic actions, taking into account both engineering issues and organizational constraints (technical and organizational dimensions of resilience).

They key tasks related to the development of decision support methodologies that can integrate both the engineering and social science aspects needed to achieve quantification of resiliency will continue in Year 7, moving beyond the proof-of-concept stage to consider actual data related to the MCEER Demonstration Hospital (testbed).

A description of the integration between tasks is presented in Volume I.
### MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>042001</td>
</tr>
</tbody>
</table>

**Task Title:** Displacement-based Energy Dissipation Systems and Structural Fuses in controlling damage of non-structural systems

**Investigator:/ Institution:**
- Michel Bruneau, University at Buffalo*
- Michael Constantinou, University at Buffalo

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This task expands on previous work investigating the use of metallic displacement-based energy dissipation systems, by integrating control of the performance on non-structural systems as one main performance objective beyond the control of structural response. Work is conducted to develop the structural fuse concept, and determine what level of protection it can also provide to secondary systems in Hospitals.

The approach pursued here is to strengthen and stiffen the structural system, while enhancing its energy dissipation capability in a controlled manner that minimizes demands on the existing structural and non-structural systems.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

A first part of this task consists in the quantitative formulation of a theoretical framework for the structural fuse concept, and identification and consideration as part of that framework of the parameters that constrain the application of the structural fuse concept for metallic displacement-based energy dissipation systems. In the current context, and by analogy, a structural fuse is a structural component that absorbs the impact of a “structural overload” (i.e. an earthquake), and that can be relatively easily replaced. As such, two conditions must be met for the structural fuse concept to exist (in its purest form): (a) All structural elements, except the structural fuse, must be undamaged during an earthquake; (b) The structural fuse must be replaceable, in a way that allows the structural frame to return to its initial position (i.e. free of residual deformations) prior to re-installation of a replacement structural fuse. In a rigorous sense, this could be taken as requiring that the structural fuse be sufficiently stiff to constraint deformations of the structural frame to the elastic range. To achieve this objective, the first research task is to identify the domain of possible solutions for such a structural fuse concept, and to assess whether real-life applications can exist within that theoretical domain. A second task is to identify which types of metallic displacement-based energy dissipation systems can most effectively provide the target structural response modification, and which type are most compliant to give the designer the flexibility to achieve an actual structural control design (and under which conditions this can be achieved). Unbonded braces, shear panel systems, triangular...
added damping and stiffness (TADAS) systems, and steel plate infills will be considered as part of this investigation.

A second component of this task is to extend the above concept to address the limits and constraints that must be met to provide seismic protection of non-retrofitted secondary systems (also known as non-structural systems). As such, the floor displacement, velocity, and acceleration spectra generated for each type of metallic displacement-based energy dissipation systems will be generated, and their quantitative impact on the performance of certain types of equipment will be investigated. As this will be conducted in parallel with MCEER funded tasks that consider other structural control strategies and/or limit states for various non-structural systems, this will allow to establish a compendium of possible solutions (outlining the advantages/disadvantages of each system and its possible range of applications), that itself could be used to formulate hybrid solutions to deliver all (or most) of the performance objectives.

A third component of this task is to formulate improved types of metallic energy dissipating systems that can contribute to achieve the objectives of seismic resilience, while being more adaptable to cope with practical on-site conditions, and more compliant to meeting the practicing engineer design objectives (particularly with respect to the need to avoid unnecessary overstrength in a capacity design perspective). Detailed formulation of the best concepts will depend in large part on the outcomes of Year 6 research, but it is anticipated that plate weakening strategies that rely on regular distribution of specially designed holes will be one of the strategies considered. All solutions considered will have to be practical and cost-effective, while meeting the primary design intent.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

To the best of the investigator’s knowledge, no similar work is currently being conducted in the US. While research in Japan and Taiwan has focused on the use of many different types of displacement-based energy dissipation systems, few of these systems have found implementation in the US. However, in the last few years, unbonded brace systems and steel plate shear walls have become of much interest in the US. Coupling this interest with MCEER’s objectives of seismic resilience provides significant opportunities to achieve solutions of broad appeal that can control both the seismic performance of structural and non-structural systems. The approach followed in the proposed research also makes it possible to consider issues of minimal seismic retrofit disturbance, optimization of energy-dissipation, and quantification of performance objectives. These important issues have not received much attention to date.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

Recently published papers have described part of the results obtained to date. As part of Year 6 activities (underway), two types of steel plate shear wall systems, using light-gauge flat plate (Specimen 1) and corrugated plate (Specimen 2) have been tested. In addition, tests were completed on light gauge partition walls having X-bracing plates laterally restrained by cold-
formed standard partition studs. These specimens were designed taking in account characteristics of the MCEER Demonstration Hospital, and analytical results that suggested that relatively thin steel plates might provide an adequate seismic retrofit solution. In addition, as part of Year 6 activities, preliminary work started to formulate improved infill systems to enhance seismic performance (and allow among many thinks the use of thicker hot rolled sections), while continuing to ensure implementation of capacity design principles.

As a result of this research, a technical report was written (under review) and was submitted to the NEHRP Technical Subcommittee S6 in their development of design provisions for seismic metallic infills for possible inclusion in Chapter 8 of the 2003 NEHRP Provisions.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The project plays an important role in support of the definition of seismic resilience, particularly with regards to control of performance of secondary systems (in terms of reduction of probability of failure, consequences of failure, and time to recovery). A rigorous implementation of the structural fuse concept through displacement-based energy dissipation systems (as sacrificial elements) can provide a satisfactory solution at all three levels.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

Up to Year 6, this works was conducted in parallel with efforts on displacement-based energy dissipation systems with composites (Aref) and ECC (Billington). In Year 7, research will become more integrated with efforts to control of the seismic performance of hospitals (many researchers involved). The proposed Year 7 task is therefore designed to be compatible with the focus on performance of secondary systems described to be key by the system diagrams for Thrust Area 2. Monthly meetings (started in Year 6) of researchers working on this topic of Thrust Area 2 are planned throughout Year 7.

Year 7 work will also lead to integration into the decision support methodologies developed by by Dargush/Alesch/Petak, and Grigoriu/Winterfelt.

**Possible Technical Challenges:**

The proposed task is a challenging proposition because the concept of structural fuse, while mentioned in the past, has never truly been rigorously formulated. This research attempts to quantify the concept, and consider which types of implementations are needed to achieve the resilience objectives. Other challenges lie in the development of innovative and cost-effective structural response modification systems that can simultaneously control response of secondary systems, using metallic-based devices, something that has again never been attempted.
### Anticipated Outcomes and deliverables:
(Also indicate those of particular benefit to IAB members and other end users.)

New advanced technologies for the seismic retrofit of critical buildings (i.e. acute care facilities) having flexible frames, and that can provide a determined level of response to secondary systems.

A document outlining design concepts with worked examples (see Education outcomes below).

Both of the above outcomes are deemed to be valuable by MCEER IAB members such as OSHPD and practicing engineers involved in seismic retrofit of hospitals (such as KPFF Engineers).

### Potential end-users beyond academic community: (IAB members and others.)

Practicing engineers who will eventually design retrofit/repair systems using such strategies (many of which are MCEER IAB members).

OSHPD (MCEER IAB member) who would use these tools to assist their consultants.

Acute care facility owners who will be able to ensure the seismic survival and full operational critical facility following an earthquake.

### Educational outcomes and deliverables, and intended audience:

Knowledge generated as part of this project have been summarized in papers published in referred journals and presented at conferences (see publication list below). Documents prepared as part of this project also include codified provisions currently under consideration for implementation into the *Recommended NEHRP Seismic Provisions* published by the *Building Seismic Safety Council*, usually the first step toward implementation into the AISC Seismic Provisions, itself the reference document for seismic-resistant of steel in the US.

This information also adapted to form the basis of a lecture of the course *CIE-524 Metal Structures* taught at the University at Buffalo by this task leader. The approaches developed through this research will be included in future professional development courses on the use of energy dissipation systems for seismic retrofit, to be attended by professional engineers. They will also be included in a short document outlining the retrofit design concepts, with a complete example, that will be prepared for use by practicing engineers. The California Office of Statewide Health Planning and Development (OSHPD) has already agreed to endorse and distribute such a document when available.

The systems studied within this task also hold the promise that they could also be implemented in new constructions, thereby leveraging the technology transfer and outreach activities in a significant way.

*Refereed Journal:*


Vian, D., Bruneau, M., “Tests to Collapse of SDOF Frames Subjected to Earthquake II.A-1.76

**Other Publications:**
Berman, J., Bruneau, M., “Cyclic Testing of Special Steel Shear Walls and Modular Infill Panels”, accepted for presentation at the Fourth International Conference on Behavior of Steel Structures in Seismic Areas - STESSA 2000, Naples, Italy, June 2003.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

- Formulation of Secondary Systems Control Parameters – Focusing on control of floor displacements, velocities, and accelerations as resiliency objectives: April 1st – September 31st, 2004:
- Shake table testing is being contemplated (late Year 7 or early Year 8), but since details of specimen and purpose of test will largely depend on findings from Year 6 task, scheduling is awaiting Year 6 research findings.

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

Currently working in this project (Year 6 research), under supervision of Michel Bruneau, are:

- Ramiro Vargas (Ph.D. student), Darren Vian (Ph.D. student), and Dr. Oguz Celik (visiting professor from Technical University of Istanbul, Turkey). Vian and Vargas will work on the Year 7 task. It is hoped that an REU student could provide assistance during the summer. Addition of a third Ph.D. student is expected, depending on Year 6 findings.

**Possible Direction of Work in Subsequent Years:**

- Development of fragility information for systems retrofitted with metallic energy dissipation systems and structural fuses, both for structural and non-structural performance.
- Integration of retrofit strategy into the decision methodologies being developed by other MCEER researchers.
- Development of design document for use by practicing engineers (see educational outcomes section above).
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>042002</td>
</tr>
</tbody>
</table>

**Task Title:** Modeling visco-elastic composite panels and impact on floor velocities and accelerations

**Investigator/ Institution:**
- Amjad Aref* / University at Buffalo
- Andrei Reinhorn / University at Buffalo
- Gary Dargush / University at Buffalo

* indicates task leader

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

The objectives of this study are: (a) Implementation of constitutive relations and special finite elements in existing computational platforms to model the visco-elastic composite panels within 2-D and 3-D models. (b) Using the derived computational tools, perform structural simulations of the demonstration projects utilizing the visco-elastic composite panels to assess their impact on floor accelerations and velocities.

**Problem Description and Research Approach of Proposed Work for Year 7:** *(Detailed description of research to be conducted and methodology to be used.)*

In support of Thrust Area 2, Seismic Retrofit of Emergency Care Facilities, we have developed three visco-elastic composite panels—namely, (1) a multi-layer infill panel, (2) multi-panel infill system, and (3) a multi-box infill system. The first concept is intended for reducing the displacements, and it is capable of providing a moderate amount of damping. However, concepts (2) and (3) are intended for introducing moderate to high damping into the structure in which interface visco-elastic materials combined with polymeric honeycomb material are laid out within the panels to provide the desired damping. The conceptual designs were analyzed, and then tested in a sub-assemblage of nearly full-scale prototypes on the strong floor to verify their structural performance. Moreover, the data produced by these tests were used for devising simplified analysis and design procedures of the composite panels. However, we need to take these conceptual designs from the proof-of-concept stage into applications to a real structure (demonstration projects) by means of numerical simulations. Therefore, the approach outlined here primarily reflects the objectives of this task.

**The Research Approach:**
To successfully address the modeling issues of the visco-elastic composite panels, we need to derive and implement (1) constitutive relations and special finite elements (FE) that can be used within a 2-D and 3-D finite element model or a structural analysis program. Under the category of finite element programs, we are planning to use ABAQUS or ADINA because each of these
commercial FE software allows for user subroutines to be compiled with the computer program thereby the required computational tools (constitutive models and special elements) can be implemented. However, under the category of structural analysis programs, we identified SAP, IDARC, and DRAIN-2D as potential platforms to implement material models and new special finite elements.

(2) The implementation of computational tools will allow us to perform structural simulations of the composite panels when used for retrofitting the demonstration projects (emergency critical facilities).

There are two fundamental questions that any researcher dealing with supplementary damping technologies is trying to answer, and in our case they are: (1) what is the number and capacity of the visco-elastic composite panels? And (2) what is the optimum distribution that leads to significant reduction of floor accelerations, velocities, or other performance measures?

While the derivation and implementation of constitutive models and special finite elements are inherently basic research tasks, our primary pursuit will be to utilize the computational tools to study the impact of the developed visco-elastic composite walls on reducing the floor displacements, velocities and acceleration of the demonstration projects. Hence, the final outcome is geared toward fulfilling the MCEER’s goal of enhancing the seismic resilience of communities by improving the seismic response of emergency critical facilities.

Assessment of State-of-the-Art:  (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The structural simulations of visco-elastic composite panels within existing general-purpose finite element software is a major challenge that requires, implementation of either new elements or user defined subroutines to define the visco-elastic material properties. As part of other related research dealing with modeling composite bridges, the principal investigator has been engaged in the development of user-defined subroutines to simulate the nonlinear behavior of such structures. Thus, applicable models can be used or modified to model the visco-elastic composite panels.

Progress to date:  (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

The milestones to-date are:

- Development of visco-elastic composite panels conceptual designs
- Tailoring interface visco-elastic materials by experimental and analytical studies, and completion of the characterization of their material properties
- Completed analytical studies of composite panels within a sub-assemblage of a steel frame
- Completion of experimental verification of the composite panels
- Simplified Analysis and design Procedures

In year 6, the experimental verification of the second and third composite panel was completed. Simplified analysis and design procedures of all three concepts were also completed.
Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

This research task will support the MCEER strategic plan by developing a set of visco-elastic composite panels that will be ready for implementation in emergency critical facilities to enhance the seismic resilience. The visco-elastic composite panels devised in this task complement and play an integral part of the collective effort undertaken by Thrust Area 2 researchers who are developing other kinds of seismic retrofitting technologies. Along with the development of composite systems for enhancing the seismic response of critical facilities, we are developing computational tools that can be used by engineers to design the composite panels. Such tools include simplified analysis and design procedures (developed in year 6), and more rigorous computational tools that we are proposing to carry out in the year 7.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The integration of this task with other tasks entail the following:

1. Research in composite panels produced three distinct conceptual designs. The distribution of the various panel designs within a structure can be integrated in the evolutionary optimization framework that Dr. G. Dargush is working on whereby the optimum number and distribution of panels can be determined to produce an optimum seismic retrofitting strategy. The objective function can be tailored to produce the optimum design with respect to performance measures related to the structural system, however, upon identification of performance levels of critical non-structural components, optimum solutions can be similarly investigated.

2. The conceptual composite panels under investigation in this task can be combined with other researchers’ proposed systems to produce hybrid energy dissipation strategies. Since the ultimate goal in Thrust Area 2 is to improve the seismic resiliency of emergency critical facilities, interaction with other researchers in this area will be a positive factor to achieve the desired goal by creating a spectrum of robust hybrid retrofit strategies that can be used.

3. In the development of constitutive models and special FE elements, we will collaborate with Dr. Reinhorn to implement elements or material models in IDARC. Moreover, in our effort to implement visco-elastic constitutive models in ABAQUS or ADINA, we will also collaborate with Dr. Dargush.

Possible Technical Challenges:
The technical challenges are:

- Numerical simulations of the steel frame with visco-elastic panels that contain both the 3M visco-elastic materials and polymeric honeycomb cannot be represented by 3-D finite element models because of the lack of constitutive relations that describe the volumetric behavior of this material combination. Therefore, calibration of constitutive models will be needed to successfully implement a user-defined subroutine that describes the visco-elastic model in 3-D finite element commercial software.
• A second challenge pertains to the modeling of contact behavior of the panels with the surrounding frame. When the visco-elastic composite panel comes in contact with the surrounding frame at high lateral drift levels, the friction induced at the interface contributes to the energy dissipation. Therefore, consideration of the contact behavior in the numerical simulations is another challenge that we have to address.

• A third challenge is related to the numerical stability of the finite elements and the material models that we are planning to derive and implement in FE software, and in structural analysis programs.

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Three conceptual energy dissipating visco-elastic composite panels. 2) Simplified analysis and design procedures for the visco-elastic composite panels tailored for use by practicing engineers. 3) Constitutive relations for visco-elastic material and special elements implementation in commercial FE software through user defined subroutines. 4) Dissemination of findings in archival journals and conferences. Two refereed journal papers are currently in press and will appear in the next couple of months (See Contribution To MCEER Objectives).</td>
<td>1) Results of using high performance viso-elastic composite panels, after they have been tested in the laboratory and numerical simulations validate their effectiveness in a structural system can be used in the demonstration project. 2) The simplified analysis and design procedures are readily available for engineers. However, computational tools related to constitutive models and special finite elements will be made available to researchers and engineers upon completion. 3) The research on composite panels has been partially supported by a composite manufacturer (ANCOR Industrial Plastics, Inc.), and a supplier of visco-elastic material (Sumitomo 3M LTD., Japan).</td>
</tr>
</tbody>
</table>

**Educational outcomes and deliverables, and intended audience:**

The findings of the research dealing with analysis and design procedures have been used in a graduate course at UB (CIE528 composite structures). Integration of the findings of this research in a graduate course will facilitate and promote the use of such systems, thus accelerating the transfer of research into industrial applications.
**Project Schedule and Expected Milestones for the Project:**  
(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)

**Fall:** Derivation and implementation of constitutive models that describe the visco-elastic behavior in user defined subroutines in ABAQUS or ADINA.

**Spring:** Implementation of special elements in structural analysis programs (IDARC, DRAIN-2D, or others). Simulations of composite panels in 2-D and 3-D models of emergency critical facilities to assess the impact on various performance quantities.

**Summer:** Continuation of the 2-D and 3-D simulations, and coupling the simulations with optimization strategies developed by Dr. Dargush and his team.

**Team Members:**  
(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

Amjad Aref*, Principal Investigator, Assistant Professor, Department of Civil, Structural, and Environmental Engineering (CSEE), University at Buffalo.
Andrei Reinhorn, Professor, CSEE, University at Buffalo.
Gary Dargush, Professor, CSEE, University at Buffalo.
WooYoung Jung, Ph.D. candidate, CSEE, University at Buffalo.
Justin Jecewicz, M.S. candidate, CSEE, University at Buffalo.

**Possible Direction of Work in Subsequent Years:**

In the following years, using mature research efforts in the areas of computational tools proposed in year 7, optimal retrofitting strategies using the composite panels will be investigated. Specifically, we will address the impact of implementing composite panels retrofitting strategies on the response of non-structural components. Moreover, The implementation of visco-elastic material models and special finite elements in any computational framework will continue to be part of future research. In particular, we will continue to enhance the robustness and accuracy of the implemented computational tools.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>042003</td>
</tr>
</tbody>
</table>

**Task Title:** Semi-active response reduction technologies and their implementation in buildings and non-structural components

**Investigator/ Institution:** George Lee*, Mai Tong, Zach Liang and Andrew Whittaker / Univ. at Buffalo

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This task is a continued effort on development of state-of-art semi-active control technology (primarily smart viscous fluid dampers) together with a strategic industry partner (Enidine Inc.), and the formulation of dynamic principles and design guidelines for buildings, equipment, and other infrastructure systems whose seismic performances are enhanced by added smart dampers. This general project goal remains the same for years 6, 7 and 8.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

Viscous sub-linear dampers have been proven effective for reduction of building responses under seismic excitations. Typical design of passive viscous dampers will assume that building deforms elastically. However, under major earthquakes, when structural ductility becomes a dominant energy dissipation factor, the portion of response reduction due to added passive energy dissipation devices is significantly less. Using semi-active methods to adjust the behaviors of passive dampers may provide a better solution to increase the effectiveness of the added devices. In year 6, we examined various viscous energy dissipation devices with regards to the different building response levels and identify corresponding semi-active control schemes to enhance the passive devices.

In year 7, we continue the study that began in year 6 by focusing on the modification and carrying out prototype experiments of the A-model (Enidine device) which was a very sophisticated model jointly developed by Lee/Liang/Tong and Enidine for naval applications. The objective of year 7 research is to primarily simplify the A-model (in control scheme and in cost) for seismic application as added features to typical passive devices (base isolators and energy dissipation devices).

In addition, we propose to radically simplify the semi-active control technology by exploring the possibility of replacing the electronic control system of the current A-model by simple mechanical means (single action fail-safe function) and by other approaches for cost-effective earthquake engineering applications.

II.A-1.83
All hardware developments in this task will be working with the strategic partner, Enidine, Inc. Analytical validation/simulations will be coordinated with the NYS hospital project by using its buildings and non-structural components during year 7. In year 8, when the devices are ready for experimentation, it will be part of the on-table experimentation planned by MCEER’s thrust area 2 on hospitals.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

Semi-active control systems for seismic applications may be simply described as smart dampers or devices with variable damping and stiffness that can be controlled with minimum energy expenditure.

There are two major research thrusts in developing semi-active systems for earthquake engineering applications. One utilizes smart fluids (e.g., ER fluid dampers) carried out by B.F. Spencer of MCEER and others outside MCEER. The other controls the openings of fluid paths in a viscous fluid damper developed by Lee, Liang and Tong of this research task (RSPM).

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

- Completed the design process for semi-active control of the UCLA building. Experiences reported in a paper of 7NCEE (July 2002).
- Decision was made with Enidine to discontinue the actual implementation of the building in view of all the lessons which have been learned through extensive computer modeling efforts. Instead, retrofit of a new structure in Washington is being pursued by Enidine.
- Analytical development began to modify the RSPM system (Real-time Structural Parameter Modification) to be a fail-safe device (single-action protective device for life safety design) and to be a performance-enhancer of selected passive devices (e.g., base isolators). These efforts are to be continued in Years 6 and 7.
- Optimized control device configuration analysis and software program (two papers submitted for publication in 2002).
- One graduate student working towards Ph.D. (degree expected May 2003).

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

Earthquake resilient communities require functioning medical services, particularly after a devastating event. Using semi-active response control systems is potentially a cost-effective means to retrofit hospital buildings and/or expensive, precision equipment in order for the hospital to perform medical services. In addition, development of semi-active system represents state-of-art advancement of new knowledge by MCEER that may be applied by many fields.
**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

Semi-active control devices is one of several advanced technologies to be used in retrofit of hospitals and in protecting non-structural components in hospitals against strong earthquake ground motions. This task will be part of a team effort in experimental evaluation of various devices/approach (on-table experimentation) and in formulation of retrofit strategies by using benchmark hospital buildings (NYS and CA hospitals).

Professor Andrew Whittaker is an expert on transforming research results for adoption in design guidelines. He is expected to make a contribution to facilitate the process of introducing semi-active control technologies eventually into standard engineering practice.

**Possible Technical Challenges:**

Theoretical background for the RSPM technology has been well established by the PI and his co-workers of this task. New analytical efforts to improve the system has begun in 2002 that must be carried out in concert with the technical group of Enidine to ensure that modification to the smart dampers can be actually machined and manufactured. Enidine Inc. will provide the A-models of the semi-active device for us to pursue the necessary research study. Major technical challenges are in the detailing of device modification, that must be carried out with Enidine engineers closely together. This may be a very time consuming process.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

- Complete analytical study to modify the current RSPM technology for hardware development by MCEER strategic partner, Enidine Inc.
- All fundamental studies resulting in new knowledge will be prepared as research papers for journal publication.

**Potential end-users beyond academic community:** *(IAB members and others.)*

Various future application of semi-active control devices will be pursued by Enidine Inc. In addition, new knowledge in semi-active control, to be reported in our research papers, should also be welcomed by other manufacturing companies and design firms concerning earthquake protection of structures.

**Educational outcomes and deliverables, and intended audience:**

Research experience of one graduate student and one post doctoral fellow (part time)

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

Fall 2003 – Spring 2004: Carry out two separate enhancement strategies for semi-active enhanced passive devices.

Summer 2004: Experimentation of simplified semi-active model.
**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

- Basic Research Group: George C. Lee*, Mai Tong, Zach Liang, Suwen Chen and one part time graduate student (all from University at Buffalo)
- Other MCEER Researchers: Andrew Whittaker (University at Buffalo)
- Strategic Industry Partner: Mike Sino, Shubin Ruan, Mary Kerns (Enidine Inc.)

**Possible Direction of Work in Subsequent Years:**

This task will be continued into year 8 for actual development and manufacturing of the prototype for laboratory evaluation, and the development of a plan for the implementation of the devices in actual buildings.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 042004</th>
</tr>
</thead>
</table>

**Task Title:** Retrofit through weakening of structures with damping enhancement: Development of framework and tools to automate and integrate fragility sensitivity in global and local structure evaluation

**Investigator/Institution:**
Andrei M. Reinhorn *, University at Buffalo
Andrew S. Whittaker, University at Buffalo

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

A new procedure to retrofit existing structures subjected to seismic excitation is proposed. The main features are the reduction of maximum acceleration and associated forces in buildings subjected to seismic excitation by reducing their strength (weakening). The weakening retrofit, which is an opposite strategy comparing with strengthening, is particularly suitable for buildings having strong components and foundation supports or having weak brittle components. However, by weakening the structure large deformations are expected. By adding supplemental damping devices it is possible to control the deformation within desirable limits. The structure retrofitted with this strategy will have, therefore, a reduction in the acceleration response and a reduction in the deformations, depending on the amount of additional damping introduced in the structure.

The assessment of efficiency of this strategy is done using fragility evaluation and fragility sensitivity. This task develops an automated tool for calculating the fragility and fragility sensitivity based on inelastic analysis. The framework is validated by a shake table test using a benchmark structure developed in previous projects.

In summary, the approach pursued here is unique in that it consists in simultaneously weakening the structural system, and enhancing its damping capability.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

This task will explore a new global retrofitting method, aimed at reducing both displacements and accelerations in order to protect building and secondary (non-structural) systems. The retrofitting procedure consists in: (a) weakening the building by introducing some disconnections in the structure, that to decrease its lateral strength (but increasing the demanded displacements); (b) adding damping devices to reduce and control the displacements.

This method has some similarities with the base isolation method when used together with damping, because it changes the dynamical properties of the structure reducing both the
acceleration and the displacement.

In this task both the effectiveness of the method and its easy applicability to existing buildings are studied. An experimental study of weakened frames is made using a steel model with shake table excitation. The analysis of the structure for the different steps of the retrofitting procedure (original structure, weakened structure, weakened and damped structure) is made through a spectral response approach. Such an analytical procedure, proposed for undamped structures, is specifically adapted to be applied to damped structures. The proposed method leads to a simplified and effective evaluation of the structural response of damped structure under seismic excitation.

The proposed retrofitting method is applied to a case study in order to show the response of the structure for each step of the procedure. Also the proposed spectral analysis is tested on the case study by comparing the obtained response of the structure with that provided by a nonlinear dynamic analysis. The case study is using the analytical model developed for hospital structure by Whittaker et al in a separate task.

Both analyses would show if the proposed retrofitting method would be effective in reducing displacements and acceleration in the structure. The efficiency of this procedure will be proven using fragility sensitivity. For that purpose the analysis tools are reprogrammed to produce an automated procedure for analysis, fragility evaluation and sensitivity calculations.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The weakening of structures is not new. The FEMA305/306 for new construction recommend designing the structure weaker and compensate for the large deformations by adding damping. The method has never been evaluated experimentally and analytically. Moreover, existing construction, which experiences damage and inelastic deformations, can be retrofitted by using the same concept, however, the design and the evaluation are not as trivial as for new constructions due to the inelastic behavior.

Moreover the use of fragility sensitivity for individual structural evaluation is a new approach. Developed originally by Grigoriu at MCEER in previous years, this sensitivity analysis requires tools which are not available to the community, but which are readily available to the research team and with minor modifications such sensitivity can be obtained. A software platform will be developed (see separate Networking sub-task)

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

Initial evaluations with a reduced suite of site ground motion showed already the potential of the suggested solution. The analysis pointed out the dependence of the proper solution to the amount of added damping. A summary paper was presented at the investigators’ meeting in January 2003.
Role of Proposed Task in Support of Strategic Plan:  *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The proposed task will develop a tool for rapid evaluation of fragility and sensitivity of fragility, which can be used for evaluation of losses and damages.

The suggested retrofit technique presented in the case study addresses a way of reducing the earthquake impact on the whole structure and on local nonstructural components which are more sensitive and which influence directly functionality of the building.

Task Integration:  *( Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The analytical tool used for the evaluation of this new retrofit solution, will be used along with other alternative tools, by all members of the Thrust area 2 to evaluate solutions of innovative global modification techniques. (in collaboration with Whittaker, Aref, Constantinou). The solution addresses a good part of global response, but indirectly protects the whole system (Whittaker). The fragility evaluation will be able to prove the efficiency both in strength and in economic savings, while it will be further used to prepare an intelligent decision system – Dargush / Petak / Alesh.

Possible Technical Challenges:

The development of a simplified solution for fragility sensitivity evaluation is a problem related to the nonlinear behavior of materials which produces usually unpredictable results. The validation of such development with information-collected form the experimental component is essential.

Anticipated Outcomes and deliverables:  *(Also indicate those of particular benefit to IAB members and other end users.)*

Proposed solution for global retrofit of structures presented ina documented report

An analytical solution / tool (software) for evaluation of efficiency of solution using fragility sensitivity approach

Possible end-users beyond academic community:  *(IAB members and others.)*

The solution will be used by the engineering community for retrofit of structures

Educational outcomes and deliverables, and intended audience:

The method will be disseminated in the design class CIE 619 at University at Buffalo in cooperation with A. Whuittaker.
**Project Schedule and Expected Milestones for the Project:** (Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)

The case study will be developed first and the components of the analysis of fragility will be identified. (Spring 2004). The platform will be assembled using IDARC3D and examples will be prepared (summer 2004)

**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- Sivaselvan, M. PhD, Post-Doctoral Associate
- Roh, S.H., PhD Candidate, graduate student
- Dr Stefania Viti, Visiting Scientist from University of Florence.

**Possible Direction of Work in Subsequent Years:**

- Refinement of the “weakening and damping approach” for structural and non-structural systems.
- Refinement of fragility sensitivity approach
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 042005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Performance demand assessment, limit state identification, and fragility curves for nonstructural components and contents in acute care facilities</td>
<td></td>
</tr>
<tr>
<td>Investigator/Institution:</td>
<td>Andrew Whittaker, University at Buffalo, (PI)*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Michel Bruneau, University at Buffalo</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Andrei Reinhorn, University at Buffalo</td>
<td></td>
</tr>
<tr>
<td>* indicates task leader</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Statement of Project Goals:

The following items are the goals of this Year 7 project.

1. Collect and synthesize non-structural-component and -content fragility data for emergency care facilities from MCEER, USC-FEMA, and other sources to populate the MCEER non-structural component/content database.


3. Establish the vulnerability of selected non-structural components and contents in the WC60 Northridge hospital (fixed base and isolated configurations) using the MCEER fragility framework.

4. Develop an experimental program for earthquake simulator testing in Year 8 to validate the analytical formulations of item 2 and augment existing knowledge on the vulnerability of selected non-structural components.

A separate networking subtask has been submitted. The networking subtask statement describes the proposed databases and the associated fragility-based computational tool that will be made available to the MCEER Users Network.

Problem Description and Research Approach of Proposed Work for Year 7:

Each of the four goals listed above is discussed in turn below.

The vulnerability of non-structural components and contents will often determine whether a hospital or emergency care facility remains operational after moderate-to-severe earthquake shaking. As such, robust characterization of the vulnerability of key non-structural components and contents is needed. The fragility approach is being used by MCEER for such characterization. Fragility data for the key components and contents will be assembled where available from MCEER, USC-FEMA, and other sources. This information will be used to populate the MCEER non-structural component/content database. The database will be made available to other researchers in Thrust Area 2 via a networking subtask.

Analytical formulations for the fragility assessment of free-standing non-structural...
components/contents have been published in the past 18 months by Professors Soong and Makris. These formulations will be reviewed and then coded as Matlab .m files for use by the MCEER researchers in Thrust Area 2. The general formulations will be extended to specific components and contents in acute care facilities, with input from OSHPD and MCEER IAB members, to develop sample but realistic fragility curves for such components and contents. Earthquake simulator testing in Year 8 will establish the validity of both the general formulations and the specific fragility curves.

The MCEER fragility framework is one technically viable approach for the performance-based seismic design of new and retrofit construction of emergency care facilities. The framework mapped out at the MCEER 2002 Thrust Area 2 research team meeting at the University at Buffalo now forms the basis of task integration in Thrust Area 2. The Year 7 work will complete the trial implementation of the framework using the fixed base and base isolated versions of the WC60 building with a clear focus on the vulnerability of the non-structural components and contents. One important activity, to be conducted in conjunction with other MCEER Thrust Area 2 researchers, is to extend non-structural component fragilities and non-structural component performance levels to system fragilities and system performance levels.

A program for earthquake simulator testing (to be conducted in Year 8) will be prepared to validate the generalized formulations and specific fragility curves described above and augment existing knowledge on the fragility of selected non-structural components and contents (to be chosen by the MCEER research team with input from OSHPD and the MCEER IAB) that are not amenable to analysis (e.g., partitions, sprinkler systems). Earthquake histories for testing will be derived from synthetic motions for fragility evaluation and motions predicted from response-history analysis of the fixed base and base isolated WC60 building.

To maximize the benefit of the work conducted by individual MCEER investigators and to best serve the stated need for program integration, a database of information and knowledge related to emergency-care-facilities, mathematical models (on a variety of platforms), and non-structural fragilities will be established in close consultation with Professor Reinhorn and other MCEER Thrust Area 2 researchers. The databases and the evaluation tools will be developed, published, and distributed through the MCEER Users Network as part of a separate networking task.

**Assessment of State-of-the-Art:**

Limited fragility data for non-structural components in emergency care facilities are available but the available data have not been processed in a common manner and not all are readily available for use by the MCEER research team and members of the MCEER IAB. Much additional fragility data are needed to implement performance-based earthquake engineering. *(The proposed work will collect and process available fragility data and make plans for collecting new data as needed. Further, the proposed Yr 8 experimental program will augment the limited fragility data currently available.)*

Performance-based earthquake engineering (PBEE) of building structures is generally undertaken using documents such as FEMA 273/274/356. These documents make use of discrete performance levels and hazard levels that are linked to form performance objectives. Performance levels for non-structural components are somewhat ambiguous and are currently
given for broad classes of components rather than manufacturer specific components. The
reliability of a system design that nominally meets the stated performance objective is unknown.
Much additional information on non-structural component limit states are needed before PBEE
can be broadly implemented. *(The proposed work focuses attention on emergency care facilities
for which the limit states of response for non-structural and structural components can be
accurately defined. Relationships between non-structural component and building fragilities will
be established.)*

**Progress to date:**

Three demonstration hospital structures have been designed and data are now available at the
MCEER website. Included in the materials at the web site are (a) an 80-page report describing
the analysis and design of the three separate buildings (WC70, WC60, and EC70), (b) the
SAP2000NL input files that can be used for the analysis of the three buildings, and (c) drawings
of the three buildings in AutoCAD. All of these files can be downloaded. *(Completed in Summer
2002)*

The fragility framework has been established and is now being documented. *(Scheduled for
completion in late Spring 2003)*

An OpenSees model of the Northridge hospital has been developed and is now being de-bugged.
Information from Professor Fenves at Berkeley is needed to complete the model.

A M.S. thesis on the fragility of suspended ceiling systems and improved strategies for
performance (fragility) assessment of non-structural components and contents is being prepared.
*(Scheduled for completion in Summer 2003)*

An MCEER report related to the fragility of the MCEER demonstration hospital is being
prepared. *(Scheduled for completion in Summer 2003)*

**Role of Proposed Task in Support of Strategic Plan:**

The proposed work in Year 7 supports the MCEER strategic plan and will operate at all three
levels of the new MCEER 3-plane chart, namely, (1) to develop valid and applicable scientific
knowledge based on fundamental research, (2) to integrate fundamental knowledge into testable
technologies and tools, and (3) to evaluate the efficacy of the knowledge, technologies, and tools
using the MCEER demonstration hospital.

The Year 7 task product will provide a framework for the assessment of the efficacy of global
and local design and retrofit strategies.

**Task Integration:**

The fragility framework serves as an integrating tool for much of the work conducted in Thrust
Area 2 because it can be used to judge the utility of protection technologies and retrofit
strategies and devices for reducing the vulnerability of non-structural and structural components.

**Possible Technical Challenges:**

None expected at this time.
### Anticipated Outcomes and deliverables:

| Sample fragility data (*IAB and design professionals*). |
| Integrated fragility framework for performance-based earthquake engineering (*IAB, ATC-58 project*). |
| Matlab files for the analytical development of fragility curves for selected non-structural components. |
| Databases (*IAB and design professionals*). |

### Potential end-users beyond academic community:

| Design professional community and facility administrators for use in performance-based earthquake engineering of hospitals. |
| The ATC-58 project: a national FEMA-funded effort to develop guidelines for performance-based earthquake engineering. The PI is a leading player in this endeavor. |

### Educational outcomes and deliverables, and intended audience:

- Information/deliverables to be included in the UB graduate class in earthquake engineering (CIE 619). Intended academic audience is graduate students.
- Other impacted groups will include (a) the design professional community, and (b) members of the ATC-58 SPP and NPP teams.

### Project Schedule and Expected Milestones for the Project:

**Summer 2004:** Collect and disseminate analytical formulations for fragility of selected freestanding non-structural components.

**Fall 2004:** Upload all fragility information to the MCEER database. Document vulnerability of non-structural components in WC60 structures. Demonstrate the use of fragility framework considering the interaction of the fragilities for non-structural and structural components. Complete planning for earthquake simulator testing program.

### Team Members:

- The graduate student hired for the Year 5 work will continue in Year 7.
- Close collaboration with Professors Bruneau, Constantinou, Lee and Reinhorn is anticipated.

### Possible Direction of Work in Subsequent Years:

- Execution of the earthquake simulator-testing program in Yr 8.
- Development of the fragility framework to address ATC-58 team input.
- Continue to populate the non-structural component/content fragility database.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>042006</td>
</tr>
</tbody>
</table>

Task Title: Performance of Secondary Systems in Structures with Seismic Protective Systems

Investigator/ Institution: Michael C. Constantinou*, University at Buffalo

* indicates task leader

Statement of Project Goals:

(a) Develop a comparison of performance of secondary systems in structures designed with contemporary seismic isolation and damping systems having a range of design parameters, and

(b) Develop guidelines on the selection of seismic isolation and damping hardware for achieving specific performance levels.

Problem Description and Research Approach of Proposed Work for Year 7:

It is desirable, but not always achievable, to design hospitals for Performance Level of either Immediate Occupancy or Operational (per FEMA 273 definitions). Seismic isolation and energy dissipation (particularly as described in the 2000 NEHRP Recommended Provisions for Seismic Regulations) may be the only proven construction technologies that can achieve these performance objectives. Yet, methodologies for the design of non-structural systems to achieve these performance levels are not available.

In order to develop methodologies for the design of hospitals for the immediate occupancy and operational performance levels, it is necessary that (a) performance limits for non-structural systems are established, and (b) the dynamic response of non-structural systems is determined. This project intends to contribute towards the understanding of the behavior of secondary systems within structures with seismic isolation and damping systems, and towards the accurate prediction of the dynamic response of these systems.

Recently completed studies on the behavior of structures with seismic isolation and damping systems (experimental and analytical work of Eric Wolff at UB) resulted in (a) a wealth of experimental results on systems of contemporary design, including data related to secondary system response, and (b) comparisons of analytical and experimental responses that demonstrate capability to accurately predict the response of secondary systems.

With the verification of accuracy of methods of analysis of secondary systems in structures with seismic isolation and damping systems, this project will concentrate on a systematic study of the response of secondary systems with the purpose of (a) providing a comparison of performance of secondary systems in structures designed with contemporary seismic isolation and damping systems having a range of design parameters, and (b) providing guidelines on the selection of...
seismic isolation and damping hardware for achieving specific performance levels.

The approach to be followed is based on dynamic analysis of structures with the following attributes:
(a) Range of structural systems with different stiffness (period) characteristics, (b) Range of seismic isolation and damping systems, including lead-core, elastomeric, combined elastomeric-sliding, Friction Pendulum, linear viscous, nonlinear viscous and yielding steel systems, (c) Range of parameters for each system, including parameters for upper/lower bound analysis for each particular system, and (d) Range of seismic excitations, including far-field, near-field and soft-soil motions, all represented by suites of motions having a representative average spectrum.

The assessment of performance will be based on response quantities of points of attachment of secondary systems (neglecting the interaction of the structure and the secondary systems), which will include peak accelerations, peak velocities and spectral accelerations over a wide range of frequencies, as well as interstory drifts.

Assessment of State-of-the-Art:

At this time it is apparent that:
• The seismic vulnerability of complex non-structural systems is not yet established (hence the effort in the MCEER hospital project),
• Methodologies for determining the probability of failure of complex non-structural systems on the basis of fragility and sensitivity are in the development stage (current MCEER effort), and
• Methodologies for design of non-structural systems to achieve Operational or Immediate Occupancy Performance Levels do not exist.

It is thus a paradox that either single-parameter statements on the performance of secondary systems in seismically isolated structures or structures with damping systems have been included in performance specifications, and that some researchers have reached general conclusions that certain isolation systems have significant and harmful impact on the contents of isolated buildings. For example, Skinner et al. in their 1993 book on seismic isolation conclude that isolation systems with high non-linearity have very high attack on building contents. The result is entirely based on analysis of a simple four-degree-of-freedom system subjected to the 1940 El Centro NS input and by using the top floor acceleration response as the parameter for assessing performance of secondary systems. Yet a simple example from the sample of experimental results in the work of Eric Wolff at UB provides a different picture. The figure below presents floor acceleration spectra for a 5-percent damped oscillator calculated using the floor acceleration histories recorded in shake table experiments of a six-story isolated building model excited with the 1940 El Centro S00E component, scaled up by a factor of 200%. The building model had a weight of 233 kN and a fundamental period (in the quarter length scale of the experiment) of 0.43 sec. The isolation system consisted of either Friction Pendulum bearings, low damping elastomeric bearings, low damping elastomeric bearings with added linear viscous dampers, or combined sliding and elastomeric bearings. All four systems had an effective period (per IBC, 2000) in the range of 0.93 to 1.1 sec, thus they were comparable in terms of the isolation effect due to the period shift. The effective damping varied from 0.05 in the elastomeric system to as high as 0.38 in the highly nonlinear Friction Pendulum system.
On the basis of the results in this figure and considering the performance of numerous secondary systems in a building structure, which are affected by spectral accelerations over a wide range of frequencies, the Friction Pendulum and the combined elastomeric/sliding isolation systems are likely to have the least impact on the contents of the building. Interestingly, these two systems are highly nonlinear, whereas the other two are typically presumed to be linear elastic and linear viscous. That is, the results in this figure totally contradict the notions advanced in previous studies.

It should be noted that it is generally accepted that properly designed seismic isolation systems have substantial beneficial effects on the response of non-structural systems by comparison to the response of non-structural systems in conventional structures. This conclusion is based on limited analytical studies such as those reported in Skinner et al. (1993) and Fan and Ahmadi (1990), and the experimental studies of Kelly and Tsai (1985) and Juhn et al. (1992). The experimental studies of Kelly and Tsai (1985) at Berkeley and Juhn et al. (1992) at UB concentrated on elastomeric and sliding isolation systems, respectively, both however of design and construction that do not correspond to those of isolation systems in use today. Nevertheless, both studies attempted analytical prediction of the response of secondary systems, with Kelly and Tsai presenting a simplified method applicable only to linear systems (such as low-damped elastomeric systems). While the studies correctly predicted trends in the response of secondary systems, peak values of interest in design could not be accurately predicted.

There are no studies on the behavior of secondary systems in structures with damping systems.

Accurate prediction of the response of secondary systems in seismically isolated structures is important in performance-based design. Available tools for analysis of seismically isolated structures have not been evaluated for accuracy in the prediction of the dynamic response related to secondary system design. Moreover, the evaluation of accuracy of these tools in the prediction of the dynamic response of the primary system has been limited. The study of Eric Wolff at UB performed such an evaluation by (a) generating a wealth of experimental results on contemporary seismic isolation systems and (b) comparing the experimental responses to analytically obtained results using currently available computer software. The availability of this work allows for the accurate study of the response of secondary systems in structures with seismic isolation and damping systems, which are designed using contemporary principles.
Comparison of 5-percent Damped Response Spectra of Tested Isolated Model Moment Frame Structure in El Centro 200%

El Centro S00E 200%, MF

- FPS, $T_{eff}=1.1$ sec, $\beta=0.38$
- Low Damping Elastomeric, $T_{eff}=0.93$ sec, $\beta=0.05$
- Sliding & Elastomeric, $T_{eff}=1.1$ sec, $\beta=0.23$
- Elastomeric with Linear Dampers, $T_{eff}=0.93$ sec, $\beta=0.29$

Comparison of 5-percent Damped Response Spectra of Tested Isolated Model Moment Frame Structure in El Centro 200%
**Progress to date:** None, other than the earlier related work of Eric Wolff, which was briefly described above.

**Role of Proposed Task in Support of Strategic Plan:**
The proposed work supports the MCEER strategic plan because (i) involves fundamental research in order to develop scientific knowledge, (ii) transforms this fundamental knowledge into tools for the profession (the tools guidelines for selection of seismic isolation and damping systems for non-structural system performance and tools for the analysis/design), and (iii) involve new technologies which is the main theme of MCEER’s concentration.

**Task Integration:**
The proposed work intend to provide practicing engineers with verified tools for the analysis and design of critical facilities with seismic isolation and damping systems for which objectives on the performance of both the structural and the non-structural systems need to be met. The work complements the main theme of MCEER for the development of a fragility-based framework for the performance-based design of hospitals. While the methodologies for this framework may be developed in a generic approach, their practical application requires the use of verified analysis and design tools. This work will contribute in the development of these tools.

**Possible Technical Challenges:**
Work is ambitious but has been possible so far with contributions from practicing engineers, cooperation with other MCEER researchers (primarily Dr. A.S. Whittaker) and matching funding and support provided by industry.

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables:</th>
<th>Potential end-users beyond academic community:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Report on work done.</td>
<td>1) Design professionals.</td>
</tr>
<tr>
<td>2) Commentary in 2006 version of NEHRP Recommended Provisions on secondary system response in structures with seismic isolation and damping systems.</td>
<td>2) Code developing agencies (BSSC for NEHRP, ASCE-7, SEAOC).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Educational outcomes and deliverables, and intended audience:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Information/results to be published and presented at conferences.</td>
</tr>
<tr>
<td>2) Results to be presented by cooperating practicing engineers (an approach successfully tried in the past. For example, Mr. Martin Johnson of EQE presented work accomplished in years 5 and 6 of MCEER in lectures organized by SEAOC).</td>
</tr>
<tr>
<td>3) Material to be presented to students directly in courses at UB (CIE625, Seismic Isolation).</td>
</tr>
</tbody>
</table>

**Project Schedule and Expected Milestones for the Project:**

- **Summer 2003:** seismic excitation suites selected, methodology for structure and isolation/damping system design and parameter selection established
- **Fall 2003:** Complete analyses of seismic isolated structures
- **Spring 2004:** Reduce and interpret data, begin study of structures with damping systems (this study requires more effort given that limited inelastic action in the structural system may occur)
- **Summer 2004:** begin guideline formulation
**Team Members:**
1) Graduate students: Eleni Pavlou, Panayiotis Roussis
2) Faculty collaborator: Dr. Andrew S. Whittaker.
3) TS 12 members: Martin Johnson, Charles Kircher, Robert Hanson, Tom Hale. Investigator chairs the TS12 and will seek guidance from members of the committee who have experience in the applications of seismic isolation and damping systems to hospitals.
4) OSHPD, CA collaborator: Tom Hale.
5) Investigator: Michael C. Constantinou.

**Possible Direction of Work in Subsequent Years:**
The described work is multi-year and is intended to continue beyond year 7.
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 042007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Experimental data for performance of piping distribution systems</td>
<td></td>
</tr>
<tr>
<td>Investigator/Institution:</td>
<td>Emmanuel “Manos” Maragakis /University of Nevada, Reno Ahmad Itani / University of Nevada, Reno</td>
<td></td>
</tr>
<tr>
<td>Team Member/Institution:</td>
<td>Mircea Grigoriu / Cornell University</td>
<td></td>
</tr>
<tr>
<td>* indicates task leader</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Statement of Project Goals:
(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The main goal of the proposed research is to continue the shake table tests of hospital piping distribution systems. The general layout of the system was designed in collaboration with OSHPD in year 5. The first shake table experiment will be conducted the week of April 7, 2003 (part of the research of year 6). The objectives of the tests are the identification of the capacity characteristics of the systems as well as its weak points and failure modes. The proposed systems in year 7 will include copper and steel threaded pipes and be tested with and without bracing or other devices that can be used to improve its seismic performance, in order to assess their effectiveness. The results will also be used for the identification of critical components and to provide information to Mircea Grigoriu’s team, who are performing analytical studies and are developing the fragility information for these systems.

## Problem Description and Research Approach of Proposed Work for Year 7:
(Detailed description of research to be conducted and methodology to be used.)

Functioning of a complex critical facility, such as a hospital, after an earthquake, relies heavily on proper functioning of its non-structural components such as fire suppression and water distribution systems, elevators and critical medical equipment. In recent earthquakes hospital piping systems suffered significant damage, which resulted in significant reduction of the functionality of the facilities.

A typical hospital piping distribution system is a geometrically complex network including several straight or angled pipe connections, connections of pipes to rigid elements such as water heaters, heat exchangers, pumps and sprinkler heads as well as several pipe floor crossings. The network consists of vertical piping systems running across hospital floors and horizontal systems, which run primarily in the plane of a floor. The pipes are suspended from the frame of the structure. Due to the complexity of these systems there are many unknown aspects of their behavior during an earthquake and many coupled parameters that control their response. Furthermore, the effectiveness of proposed retrofitting methodologies such as bracing is unknown. To answer these questions and improve our understanding on the seismic response of these systems, a series of analytical and experimental studies need to be conducted.

The main objective of the proposed research project will be to continue the performance of shake table experiments of hospital piping sub-systems. The following approach will be followed:
- Review carefully the results of the first system that will be tested the week of April 7, 2003.
- Meet with consultants and OSHPD engineers in order to finalize the geometry of the second hospital piping sub-system that will be tested. At this point, after recent preliminary discussions with OSHPD engineers it has been recommended that two systems, with the same geometry as the system tested in year 6 be tested. One will consist of copper pipes and the other of steel pipes with threaded connections. The system tested in year 6, consisted of welded connections. Copper and steel threaded pipes are widespread in hospitals, and by using the same geometry a direct comparison of the performance of these three common piping details can be made.
- Design the final shake table experimental set-ups.
- Perform a preliminary finite element analysis of the experimental set ups in order to obtain preliminary analytical response and failure data and finalize instrumentation and selection of input motion.
- Construct the specimen using the rigid frame constructed in year 6, from which the pipes of the systems will be suspended. The specimen will include actual field plumbing details around elements such as valves, water heaters and heat exchangers. The pipes will contain water under pressure.
- Perform the experiments without using any bracing. The specimens will be subjected to incrementally increasing excitation levels until significant damage, water leakage or failure are observed.
- Repeat the experiments with a bracing system.
- Perform an initial analysis of the data and obtain capacity information and evaluate the effectiveness of pipe bracing on the seismic response of the tested piping systems.
- Meet with OSHPD engineers and other researchers, discuss the results and identify needs for further experiments.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Recent earthquakes exposed the vulnerability of piping systems in California hospitals. The investigation reports by the Office of Statewide Health Planning and Development (OSHPD) reported that most damage to California hospitals was due to failure of nonstructural components. In fact, the Earthquake Engineering Research Institute (EERI) reported the availability of 1750 beds in intensive care units in Los Angeles County before the 1994 Northridge earthquake. However, after the earthquake only about 200 of these beds were available. Most of this significant loss was due to failure of mechanical systems such as pipe networks and connections. This unforeseen nonstructural damage limited the serviceability of several hospitals in the LA County.

Experimental testing of mechanical systems has been limited to component testing of pipes. These component tests were conducted on small-scale pipes and few connection details. Recent earthquake such as the Northridge earthquake showed that the seismic response of piping systems is complex since there is an interaction between the structural frame response, the pipes and the type of bracing details. Component testing cannot capture this interaction. The first of a series of shake-table experiments of piping sub-systems will be conducted the week of April 7, 2003 as part of the year 6 phase of this project.
**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

In year five, in consultation with OSPD engineers and consultants, a piping sub-system was identified. After several iterations the experimental specimen representing the system has been designed. The experimental set-up, including a rigid frame from which the pipes can be suspended was designed in year 6 (Fall 2002). The bracing system was designed by brace manufacturers. The shake-table experiments of the braced and un-braced systems will be conducted the week of April 7, 2003 as part of the year 6 phase of the project.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

Since no other shake-table tests of piping distribution systems have taken place in the past, the proposed series of tests is a fundamental research experiment contributing to the basic understanding of the seismic behavior of these complex systems. They will also allow the assessment of the effectiveness of seismic strengthening methods, such as bracing or other techniques that will be tested in up-coming years. This assessment is necessary for the implementation of these loss-reduction technologies. Furthermore, the results of the proposed experiments will be used for the calibration and validation of analytical tools aiming at the development of fragility information of hospital piping distribution systems. This fragility information is necessary for the assessment of the seismic risk and the development of seismic strengthening methodologies of a critical facility such as a hospital.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The experimental results will be used for the calibration of analytical models for non-structural systems in a health care facility that will be developed by Mircea Grigoriu’s team. The project will also contribute to the Task on the Networking Experimental Facilities

**Possible Technical Challenges:**

1. Fabricate the piping specimen including realistic plumbing details. Most of the fabrication will take place on-site the UNR Large-Scale Structures Laboratory. The fabrication methods used for the fabrication of the system tested in year 6, will be used for the year 7 specimens.
2. Develop shake table motions that can expose the weak links of the system, show possible modes of failure and demonstrate the effectiveness of the bracing system.
3. Suspension of the piping system from the frame and installation of bracing.
4. Modeling the system before the experiment in a simple manner with the expectation to identify the areas where damage is expected and develop an effective instrumentation plan.
5. Definition/identification of failure (other than water leakage)
**Anticipated Outcomes and deliverables:**
*(Also indicate those of particular benefit to IAB members and other end users.)*

- Final design of a hospital piping sub-system.
- Possible modification of the experimental protocol for the shake table test of the piping system developed in year 6.
- Information on the dynamic response of hospital piping sub-systems made out of copper and steel threaded pipes.
- Information on the effectiveness of bracing on the seismic response of piping systems.

**Potential end-users beyond academic community:** *(IAB members and others.)*

- Experimental researchers
- Experimental researchers
- MCEER researchers working on development of fragility curves – other researchers, consultants and state engineer working on hospital piping systems
- Researchers, consultants and state engineers (OSHPD and other similar agencies)

**Educational outcomes and deliverables, and intended audience:**

Contribution to the general educational goals of the overall program 2.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

**Task 1:** Finalize the design of the shake table experiment for the piping sub-systems, which include a hot water heater tank, a heat exchanger and pumps. The pipes will contain water under pressure. The test set-up will include the rigid frame developed in year 6, from which the pipes will be suspended and braced simulating the actual as-built conditions. The pipes will most probably made out of copper in one system and out of steel with threaded connections in the other (Fall 2003).

**Task 2:** Analyze the designed piping systems (specimens) and identify necessary modifications (Winter 2003/2004).

**Task 3:** Meet with consultants and OSHPD engineers to discuss the design and analysis of the experiment and implement necessary modifications (Winter 2003/2004).

**Task 4:** Fabricate the specimen after contacting several manufacturers who could donate materials such as pipes, couplers, bracings etc. (Winter/Spring 2004)

**Task 5:** Perform the shake table tests of the sub-system identified in tasks 1-4 (Spring 2004).

**Task 6:** Perform a fundamental analysis of the results and discuss them with other researchers of Program 2, consultants and OSHPD engineers (Spring /Summer2004).
**Task 7:** Identify critical components that will have to be individually tested in subsequent years (Summer 2004).

**Task 8:** Work with consultants and OSHPD engineers to design future sub-system and a large system hospital piping experiments by using the multi-table facility at the University of Nevada, Reno (Summer/Fall 2004).

**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

The project will be under the leadership of Dr. Manos Maragakis, professor of Civil Engineering at the University of Nevada, Reno. Dr. Ahmad Itani, an Associate Professor of Civil Engineering, will be a co-principal investigator. A graduate student will be hired on the project. Dr. Mircea Grigoriu and his team from Cornell will be performing the analytical studies.

**Possible Direction of Work in Subsequent Years:**

1. Testing critical component details of hospital piping systems in coordination with the needs of other researchers in Program 2 as needed for the fragility analysis.
2. Design and conduct experiments of more critical piping sub-systems, using different bracing systems.
3. Design and conduct experiments of a large hospital piping system, by using the multi-table facility at the University of Nevada, Reno. Such an experiment, as well as the experiments of the sub-systems can be used for the evaluation of the effectiveness of seismic bracing and other technologies can be used to improve the seismic performance of hospital piping systems.
MCEER RESEARCH TASK STATEMENT

Task No. | Budget: | Yr 7 Assigned Project Number: | 042008
---|---|---|---
Task Title: Fragility Based and Rehabilitation Decision Analysis

Investigator / Institution : Mircea Grigoriu / Cornell University
Team Member / Institution : Detlof von Winterfeldt / University of Southern California
Manos Maragakis / University of Nevada at Reno

TASK STATEMENTS BY GRIGORIU AND VON WINTERFELDT WERE PREPARED JOINTLY AND THUS SHARE MANY SIMILAR COMPONENTS. HOWEVER, EACH ALSO PROVIDE ADDITIONAL INFORMATION ON THE TASKS TO BE PERFORMED BY EACH RESEARCHER.

* indicates task leader

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The main objective is the development of a methodology for (i) assessing the seismic performance of single and multiple health care facilities using fragility surfaces, (ii) selecting optimal repair/retrofit strategies for these units over a specified time horizon based on life cycle seismic hazard models and resilience measures, and (iii) integrating the Cornell probabilistic simulation model for lifetime seismic hazard and seismic system performance with USC’s decision analysis framework based on resilience measures and financial models for evaluating rehabilitation alternatives. The resulting decision analysis model will be applied to the demonstration hospital project. Fragility information developed analytically/numerically at Cornell University for selected non-structural components will be validated by the experiments performed at the University of Nevada at Reno by M. Maragakis’ team.

The proposed research contributes in an essential way to the overall MCEER goal of enhancing the seismic resiliency of communities.

Problem Description and Research Approach of Proposed Work for Year 7: (Detailed description of research to be conducted and methodology to be used.)

It is proposed to develop a method and a computer code for assessing the seismic performance of a single health care facility and networks of such facilities during a specified time interval. The methodology will be based on fragility information, probabilistic life cycle seismic hazard models, resilience measures and an integrated evaluation of hospital rehabilitation alternatives. The methodology will be developed jointly by the Cornell University team under the leadership of Professor Mircea Grigoriu and by the USC team under the leadership of Professor Detlof von Winterfeldt. The following tasks will be completed:

(1) Fragility analysis (Lead: Cornell University): A methodology for calculating fragility surfaces for structural and selected non-structural systems will be completed. Fragility surfaces
give the probability that a system reaches a damage state if subjected to an earthquake with specified magnitude and source to site distance. The input to the analysis includes (i) properties of structural/geotechnical systems, (ii) damage states, (iii) ranges of earthquake magnitude and source to site distance, and (iv) seismic ground acceleration model. Papageorgiou’s specific barrier model will be used to define the second moment properties of the ground acceleration process. Random vibration theory and/or Monte Carlo simulation techniques will be used to calculate fragility surfaces. The methodology for the fragility analysis will be applied to the demonstration hospital project. Fragility surfaces will be developed for the hospital’s structural system and a critical non-structural system in the hospital. Several damage states and retrofit strategies will be considered in the analysis. The damage states will be defined in collaboration with the USC team by combining engineering judgments of possible damage states and judgments of hospital managers and staff on level of degradation of hospital functions for these states. The resulting fragility surfaces will be delivered to the USC team.

(2) Lifetime Seismic Hazard (Lead: Cornell University): The lifetime seismic hazard model, which is the essential part of the Cornell probabilistic simulation framework, will be completed. The input to this model consists of (i) site seismicity, that is, earthquake arrival rate, magnitude and source to site distance, and (ii) reference time. A Monte Carlo algorithm will be used for generating samples of the stochastic process modeling lifetime seismic hazard. This model will be extended to include non-Gaussian properties for the seismic ground acceleration process and to account for seismic hazard at multiple sites by extending the method in “Non-Gaussian model for spatially coherent seismic ground motions, Kafali C. and Grigoriu M., paper submitted to ICASP9”.

(3) Resilience measures (Lead: USC): Seismic system performance and the Cornell probabilistic simulation model for lifetime seismic hazard will be used to predict performance on several resilience measures, which will be developed jointly with the USC team. These resilience measures will include hospital disruption, losses of life, downtime, cost and speed of recovering from damages.

(4) Analysis and evaluation of rehabilitation strategies (Joint activity by USC and Cornell University): The information collected in tasks (1)-(3) will be used to evaluate alternative rehabilitation strategies. An important component of this evaluation is USC’s financial and business model, which USC will further develop and deliver to Cornell. The methodology will be applied to the demonstration hospital project to identify an optimal rehabilitation strategy by using probability distributions over resilience measures as well as over integrated measures of resilience (e.g., total equivalent cost).

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Currently the seismic performance of structural and non-structural systems is evaluated by fragility curves depending on one parameter such as peak ground acceleration PGA. Also, existing seismic hazard models are based on the annual rate of earthquake occurrences. The use of maximum earthquake in the lifetime of a system, for example the maximum PGA at a site over a 50-year period, may be adequate for safety but provides limited information if the objective is the improvement of earthquake resilience of some structural and non-structural
systems under cost constraints. Also, another current practice is to use Gaussian processes to model seismic ground accelerations. Finally, current seismic resilience measures, such as HAZUS, are approximate and developed for groups of structures rather than single critical facilities.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

Developments in previous years include:

- A methodology for generating life cycle seismic hazard scenarios
- A framework for calculating fragility surfaces for structural/non-structural systems
- A framework for the resilience assessment for the demonstration hospital project.
- Preliminary results on the generation of realistic ground acceleration samples at a collection of sites.

Previous work focus was on the development of generation of life cycle seismic hazard scenarios and of fragility surfaces for an individual health care facility, “Seismic fragility and cost-benefit analysis of structural and non-structural systems, Ph.D. thesis, Ehab Mostafa, 2002”. These developments are going to be used in the selection of an optimal strategy for seismic rehabilitation of structural non-structural systems.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The proposed tasks for year 7 are essential for MCEER’s overall goal of improving earthquake resiliency of communities through enhanced seismic assessment and performance of health care facilities. The main objective is to increase the seismic resilience by reducing (i) the probability of system failure, (ii) the consequences due to failure and (iii) time to system restoration.

To contribute to the MCEER’s goal of enhancing seismic resiliency of communities, we will (i) develop a methodology for assessing the seismic performance of individual and multiple health care facilities using fragility surfaces, (ii) develop a probabilistic simulation model for life cycle seismic hazard, and (iii) integrate Cornell seismic performance analysis and life cycle seismic hazard model with the USC financial and business model to develop a decision analysis framework for selecting optimal retrofit strategies for these units over a specified time horizon.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

Significant interaction with following tasks funded by MCEER is being achieved:

- The development of fragility curves will use A. Papageorgiou’s specific barrier model delivering the second moment properties of the ground acceleration process.
- The results from M. Maragakis experiments on the water supply system of a structure will be
used to evaluate our model for non-structural systems in a health care facility.

- The development of relevant damage states will be done in close collaboration with the USC team. This task requires both engineering judgment (Cornell) and judgments by hospital managers and staff (to be obtained by USC).

- Resilience measures will be jointly developed with the USC team and other researchers involved in MCEER’s resilience task.

- USC will use Cornell’s damage states and fragility curves in the models to assess resilience of hospitals.

- Cornell will use USC’s business and financial model in its resilience assessment (formerly: cost-benefit analysis).

- Cornell and USC will closely collaborate in building a decision analysis tool, including associated software to assess and evaluate rehabilitation alternatives for hospitals.

**Possible Technical Challenges:**

- Development of efficient algorithms for generating fragility surfaces for non-structural systems subjected to Gaussian and non-Gaussian seismic ground motions.

- Development of resilience measures for assessing seismic performance of the selected representative structural and non-structural systems.

- The derivation of simple measures that can be used in practice to quantify the seismic resilience.

- Definition of damage states needed for the calculation of the fragility surfaces.

**Anticipated Outcomes and deliverables:**

(Also indicate those of particular benefit to IAB members and other end users.)

- Methodology for calculating fragility surfaces for specified structural and non-structural systems and damage states.

- Methodology for identifying optimal retrofit strategy for seismic rehabilitation of structural/non-structural systems under cost constraints of a network of health care facilities.

- Methodology for generating coherent, Gaussian and non-Gaussian seismic ground acceleration time histories at a collection of sites.

**Potential end-users beyond academic community:**

(Also indicate those of particular benefit to IAB members and other end users.)

- Engineering firms analyzing and evaluating rehabilitation alternatives.

- Hospital administrators and decision-makers.

- Planning agencies concerned with seismic risks.
**Educational outcomes and deliverables, and intended audience:**

- An algorithm for generating life cycle seismic hazard scenarios will be made available for the user’s network of MCEER and for classroom use (Structural Dynamics and Earthquake Engineering, CEE 678).

- An algorithm for generating realistic ground motion time histories that will be made available for the users network of MCEER and for classroom use (Structural Dynamics and Earthquake Engineering, CEE 678).

- Preliminary results are currently used in my courses on Structural Dynamics and Earthquake Engineering, CEE 678, and Structural Reliability, CEE 773 at Cornell University.

<table>
<thead>
<tr>
<th>Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Fall’ 03: Initial integration of decision analysis framework and models by von Winterfeldt and Grigoriu.</td>
</tr>
<tr>
<td>- Fall’ 03: Methodology for calculating fragility surfaces for structural and non-structural systems with Gaussian seismic ground motion. Preliminary work on the development of fragility surfaces using non-Gaussian seismic ground motion input.</td>
</tr>
<tr>
<td>- Spring’ 04: Resilience measures for a single health care facility. Networks of health care facilities will be examined later.</td>
</tr>
<tr>
<td>- Summer’ 04: Methodology for identifying optimal retrofit strategy for seismic rehabilitation of structural / non-structural systems.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Detlof von Winterfeldt / University of Southern California</td>
</tr>
<tr>
<td>Dr. Manos Maragakis / University of Nevada at Reno</td>
</tr>
<tr>
<td>Cagdas Kafali, Ph.D. student / Cornell University</td>
</tr>
</tbody>
</table>

**Possible Direction of Work in Subsequent Years:**

Results from (i) Dr. E. Mostafa’s work on the generation of life cycle hazard scenarios and on the seismic performance of structural/non-structural systems of a health care facility, (ii) Dr. C. Roth’s work on the development of sensitivity of the fragility surfaces to the structure and relevant input parameters in order to assess the sensitivity affects on rehabilitation strategies, and (iii) the proposed tasks for year 7, assessing the seismic performance for a network of health care facilities during a specified time interval, will be integrated in an effort to achieve the overall MCEER goal of enhancing the seismic resiliency of communities.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>042009</td>
</tr>
</tbody>
</table>

**Task Title:** Rehabilitation Decision Analysis

**Investigator/Institution:**
- Detlof von Winterfeldt*/ University of Southern California
- Mircea Grigoriu / Cornell University

*indicates leader for this task

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

The main objective is the development of a methodology for (i) assessing the seismic performance of single and multiple health care facilities using fragility surfaces; (ii) selecting optimal repair/retrofit strategies for these units over a specified time horizon based on life cycle seismic hazard models and resilience measures; (iii) integrating the Cornell probabilistic simulation model for lifetime seismic hazard and seismic system performance with USC’s decision analysis framework based on resilience measures and financial models for evaluating rehabilitation alternatives. The resulting decision analysis model will be applied to the demonstration hospital project.

The proposed research contributes in an essential way to the overall MCEER goal of enhancing the seismic resiliency of communities.

**Problem Description and Research Approach of Proposed Work for Year 7:** *(Detailed description of research to be conducted and methodology to be used.)*

It is proposed to develop a methodology and associated software for assessing and evaluating alternatives for the rehabilitation of hospitals. The methodology will be based on fragility information, probabilistic life cycle seismic hazard models, resilience measures and an integrated evaluation of hospital rehabilitation alternatives. The methodology will be developed jointly by the Cornell University team under the leadership of Professor Mircea Grigoriu and by the USC team under the leadership of Professor Detlof von Winterfeldt. The following tasks will be completed:

1. **Fragility analysis (Lead: Cornell University):** A methodology for calculating fragility surfaces for structural and selected non-structural systems will be completed. Fragility surfaces give the probability that a system reaches a damage state if subjected to an earthquake with specified magnitude and source to site distance. The input to the analysis includes (i) properties

II.A-1.111
of structural/geotechnical systems, (ii) damage states, (iii) ranges of earthquake magnitude and source to site distance, and (iv) seismic ground acceleration model. Papageorgiou’s specific barrier model will be used to define the second moment properties of the ground acceleration process. Random vibration theory and/or Monte Carlo simulation techniques will be used to calculate fragility surfaces. The methodology for the fragility analysis will be applied to the demonstration hospital project. Fragility surfaces will be developed for the hospital’s structural system and a critical non-structural system in the hospital. Several damage states and retrofit strategies will be considered in the analysis. The damage states will be defined in collaboration with the USC team by combining engineering judgments of possible damage states and judgments of hospital managers and staff on level of degradation of hospital functions for these states. The resulting fragility surfaces will be delivered to the USC team.

(2) Lifetime Seismic Hazard (Lead: Cornell University): The lifetime seismic hazard model, which is the essential part of the Cornell probabilistic simulation framework, will be completed. The input to this model consists of (i) site seismicity, that is, earthquake arrival rate, magnitude and source to site distance, and (ii) reference time. A Monte Carlo algorithm will be used for generating samples of the stochastic process modeling lifetime seismic hazard. This model will be extended to include non-Gaussian properties for the seismic ground acceleration process and to account for seismic hazard at multiple sites by extending the method in “Non-Gaussian model for spatially coherent seismic ground motions,” Kafali C. and Grigoriu M., paper submitted to ICASP9.

(3) Resilience measures (Lead: USC): Seismic system performance and the Cornell probabilistic simulation model for lifetime seismic hazard will be used to predict performance on several resilience measures, which will be developed jointly with the Cornell team. These resilience measures will include hospital disruption, losses of life, downtime, cost and speed of recovering from damages.

(4) Analysis and evaluation of rehabilitation strategies (Joint activity by USC and Cornell University). The information collected in tasks (1)-(3) will be used to evaluate alternative rehabilitation strategies. An important component of this evaluation is USC’s financial and business model, which USC will further develop and deliver to Cornell. The methodology will be applied to the demonstration hospital project to identify an optimal rehabilitation strategy by using probability distributions over resilience measures as well as over integrated measures of resilience (e.g., total equivalent cost).

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The work by the Cornell team is state of the art in terms of using non-Gaussian seismic acceleration models and assessing structural and non-structural performance using fragility surfaces. The work by the USC team is state of the art in terms of developing more complete consequence measures (recently expanded to resilience measures) and for evaluating rehabilitation alternatives including financial and business models. The unique part of this collaboration between the two teams is the link between engineering (damage states, fragility curves, simulation of life cycle hazards) and the social science (resilience measures, financial and business modeling, and overall decision analysis).
### Progress to date:  
(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

1. Completed the decision tree model for the hillside home (paper accepted by Risk Analysis) – originally drafted in 2000, final revision in 2002.
2. Completed a decision tree application to rehabilitating apartment buildings (Technical Report completed, paper will be submitted to Earthquake Spectra) - 2001
3. Developed a simulation model for the decision analysis and applied it to the apartment building application (model and analysis completed, paper will be submitted to Risk Analysis) - begun in 2001, completed in 2002
4. Integration of the Cornell and USC decision analysis framework – begun 2002, continuing
5. Collaborated with Jay Love of Degenkolb, Bill Petak and Dan Alesch to better understand the perspective of hospital managers regarding seismic rehabilitation decisions of hospitals – begun in 2001, continuing
6. Worked with MCEER team on resilience concept (paper submitted to Earthquake Spectra) - 2002

### Role of Proposed Task in Support of Strategic Plan:  
(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The proposed tasks for year 7 contribute to MCEER’s overall goal of improving earthquake resiliency of communities through enhanced seismic assessment and performance of health care facilities. The main objective is to increase the seismic resilience by reducing (i) the probability of system failure, (ii) the consequences due to failure, and (iii) time to system restoration.

To contribute to the MCEER’s goal of enhancing seismic resiliency of communities, we will (i) develop a methodology for assessing the seismic performance of individual and multiple health care facilities using fragility surfaces, (ii) develop a probabilistic simulation model for life cycle seismic hazard, and (iii) integrate Cornell seismic performance analysis and life cycle seismic hazard model with the USC’s decision analysis framework for evaluating and selecting rehabilitation alternatives.

### Task Integration:  
(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

- The development of relevant damage states will be done in close collaboration with the Cornell team. This task requires both engineering judgment (Cornell) and judgments by hospital managers and staff (to be obtained by USC)
- Resilience measures will be jointly developed with the Cornell team and other researchers involved in MCEER’s resilience task
- USC will use Cornell’s damage states and fragility curves in the models to assess resilience of hospitals
- Cornell will use USC’s business and financial model in its resilience assessment (formerly: cost-benefit analysis)
- Cornell and USC will closely collaborate in building a decision analysis tool, including associated software) to assess and evaluate rehabilitation alternatives for hospitals
Possible Technical Challenges:

A major challenge is to define and operationalize the concept of resilience in the hospital setting. This will be the key element of developing a decision analysis model, which will describe and evaluate all consequences of seismic decisions/events in the hospital setting. One important challenge in this task is to define appropriate damage states for hospitals, since these damage states provide the bridge between the fragility curves and the ultimate consequences to the hospitals. This task will require close collaboration between the Cornell team and the USC team.

Another challenge is the development of a business and financial model. We have learned from the past applications that the financial decision and model parameters are very important, even for individual homeowners (hillside homes) or apartment building owners (tuckunder apartment buildings). We expect the financial decisions and models to be even more important and much more complex in the hospital setting.

We also learned that many hospital managers consider seismic rehabilitation decisions in the context of their long-range strategic plans, not as an isolated decision. Thus, we will face a challenge in bounding the seismic rehabilitation problem as part of the broader strategic planning issues.

### Anticipated Outcomes and deliverables:  
(Also indicate those of particular benefit to IAB members and other end users.)

- Damage states for hospitals  
- Resilience measures for hospitals  
- Integrated software combining Cornell and USC decision analysis models  
- Prototype application to a hospital in Southern California  
- Both technical and tutorial publications describing the approach and application

### Potential end-users beyond academic community:  
(IAB members and others.)

- Hospital administrators and decision makers  
- Planning agencies concerned with seismic risks (e.g., OSHPD)  
- Engineering firms analyzing and evaluating rehabilitation alternatives

### Educational outcomes and deliverables, and intended audience:

The decision analysis framework, the software associated with it, and the application to hospital rehabilitation decisions will provide many insights in the concept of resilience, in structuring hospital rehabilitation decisions, and it can serve as a prototype for engineers and hospital administrators to analyze their own rehabilitation decisions.
**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

- Fall 03: Initial integration of decision analysis frameworks and models by Grigoriu and von Winterfeldt
- Fall 03: Development of limiting damage states for hospitals based on interviews with hospital administrators and staff
- Spring 04: Resilience measures for a single health care facility (later: for a network of health care facilities)
- Summer 04: Methodology for identifying optimal retrofit strategies for seismic rehabilitation of structural / non-structural systems.
- Fall 04: Software prototype

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

1. Detlof von Winterfeldt, Professor, USC
2. Mircea Grigoriu, Professor, Cornell University
3. Mark Benthien, Research Assistant, Master of Public Administration student, USC
4. Chaitanya Gosh, Master of Planning student, USC

**Possible Direction of Work in Subsequent Years:**

1. Extend the resilience concept and measures to other MCEER areas
2. Develop additional decision support tools for earthquake rehabilitation
3. Collaborate with Bill Petak and Dan Alesch on issues of strategic planning for hospital rehabilitation decisions
<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>042010</td>
</tr>
</tbody>
</table>

**Task Title:** Evolutionary Methodologies for Decision Support

**Investigator/ Institution:**
- G.F. Dargush, University at Buffalo (PI)*
- W.J. Petak, University of Southern California
- D.J. Alesch, University of Wisconsin

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

Our ultimate objective is to develop new algorithms, models and related software for decision support within earthquake resilient communities, based upon evolutionary methodologies. Previously, we focused on developing robust and efficient approaches for evolutionary aseismic design and retrofit (EADR) of passively damped structural systems within an uncertain environment. In Year 7, we will continue to enhance the performance of this methodology by developing multi-level formulations for transient dynamics that have the potential to reduce computational effort by an order of magnitude. However, the primary research focus will be on the development and incorporation of socio-technical models for both single and spatially distributed critical care facilities.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

Over the past three years, MCEER has supported the development of an evolutionary optimization approach for the aseismic design and retrofit of passively damped structures. Significant progress has been made and the current version is quite promising. An initial beta-version of the software (eadr_1.0) will be made available to the MCEER community in Summer 2003. Release of a subsequent parallel version (eadr_2.0) is proposed as a Year 7 Networking Subtask.

However, in order to increase applicability to more complicated and realistic structural models, we will also begin development of a multi-level transient dynamic algorithm in Year 7. Recent work on another NSF-sponsored project has led to the development of fast multi-level boundary element formulations that significantly change the computational complexity and therefore result in speedups of several orders of magnitude. Similar ideas can be used within finite element structural dynamics, although we anticipate somewhat more modest computational advantages. Of course, even a single order of magnitude improvement could have a dramatic effect on the evolutionary optimal design approach and, more generally, for structural dynamics calculations.

One of the key advantages to evolutionary algorithms is their applicability to a wide range of...
difficult combinatorial optimization problems. In Year 6, we began to investigate the potential of the evolutionary approaches for socio-technical decision modeling. As the other major subtask for Year 7, we propose to continue this investigation by increasing the range of the decision space and the reliability of the socio-technical models. We will consider situations involving single critical care facilities, as well as those associated with spatially distributed facilities.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Our research conducted over the past three years and that proposed for the next several years, attempts to make contributions at an applied level within the field of earthquake engineering and at a basic level within the disciplines of complex adaptive systems (CAS) and evolutionary algorithms. Evolutionary methods, in general, and genetic algorithms, in particular, have been employed in many fields over the last few decades, beginning with the pioneering work by Holland (1975). The books by Holland (1992), Goldberg (1989) and Mitchell (1996) provide good overviews of the subject. Applications of genetic algorithms (GA) within earthquake engineering have recently appeared, including the work by Singh and Moreschi (1999, 2000, 2001) and Li et al. (2001).

Our research differs from those above by including multiple damper types, along with nonlinear structural and passive damper models. More fundamentally, our work also differs by addressing the inherent uncertainty of the seismic environment, by introducing new knowledge-based algorithms and by proposing the concept of parallel interactive evolutionary design. Furthermore, in a practical sense, the MCEER work will produce software that can be used by researchers and industry partners to promote the development of earthquake resilient structures.

On the other hand, we believe that the proposed evolutionary methods incorporating socio-technical models, along with elements of structural design and retrofit, are completely original. While other decision support approaches may be suitable for the analysis of a very limited number of possible decisions, none are suitable for the vast range of possibilities that actually exist. However, evolutionary algorithms are ideally suited for these problems.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

In previous years, MCEER support led to the development of continuum level models for a number of control devices including a viscoelastic (VE) damper, a metallic plate damper, and an E-damper component for seismic isolation systems. Each case involved development of appropriate constitutive models. For example, a temperature and frequency dependent model was developed for VE materials and correlated with experimental data, and a two-surface plasticity model was developed for cyclic response of structural steel. Both were implemented as subroutines within the general-purpose finite element code ABAQUS. Macro-models were also developed for each device to enable efficient overall structural analysis.
Beginning in Year 4, the framework for Evolutionary Aseismic Design and Retrofit (EADR) was established and successfully applied to a series of multistory steel moment frame retrofit examples, incorporating metallic, viscous and viscoelastic dampers. The initial version runs on a single processor in a sequential mode utilizing a genetic algorithm for discrete optimization under uncertain ground motion time histories. Each structural evaluation is performed via a nonlinear transient dynamic analysis utilizing the above-mentioned models. At present, EADR may utilize either ABAQUS or an in-house state-space explicit transient dynamic code. During Year 5, effort was directed toward enhancing the functionality, robustness and efficiency of this evolutionary approach. In particular, a knowledge base is now generated to accumulate information and automatically adapt the environment during the evolutionary process. In Year 6, a more realistic seismic environment was incorporated based upon a USGS Gutenberg-Richter model, a GIS database and user-interface was introduced and a massively parallel version of the approach was developed. The result is an efficient algorithm with practical applicability for aseismic design and retrofit, and a methodology appropriate for application to more general problems of decision support.

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The development of evolutionary methods and software for decision support contributes directly to the central theme of the MCEER strategic plan. These methods have the potential to accommodate the uncertainty and complexity inherent in the socio-technical decision-making process, and thus can ultimately contribute to the development of earthquake resilient communities.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

In Year 7, the proposed research defined above will interface with a number of other on-going projects by MCEER-funded researchers. This includes the work on modeling viscoelastic composite panels (Aref, Reinhorn), semi-active response reduction technologies (Lee, Whittaker) and performance of secondary systems in protected structures (Constantinou, Whittaker). The extension of the evolutionary algorithms for more general socio-technical decision support will require close coordination with other on-going research by Petak and Alesch.

Possible Technical Challenges:

One of the primary technical challenges in the development of these evolutionary methods will be to maintain robustness and computational efficiency. The introduction of a knowledge base in Year 5 to accumulate information and to adapt the environment improved the situation considerably, as did the transition to parallel computing in Year 6. However there remains a need to improve efficiency. The multi-level methods proposed here in Year 7 are very promising, but technical challenges remain in their development.
The application of the evolutionary methods to socio-technical problems of decision support will no doubt provide even greater challenges. For example, we must resolve issues related to problem definition, parameter estimation and algorithm control.

**Anticipated Outcomes and deliverables:**
(Also indicate those of particular benefit to IAB members and other end users.)

Evolutionary Aseismic Design and Retrofit software. A parallel version will be made available on the MCEER Networking Website for MCEER researchers and IAB members.

A version of the software including a new multi-level structural dynamics algorithm will be developed on the UB CCR computing platform.

Formulations and algorithms for the socio-technical decision support of critical care facilities.

Conference and journal papers documenting progress.

**Potential end-users beyond academic community:** (IAB members and others.)

IAB members and other practicing engineers interested in the design and retrofit of structures with protective systems.

IAB members and other practicing engineers interested in fast transient dynamic analysis.

Ultimately, with the extension to socio-economic problems, all those interested in developing earthquake resilient communities.

**Educational outcomes and deliverables, and intended audience:**

A significant portion of our previous MCEER research has found its way into the graduate level courses taught by the PI. In particular, the course on Advanced Finite Element Analysis contains a significant seismic component. That course is also available to distance learners via the UB EngiNet program.

Two doctoral students (Q. Yu and Y. Wang) will have completed their degrees during Year 6. One other student (R. Sant) finished his Ph.D. in Year 5. During Year 7, we propose to provide full support for two additional doctoral students.

The software developed under MCEER support will be made available through the MCEER Networking Website. Naturally, this software can be used for educational purposes, as well as for research and development. The interactive version, in particular, could provide a very effective education tool for both graduate students and practicing engineers.
### Project Schedule and Expected Milestones for the Project:

*Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.*

Three subtasks have been discussed above. All three will be developed concurrently. The goal is to release the parallel version of the software (eadr_2.0), along with the necessary documentation by Spring 2004 under the MCEER Networking program. The remaining two tasks involving the development of a new fast multi-level transient dynamics algorithm and the enhanced socio-technical decision formulations will not be completed until the end of Summer 2004.

### Team Members:

*If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.*

- Gary F. Dargush, Professor
- Mark L. Green, Research Assistant Professor
- Ali R. Hadjesfandiari, Postdoctoral Associate
- Mikhail Grigoriev, Postdoctoral Associate
- Yunli Wang, Ph.D. Candidate
- Yufeng Hu, Ph.D. student
- One additional first year doctoral student

### Possible Direction of Work in Subsequent Years:

The development of these new evolutionary methods for multidisciplinary decision support is clearly a multiyear research program. Work in subsequent years will continue toward the development of additional socio-technical decision support functions. Additional applications of the evolutionary algorithms in crisis decision-making and recovery management may be appropriate.

One of the key issues in evolutionary structural design concerns the computational requirements associated with nonlinear transient dynamic analysis. In Year 7, we propose development of new multi-level methods to dramatically reduce the computational complexity of those required analyses. However, some additional work may be needed in Year 8 to fully realize the significant potential of these alternative computational approaches.
### MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Number:</td>
<td>042011</td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Developing Acute Care Hospital Decision Parameters into Integrated Methodologies

**Investigator:** William J. Petak*, University of Southern California  
**Institutions:**  
- Daniel J. Alesch, University of Wisconsin-Green Bay  
- Gary Dargush, University of Buffalo  
- Detlof von Winterfeldt, University of Southern California  

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The goal is to contribute to MCEER’s system objective of improving community resilience to the earthquake hazard. This is achieved by operationalizing the organizational and decision-making contextual models that are central to assessing the outcome of organizational choice alternatives about allocating capital for seismic safety to meet or exceed state and local regulations.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

One of the fundamental long-term goals of earthquake engineering research in general and MCEER in particular is to enable the development of disaster-resilient communities. The development of innovative engineering technologies is certainly beneficial in this regard. However, to prove effective, the new technologies must be implemented and the corresponding enhancements to engineering design codes must be adopted. The processes involved in technology implementation go far beyond traditional engineering concerns. It is essential to give simultaneous consideration to the organizational, economic, social, political, and legal aspects of the problem.

Within the goal of the MCEER Program (i.e., improving the resilience of critical community facilities to earthquake forces) we propose to integrate elements of work by Petak and Alesch on organizational decision-making processes with the decision-assisting model and evolutionary aseismic design and retrofit models being developed by von Winterfeldt and Dargush, respectively.

Nowhere, to our knowledge, is there an integration of computational organizational decision making processes with structural engineering choice alternatives for ensuring resilience of critical facilities. Given this condition, it is necessary that we conduct a “proof of concept” test to learn the extent to which empirically-based, computational organizational behavior models
can be integrated with normative engineering and decision-assisting models. The outcome of the proof of concept test will not be known by the start of Year 7. It is appropriate, therefore, that the investigators submit two proposed sets of action to account for the two possible fundamental outcomes of the proof of concept test.

**Year 7 Proposal, Assuming the Proofs of Concept Works**

Assuming that the proof of concept exercise indicates that solid linkages can be developed with the decision support platforms, the primary Year 7 task would be to attempt to move from proof of concept to actually integrating the Petak and Alesch decision criteria and processes into one or both of the decision-assisting platforms being developed by Dargush and von Winterfeldt.

The goal would be to identify, operationalize and integrate organizational and contextual variables that appear to be central to determining the outcome of organizational choices about allocating capital for seismic safety to meet or exceed state and local regulations and to integrate them into the decision-assisting models. The four researchers would work to determine how best to incorporate the organizational decision criteria into the decision-assisting models. Currently, Alesch and Petak are examining a broad array of variables that appear to influence risk reduction investment decisions. These include: available mitigation technology, quality of the available mitigation (e.g., perceived effectiveness of the mitigation alternative, rate of change in development of mitigation technology), causal texture of the organizational environment, the perceived and objective vulnerability of the facility to an earthquake, the resiliency of the organization to absorb losses, cost of implementation, financial capacity of the organization (e.g., market conditions, availability of capital, institutional liquidity, debt capacity, and cost of the mitigation), quality/availability of codes and regulations, managerial and owner risk profiles and perceived liability.

Further tests would be conducted to assess the utility of using the organizational decision criteria by comparing the outcomes of actual decisions by health care organizations with predicted outcomes from the decision-assisting models under different assumptions and with different values for the variables. We would expect to employ sensitivity analysis to hypothetical cases and to simulate the conditions facing sample organizations, employing the appropriate values for critical variables in those cases, and comparing model outcomes with the actual decisions made by those organizations. The results would be evaluated and appropriate adjustments made to calibrate the criteria or to reconceptualize and design their application. A technical report describing and evaluating the research would be prepared.

**Year 7, Assuming the Proof of Concept Does Not Work**

We are confident that the proof of concept will demonstrate that integrating the behavioral models into the decision-assisting platforms is possible. We are not confident, however, of the form that integration may take. The proof of concept test may indicate that the team has not yet been able to overcome the inherent difficulties associated with integrating normative and descriptive models of organizational choice -- that the behavioral model decision criteria employed by health care organizations cannot yet be integrated directly with either the Dargush or von Winterfeldt models. If that is the case, then the proposed Year 7 tasks would focus on developing alternative means for using the Petak-Alesch behavioral model of organizational
Year 7 tasks would then focus on developing a stand-alone, behaviorally-based model of organizational decision making for evaluating the acceptability, to the individual health care organizations, of alternative means and price tags for enhancing various levels of seismic safety. This model could be loosely coupled with the Dargush and von Winterfeldt decision-assisting platforms to provide constraints or directions. This approach would employ generalized simulation software to the extent that a match can be made between the model and available general-purpose simulation software. Preliminary indications are that appropriate software may be available.

The effort would also focus on identifying the conditions under which health care organizations in various sets of circumstances would find it possible or desirable to enhance seismic safety in new or existing structures, including, for example, various kinds of financial or regulatory incentives, changes in financial operating margins, or alternative forms of regulatory mandates.

The resulting model would serve as a tool for practicing professionals to better understand the effects of organizational constraints on choices for enhancing seismic safety and for researchers and students to help them gain greater understanding of the contextual constraints of seismic safety decision making.

The effort would also include tests of the extent to which the (now) separate behavioral model can be used in conjunction with the decision-assisting platform models, even without direct integration into those platforms, to enhance those platforms.

### Assessment of State-of-the-Art:
*(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

To the best of our knowledge, no work like this is being conducted anywhere. Work is, of course being conducted on both normative and descriptive decision making models and, within MCEER, work is being conducted on normative decision assisting models, but nowhere is anyone attempting to link behavioral and normative models of decision making to address complex issues of choice, particularly in the area of enhancing resiliency in the face of extreme events. Moreover, the need for such a product was expressed in February 2003 by the Applied Technology Council in connection with its ATC 58 project. ATC calls for three products: an understanding of stakeholder decision-making processes (in connection with enhancing seismic safety), developing performance-based seismic engineering characterization, and building a connection between the performance based seismic engineering framework and stakeholder decision making. This project aims squarely at contributing to the first and third of these expressed needs.

### Progress to date:
*(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

In years 4, 5, and 6, Drs. Petak and Alesch have focused their attention on three fundamental tasks. First, they focused on developing a more complete understanding of the obstacles to
implementing earthquake hazard mitigation policies and programs. They conducted an extensive and intensive literature review that cut across a number of behavioral disciplines. Using their review as a guide, they then initiated an extensive case study of the development and implementation of California’s SB 1953 -- legislation intended to result in strengthening and ultimate removal from service of acute care hospitals built before 1973. The intent was to develop an understanding of decision criteria and decision processes employed by health care organizations with regard to improving seismic safety for older acute care facilities. The first result of the work is an extensive case study centering on California’s SB 1953, integrating a critical analysis of the relevant policy making and organizational behavior literature. The case study was a necessary by-product of the effort to complete the primary objective of the task. The primary objective is, by the end of Year 6, to conduct “proof of concept” tests to learn the extent to which the results of the behavioral research can be linked with two of the fundamental models being developed in Thrust 2 for decision-assisting models. Petak and Alesch are working to complete a proof of concept test with the decision support platforms being developed, respectively, by Professors Gary Dargush (University of Buffalo) and Detlof von Winterfeldt (University of Southern California). The four will work to learn the extent to which the information about and understanding of organizational decision making for health care organizations can be incorporated in decision support models being developed by Dargush and von Winterfeldt. It is expected that the Petak and Alesch findings will either constrain or expand the array of solutions that would result in enhanced seismic safety for specific clients or classes of client either generated or evaluated by the decision-support models. The proof of concept test, along with the completed case study, will be the culmination of the Petak and Alesch Years 5 and 6 tasks.

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

Contributes to the enhancement of critical facility seismic risk reduction in a complex environment by increasing the likelihood of adoption and implementation of risk reduction measures. Bridges engineering choices with stakeholder needs to enhance critical facility robustness, thus enhancing community resiliency.

Integration: (Describe how the work performed interfaces with other tasks and researchers funded MCEER.)

The primary purpose of this project is to contribute to the development of useful decision-assisting models for making choices about how, if at all, to strengthen buildings, primarily hospitals, against losses from earthquakes. To the extent possible, this is a task intended to integrate stakeholder decision making and behavior with engineering choices. It facilitates the connection between engineering performance and stakeholder decision making and helps to integrate the efforts of Thrust 2 researchers developing decision support platforms.

Possible Technical Challenges:

Two dominant obstacles exist. Both can be side-stepped if they cannot be overcome. The first is to find an existing model platform that adequately matches the conceptual model of organizational decision making and that it can be coupled with the platforms being devised by Dargush and von Winterfeldt. If such a model cannot be found, then the challenge will be to create a symbolic model that can, subsequently, be operationalized to run as a free-standing
model, in tandem with Dargush and/or von Winterfeldt, or tightly-coupled with the Dargush and von Winterfeldt models.

The second obstacle is closely related. It centers on the challenges of coupling descriptive and normative/analytic models. The model being devised by Petak and Alesch describes how decisions are actually made by stakeholders. Dargush is constructing a model to devise robust engineering designs for structures. Von Winterfeldt is developing a normative (this is how you should do it) decision assisting platform. The team will attempt to bridge the inherent differences in the three types of models to integrate them. To our knowledge, this has not been accomplished before. The challenge is to find a way to do it, either with tightly coupled algorithms or more loosely connected sets of parameters and conditions.

**Educational outcomes and deliverables, and intended audience:**

Robert Chen, a doctoral candidate at the University of Southern California, will be assigned a research assistantship on the project. He will conduct his basic research for his doctoral dissertation on decision making in health care organizations under conditions of stress. His doctoral dissertation is intended to be a significant contribution to the literature and the results will lead directly into the achievement of the project goals; and will be considered a product of this research effort. He will work with Drs. Petak, Alesch, and von Winterfeldt directly.

The primary other educational outcome will be an expanded knowledge of organizational decision-making processes and behavior in addressing mitigation of low probability/high consequence events. The audience will consist primarily of academics, but will bridge the gaps between engineering, organizational behavior, and decision making in an interdisciplinary context.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

1st quarter: Revise conceptual model based on continued field research with healthcare organizations. Revise structure of model based on results of proof of concept tests.

2nd quarter: Members of the team work together to integrate the model with decision assisting platforms. Dargush develops algorithms for integrating parameters into his decision assisting platform. Von Winterfeldt examines the implications of alternative organizational scenarios for his decision assisting platform.

3rd quarter: Continue the collection of data, develop critical care decision typology. Elaborate the organizational decision making model as tests are performed to assess utility of the linkage between the model and the platforms.

4th quarter: Complete the model and transfer it to Dargush and von Winterfeldt for application to their decision-assisting platforms. Write final reports.

**Possible Direction of Work in Subsequent Years:**
Not known at this time.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>NYS Hospital</td>
<td>042012</td>
</tr>
</tbody>
</table>

**Investigator/Institution:**
- George Lee* and Mai Tong / University at Buffalo
- M. Shinozuka (UC Irvine)
- Joe Middleton (Bassett Hospital),
- Brian Sitzman and Ron Curtis (Cannon Design),
- Thomas Jung (NYS)

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

NYS faces a different kind of seismic risk than CA. This task is a continuing effort to address the special seismic risk in NYS. The goal is to develop a hazard evaluation and disaster preemptive decision-support platform for NYS hospitals. The platform is intended to seek owner acceptable ways to retrofit facility, develop emergency plan or use protection technologies for mitigation of earthquake and other natural and manmade disasters.

This task is unique in that it is a commitment of MCEER to NY State to carry out research for disaster preparedness for NYS hospitals against earthquake and other natural and manmade hazards.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

NYS hospitals in large metropolitan areas are subjected to infrequent, but high consequence seismic risk. In many critical healthcare facilities, both structure and non-structural systems have little or no seismic resistance. This task is to address the need for reducing this risk in cost effective ways. The target of the task is to understand the aggregated impacts on hospital medical services under a hazard condition, and evaluate the various preemptive action plans (retrofit engineering, emergency plan, long term systemic risk reduction upgrade scheme). The major steps to be taken during 2002-2004, as established in year 6, are:

**2002-2003**

1. Build a modulated tool for facility system modeling (tentatively include power, water, HVAC, fire suppression, and medical gas). This model platform will include the major function units of the system in sufficient details such as the normal and emergency operation of the system will be easily examined and the impact of the critical component breakdown can be quickly evaluated.

2. Begin to establish a database of failure modes for the critical subsystems or units of each facility systems such that in case of a breakdown, the impact and possible reactions are
clearly understood.

2003-2004

3. Complete the database and continue to build an analysis procedure for seismic problem identification and retrofit engineering solution design.

In year 7, we expect to successfully accomplish the two tasks planned for year 6 (modeling of the hospital facilities and modeling the risks associated with the major facility systems). With the integration of the two models, we will begin to explore selected disaster scenarios and to evaluate the impact of the disasters on the operation of the hospital. We will need to develop detailed list of possible damage to the facility systems, as well as a comparison of the benefits of using selected protective technologies by using NYS hospitals.

The overall strategy for the NYS hospital project may be viewed from the following figure on Disaster Impact on Hospital Medical Services. The goal of this task is to establish a platform for risk evaluation of the critical hospital facilities so that hospital owners and facility managers can benefit from it in making retrofit decisions and in regular maintenance of the facilities.

**Hazard Impact on Hospital Medical Services**

![Diagram of Hazard Impact Flow and Functional Interaction in Hospital](image)

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

There are two main efforts available in hospital modeling: individual system models (such as structural model, elevator model, pipeline model) and management models (such as human resource, logistic, supply, etc.). The MCEER hospital task is putting strong efforts to integrate physical systems model with management model. The NYS hospital project uses a problem-oriented approach addressing a limited scope as an experiment to develop an integrated platform for NYS hospitals. The specific characteristics for New York State are given above in the...
After this platform is established, it will be calibrated by using the California hospital information for possible application in other states.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

We have worked through four hospitals in NYS (two in NY city, one in Western NY, and one in Central NY). For each hospital, a database with structural model and selected non-structural components are constructed. A web based information database is setup with structural and relevant non-structural drawings, FEA models, dynamic analysis and seismic hazard risk estimation.

In 2002, the hospital evaluation framework developed in this task was enriched by the data of a central NYS hospital. The NYS hospital task researchers participated in the design and evaluation of a major renovation project in this central NYS hospital. A detailed structural analysis report was first developed followed by a comparison analysis of several retrofit schemes. Now with the completion of the design face and the successful start of the construction, the NYS hospital task is moving in to study the impact of the retrofit to the facility systems (power, water, HVAC, and fire protections). During 2003, it is our plan to fully work with this central NY hospital to develop the two necessary models as mentioned above.

The key of the research framework is still the hospital operational model based on patient flow as described before. In this regard, the framework has been substantiated with the real facility system data from the central NYS hospital. Currently, detailed flow diagrams of power, water, HVAC and fire protection systems are being developed. We have been fortunate to have full cooperation from the staff of this hospital.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

MCEER’s Strategic Plan is to help build seismic resilient communities. NYS as well as eastern U.S. has unique seismic risk: the earthquake occurrence is much less frequent than CA, however, the consequence may be much more severe than CA.

This NYS hospital project has a special mission to strategically satisfy the demand of NY State, which provided the matching commitment for NSF funding.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This task is pursued in parallel with the larger hospital task on California hospitals. First, the PIs are working with a team of industry/end users to establish a detailed hospital facility model. Then this model or platform together with associated methodologies will be shared with
researchers working on the CA hospitals for the purposes of validation and development of retrofit strategies for the CA hospitals.

**Possible Technical Challenges:**

Hospital facility systems (power, water, HVAC, fire protection) consist of many inter-dependent components. There are many factors contributing to possible failure of these components. We have collected rather comprehensive information about the components and their possible failure modes; however, to cover all the major risk factors may still be too ambitious a goal for this small research task. To protect a hospital so that it can continuously provide medical services under a disaster is an extremely complicated issue. Physical facility is only one component. Other issues must be considered including human resources and logistics etc. Given the limited funding and time, we are facing the challenge to link the physical facility operation with the overall medical service of a hospital. Our goal for the next two years is to select a few systems and develop a facility to system link model.

The current major problem facing the MCEER researchers is that a large volume of data needs to be analyzed and sorted. With the cooperation of the hospital management and staff of a central NY hospital, we hope to be able to come up with a prototype model for test run by the end of 2003.

**Anticipated Outcomes and deliverables:**

*Also indicate those of particular benefit to IAB members and other end users.*

1. Risk evaluation platform based on data from selected NY hospitals database (2003-2004)
2. Documentation of the seismic risk evaluation and decision-support platform and associated methods

**Potential end-users beyond academic community:** *(IAB members and others.)*

Hospital administrators, facility managers and planners, facility operators and technical support personnel.

**Educational outcomes and deliverables, and intended audience:**

Research experience for

1 Postdoc, part time
1 Graduate student, part time
1 Undergraduate student, part time
**Project Schedule and Expected Milestones for the Project:**  *Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.*

- **Fall 03 - Spring 04:** Completed the facility detail model and failure mode model
- **Summer 04 – Fall 04:** Integrate the two models into a prototype platform.

**Team Members:** *If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.*

- **Industry contributors:** Joe Middleton (Bassett Hospital), Brian Sitzman and Ron Curtis (Cannon Design), Thomas Jung (NYS)
- **Other MCEER contributors:** M. Shinozuka (UC Irvine), Dr. Jincheng Qi (UB)

**Possible Direction of Work in Subsequent Years:**

During 2004-2005, we intend to develop the modulated system to be applicable to other hospitals and to link the single hospital platform to regional hospital network models under development by M. Shinozuka.
## MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
<th>Project Number: 042013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Development of Web-based GIS Geotechnical Data for Hospital Sites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigator/</td>
<td>*T.D. O’Rourke, Cornell University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institution:</td>
<td>A.J. Lembo, Cornell University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* indicates task leader</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Statement of Project Goals:
(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

A unique opportunity is provided by current MCEER research on geotechnical issues associated with acute care facilities. Currently MCEER is involved in a survey of 248 individual hospital facilities in several counties of Northern and Southern California containing a total of some 1,364 buildings. The survey will mine data from reports already at OSHPD, which has offered full access and cooperation.

The project goals are to 1) develop GIS databases of borehole and subsurface information at all sites being investigated and link them to a web-based center for dissemination of geotechnical data accessible by a variety of users, 2) coordinate this effort with on-going work to create similar database access by PEER/COSMOS, researchers at USC, and SCEC, and 3) incorporate the web-based center into an undergraduate teaching module for online student instruction. This project meets the overall MCEER objectives of promoting earthquake resilient communities through advanced technologies by applying IT and GIS to provide readily accessible subsurface data for seismic hazard assessment, seismic hazard modeling, and earthquake risk reduction.

### Problem Description and Research Approach of Proposed Work for Year 7:
(Detailed description of research to be conducted and methodology to be used.)

The Year 7 project is designed to complement and expand on Year 6 work related to characterizing the geotechnical conditions at acute care facilities. Current Year 6 work is being conducted by M. Lew at MACTEC under the supervision of R. Dobry and T.D. O’Rourke. It involves mining relevant information from hospital site engineering geological reports (which include information about the sites) and seismic evaluation reports (which include information about the buildings) available at OSHPD. A spreadsheet summary is being compiled with the following information: facility name; location; buildings per site; number of licensed and GAC beds; SPC ratings; liquefaction, landslides, tsunami/seiche, surface faulting, seismically induced flooding potential, and seismic motion hazards; and building characteristics. This information will be used for a statistical assessment of hospital sites and systematic evaluation of the main geotechnical factors that will affect hospital performance during futures earthquakes.

The data set being compiled will record the potential for liquefaction, landslides, site amplification, etc. as indicated in the site engineering geologic reports. It will not include explicit borehole logs or detailed data about the subsurface conditions at hospital site, contained in these reports. The Year 7 project is designed to take advantage of the opportunity...
afforded by data mining of hospital sites to create a web-based center for subsurface data and borehole information in a GIS format.

The proposed work for Year 7 follows from the project goals:

1. **Web-based GIS Database of Borehole and Subsurface Information**

   Borehole and subsurface information will be collected and digitized from the hospital site engineering geologic reports. This information will be linked through ArcIMS to GIS maps of hospital sites and boring locations. The GIS will be available at an MCEER website created by Cornell researchers. The information will be linked and digitized in two steps. First, the borehole data will be scanned and made accessible at the website by hyperlink to borehole log images. Links can also be created to the geotechnical reports in pdf format. This first step allows for relatively rapid creation of the website and dissemination of information at a rudimentary level. The second step will involve transferring the borehole data into relational database software. Access® is currently considered a good candidate because of its relatively low cost, ease of use, and broad availability. It can also be linked to ArcIMS. The relational database will connect with the web-base GIS so users can click on boreholes and query data and use them for analysis purposes. This platform will also allow users to create GIS surfaces showing water table elevation, zones of liquefiable soils, elevation of underlying hard and/or dense deposits, etc.

2. **Coordination with Other Databases and Earthquake Center-based Activities**

   In developing this task statement, researchers at the University of Southern California (USC), Southern California Earthquake Center (SCEC), California Geologic Survey (CGS), US Geologic Survey (USGS), Pacific Earthquake Engineering Research Center (PEER) and COSMOS were contacted. There are many existing databases and GIS platforms used by these organizations. There are several activities underway with input from a large user community. These activities involve the PEER/COSMOS Project on Archiving and Web Dissemination of Geotechnical Data (http://geoinfo.usc.edu/gvdc) and the Geotechnical Information ITR Project at USC (http://geoinfo.usc.edu/itr). The architecture adopted in the PEER/COSMOS project is proposed for this work. The PEER/COSMOS project uses ArcIMS, which is the preferred ESRI software at Cornell. Hence, the project has been designed to be immediately compatible with the GIS and database technologies being used by sister organizations. The project will also maintain a continuing dialogue and collaboration with the institutions mentioned above. In this way, the databases and website created will be consistent with those being developed elsewhere. The data at other sites will also be accessible to MCEER researchers, industrial partners and affiliates, and students.

3. **Education Module**

   The College of Agriculture and Life Sciences at Cornell University through the Faculty Innovation Grant is supporting the creation of an ArcIMS web server application to initially function as a central repository of geographic data for three different courses at Cornell: Resource Inventory Methods, Geographic Information Systems, and Spatial Statistics. Dr.
Arthur J. Lembo, Jr. from the Department of Crop and Soil Sciences, who oversees this activity, currently devotes half his time performing research with the School of Civil and Environmental Engineering.

The application will allow students to access course related GIS data and applications from their dormitory or other remote locations via the Internet. Using ESRI's ArcIMS, Cornell will create specific applications in support of laboratory exercises and lecture material. To accomplish this, Cornell will utilize the existing ESRI site license for ArcIMS, separately purchase a dedicated server in support of the application, and obtain ESRI certified training for administering the map server technology. Finally, through the efforts of the Academic Technology Center, Cornell will provide programming support services to implement the application. Initially, the data will be loaded into an ESRI geodatabase for access by students through ArcIMS.

The scaleable architecture offered by ArcIMS will allow Cornell to offer the MCEER data as another ArcIMS service, with password protection, for use by MCEER, other researchers, and students. Additionally, the dedicated server has been designed to accommodate other geospatial data related to the MCEER project. The cooperative effort at Cornell will allow for quick implementation of map server applications. It will support the vision of the Faculty Innovation in Teaching Grant to make the ArcIMS application available to both MCEER researchers and students engaged in undergraduate and graduate courses. The Cornell educational web site will be linked to the MCEER web site to provide access for MCEER visitors who are interested in this educational component.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Cooperative US-Japan research supported by MCEER, NSF, and PEER has led to the acquisition, visualization, and web-based GIS access of subsurface data at worldwide sites, including Los Angeles areas affecting the LADWP water supply (e.g., Bardet, et al. 1999 a and b, Bardet and Hu, 2003, Swift and Nigbor, 2001). Web-based sites, equipped with GIS, for acquisition of geotechnical subsurface data have been or are in the process of being developed (http://geoinfo.usc.edu/gvdc, http://geoinfo.usc.edu/itr, http://geoinfo.usc.edu/peer, http://geoinfo.usc.edu/rosrine).

A recent workshop supported and organized by PEER and COSMOS (Stepp et al., 2001) was focused on archiving and web dissemination of geotechnical data. The objectives of the workshop were to develop consensus recommendations for classifying, archiving, and Internet distribution of various geotechnical data. The most important result of the workshop is that the creation of a web-based center for distributing geotechnical data from multiple linked databases is principally a process of applying existing technologies for digital database structures and Internet communications. Dissemination of data can be accomplished through a central hub, which could house data, but would certainly house metadata and/or indices that permit access through various linked databases from various contributors. In such a configuration, the virtual center can expand its linkages to any number of geotechnical data collections.

Current NSF supported ITR research at USC is focused on supplying ITR solutions for exchange
and utilization of geotechnical data (http://geoinfo.usc.edu/itr). The research objectives include the definition of versatile data structures and the development of metadata and data mining tools.

As discussed above, Cornell researchers have spoken at length with USC researchers and PEER/COSMOS organizers to prepare this task statement. The proposed work is fully compatible with the current model of a web-based virtual center being created by PEER/COSMOS. Moreover, key owners and developers of geotechnical databases at SCEC, USGS, and CGS have been contacted during the development of this work statement. The research plan is fully consistent with the state-of-the-art and ongoing activities to disseminate geotechnical data.

References


Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

Progress to date has involved meetings in Los Angeles among R. Dobry, M. Lew, and T.D. O’Rourke to make a preliminary evaluation of the information contained in hospital site geotechnical reports. A spreadsheet format was developed for collecting data in 12 different categories. Work study students have been hired by MACTEC, reports have been sent from OSHPD to the MACTEC office in Los Angeles, and work has commenced on transcribing information from the reports to the spreadsheet database. In addition, several hospitals sites have been visited by R. Dobry, M. Lew, and T.D. O’Rourke, and detailed geotechnical information and post-Northridge earthquake observations and photos have been collected for the Northridge Hospital site. The photos clearly show the occurrence of liquefaction throughout the site.
Contact has been made with the principal organizations that archive geotechnical data for the Los Angeles area, including SCEC, USC, PEER/COSMOS, CGS, USGS, and OSHPD. For example, a meeting was held between T. Jordan (Director of SCEC) and T.D. O’Rourke in Washington, DC to discuss SCEC databases and GIS format, and to coordinate with SCEC on geotechnical database development.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The proposed work supports the strategic plan by providing an Internet-oriented geotechnical database, useful for assessing liquefaction potential, liquefaction-induced ground deformation, seismic site response, landslide activity, water levels, soil strata, liquefiable layers, etc. This database will be coordinated with the California Earthquake Centers and other organizations that archive borehole information in the Los Angeles area. The database will support soil-structure interaction analyses at hospital, water supply, and electric power sites. Hence, the database provides valuable overarching information for both the Lifelines and Hospital Thrusts. Moreover, the GIS developed for the acute care facilities will provide the basis for evaluating individual sites as well as the regional hospital systems and its interactions with transportation, water supply, and electric power systems.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The results of the survey and other aspects of the study will be of interest to PIs doing structural research in Thrust 2.

**Possible Technical Challenges:**

Technical challenges include:

1. Coordination of database development between researchers at Cornell and companies and agencies in California.

2. Proper QC/QA procedures to ensure accuracy and reliability of data sets, plus any limitations related to the inherent quality of data in the OSHPD reports and the adaptability of geotechnical report information into a relational database.

3. Adaptation difficulties when applying ArcIMS 4.0 to spatial analysis on the Internet.

4. Definition of functional requirements, standardized data formats, data indices, and data exchange standards among multiple users.
| **Anticipated Outcomes and deliverables:**  
(Also indicate those of particular benefit to IAB members and other end users.) | **Potential end-users beyond academic community:**  
(IAB members and others.) |
|---|---|
| - Statistical assessment of geotechnical issues at hospital sites to support decisions regarding MCEER geotechnical research.  
- Comprehensive geotechnical GIS database that is accessible through the Internet to multiple users.  
- Overarching capability to query and analyze geotechnical data throughout the Los Angeles region. | Geotechnical engineers, structural engineers, building officials, hospital regulators (including OSHPD), and hospital community (including owners, administrators, and facilities managers). Lifeline managers and engineers for water supply, transportation and electric power systems |

**Educational outcomes and deliverables, and intended audience:**  
- Web-based geotechnical database accessible by multiple users. The intended audience here includes lifeline agencies, government, planners, engineers, and universities.  
- Repository for geographic data to support undergraduate and graduate courses. The application will allow student access to course-related GIS data, operations, and analyses from their dormitories or other remote locations via the Internet. The GIS database will be incorporated into three Cornell courses, and used for homework and design projects.

**Project Schedule and Expected Milestones for the Project:**  
(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)

**Summer 03:** Spreadsheet database for 248 hospital sites and statistical analyses to evaluate the importance of geotechnical conditions throughout the complex of acute care facilities.

**Winter 03:** Preliminary web-based GIS geotechnical database hyperlinked to borehole images and geotechnical report information.

**Summer/Fall 04:** Web-based geotechnical database linked through relational database software to allow for data queries and analyses.

**Fall 04:** Fully operational repository of geographic information, including the geotechnical database, to support undergraduate and graduate courses. Incorporation of the repository in actual courses at Cornell.
Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- T.D. O’Rourke, Professor, P.I.
- A.J. Lembo, Senior Research Associate, co-P.I.
- Graduate Research Assistant

Possible Direction of Work in Subsequent Years:

In future years the databases will be used for evaluating hospital and lifeline performance under various scenario earthquakes. The databases can also be used to assess the interactions among regional hospital system and the transportation, water supply, and electric power networks.
THRUST AREA 3: Emergency Response and Recovery

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

A key point is that while response and recovery activities must be undertaken as rapidly as possible when a major earthquake disaster strikes, it is equally important that the activities that are undertaken are appropriate ones—that is, that they employ resources effectively and in ways that contain losses and facilitate optimal recovery. MCEER’s Thrust Area 3 research activities thus center on two interrelated objectives that are of critical importance to society: improving both the speed with which response, restoration, and recovery activities are undertaken and the quality of the decisions that are made in the immediate and longer-term post-impact period.

A description of the integration between tasks is presented in Volume I.
### MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number:</th>
<th>043001</th>
</tr>
</thead>
</table>

**Task Title:** Advanced Technologies for Loss Estimation, Development of Damage Functions, using Remotely Sensed Data and Real-Time Decision Support Systems

**Investigator:** Ronald T. Eguchi,* ImageCat, Inc.

**Institution:** Bijan Houshmand, Remote Sensing and Communications Consultant  
M. Shinozuka, University of California, Irvine  
A. Papageorgiou, University at Buffalo

*indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This task focuses on the development and application of remote sensing technologies for building inventory development, real-time earthquake loss estimation, and post-earthquake damage detection. Ultimately, these technologies will be adapted for real-time decision support systems. In order to validate the methodologies, data from several recent earthquakes is being used, including: the 1994 Northridge; the 1995 Kobe; the 1999 Turkey; the 1999 Taiwan; and now the 2001 Bhuj event.

This task involves four investigators/institutions: Eguchi (ImageCat and Task Coordinator), Houshmand (Consultant), Papageorgiou (SUNY), and Shinozuka (UCI). ImageCat is concentrating on the use and application of optical and SAR technology for building inventory development and post-earthquake damage detection in large regions. Houshmand is providing support to overall project team in the area of SAR technology. He has been instrumental in helping research team members acquire software tools to process SAR data and in interpreting the results of SAR correlation and coherence studies. Papageorgiou is focusing on the application of GPS technology for post-event damage assessment. Whereas, optical and SAR remote sensing technologies measure changes to the earth’s surface due to both tectonic ground displacements and building or infrastructure damage, GPS-derived observations only measure changes due tectonic ground displacement. Our goal is to use these GPS observations (displacements) to recalibrate SAR measurements to clearly identify those areas affected primarily by changes caused by building or infrastructure damage. Shinozuka will be using SAR, optical and LIDAR technologies to detect damage to individual buildings. Using a variety of statistical techniques (correlation analysis, principal component analysis, Bayesian-based Markov random field analysis), Shinozuka is attempting to quantify different damage states (such as total or partial collapse) using higher resolution SAR or LIDAR data. This work complements the research that ImageCat is doing on regional damage assessment methodologies. Each investigator has submitted as separate task statement that elucidates the approach being used to assess post-earthquake damage using some type of remote sensing technology. Combined, these research efforts provide a comprehensive approach at regional and facility-specific damage assessment using remote sensing technologies.
Problem Description and Research Approach of Proposed Work for Year 7: (Detailed description of research to be conducted and methodology to be used.)

Advanced technologies, such as remote sensing, are emerging as useful post-earthquake evaluation tools. Recent studies in Japan, Europe and the U.S. have shown that satellite-based imagery can identify broad zones of damage following significant earthquake events. In some cases, damage caused by widespread liquefaction and fire-following effects can be determined from low-resolution, remotely sensed data (Kobe earthquake). More recently, damage sustained in urban environments has been identified on both low and high-resolution optical coverage (Bhuj). In the long-term, it is expected that the use of remotely sensed data will help to facilitate post-earthquake decision-making and ultimately, improve the overall response.

This particular task involves the use of advanced technologies in real-time decision support systems. Research will investigate the application of these technologies during: (a) the immediate response period (initial days following a large earthquake); (b) the early recovery period (several weeks following the earthquake); and (c) as a key component of longer-range mitigation programs. The study approach will identify ways in which decisions made during these disaster periods (or the timeframe under which the decisions are made) can be improved through the integration of remote sensing technologies, based on an initial study of methods and procedures that are currently employed in the decision making process.

Specific Year 7 assignments by task leader include integrating preliminary remote sensing damage detection algorithms with loss estimation tools (HAZUS, EPEDAT), developing multi-sensor data fusion techniques, and investigating the significance of data scaling issues in damage detection methodologies.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The research conducted by MCEER is unique within the U.S. research community. Overseas, studies concerning the use remote sensing technologies for post-earthquake damage detection are being conducted by the Earthquake Disaster Mitigation Research Center (EDM) in Miki, Japan, and more recently in the UK, by researchers at Cambridge University. Collaborative research with EDM is currently being undertaken for several events, including: the 1994 Northridge; the 1994 Kobe; the 1999 Marmara, Turkey; and the 1999 Chi-Chi, Taiwan earthquakes. Following initial discussions, the project team has recently proposed a data sharing exercise with Cambridge University.

A number of geophysical groups in the U.S. and Europe are investigating the use of interferometric synthetic aperture radar (IFSAR) for earthquake response. However, this research is primarily concerned with measuring the displacement or strain fields surrounding large magnitude earthquakes.

Further research efforts are currently being launched by several other federal agencies, including DOT and NASA, to develop methodological bases for the use of remotely sensed data in disaster response. These programs are in the “truth of concept” phase. MCEER researchers are actively involved with a number of these programs.
**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

During the first six years, research efforts have concentrated on: (1) modeling urban areas using synthetic aperture radar technology; (2) exploring the use of optical imagery to separate the urban environment from natural surroundings; (3) developing a framework with which to assess post-earthquake damage, using optical and IFSAR data and devising preliminary post-earthquake damage detection algorithms, for locating collapsed urban structures; and integrating GPS and SAR data and information in the assessment of post-earthquake ground displacements and building damage.

Residential, commercial, and industrial areas in Los Angeles have been successfully characterized in terms of ‘building height signatures’. Building height signatures are constructed by summing total building footprint areas across various story height categories (height is obtained from IFSAR elevations). Analysis of the three different landuse types indicates that the building height signatures vary according to parameters including: curve shape; slope; intercept; and maximum story height. The principal value of these models lies in the quantification of total floor area, from which the total building replacement cost is computed. During the past year, research has been conducted to determine the stability of building height signatures to scaling issues.

Progress has also been made with the use of ERS SAR and SPOT optical imagery to detect earthquake damage after major earthquakes. Preliminary findings for the 1999 Marmara event show that a comparative analysis of ‘before’ and ‘after’ satellite imagery reveals damage sustained by buildings. The project team has devised various change detection indices describing the extent of these changes, including: intensity difference; correlation; and coherence. The indices have been compared with ‘ground-truth’ data for two towns in Turkey (Goleu and Adapazari). In both cases, qualitative inspection suggested that the magnitude of change detected in satellite images is directly proportional to the amount of observed building damage. The higher resolution afforded by SPOT coverage provides the greatest distinguishing capability. During the past year, progress has been made with the development of quantitative building damage detection algorithms for the 1999 Marmara earthquake. Preliminary damage functions have been produced for the SAR and optical coverage, expressing the concentration of collapsed structures as a function the previously listed indices of change. Further exploratory research has focused on the value of data fusion for enhancing the information content provided by these measures. Several approaches have been devised, employing innovative sensor and Bayesian decision fusion techniques.

In addition, we are comparing displacement and strain field maps derived from GPS measurements with those developed from SAR interferometry. The research challenge here is whether we can discern damage to the urban environment by merging data from different sources and technologies. If successful, we plan on extending this analysis to the Chi-Chi, Taiwan earthquake.
**Role of Proposed Task in Support of Strategic Plan:**  *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The development of new technologies that quantify post-earthquake damage in near real-time is a critical step towards improving contemporary response and recovery procedures. As an element of Thrust Area Three, these technologies will enhance community resilience, by: (1) helping emergency officials to identify severely impacted areas in near real-time; (2) contributing to decision support systems that must prioritize response activities based on need, opportunity and available resources; and (3) aiding the communication of critical response information using wireless technologies.

**Task Integration:**  *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This task focuses on the development and use of advanced technologies for emergency response and recovery. New tools and more comprehensive databases of the urban environment are required to improve the speed and reliability of response to major disasters. Thrust Area 3 will result in better tools for emergency planners and officials.

As a result of this research, it is anticipated that planners will have access to better information on exposed assets, more reliable methodologies to project future earthquake losses, and real-time decision support systems that will identify post-earthquake damage within a matter of hours. Critical in this development will be the integration of emerging remote sensing technologies, including: synthetic aperture radar, high-resolution optical satellite imagery, GPS-based tools, distributed geographic information systems (GIS), and improved database management systems. To facilitate the transfer of large datasets and files during a post-earthquake crisis period, research efforts will also focus on the development of more efficient procedures using wireless and broadband communication technologies.

**Possible Technical Challenges:**

The technical challenges associated with testing and validating new technologies are considerable. While the limited nature of available data sets is a concern, demonstrating the efficacy of new technologies compared with conventional and perhaps, more accessible methodologies could create implementation issues. If successful, however, the potential for more accurate and timely post-event loss estimates is extremely high.
**Anticipated Outcomes and deliverables:**
(Also indicate those of particular benefit to IAB members and other end users.)

- Report documenting the development of building height signatures
- Report documenting methodology and models for post-event damage detection.
- Case studies involving U.S. and foreign earthquakes.
- Possible collaboration between several government agencies (LA City and CA OES) and MCEER in pilot studies.

**Potential end-users beyond academic community:** (IAB members and others.)

- Government Agencies: LA City, LA County, California Governor’s Office of Emergency Services, Federal Emergency Management Agency, DOT, NASA.

**Educational outcomes and deliverables, and intended audience:**

Seminars on the use of advanced technologies for post-earthquake damage detection. Intended audience: students, industry representatives.

**Project Schedule and Expected Milestones for the Project:** (Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)

- Report on Opportunities to Improve Crisis Response using Wireless Communication technologies, Summer 2004

**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- Ronald T. Eguchi, ImageCat, Inc., Team Leader
- Charles K. Huyck, ImageCat, Inc.
- Beverley J. Adams, ImageCat, Inc.
- Bijan Houshmand, Consultant
- M. Shinozuka, UCI
- A. Papageogiou, SUNY

**Possible Direction of Work in Subsequent Years:**

- Integration of remote sensing with decision support systems, including near real-time loss estimation programs, e.g., HAZUS, EPEDAT
- Leveraging Information Technologies for Crisis Response (Data Fusion, Mining, etc.)
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Project Number: 043002</td>
</tr>
</tbody>
</table>

**Task Title:** Advanced Technologies for Loss Estimation, Development of Damage Functions using Remote Sensing and Real-Time Decision Support Systems

**Investigator/Institution:**
- Bijan Houshmand*, Remote Sensing and Communications Consultant
- Ronald T. Eguchi, ImageCat, Inc.
- M. Shinozuka, University of California, Irvine
- A. Papageorgiou, University at Buffalo

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This particular task complements work being done by ImageCat, Shinozuka (UCI) and Papageorgiou (SUNY). This task involves project support to ImageCat and UCI in the area of synthetic aperture radar (SAR) modeling. In addition to providing technical support in this area, Houshmand will help to secure software to analyze raw SAR data, i.e., tools to produce correlation and coherence maps. Houshmand will also begin a new task to examine how wireless communication technologies can be used to facilitate real-time damage assessment. Specific research challenges include the transfer of large datasets from various kinds of sensors, and the collection of high-resolution imagery using unmanned aerial vehicles.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

Houshmand will continue to support ImageCat and UCI in the development of near real-time damage detection methodologies using advanced remote sensing technologies. He will work directly with Papageorgiou to reconcile how GPS observations can be used to recalibrate SAR data to isolate building or infrastructure damage from tectonic ground displacements. This application will involve at least two earthquakes: 1999 Marmara, Turkey earthquake and the 1994 Northridge earthquake.

Communication technologies have advanced tremendously in the past decade. The ability to transmit information, voice, imagery and data has increased due to advances in fiber optic infrastructure, fast telecommunication switches and wireless technologies. Many population centers throughout the world are now connected via high-speed telecommunication networks. The goal of this research is to investigate the potential contributions of the current and near future communication technologies to real-time response to disasters. Our research will concentrate on data handling requirements that will facilitate the transfer of large and rich datasets from different types of sensors. We will explore the possible use of unmanned aerial vehicles (UAVs) to collect imagery after an event like an earthquake. We will explore whether these data can be effectively transmitted via a wireless network to a base station, and then to disaster management centers. We will begin this research by investigating the communication requirements necessary to develop such a system. This research task is a natural extension of Year 1 through 5 research; the focus here is on identifying efficient conduits or means of making remote sensing imagery available to end-users as soon as possible. We believe that with current advances in data collection methodologies – such as UAVs – data can be collected and made available in real time.
**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

Change detection using remote sensing technology is an active field of research. We are one of the few teams that are performing this research for damage detection due to earthquake. Our work is unique in terms of merging various remote sensing technologies such as SAR, GPS, and optical imagery for improved damage detection. Wireless communication technologies are also being developed for response to disasters. We are investigating the state of the art of this technology and how this technology can be integrated with MCEER work.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

We have compared the GPS-derived displacements with interferometric correlation maps. We have investigated the state of the art for wireless communication technologies for response to disaster.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

See task statement for ImageCat.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This task focuses on the development and use of advanced technologies for earthquake loss estimation and real-time response. This task contributes to the earthquake loss estimation tasks and to the response and recovery program (Thrust Area 3).

**Possible Technical Challenges:**

The technical challenges associated with the testing of new technologies are considerable. Not only are we dealing with limited data sets, but to demonstrate the efficacy of these new technologies as compared to conventional and perhaps, more accessible methodologies, could pose some challenging implementation problems. If successful, however, the potential for more accurate and timely post-event loss estimates is extremely high. Data from recent damaging events, such as the 1999 Turkey and 1999 Taiwan earthquakes are helping significantly in overcoming these obstacles.
<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical report documenting methodology and results on post-earthquake damage detection analysis.</td>
<td>Loss estimation modelers, government agencies, emergency managers.</td>
</tr>
<tr>
<td>Technical report documenting the comparison of ground survey and our results on post-earthquake damage detection assessment.</td>
<td>Loss estimation modelers, government agencies, emergency managers.</td>
</tr>
<tr>
<td>Technical report documenting the operational communication technologies, and their potential applications for Real-Time Decision Support Systems.</td>
<td>Emergency managers, government agencies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Educational outcomes and deliverables, and intended audience:</th>
</tr>
</thead>
<tbody>
<tr>
<td>See ImageCat statement.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>See ImageCat Statement.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)</th>
</tr>
</thead>
</table>
| Project leader: Ronald T. Eguchi, ImageCat, Inc.  
Professor Shinozuka, UC, Irvine  
Professor Papageorgiou, SUNY, Buffalo |

<table>
<thead>
<tr>
<th>Possible Direction of Work in Subsequent Years:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Further research on the efficacy of wireless communications technologies for emergency response.</td>
</tr>
</tbody>
</table>
MCEER RESEARCH TASK STATEMENT

Task No. | Budget: | Yr 7 Assigned Project Number: 043003
--- | --- | ---

**Task Title:** Validation and Verification of Advanced Technologies for Loss Estimation

**Investigator:** A. Papageorgiou*, University at Buffalo

**Institution:**
- Ronald T. Eguchi, ImageCat, Inc.
- Bijan Houshmand, Remote Sensing and Communications Consultant
- M. Shinozuka, University of California, Irvine

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

1) Completion of the 1999 Chi-Chi, Taiwan, and 1994 Northridge earthquake tectonic displacement fields.
2) Preparation of a report that summarizes the results of all three case studies, i.e., 1999 Izmit, Turkey, 1999 Chi-Chi, Taiwan, and 1994 Northridge, California, earthquakes.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

This particular task complements work being done by ImageCat and Shinozuka by offering another sensor technology for immediate post-earthquake damage assessment. Whereas optical and SAR remote sensing technologies provide a means of detecting changes to the earth’s surface from both ground movement and damage to structures, GPS technology focuses exclusively on relative changes caused by tectonic displacement. The research concept that is being explored here is whether more accurate assessments of building and infrastructure damage can be determined by merging or fusing data from satellite imagery and GPS observations. The objective in this task is three-fold: 1) correlate surface changes with ground truth or field data using GPS observations only, 2) compare regional maps of relative displacement (i.e., interferograms) developed from SAR and GPS observations, and 3) determine whether we can improve SAR correlation or coherence maps – which are indicators of building damage - by adjusting for tectonic ground shifts that are evident in GPS-derived data. To test whether these objectives can be achieved we are studying three earthquakes: 1994 Northridge earthquake, 1999 Marmara, Turkey earthquake and the 1999 Chi-Chi, Taiwan earthquake. So far, we have already developed GPS-derived displacement maps for the first two earthquakes. Year 7 will focus on the Chi-Chi, Taiwan earthquake. Successful application of the techniques described by this particular research element will help to improve our ability to reliably assess damage on a broad regional scale using remotely sensed data. This task is being performed in parallel to one being conducted by Houshmand. Houshmand is developing interferograms for the earthquakes above using SAR data.

Our task is straightforward. Specifically, we want to compute the co-seismic (tectonic) displacement field
produced by a given earthquake. In order to accomplish this we need to know:

1) The slip distribution on the plane of the causative fault.
2) The Green’s tensor of a shear dislocation embedded in the Earth.

The displacement field on the surface of the Earth is computed by convolving the slip distribution on the plane of the causative fault with the Green’s tensor of a shear dislocation embedded in the Earth.

The slip distribution on the fault plane is estimated using a formal inversion of GPS data. This is a rather well established procedure that has been developed and implemented by seismologists.

As Green’s tensor of a shear dislocation embedded in the Earth we use the Green’s tensor of a shear dislocation embedded in homogeneous isotropic elastic half-space. [In fact, homogeneous isotropic elastic half-space is the model that is used in the inversion to represent the Earth. Therefore, for consistency, the same Green’s tensor must be used in the forward simulation]. Analytical expressions for the above Green’s tensor have been derived and published in the literature by Okada (Bull. Seismol. Soc. Am. 75, pp. 1135-1154, 1985). In our forward simulation we use the abovementioned analytical expressions.

Based on the above procedure, we have developed a computer program and we have used it to compute the displacement field for the 17 August 1999, Mw 7.5, Izmit, Turkey earthquake. For the forward simulation we used the slip distribution inferred by Reilinger et al. (Science 289, pp. 1519-1524, 2000) using GPS measurements recorded in the station network shown in Figure 1. The displacement field that we obtained with the forward simulation is shown in Figures 2 (horizontal displacement) and Figure 3 (vertical displacement). The agreement of the computed displacements with the recorded displacements at the GPS stations is excellent (the corresponding figure is not shown here for economy of space).

Figure 1: Map of Izmit region showing GPS sites.
Figure 2: Horizontal component of displacement field.
[The maximum displacement shown on the grid is equal to 2.5 m.]
We have repeated the above-described analysis for the 1994 Northridge earthquake using the slip distribution that Wald et al. (BSSA, S49-S70, 1996) inferred by inversion of geodetic and strong motion data. The field of the horizontal component of displacement is shown in Figure 4.

Figure 3: Vertical component of the displacement field.
[Scale is in meters]

Figure 4: Field of the horizontal component of displacement.
We are currently in the process of obtaining the tectonic displacement and strain field for the 1999 Chi-Chi, Taiwan earthquake. In particular, for this earthquake the near-fault deformation was exceptionally severe, contributing to significant damage of important structures such as dams that were located in the vicinity of Chelungpu fault (i.e., causative fault).

In Year 7 we would like to complete our calculations related to the 1999 Chi-Chi and 1994 Northridge earthquakes, refine some of the calculations related to the 1999 Izmit earthquake, and present the results of our study in the form of a final report (the latter prepared in collaboration with Dr. Bijan Houshmand).

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

Research work referenced in our work statement and related to our work is reported in the following journal papers:


**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

We have completed the computations for the 1999 Izmit, Turkey and 1994 Northridge, California earthquakes. Samples of the results of these computations are shown in the work statement above.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

Key component in establishing remote sensing as a viable tool for response. More effective response capabilities will lead to higher levels of community resiliency.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This task is an integral part of the remote sensing task in Thrust area 3: Response and Recovery. We are currently working with ImageCat and Dr. Bijan Houshmand on this task.

II.A-1.153
## Possible Technical Challenges:

Integration of two sets of technologies (GPS and SAR) will pose the most significant challenge. Our overall task workplan will address this issue by examining the application of these technologies to several different events (1999 Turkey, 1999 Taiwan and 1994 Northridge earthquakes).

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Report documenting methodology and test bed examples.</td>
<td>Emergency responders and managers.</td>
</tr>
</tbody>
</table>

## Educational outcomes and deliverables, and intended audience:

<table>
<thead>
<tr>
<th>Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full report documenting case studies – Summer 2004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)</th>
</tr>
</thead>
</table>

## Possible Direction of Work in Subsequent Years:

Application to new earthquakes if current applications prove to be successful.
### MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 043004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Urban Damage Assessment Using Remote Sensing Technology and Real-time Decision Support</td>
<td></td>
</tr>
<tr>
<td>Investigator/Institution:</td>
<td>M. Shinozuka*, University of California, Irvine</td>
<td></td>
</tr>
</tbody>
</table>

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This project primarily focuses on development of implementable real-time remote sensing technologies to identify the extent, location and mode of seismic damage sustained by urban built environment. Post and pre-event digital (SAR, optical and possibly LIDAR (light detection and ranging)) images obtained from ground, aerial and satellite platforms are used for damage identification. The technical basis of this project is built on the digital image processing techniques existing at UC Irvine, and in this context, we will further improve the correlational analysis, principal component analysis, and Markov random field approach.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

This study will develop and improve methods of digital image processing pertaining to urban seismic damage assessment and detection of more specific structural damage. For this purpose, pre- and post-disaster images will be used. Building on the successes in utilization of the correlation analysis, PCA (principal component analysis) methods with optical data and the coherence analysis method, Bayesian-based Markov random field approach with the SAR data, we initiated to work on other methods of damage identification which are potentially more useful and/or more easily implementable for post-disaster decision making. These methods will include pattern recognition technology utilizing wavelet formulation, and usage of ARC/VIEW software for damage identification and characterization. In Year 7, we continue to work on these other methods and in addition to initiate an effort to measure ground surface strain caused by an earthquake with available GPS data to calibrate the measurement.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

We have kept abreast of the SAR applications and development. Also, our effort for urban damage identification utilizing optical data has been at the cutting edge of the-state-of-the-art. SAR interferogram can be obtained either by repeat-pass scheme (single antenna on board) or by
single-pass approach (two antenna connected together with a rigid baseline). SAR high altitude satellite systems have one antenna on board and make the repeat-pass interferometry implementation feasible. ERS-1 and ERS-2 (European Remote Sensing Satellites) and RadarSat1 (Canadian satellite) are high altitude SAR satellite systems that provide global coverage continuously. JERS-1 and JERS-2 (Japanese Earth Resource Satellites) were other platforms that mapped the earth in the microwave region of electromagnetic spectrum during their operations. These satellites provide an approximated ground resolution of about 20 meters (RadarSat-1 can provide 10 meter resolution in the Fine Mode) suitable for regional monitoring and change detection. The launch of RadarSat2 is being planned for the year 2003. This SAR system will provide an additional Ultra Fine Mode that will deliver data with 3 meters ground resolution. However, this project is unique in that we acquire SAR satellite data of before and after the earthquakes for the Los Angeles area, develop suitable algorithms for differential interferometric studies, and calculate remotely sensed displacement field related to the seismic activities or ground activities which will be correlated to urban seismic damage. Furthermore, we intend to calibrate the remotely sensed displacement field with the use of GPS data. The calibration will involve the interpretation of the difference and the modification of the algorithms.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

In Years 1 and 2, the study pursued the development of methods to identify the extent and mode of structural damage due to earthquake by means of satellite- or air-borne SAR images of each structure before and after the seismic event. The simulation of SAR image of structures was demonstrated to be a useful tool. The resulting technical paper was published in Journal of Engineering Mechanics, ASCE. In Year 3, applications of optical images were attempted for damage identification with an emphasis on reconstruction of 3-D models. Also, in Year 3, Babak Mansouri, a graduate student working on SAR imaging, received a Telecommunications Advancement Research Fellowship from the Telecommunications Advancement Organization of Japan to spend two months (February 1- March 31, 2000) at the Hamamatsu Lifeline Research Center in Hamamatsu, Japan. There, he studied a wireless data collection system from monitoring and control of city lifelines. The technical accomplishments in Year 3 and the first half of Yrs. 4~5 were published in a total of 6 papers published in the proceedings of the 7th and 8th Annual International Symposium of SPIE on Smart structures and Materials. Three Ph.D dissertations were completed by Hung-Chi Chung, “Digital Image Processing for System Identification”, Babak Mansouri, “Remote Sensing: Feasibility of Change/Damage Detection in Urban Areas and Structures by Synthetic Aperture Radar (SAR) Imagery” and Ali Rejai, “Unsupervised Change Detection in Remotely Sensed Images”.

**Year 6**

In Y6, Markov Random Field (MRF) theory is used for analyzing the spatial or contextual dependencies of urban damage. In its primary steps, it defines sites and the neighboring property that is essentially mutual. It further defines a site and a clique as a subset of sites with different possibilities for neighboring the other sites, and a configuration as a realization of the field. The
Markovianity property imposes contextual dependency of the label assignments to a neighborhood and their interactive behavior. For change detection application in remotely sensed images, the MRF method showed a significant promise and a report is being written to demonstrate its use.

### Role of Proposed Task in Support of Strategic Plan:

*Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.*

This task is carried out as part of MCEER’s effort to provide decision support tools for post-earthquake disaster mitigation. The MCEER research team demonstrated, through a number of publications including a report of its own reconnaissance experience, the usefulness of remote assessing techniques in identifying the location of extensive seismic damage in urban areas in relation to the 1999 Marmara Earthquake in Turkey. To develop real-time post-disaster decision support tools for earthquake emergency response is MCEER’s strategic plan to mitigate seismic disaster and to enhance seismic resilience of the community, and in this context, this project plays a significant and important integrative role.

### Task Integration:

*Describe how the work performed interfaces with other tasks and researchers funded by MCEER.*

With R. Eguchi serving as group leader, this task is closely coordinated with the research being carried out by R. Eguchi, and A. Papageorgiu, and will be, integrated into the effort by MCEER’s response and restoration group to provide technical support for post-earthquake decision making at various levels.

### Possible Technical Challenges:

Availability of affordable super-high resolution satellite-borne optical images for civilian applications remains to be somewhat uncertain. Ikonos optical satellite images with resolution of 1 m range and LIDAR images also with high resolution will be highly useful, but remain to be expensive to acquire at this time. Integration of the technologies developed under this task with the effort expended in other MCEER tasks for the purpose of urban seismic damage evaluation also requires some effort.

### Anticipated Outcomes and deliverables:

*Also indicate those of particular benefit to IAB members and other end users.*

- Computer codes for practical damage detection using SAR and optical images
- Analytical method to estimate ground surface strain seismically induced on the basis of SAR interferometric.

### Potential end-users beyond academic community:

*IAB members and others.*

Researchers, government agencies and emergency response profession
Educational outcomes and deliverables, and intended audience:

A number of undergraduate and graduate students will be recruited and work with post-doctoral researches. They will be trained as junior researcher in the remote sensing area with the depth and breadth of understanding of that technology needed for urban damage estimation purposes. The deliverables include technical reports, their MS and Ph.D. dissertations, and poster-session materials in the MCEER and/or EERI conferences.

Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)

Summarizing the research results up to Year 6 in fall, preliminary studies for new methods in winter, and research on selected new methods in spring and summer.

Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

Masanobu Shinozuka, Principal Investigator, UCI

T.C. Cheng, Professor of Electrical Engineering, USC

Chin-Hsiung Loh, Professor of Civil Engineering, Director of National Center for Research on Earthquake Engineering, Taiwan

Hung-Chi Chung, Research Associate, UCI

Hung Seok Park, Visiting Research Scholar, UCI

Jin Hak Yi, Visiting Research Associate, UCI

Chul-Young Kim, Visiting Research Scholar, UCI

Il Young Jang, Visiting Research Scholar, UCI

Young-Gon Kim, Visiting Research Scholar, UCI

Hyung Jin Lee, Visiting Research Associate, UCI

Sang Hoon Kim, Research Associate, UCI

Hope Seligsen, Graduate Research Assistant, UCI

Youwei Zhou, Graduate Research Assistant, UCI

Adelina Pirijanyan, Undergraduate Student, UCI

Ghada Hamed Hamza, Undergraduate Student, UCI
Possible Direction of Work in Subsequent Years:

In Year 7 and beyond, GPS-compatible GIS applications will continue to be developed for rapid regional damage assessment. Use of optical, SAR and possibly LIDAR images of super-high resolution will provide near ground truth verification in near real-time, and this capability in turn will support search/rescue and other emergency response activities and related decision making.
### MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>043005</td>
</tr>
</tbody>
</table>

#### Task Title:
Comprehensive Community Recovery Modeling

#### Investigator/Institution:
Stephanie Chang / University of Washington

* indicates task leader

#### Statement of Project Goals:
(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This project aims to develop a decision-support tool for urban disaster recovery. The core effort focuses on developing a simulation model of disaster recovery. In Year 6, the objective is to refine the prototype model, specifically with respect to the modeling of resilience measures, intra-urban migration, and policy variables. Year 7 efforts will complete the development of a “first-generation” recovery simulation model. This will involve model refinements, further calibration and validation, and development of visualization capabilities.

#### Problem Description and Research Approach of Proposed Work for Year 7:
(Detailed description of research to be conducted and methodology to be used.)

This project will improve the prototype comprehensive model of community recovery that has been developed in previous years. In contrast to loss estimation models, the recovery model places much greater emphasis on the timepaths by which a community recovers from disaster. It seeks to capture how economic disruption losses accumulate over time, result from interactions within the neighborhood and community, and are influenced by response and recovery decisions. Such a model of the urban disaster recovery process can provide a means for informing and evaluating public decisions that can facilitate recovery. The project in Year 7 consists of two subtasks: (1) model refinement, calibration and validation, and (2) model presentation.

Model refinement, calibration and validation efforts will address problems that have been identified in prior tests of the prototype model. One important problem is the issue of model “flat-lining,” in which the predicted recovery timepaths stall prematurely. This outcome derives from the way certain model equations are specified with respect to key driving variables such as lifeline restoration. To address this problem, the equations will need to be revised; for example, by adding exogenous trend variables. Such revisions will be based in part on calibrations to extensive data that have been gathered and developed for the Kobe earthquake.

A second refinement will be to recast the model in probabilistic terms. Although the current prototype was designed in a probabilistic framework, the implementation to date has been deterministic in order to facilitate testing and validation. Recasting the model in probabilistic terms will involve respecifying the recovery transition equations as Markov chain processes, where the movement of an agent from one recovery level to the next is governed by
probabilities of transition.

A third issue concerns refining the model to facilitate calibration to actual disaster events. This will involve revising how recovery is measured in the model to better relate it to the types of data that are likely to be available following a disaster, such as population and employment. Efforts to broadly validate the model against the Kobe earthquake will be completed. These improvements will lead to the development of a “first generation” recovery simulation model.

In addition to model improvements, a second subtask will focus on the presentation of the model outputs. Currently, the model generates a very large volume of output data on many different dimensions of recovery. Summary routines will be added to the model to efficiently and effectively present the results. Visualization capabilities will be added.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

While a number of earthquake loss estimation models exist and are being developed, both within and outside of MCEER, none emphasize the dynamics of the recovery process. The simulation model being developed here is unique in its attempts to capture the full picture of community recovery – particularly in terms of interaction effects across space, time, and community sectors, and in its consideration of a broad range of pre- and post-disaster decision variables.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

A prototype simulation model has been developed and implemented in Matlab. In the last year, this prototype has been expanded to represent a hypothetical urban area with 4 neighborhoods and 100 businesses and 100 households in each neighborhood. Sensitivity analysis has been conducted. Data from the Kobe earthquake have been used to partially validate the model in terms of broad outcomes. While results are promising, the model testing has revealed some key issues that need to be addressed (as discussed above). A book chapter has been accepted for Modeling Spatial Economic Impacts of Natural Disasters, eds. Y. Okuyama and S. Chang (forthcoming from Springer-Verlag). An MCEER Technical Report has been drafted. A paper will shortly be submitted for the MCEER 2002-03 Research Accomplishments volume.

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The proposed research will support MCEER’s strategic plan by contributing toward a decision-support system for disaster recovery. It develops a comprehensive model of community recovery, which quantifies the social and economic dimensions of community resilience. This model provides emergency managers and planners with a tool for exploring the complexities of how decisions (e.g., implementing mutual aid agreements) influence community recovery and resilience.
Task Integration: *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This work provides a basis for implementing and testing community resilience measures being developed by other MCEER researchers, inc. K. Tierney. It can help determine inputs and calibration points for CGE modeling of indirect economic impacts by A. Rose. It will benefit from work on decision variables, loss reduction strategies, and their effectiveness that is being conducted by W. Petak and D. von Winterfeldt.

Possible Technical Challenges:

Probabilistic modeling will be a challenge and may involve tradeoffs with computational efficiency. Model calibration and validation remain challenges since empirical data are sparse and complex to interpret for this purpose.

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: <em>(Also indicate those of particular benefit to IAB members and other end users.)</em></th>
<th>Potential end-users beyond academic community: <em>(IAB members and others.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>“First-generation” disaster recovery simulation model</td>
<td>National, state, and local level government agencies concerned with disaster recovery</td>
</tr>
<tr>
<td>Paper submitted for journal publication</td>
<td>Emergency managers and planners</td>
</tr>
<tr>
<td></td>
<td>Utility agencies</td>
</tr>
</tbody>
</table>

Educational outcomes and deliverables, and intended audience:

Training of 2 graduate students.

In addition, the recovery model itself can serve as an educational tool for emergency managers and planners.

Project Schedule and Expected Milestones for the Project: *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

- **Fall 2003:** Refine model by respecifying key equations and outputs, and conducting further calibration.
- **Winter 2003:** Complete model validation against Kobe case.
- **Spring 2003:** Implement probabilistic version of model.
- **Summer 2003:** Develop summary routines and visualization capabilities for model outputs. Write up for publication.
**Team Members:**  *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

S.E. Chang, Principal Investigator  
S. Miles, graduate research assistant (GRA)  
another GRA, to be determined

**Possible Direction of Work in Subsequent Years:**

Application of prototype model to an actual urban area, e.g., Los Angeles. Assessment of how advanced technologies and methodologies for lifelines and in response and recovery could affect community resilience.
MCEER’s USER NETWORKS

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

A description of the integration between tasks is presented in Volume I.
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Project Number: 044001</td>
</tr>
</tbody>
</table>

**Task Title:** Networking of Computational, Experimental and Educational Facilities – Develop and coordinate the sharing infrastructure for center-wide products

**Investigator/Institution:**
- A. M. Reinhorn*, University at Buffalo
- E. Maragakis, University of Nevada, Reno **
- A. Dargush, MCEER ***

* Indicates task leader  
** Funding requested in a separate Task Statement  
*** Funding from the Education Program

## Statement of Project Goals:
(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The objective of this task is to develop the networking infrastructure for sharing newly developed products of research and disseminate them through educational programs. The infrastructure includes equipment and software for communication and linking of physical facilities with software and databases produced by the research tasks. Moreover the development includes distribution of information via web-based operations to educational programs at MCEER institutions and its minority based universities. Further work in this task includes a functional integration of the information collected to develop an integrated platform.

## Problem Description and Research Approach of Proposed Work for Year 7:
(Detailed description of research to be conducted and methodology to be used.)

Following the achievements in previous years, the Networking Program is focusing on development of a distributed infrastructure of access to products created in the main research tasks. The infrastructure has grown by integrating individual software products and databases, developed for evaluation of structures and lifelines and for surveying damage. While the products integrated in the network are those, which became available in the previous research tasks, those products do not cover the overall center-wide mission as reflected in the system diagram.

The restructured networking program is intended to integrate products from the whole system to enable all tasks and approaches specified in the system diagram. The Networking Program identifies products developed in the research tasks, products missing in the “overall system platform” see diagram below -, and plans networking sub-tasks, which can complement and complete the platform.

The networked products cover evaluation procedures and databases, which are stored at institutions, which developed them, and procedure to access and use them. The access is based on a series of web-access procedures developed as templates, - or example programs –, which facilitate use by researchers, industry partners and other users.
Moreover the networking program facilitates use of the center information by students and researchers for education purposes through web-based distribution. Webcast seminars and other lectures, video-teleconferences and other virtual meetings are supported with infrastructure developed in house using low budget communication systems through web and point-to-point connections.

The program in cooperation with the Education Program – Andrea Dargush - intends to develop a multidisciplinary seminar, which covers the integrated engineering and social science aspects. The Networking Program will provide the infrastructure for development of such seminar without displacing the speakers and the audience.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

The work done in this program is generic and although elements are being developed in NEES initiative, through its CHEF and GLOBUS components, the current program provides both content and infrastructure, while testing its usefulness.
**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

The current program is a restructure of an initial development. The restructuring brought new subtasks, which are currently in latest stages of completion and integration in the network. Templates to facilitate integration, instruction to researchers on integration procedures and examples were developed.

An infrastructure of webcasting and recording educational activities and supported with personnel involving professionals from the Computer Science and Engineering, graduates and undergraduates.

The products of this networking can be accesses through the MCEER website Users Networks or [http://civil.eng.buffalo.edu/users_ntwk/](http://civil.eng.buffalo.edu/users_ntwk/)

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The proposed task is intended to create an integral platform for the research task products, and make them available to the research, education and industry communities. The platform and its components are based on the system diagram and are aimed to provide the overall tools to achieve the strategic goals.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The nature of this task is integration of work done by all other center investigators. The system based platform shown in the diagram above show the tasks integration with the tools developed in this task. The tools developed here are providing the functional links, storages and access to the tasks in the diagram.

The development of the Multidisciplinary Seminar is done in cooperation with the Education Program

**Possible Technical Challenges:**

Technical challenges are numerous since the technology available although apparently simple is largely untested and the development of the tools requires a combined understanding of information technologies (IT) as well as earthquake engineering and socio-economic science issues. Immediate challenges are in the web integration of audio video with two-way interaction at multiple sites. This will be tested between the two coordinating institutions before the implementation to other institutions.
<table>
<thead>
<tr>
<th><strong>Anticipated Outcomes and deliverables:</strong>&lt;br&gt;<em>(Also indicate those of particular benefit to IAB members and other end users.)</em></th>
<th><strong>Potential end-users beyond academic community:</strong> <em>(IAB members and others.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Website with access to software and databases with self guided instructions for use.</td>
<td>Researchers at member institutions and at large.</td>
</tr>
<tr>
<td></td>
<td>Students and teachers in educational programs</td>
</tr>
<tr>
<td></td>
<td>Industry partners and others.</td>
</tr>
<tr>
<td></td>
<td><em>Note: Some of the products are accessed restricted depending on the research teams</em></td>
</tr>
</tbody>
</table>

**Educational outcomes and deliverables, and intended audience:**

The infrastructure for delivery of web based information is already used in WEBCAST lectures an seminars and in virtual meetings over the web.

The development of the infrastructure for the multidisciplinary seminar along with its materials provided by the Education Program will produce also modules for education community-wide.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

This task is based on completion of subtasks in the other research tasks. Therefore all the outcome of this task is expected at the end of Year 7. However, intermediary products such as templates, integration software, hardware for web connectivity are expected within six months after the start of the Year 7.

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

The work is done in cooperation with Prof. Maragakis, University of Nevada Reno, Mr. Jason Hanley, BS Comp.Science (part time) and an undergraduate student (to be named). In addition coordination will include the faculty at other institutions involved in the above task.

**Possible Direction of Work in Subsequent Years:**

In the future years, efforts will be directed to provide a shell platform for integration of the computational information and the databases. Interface software (API’s) and automated integration procedures would be developed.
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Number:</td>
<td>044002</td>
<td></td>
</tr>
</tbody>
</table>

## Task Title:
Networking of Experimental Facilities

### Investigator/Institution:
M. Maragakis* and S. Elfass
University of Nevada, Reno

### Team Members/Institutes:
A. Reinhorn, University at Buffalo
A. Dargush, MCEER.

* indicates task leader

## Statement of Project Goals:
*(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

Enhance the current network system to allow a better interaction and information exchange among the experimental and computational facilities and laboratories of the participating institutions in MCEER as well as laboratories of other institutions from around the country or the world through the Internet. Such an interaction includes, but not limited to, sharing up-to-date information as well as providing a virtual presence via video teleconference and webcasting.

## Problem Description and Research Approach of Proposed Work for Year 7:
*(Detailed description of research to be conducted and methodology to be used.)*

The objective of this proposal is to continue the steps taken towards the development of a large-scale network system for the purpose of networking of MCEER experimental and computational facilities through the Internet. This network system will allow researchers and engineers to share the up-to-date information about the laboratory experimental facilities and research activities and achievements performed by different institutions. Steps have been taken already in year 6 toward the accomplishments of networking of the facilities. It is necessary, however, to complete and test the available solutions. In year 7 the goals of this task are to:

- Design and implement new online protocols for sharing information about:
  - Computational platforms that can be used as a guideline for describing computer programs, algorithms, or anything to do with numerical computations or data processing that have been developed at any participating university or research institute.
  - Survey data from damage assessment reports generated by investigators after earthquakes.
  - Images compiled from reconnaissance studies performed by investigators after earthquakes.
- Explore the enhancement of the current “Live Video Webcast” system by implementing new technologies that would allow an interactive classroom type of presentation through the Internet for networking of experimental activities, seminars, and online classes among...
researchers, engineers, and students from different institutions.

- Coordinate the subtasks producing the databases and provide assistance until production is complete
- Continuously update and maintain the current available experimental networking services such as the up-to-date technical publications on several research topics performed at UNR, the information about the experimental facilities at UNR (including detailed list of lab equipment, their specifications, and photos), etc

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

There is an ongoing effort through NEES, to employ the Internet technology to link various Earthquake Engineering research facilities. The main goal of this effort is to provide remote users from different universities with telepresence and teleoperation capabilities. The project proposed in this proposal includes activities complimentary to NEES. The focus of this project is the development of different templates aimed at enhancing the current capabilities of sharing of information between different universities and research institutes.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)*

The following is a summary of the achievements towards the objectives of Task 4.1 through the web site of the Bridge Research and Information Center (BRIC), which is headquartered at the University of Nevada, Reno: (i) an advanced network system has been employed for Internet “Live Webcast” of the experimental events performed at UNR using Microsoft Media technology, (ii) an online protocol for sharing information about experimental activities including achievements and test procedures that could be used as a guideline for future tests has been developed. This protocol also includes dissemination of experimental test results, photos, and video clips. A sample of the protocol is published on BRIC web site, (iii) an advanced video teleconference equipment is in use for live interaction through the Internet, (iv) updating the online detailed inventory which provides up-to-date information about the experimental facilities of the structures laboratory at UNR as well as a detailed listing showing number, models, and specifications of the available equipment to be used for experimental facilities networking purposes among different institutes, (v) a complete list of technical reports that were published by the Department of Civil Engineering at UNR has been developed including abstracts and photos and video clips of several experimental tests. This can be used for sharing the most recent research findings and achievements of research studies performed at UNR with other researchers and engineers from different institutions.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

All the objectives of this proposal are related to networking experimental and computational facilities, sharing data and disseminating effectively research results. These efforts contribute not only to enhancing the efficiency of research performed at MCEER, but also to more efficient
dissemination of the results to other researchers, practicing engineers and the community in general.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The techniques developed in this project will be applied for the dissemination of information from experimental and analytical results performed in other MCEER programs. For example all of the results, pictures, and video of the hospital piping distribution systems tests that will be performed at UNR as part of Program 2, will become available using the protocol that will be developed in this task. The other developed techniques regarding computational platforms, survey data from damage assessment reports, as well as images compiled from reconnaissance studies will be made available to be integrated and adopted by participating universities.

**Possible Technical Challenges:**

An important challenge is developing a generic protocol capable of encompassing all of the contributing factors for any subject. This requires an intensive interaction between the protocol developer and the various researchers who will be using these protocols. Another important challenge is the integration of tools necessary to conduct efficient classroom-type seminars to the current web cast equipment. This will require Advanced Internet programming as well as hardware, which may be beyond the budget requested for this task.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

- A protocol using a state-of-the-art network system for dissemination of information about computational platforms through the Internet.
- An online protocol for dissemination of information about survey data from damage reports.
- A protocol to catalog images compiled from reconnaissance studies performed by investigators after an earthquake.
- Explore the enhancement of the current web cast equipment to allow an interactive classroom type of presentation through the Internet.

**Potential end-users beyond academic community:** *(IAB members and others.)*

- MCEER researchers, other researchers and practicing engineers.
- MCEER researchers, other researchers and practicing engineers.
- MCEER researchers, other researchers and practicing engineers.
- If implemented, MCEER researchers, other researchers and practicing engineers.

**Educational outcomes and deliverables, and intended audience:**

All the tools developed in this project are related to the networking of experimental and computational facilities of MCEER and the availability of research results, pictures and videos.
on the Internet. Furthermore, web casts of tests and exchange of templates will become available on a routinely basis. Therefore, these tools and the web available information can be used in the educational activities of MCEER.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

**Task 1:** *(Fall 2003)*
Design and implement the protocol for electronic dissemination of information about computational platforms.

**Task 2:** *(Spring 2004)*
- Design and implement for the protocol for electronic dissemination of survey data from damage assessment reports.
- Design and implement the protocol to catalog images compiled from reconnaissance studies conducted after catastrophic events

**Task 3:** *(Summer 2004)*
Explore the enhancement of the current “Live Video Webcast” system by implementing new technologies that would allow an interactive classroom type of presentation through the Internet for networking of experimental activities, seminars, and online classes among researchers, engineers, and students from different institutions.

**Task 4:** *(Throughout the year)*
- Close coordination of subtasks producing the databases and assistance until production is complete.
- Continuous efforts for updating, implementing and maintaining the currently available experimental networking services will be made. This includes updating the information about the experimental laboratory facilities and capabilities at UNR, the detailed list of lab equipment and their specifications, the most recent publications containing information about findings and achievements of experimental research activities performed at UNR, the experimental protocols and others.

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

This project will be under the directions of Emmanuel “Manos” Maragakis, professor and chair of civil engineering department at the University of Nevada, Reno. Dr. Sherif Elfass, information manager, will be the co-principal investigator for this project. Dr. A. Reinhorn, University at Buffalo, and Dr. A. Dargush, MCEER, will be the other team members.

**Possible Direction of Work in Subsequent Years:**

The following are the projections for future years:
- Using the developed template for reporting results of experimental and computational
research studies performed at UNR or by MCEER researchers as well as researchers and engineers from other institutions

- Continuously updating, implementing and maintaining the current provided experimental networking services to the civil engineering community.
- Initiate the framework for a web-based database of most recent technical publications with information about up-to-date research achievements and activities performed at other agencies.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned Project Number: 044003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title: Networking of Computational, experiment and Educational Facilities: Complementary Subtasks from main tasks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigator/ Institution: A. M Reinhorn*, University at Buffalo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. Chang, U. of Washington</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R. Eguchi, ImageCat, Inc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Grigoriu, Cornell University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. O’Rourke, Cornell University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G.C. Lee, University at Buffalo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. S. Whittaker, University at Buffalo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. Dargush, University at Buffalo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Shinozuka, University of California at Irvine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates task leader

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

1. S. Chang "Direct Losses, Social Impacts, and Community Resilience – Los Angeles Lifeline Study” (Subtask of Thrust Area 1 and 3)
2. R. Eguchi: “Satellite Imagery Database & MCEER Virtual Reconnaissance System (VRS)“ (Subtask of Thrust Area 3)
3. M. Grigoriu, "Fragility Based and Rehabilitation Decision Analysis” (Subtask of Thrust Area 2 and 1)
4. A.S. Whittaker: “Fragility database for hospital structures” (SubTask of Thrust Area 2)
5. A.M. Reinhorn: “Development of framework and tools to automate and integrate fragility sensitivity in global and local structure evaluation - software” (Subtask of Thrust Area 2)
6. G. Dargush, “Software for Evolutionary Methodologies for Decision Support ” (Subtask of Thrust Area 2 and 3)
7. G.C. Lee “Database of the information system of NY State hospitals” (Subtask of Thrust Area 2)
8. Tom O’Rourke; “Web-Based GIS database of water distribution system”, (Subtask of Thrust Area 1)
Problem Description and Research Approach of Proposed Work for Year 7: (Detailed description of research to be conducted and methodology to be used.)

S. Chang " Direct Losses, Social Impacts, and Community Resilience – Los Angeles Lifeline Study" (Subtask of Thrust Area 1 and 3)

In MCEER's new systems approach, the quantitative measurement of resilience is a central area of new research. This project aims to develop a loss model and related measures of community resilience for the Los Angeles lifeline study. The objective in Year 6 is to transfer the Memphis lifeline loss model framework to L.A. and expand it in the direction of social losses. In Year 7, I propose to refine the L.A. loss model in three ways: (1) Performance objectives, which are needed to quantify resiliency, will be revised. This will be accomplished through consultation with lifeline management practitioners, as well as other MCEER researchers. (2) The “social resiliency” dimension of the model will be expanded to include outages to hospitals. This will entail collecting data on the L.A. regional hospital system. (3) Preliminary testing of the model will be conducted. Results from MCEER's engineering models of water and power damage, outage, and restoration in L.A. will be incorporated to the extent that they are available. If unavailable, dummy data will be used in the interim. This networking subtask is associated with a main task in which a loss model and related measures of community resilience are being developed for MCEER's Los Angeles lifeline study. The networking products to be prepared in Year 7 include a software tool and example for evaluating social and economic measures of resilience. In the networking subtask for the L.A. lifeline study, it is proposed to prepare some web-based computational databases. These databases will include the results of the preliminary testing of the L.A. loss model. The results will pertain to resiliency outcomes (technical, organizational, social, and economic) for various testing scenarios. The loss and resiliency software would be designed to facilitate future integration with engineering models that other MCEER researchers are currently developing for water and electric power damage, outage, and restoration. The example would pertain to a testing scenario. Association documentation will be developed.

R. Eguchi: “Satellite Imagery Database & MCEER Virtual Reconnaissance System (VRS)“ (Subtask of Thrust Area 3)

The initial purpose of "Contribution #5 - Networking" was to create an on-line catalog of aerial and satellite images of recent disasters. Following a positive response from the research community, this initial task expanded into a system that would not only catalog recent events, but also provide data for future events in near real time. The final product, VRS (Virtual Reconnaissance Survey) will allow researchers to share spatial data on-line through a web browser. A base map consisting of publicly available spatial datasets such as pre-event satellite imagery, elevation maps, streets, schools, hospitals, lifelines, and political boundaries will provide contextual information for an event. HAZUS results, post-event imagery, observations of damage, photos, and video linked to GPS data will be uploaded to a server, integrated with VRS, and easily viewed on top of the base map. The end user will view all this data simply as a map interface in a web browser, although it will have the capability to integrate the results of advanced technology research. This may ultimately prove very useful for the not only research community but also to emergency responders. To date, research has focused on building and verifying the toolkits to effectively distribute the data, such as wavelet compression and Internet Map Servers. In the current research year, we are developing the system architecture, the database design, and the user interface, all of which will culminate in a prototype. The aim here
is to have an "Event Template" that could be immediately customized for any location in the world. In the following year, we will pilot test the program and resolve issues such how to obtain, serve and store massive world datasets. Additionally, we will investigate technical issues surrounding deployment such as security and the scalability of wavelet compression and streaming video.

**M. Grigoriu, “Fragility Based and Rehabilitation Decision Analysis” (Subtask of Thrust Area 2 and 1)**

A computer code will be developed for assessing the seismic performance of an individual acute health care facility based on cost-benefit studies. The code has three essential components; (1) life cycle seismic hazard scenarios at a site following models developed by M. Grigoriu and A. Papageorgiou, (2) response analysis for linear structures subjected to Gaussian ground motion input, and fragility surfaces for specified limit states, and (3) cost histograms for different retrofitting strategies using D. vonWinetrfelt’s financial model. The code output will be an optimal retrofit strategy for seismic rehabilitation. MCEER demonstration hospital will be used as a case study and necessary user guides will be provided. The simplifying assumptions, namely linear structure and Gaussian ground motion, will be eliminated in the following years.

**A.S. Whittaker: “Fragility database for hospital structures” (SubTask of Thrust Area 2)**

The scope of this subtask is to continue development, publication, and distribution of a database and the associated knowledge tools for use by the Users Network of MCEER. The database will include (a) mathematical models of MCEER-studied emergency care facilities, including models of the three demonstration hospitals for use with one or more computational platforms [SAP, IDARC, OpenSees], (b) results of the analysis of the models by MCEER researchers, (c) fragility data for non-structural components that are commonly found in hospitals, and (d) Matlab files for the generation of fragility curves for user-defined inputs. Sample results will be presented to the Users Network with a Users Guide. The database of information and knowledge related to emergency-care-facilities and mathematical models (on a variety of platforms) will be established in close consultation with Professor Reinhorn to maximize the benefit of the work conducted by individual MCEER investigators and to best serve the stated need for program integration. The database and its evaluation tools will be developed, published, and distributed through the MCEER Users Network.

**A.M. Reinhorn: “Development of framework and tools to automate and integrate fragility sensitivity in global and local structure evaluation - software” (Subtask of Thrust Area 2)**

The scope of this subtask is to continue development, publication, and distribution of a methodology to determine the fragility of structures using a spectral approach in presence of high damping and severe inelastic behavior. A software platform will be developed to include the a) evaluation of the structure response domain in presence of uncertainties using spectral capacity approach; b) evaluation of conditional probability of exceeding a set of limit states – fragility curves; b) evaluation of cumulative probability of exceeding limit states in a given scenario; d) idealization of the fragility curves using minimum likelihood approach; e) evaluation variation of fragility (sensitivity) due to variation of specified parameters. The development of the above approach will be made in the main research task. The networking subtask will deal with the packaging of the above platform development of suitable examples and instructions and users manuals in electronic / web format.
G. Dargush, “Software for Evolutionary Methodologies for Decision Support” (Subtask of Thrust Area 2)

The ultimate overall objective is to develop new algorithms, models and related software for decision support within earthquake resilient communities. The work in this sub-task will create an enhanced version of the software (EADR_2.0) for dissemination within the MCEER Users Network. For Year 7 Networking sub-task, the EADR capability will be extended to permit simulations that utilize massively parallel distributed shared memory computational facilities, such as the 616 P4 processor Dell Linux Cluster at the UB Center for Computational Research. Additionally, we will incorporate the more realistic USGS Gutenberg-Richter seismic environment models in this EADR_2.0 release, which is planned for late Spring 2004.

G.C. Lee “Database of the information system of NY State hospitals” (Subtask of Thrust Area 2)

The information system of NY State hospitals offers the users of MCEER network a comprehensive database of real hospitals. The system consists of 4 hospitals with different structures (steel, and reinforced concrete) and different height (5 story to over 20 story) built in different time periods. Since NY State has lower seismic hazard level, critical health facilities have different seismic related problems than those in CA. The four hospitals also implement different emergency response systems. The information system includes structural information (drawings and structural models), seismic ground motion for the area (linked to other site), non-structural system information (drawings, site visit information), structural analysis results and emergency response information related to some particular utility systems.

Tom O’Rourke; “Web-Based GIS database of water distribution system”, (Subtask of Thrust Area 1)

The networking product is a web-based GIS database of 1994 Northridge earthquake damage to water distribution pipeline and timber frame one and two-story residential houses, including approximately 12,000 km of water distribution pipelines according to pipe type, and 164 strong motion recordings. Cornell researchers working for MCEER have developed a GIS database of water supply pipeline and timber frame residential building damage resulting from the 1994 Northridge earthquake. The database involves the records of more than 1000 pipeline repairs, approximate locations of water trunk and distribution lines, complete strong motion records at 164 places, and data pertaining to permanent ground deformation, surficial soils, groundwater tables, topography, and street system. The database, which is of unprecedented size and complexity, will be made available to selected users through Internet access. Security measures and selective access to legitimate researchers and users may need to be enacted with input from the Los Angeles Department of Water and Power (LADWP). It is envisioned that the database will involve GIS damage to water distribution piping, residential timber building damage, pipeline network, 164 geocoded strong motion records, and data related to topography, permanent ground deformation, surficial soils, and road network.

M. Shinozuka, “Integrated evaluation of system performance – Transportation – software” (SubTask MCEEER Transportation.)

It is proposed that a window-based efficient computer code “Lifeline T” (T for Transportation; MCEER has Lifeline W for water system) that produces a state of traffic flow in a seismically damaged as well as intact transportation network will be used as a testbed for analytical
networking. The code consists of a number of modules that pertain to scenario earthquake development with associated attenuation laws, shake map database, ground motion time history database, liquefaction susceptibility and probability estimation, development of fragility curves for component facilities, network topology, traffic flow capacity at link and network levels, assessment of physical seismic damage immediately after the event, spatio-temporal dependence of origin and destination matrix under operational and emergency conditions, socio-economic impacts of physical damage and functional impairment due to earthquake and other causes. It is expected that these modules will be improved or augmented by alternatives by network users on the basis of their expertise and research. Each improvement or augmentation will become a part of Lifeline T with contributors’ name and date of contributions so recognized. This is a networking sub-task for the TASK “Advanced Technologies for Loss Estimation and Development of Damage Function Using Remote Sensing and Real-Time Decision Support Systems”. The work in this subtask will create an initial code Lifeline T in a format that can be shared by the Users Network of MCEER.

All sub-tasks are selected to complete the system diagram in a future platform of software and databases:

II.A-1.180
Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

This is a generic activity of MCEER

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

The MCEER Users Network already includes information of Work in Progress made available to the Center’s investigators

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The above tasks will provide the computational tools and databases for potential users on the MCEER Users Network to support

1. Research by all MCEER investigators
2. Applications for practicing professionals where applicable
3. Educational material

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The work in this task is derived from various Center’s tasks and provide the base for distribution of information to the other tasks. Moreover facilitate transfer of information to the other projects in the other Engineering Research Centers

Possible Technical Challenges:

Development of templates for common use by subtask developers.

Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)

<table>
<thead>
<tr>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Lifelines Utilities</td>
</tr>
<tr>
<td>2) Engineering Consultants</td>
</tr>
</tbody>
</table>

1. Websites linked in the MCEER Users Network
2. Computational Tools for Loss evaluation, pipe analysis, hospital buildings evaluations, etc

Educational outcomes and deliverables, and intended audience:

All materials are raw materials for earthquake engineering applications and would be integrated in class modules where applicable.
### Project Schedule and Expected Milestones for the Project:
*(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

See task description

### Team Members:
*(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

See List of Investigators

### Possible Direction of Work in Subsequent Years:

Further Enhancement of Users Network by integrating software in a common platform according to the system diagram
MCEER Education and Outreach Activities

The primary purpose of this effort is to provide an interface between ongoing research activities of the center and the primary beneficiaries of this information - its end users. MCEER has a mission to increase the awareness of the general public about earthquake hazard and risk, to encourage greater involvement in the studies and professions related to earthquake hazard mitigation, to promote adoption of measures to mitigate earthquake hazards and to share emerging research findings with the hazard community at large.

Specific tasks within this effort are intended to develop educational tools and products that can be used by individuals at several levels, to create and conduct programs that encourage students to pursue earthquake studies and to be directly involved in inquiry-based earthquake research, to improve the interface between students and members of practice, and to encourage the involvement of those groups traditionally underrepresented in engineering.

A description of the integration between tasks is presented in Volume I.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>045001</td>
</tr>
</tbody>
</table>

**Project Number:** 045001

**Task Title:** Educational Developments

**Investigator/Institution:** Andrea Dargush*/MCEER

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

To develop educational materials and programs to assist precollege students and teachers to understand basic earthquake concepts and the role of engineering in mitigating the effects of such disasters. In conducting these activities, an important component will be to convey the role and importance of socio-economic systems in preparedness and recovery associated with earthquakes. Lastly, these activities will be constructed to encourage further study in these areas at the university level.

**Problem Description and Research Approach of Proposed Work for Year 7:** (Detailed description of research to be conducted and methodology to be used.)

The activities to be conducted will support existing goals of science standards and curricula, so that learning modules and tools can be easily integrated into middle or high school level classes. The intent will also be to assist teachers without training in earth science or physics to master earthquake content that they may required to address. This will be carried out through teacher professional development activities, which will expose teachers to earthquake and engineering concepts, particularly within a research environment, while working with MCEER staff and researchers to develop thematic materials to be used in the classroom. Assessments of learning tools will be solicited to assure accuracy, useability and applicability. The use of Internet-based learning tools as effective learning devices will also be evaluated.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The task parallels similar tasks being carried out through NSF, USGS and Department of Education initiatives, which support the current No Child Left Behind legislation. It is important to support the continued development of teachers to build content knowledge and to provide access to educational programs or activities that will assist them in meeting curricular goals. The involvement of people from different elements of the earthquake community - academia, industry, government - is something that can be contributed and unique to MCEER in development of educational programs. MCEER will be working at the forefront with other similarly-minded groups to try to promote STEM (science/technology/engineering/mathematics) education and career pursuit.

**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2002, to March 31, 2003.)

MCEER research activities continued outreach to public and precollege audiences. MCEER provided mentorship in the classroom, through the web, and at major science fairs. In the public awareness arena, MCEER was featured in a major article in the Sunday edition of the *New York Times*, which described the seismic hazard and risk posed to the region and the work being done...
to mitigate these affects. The development of a workshop to examine the lack of diversity in the disaster profession is continuing.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The mission of MCEER is to help build more disaster resilient communities. Education is very important in building awareness, encouraging an understanding of risk and embracing changes needed to improve earthquake resistance. Both model and approach to execute this are equally transferable to multiple audiences. Further involvement of industry partners will help guide development of educational materials to a broader community.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The task is fully integrated with all research thrust areas, and in significant extent to the networking program, which helps make dissemination of information more feasible.

**Possible Technical Challenges:**

All outreach communities do not have equal access to technical communication facilities or computer technology. All states do not have the same curricular standards, and there is a certain amount of opposition among teachers over new imposed standards.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

<table>
<thead>
<tr>
<th>Improved materials for use in classroom</th>
</tr>
</thead>
</table>

**Potential end-users beyond academic community:** *(IAB members and others.)*

Use for public at large, congressional staff associates, other government officials

**Educational outcomes and deliverables, and intended audience:**

New tools and materials developed will be made broadly available by CDROM and the web, and alternative media as appropriate for intended audience. MCEER has a substantial home-school audience and will try to work with them to develop resources to adequately address their needs.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g., Fall, Spring, Summer.)*

- Spring 2003: Diversity working group meeting
- Summer 2003: Teacher workshop
- Fall/Winter 2003: Science Fair workshops and exhibits

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

- George Lee
- Andrea Dargush
- Andrei Reinhorn
- Dorothy Tao
- Shari Salisbury

**Possible Direction of Work in Subsequent Years:**

Working with the networking program should greatly facilitate increased exposure to various audiences in the coming year. Additional involvement in other K-12 activities with USGS and others shall help expand its potential outreach.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
<th>Project Number: 045002</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Passive Connection of Adjacent Buildings under Earthquake Loading

**Investigator/Institution:** Makola M. Abdullah / Florida A & M University

* indicates task leader

**Scope:** (100 words or less - description for contract purposes)

Larger and more flexible structures are being constructed; as a result there is an increasing need for more effective, efficient and innovative control strategies. One such novel method is the idea of connecting adjacent structures. This control method has the merit of generating sufficient control forces under low frequencies, a property that is necessary for minimizing the response of high-rise structures.

**Problem and Approach:**

The Tasks for completing the project include, but are not limited to:

- **Structure Identification and Modeling**
  - Foundation and Soil Type
  - Structural Materials
  - Structural Framing
  - Structural Connections
  - Interior and Exterior Non-Structural Components

- **Passive Control Design**
  - Connect Similar Size Structures With Passive Damping Elements
  - Find The Optimal Damping Elements
  - Connect Structures With Passive Stiffness And Damping Elements
  - Find The Optimal Stiffness And Damping Elements
  - Verify Results With Experiments On Small Scale Shaking Table

- **Optimal Design and Placement of n-Controllers**
  - Using 2 Structures of different heights, find the best location for a single controller
  - Using 2 Structures of different heights, find the best location for a multiple controllers

- **Systems of Structures**
  - Design a measure of overall system building response for multiple structures
  - Connect Multiple Structures in 3D and reduce the measure of overall system building response
**Justification:** *Describe how the effort will make a unique, useable contribution to the MCEER strategic plan and earthquake hazards mitigation.*

This effort hopes to help discover viable passive control methodologies to mitigate earthquake damage in adjacent buildings.

**Progress to date:** *(if ongoing effort)*

**Possible Technical Challenges:**

- Finding Closed form design criteria for the passive connections between structures.
- Finding suitable measures of the performance of systems of buildings from earthquakes

**Anticipated Outcomes/ deliverables:**

A design criterion for connecting adjacent structures.

**Potential end-users beyond academic community:**

Structural Engineers

**Educational outcomes and deliverables, and intended audience:**

In addition to research, we will continue to be involved in outreach and educational activities. These activities include:

1) Visits of K-12 students and teachers to our research lab and visits of researchers to schools.

2) A short curriculum for K-12 students on Earthquake and Natural Hazard Engineering.

3) Including MCEER research results in the course Earthquake and Wind Engineering.

**Project Schedule:** *(milestones and estimated time of achievement; e.g. Fall, Spring Summer)*

<table>
<thead>
<tr>
<th>Task</th>
<th>Estimated Semester of Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure Identification and Modeling</td>
<td>Fall 2003</td>
</tr>
<tr>
<td>Passive Control Design</td>
<td>Fall 2003</td>
</tr>
<tr>
<td>Optimal Design and Placement of $n$-Controllers</td>
<td>Spring 2004</td>
</tr>
<tr>
<td>Systems of Structures</td>
<td>Summer 2004</td>
</tr>
</tbody>
</table>

**Task Integration:** *Describe how the work performed contributes to a larger task within the program; what contributions are anticipated.*

**Projected future work:**

II.A-1.188
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr Assigned: 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Number:</td>
<td>045003</td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Non-Linear Dynamic Analysis of a Multi Story Building  
**Investigator:** Rupa Purasinghe  
**Institution:** California State University at Los Angeles  
* indicates task leader

**Scope:** (100 words or less - description for contract purposes)

This research involves Non-Linear Dynamic analysis of a multistory building in the context of performance based seismic design. This will be based on the static push-over analysis results of year 5 (third year for this project), response modification technology (passive dampers) application results of year 6 (fourth year for this project). A non-linear time history dynamic analysis with material non-linearity of building elements will be performed. Several students will be trained in non-linear dynamic analysis of a building.

**Abstract:** (500 words or less - summary of activity and outcome)

A 2-D and 3-D models of the multistory building with material nonlinearity will be subjected to non-linear time history earthquake loading, as part of a retrofit strategy. The results will be used to identify performance levels of the building.

**Task Integration:** Describe how the work performed contributes to a larger task within the program; what contributions are anticipated.

The proposed project will help apply non-linear time history analysis technologies to a multi story building. This is the natural continuation of the Year 6 (third year for this project) tasks of the non-linear push over analysis. Also this activity will help educating students for careers in earthquake engineering, thereby contributing to the educational interface program of the MCEER.

**Justification:** Describe how the effort will make a unique, useable contribution to the MCEER strategic plan and earthquake hazards mitigation.

Non-linear time history analysis with material non-linearity will better predict building performance, and practicing engineers increasingly use it. As such this research will provide a very appropriate application technique in earthquake hazard mitigation.

This project will train students in latest practice based technology in earthquake hazard mitigation, and hence enhance the Educational Interface Program of the MCEER.
**Problem and Approach:**

The project seeks to study application non-linear time history analysis method of performance based seismic design of a multi story building. The approach used will be structural simulation using 2-D and 3-D models of SAP 2000/ETABS programs.

**Progress to date:** (if ongoing effort)

With the year 6 funding (third year for this project), a non-linear static push over analysis is being performed.

**Possible Technical Challenges:**

i) Accurate non-linear modeling of building elements for analysis.
ii) Interpretation of simulated results.

**Anticipated Outcomes/ deliverables:**

| i) | Non-linear Materials computer models for time history analysis. |
| ii) | Performance Level determination of building. |

<table>
<thead>
<tr>
<th>Potential end-users beyond academic community:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practicing Engineers in Earthquake Engineering</td>
</tr>
<tr>
<td>As this is a practice-oriented project, practicing engineers will benefit from the outcome of the project.</td>
</tr>
</tbody>
</table>

**Project Schedule:** *(milestones and estimated time of achievement; e.g., Fall, Spring Summer)*

| i) | Modeling of the multistory building with material non-linearity (Fall 2003) |
| ii) | Non-Linear Time history analysis (Winter 2004) |
| iii) | Retrofit recommendations (summer 2004) |

**Educational outcomes and deliverables, and intended audience:**

| i) | Non-Linear Models of a multistory building |
| ii) | Training students in advanced technologies in earthquake engineering |

**Projected future work:**

Advanced Control Strategies for Control of buildings
MCEER RESEARCH TASK STATEMENT

Task No. Budget: Yr 7 Assigned

Project Number: 045004

Task Title: Integrated Research and Education on Engineering Effects of Earthquakes, Blasts and other Man-Made Hazards

Co-Investigators: Anil K. Agrawal* and George Mylonakis

Investigator Institution: City College of New York

* indicates task leader

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The goal of the project is to develop an integrated research and education approach to investigate the effects of earthquakes, blasts and other man-made hazards with emphasis on minority students. The work is intended to motivate undergraduate students learn about advanced concepts in structural dynamics and earthquake engineering through seminars, laboratory experiment participation and research under the mentorship of a graduate student. The final outcome of the task is to have new graduates with increased awareness about the destructive effects of earthquakes, blasts and other man-made hazards, and recent developments to reduce the risk of damages during these hazards.

Problem Description and Research Approach of Proposed Work for Year 7: (Detailed description of research to be conducted and methodology to be used.)

Structural Dynamics and Response Modification of Structures

Educational Component:

With the Year 5 and 6 funding for integrated research and education of undergraduate students, the PI started an individual study course on structural dynamics; earthquake engineering and response modification of structures during Spring 2002. The course had four minority students, including two women. The students studied basic concepts of structural dynamics, learned response simulation using Matlab and Simulink, and develop simple computer modules in Simulink to study effects of damping and other response modification strategies. The students studied assigned topics from a textbook in groups, and discussed with the Graduate Student Researcher and the PI about the topics covered. Using the experience gained during Spring 2002, the individual study course is offered to three undergraduate students during Spring 2003. The course includes theoretical as well as experimental concepts using the instructional shake table from Quansar Consulting and the Structural Dynamics and Control Laboratory with the 5-tons shaking table facility. Besides theoretical and experimental components described above, students are exposed to advanced concepts of structural dynamics and earthquake engineering through seminars. A seminar on WTC collapse and possible solutions, and seismic retrofit of Reinforced Concrete Building at the City College Campus was organized in October 2001. This seminar discussed in detail about possible causes of collapse of the WTC towers and several engineering solutions that could have prolonged the collapse of towers. The seismic retrofit portion of the seminar was based on retrofit of buildings using ATC...
40 and FEMA 273. Seminars on progressive collapse, seismic design in Northeast USA, development of smart energy dissipative systems have been organized during the Year 6.

For the Year 7 Educational Approach, the PI propose to expand the educational activities to a wider scale by (i) staring a regular elective course for seniors that will integrate the Instructional Shake Table, the 5-ton shaking table and Matlab simulation, (ii) involving k-12 students from the High School recently opened at the City College of New York with a focus on Science, Engineering and Mathematics, and (iii) integrating few topics on smart energy dissipating systems as special project in graduate course on structural dynamics.

Another component of the proposed integrated research and education initiative is the participation of undergraduate students in international research program. Last year, one of the students, Ms. Susan Romero, was accepted for Research Experience for Undergraduates program in Japan during Summer 2002. In Japan, she participated in research on semi-active control systems at the University of Tokyo, Japan, and the Kobori Research Institute of Kajima Corporation. This year, Ms. Miriam Vergas, an undergraduate student in Civil Engineering, has been accepted to participate in the program at the Tokyo University during summer 2003.

**Research Component**

The focus of research component of this project will be on theoretical and experimental research on passive and semi-active protective systems. The students currently taking the individual study course will take part in research on these systems. The students will investigate theoretical concepts, such as optimal distribution of dampers in buildings, performance of semi-active controllers during near-field earthquakes, etc., under the supervision of a Graduate Student Researcher during the Year 7 cycle. The focus of experimental research will be to train students about the use of advanced equipment for research on structural dynamics and earthquake engineering, lessons on effects of earthquakes on buildings with advanced protective devices, etc. The PI has completed the establishment of a 5 feet x 5 feet shaking table system that will also be used for research by undergraduate students.

The research group at the CCNY has developed an analytical model of near-field ground motion pulses to optimize the design of energy dissipation systems. Preliminary results show that the passive dampers are effective only when the frequency of structures is close to the predominant period of ground motions. For semi-active dampers, it has been shown that they are as effective as active control systems using the same force capacity when controllers are designed by incorporating the model of ground motions in the controller design. Further research efforts are directed in this direction. Experimental tests are also planned to verify the numerical results.

In summary, this component will provide undergraduate students an opportunity of (i) hands-on experience in earthquake engineering and structural dynamics through an individual study course, (ii) seminars by experienced structural engineers on seismic design of structures, (iii) site visits to see the landmark structures and experiments in structural dynamics, and (iv) participation in research on intelligent structural control devices and new approaches to design buildings for protection against terrorist attacks. A continuous development of the integrated research and education program at the City College will certainly encourage undergraduate students, including minorities and women students, to pursue graduate studies in earthquake engineering.
Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

This program complements the research and educational goals of the MCEER through an active involvement of a predominantly minority institution in advanced research on structural dynamics and earthquake engineering.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

During the Year 5 and 6 funding, undergraduate students were offered the individual course in structural dynamics and earthquake engineering, seminars were organized on earthquake engineering, and research was conducted by undergraduate student under the mentorship of a graduate student in the area of semi-active friction dampers. One of the undergraduate students, Ms. Susan Romero, was selected to participate in the REU program in Japan funded by the NSF.

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The proposed effort will make a unique contribution in the strategic plan of MCEER by promoting the education and awareness in the area of earthquake engineering, advanced theoretical and experimental research on semi-active dampers and transfer of knowledge to practicing community through seminars and recruitment of trained engineers.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

Possible Technical Challenges: Possible technical challenges exists in motivating undergraduate students involve in advanced research, which keeping their other required course work and educational activities unaffected.

Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)

The outcomes of the project benefit IAB members in the form of better trained engineers capable of better incorporating seismic design concepts in actual design.

Potential end-users beyond academic community: (IAB members and others.)

Potential end-users are IAB members and the practicing community. Potential end users of the research component are the academicians and industry interested in developing structural control systems.

Educational outcomes and deliverables, and intended audience:

Potential educational outcomes of the project are:

(i) Hands-on experience in earthquake engineering and structural dynamics through an individual study course,

(ii) Seminars by experienced structural engineers on seismic design of structures,
(iii) Site visits to see the landmark structures and experiments in structural dynamics
(iv) Participation in research on intelligent structural control devices and new approaches to design buildings for protection against terrorist attacks.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

The project duration is 12 months, from October 1, 2003 to September 31, 2004. The student work during Spring, Summer and Fall semesters to achieve the described objectives.

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

**Undergraduate Students:** Ms. Myriam Vergas, Eugene Boronow, Walter Sarafian, and Alma Platero

**Graduate Coordinators:** Ms. Pan Ying, Mr. Yi Zhihua

**Possible Direction of Work in Subsequent Years:** The individual study course will evolve into a one semester design elective course offered to students regularly. The undergraduate research component has stronger focus on experimental research. The CCNY has a new Campus High School with focus on promoting students to engineering. Efforts are made to involve high-school students in this research and education initiatives. Current undergraduate students will mentor high-school students in a research partnership to encourage undergraduate students pursue studies in civil engineering. The 5-ton shaking table facility will be completely integrated into educational components for undergraduate and graduate students.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 7 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Project Number: 045005</td>
</tr>
</tbody>
</table>

**Task Title:** Web-based Modules for Earthquake Engineering Education

**Investigator/Institution:** B. F. Spencer, Jr., University of Illinois at Urbana-Champaign

* indicates task leader

**Statement of Project Goals:**

This effort focuses on increasing the prominence of MCEER as an Internet source of information both about earthquake engineering for the general public and also about complex issues involved in earthquake engineering for graduate students and professionals. Currently, the Internet is one of the most efficient and cost-effective ways to disseminate information on a wide-scale, and for that reason, we desire to utilize it as a means of education. We are, therefore, proposing two main educational efforts. First, we will continue in our successful development of virtual experimental modules, which have proven to be an important educational resource for structural dynamics, and we will also continue to represent MCEER in the coordination of the tri-center graduate educational efforts. Second, we will initiate a new effort this year which is to provide the public with increased awareness and interest in earthquake engineering by means of a web-based application.

Recent seismic calamities in Chi-Chi, Taiwan and Tecomán, Colima, Mexico, have underscored the tremendous importance of understanding earthquakes, especially the way in which civil engineering structures respond during such dynamic events. The (MW) 7.6 1999 Chi-Chi Earthquake’s death toll was 2,400, and more than 10,000 people were injured. About 30,000 structures were moderately to severely damaged, leaving many thousands of people temporarily homeless. A few months ago, an MW 7.6 earthquake struck Tecomán, Colima, Mexico. 21 deaths were confirmed, with around 500+ injured people. Approximately 13,493 buildings were badly damaged or destroyed, and officials estimate that thousands of people were left homeless. The military established 56 disaster assistance centers to provide food, shelter, and medical assistance.

The current generation of structural engineers is now being trained in university graduate and professional programs, where they strive to better understand and effectively deal with the design of earthquake resistant structures so as to reduce the associated human and financial losses incurred in large seismic events. One of the challenges of teaching graduate and professional level students about the fundamentals of earthquake engineering is giving them an intuitive understanding of the dynamics of structures and its importance to design. Demonstrating the concepts of structural dynamics using static chalkboards or books is difficult. Often the mathematical procedures taught obscure the physical motivations and problem insights, leaving the students unable to interpret the results of their analyses in their proper engineering context. Part of the difficulty faced by engineering educators is that laboratory demonstrations are required to effectively teach many concepts. Students need to be able to
conduct a wide range of studies that can bring out fundamental issues in the earthquake response and design of civil engineering structures. Unfortunately, few instructors have experimental facilities readily available to them that are capable of even small-scale earthquake engineering experiments. For those who do, such experiments can be time consuming and expensive. Consequently, the majority of earthquake engineering classroom experiences are entirely analytical in nature.

Additionally, as educators, we must make the general public more aware of the science of earthquakes and the importance of earthquake engineering. With increased awareness, the public will not only know how to respond to earthquake events and aftershocks, but they also gain insight into how they may actively prepare for such events. This effort, therefore, seeks funds for two educational activities: to continue in our development of web-based modules which have proven successful in better educating graduate students as well as practitioners in the area of structural dynamics, and a new effort initiated this year, to provide the public with increased awareness and interest in earthquake engineering. The following section describes the planned approach to accomplish these efforts.

Planned Approach
The ongoing development of modules has been one of the tangible outcomes of the MCEER funded educational project at University of Illinois at Urbana-Champaign (UIUC). These modules are a series of virtual laboratory (VL) experiments which support earthquake engineering research and education. The modules, accessible at [http://cee.uiuc.edu/sstl/](http://cee.uiuc.edu/sstl/), provide earthquake engineering students, researchers and practitioners throughout the world with a means to interactively develop fundamental understanding and intuition regarding several topics in earthquake engineering via the World Wide Web. The VL experiments are based on computer simulation and have been fully documented with extensive online help pages. They were developed on the Java platform to minimize administrative overhead associated with maintenance of the VL. With approximately 500 visitors per month, these Java VL experiments have proven to be a popular and effective means for students to gain knowledge in these areas of earthquake engineering. Module development efforts in years 6 and 7 will follow this successful approach.

A new activity that we are initiating this year is the development of an interactive web-based application to gain public interest in earthquake engineering and in MCEER. The application would consist of a 10-15 minute program explaining some of the fundamentals of earthquakes and earthquake engineering, followed by an interactive portion, where visitors can get a “hands-on” feel for earthquakes and structural responses. An example of what we envision for the program portion can be found at: [http://www.nd.edu/~eeriund/whatisit.htm](http://www.nd.edu/~eeriund/whatisit.htm), a short informational presentation for the Shakes and Quakes Outreach Program at the University of Notre Dame. It has attention-grabbing music and pictures, and it is easy to follow and fun to watch. We desire our entire application to answer the following questions and other important topics: What is an earthquake? What do earthquake engineers do? What issues are they concerned about? What is MCEER, and what do they do? Why do so many different types of engineers and scientists need to be involved?
Current Status, Near-term Goals, and Deliverables

While the above interactive application is still in a preliminary conceptual phase, the other efforts are ongoing and have experienced success. For example, the existing Java VL experiment modules include the following simulations: Structural Control using Tuned and Hybrid Mass Dampers, Linear and Nonlinear Base Isolation, and the most recently added module, Simulation for Nonlinear Structures. Developed at UIUC and available at http://cee.uiuc.edu/sstl/java/twostory/animation.html, this VL module allows the user to select different nonlinear models to represent the behavior of the structure, to change the parameters of the structure, and to choose different earthquake ground motions to do analysis. This module is intended to increase understanding and provide a conceptual “feel” for various parameter changes on the performance of nonlinear structures under different excitations.

Efforts are ongoing to further expand the available modules. One of the deliverables for this year will be a new VL module that can simulate the response of an $n$-degree-of-freedom nonlinear structure. This module will include features for various types of supplemental damping devices in the analysis (e.g. linear and nonlinear viscous dampers, yielding hysteretic dampers, etc.).

Another deliverable for this year will be representation of MCEER in the center-to-center coordination and development of graduate level web-based instructional modules. This collaborative among the centers is intended to augment existing engineering programs at affiliated institutions by building on the academic expertise of faculty at other member universities.

The interactive web-based program to increase earthquake awareness in the general public has just been initiated. We plan to partner with George Lee and Andrea Dargush to set the scope and form of project. We are interested in closely coordinating with MCEER personnel in order to make the application the most beneficial to the public and to both existing and future earthquake engineers. The deliverable for this aspect of the project will be the formulation of the framework for this interactive web-based module.

Proposed Efforts for Years 7 and 8

Future developments for the VL modules include producing more dynamically complex modules. We would like to add $n$-degree-of-freedom active and semi-active structural control systems, and we will also consider real-time remotely controlled laboratory experiments. The specific direction of our module development will be formulated based on the experiences gained from previous modules developed, discussions with MCEER personnel, and feedback from the earthquake engineering community. In all cases, we will develop appropriate documentation and user manuals for the modules.

Representation of MCEER in coordination of the educational activities of the three Earthquake Centers will have been established. Once the centralized educational repository is functional, it must be kept current and regularly maintained/updated in order to attract visitors and keep them
as repeat visitors. Educational content must be added as they are available so that the public may rely on the site.

In these future years, we plan to work closely with George Lee and Andrea Dargush to put together and unveiled the interactive web-based outreach module. We are confident that it will be a great success, attracting visitors worldwide, including families or classes in computer laboratories. This application as well will need to be maintained and expanded in order to retain repeat visitors.
Year 6 Project Descriptions
Overarching Center-wide Cross Program

Research Activities
<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:**
“Earthquake Simulation Tools for Implementation in Integrated Methodologies”

**Investigator:** Apostolos S. Papageorgiou  
**Institution:** University at Buffalo  
* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

Modeling and prediction of earthquake ground motion in continental United States, with particular emphasis in Eastern North America (ENA).

Our task is the synthesis/simulation of strong ground motion input over the entire frequency range of engineering interest as well as the prediction of various measures of strong ground motion (e.g. $a_{\text{max}}$, $v_{\text{max}}$, $d_{\text{max}}$, $SA$, $PSV$, etc) for earthquake events in continental United States, with particular emphasis in Eastern North America (ENA).

The synthesis/simulation and prediction techniques of strong ground motion should account properly for site effects and should be valid for sites both near an extended fault/source as well as at far-field.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

Our task is the synthesis/simulation of strong ground motion input over the entire frequency range of engineering interest. For this task we have adopted two separate approaches:

1. The Stochastic (Engineering) Approach  
2. The Kinematic Modeling Approach

We started our work with the Stochastic (Engineering) Approach because it is very expedient and, for most engineering applications adequate enough. The computer codes that we have produced may be used for providing earthquake input representative of earthquakes in ENA. In response to the request of MCEER researchers working on projects related to lifelines located in California, we shall extend the applicability of these codes so that they can be used for any location in the continental United States (including California). The basic approach remains the same and only the parameters of the model(s) have to be modified appropriately. Calibration of the model(s) that we propose to use requires uniform processing of the response spectra of a carefully selected collection of Californian records (available on the COSMOS database).

In parallel to the above efforts we started the development and implementation of the Kinematic Modeling Approach that we have described in previous task statements and progress reports. Development of this strong motion synthesis method is necessary in order to address the shortcomings of the Stochastic Approach. The latter synthesis approach cannot be used for the synthesis of near-source ground motions and can capture important propagation path effects (such as Moho reflections and scattering effects) approximately at best.
As part of the development efforts of the Kinematic Modeling Approach, we have initiated several subtasks (see Years 3 & 4 Task Statements). Below, we list these subtasks (and their status) along with the new subtasks that we propose for Year 6:

1. **Scattering effects of the lithosphere**: Scattering effects are a very important consideration in the synthesis of ground motion in ENA. We have initiated the collection of seismograms of small events that have been recorded in ENA (US and Canada) by various networks (including broadband, short period and strong motion networks) with the intention of performing analysis that will provide values of important parameters (e.g. quality factor $Q$ and scattering coefficient $g$) of the scattering characteristics of the lithosphere in ENA. Our objective is to synthesize results developed in the field of *Stochastic Seismology* with techniques for the generation of evolutionary stochastic processes developed in the field of *Probability Theory* (such as the *Spectral Representation* developed by Prof. M. Shinozuka; see also “*Applied Non-Gaussian Processes*” by Prof. M. Grigoriu). We expect the outcome of the “marriage” of the above two fields to be the development of a simulation methodology of realistic Green’s functions that reflect the characteristics of a particular tectonic region. We remind the reader that the Green’s function is one of the two elements (the other being the slip on the fault plane) required by the Kinematic Modeling Approach for the simulation of strong ground motion.

2. **Variable size sub-events**: We have completed our investigation on the effect of variable size sub-events on the prediction of ground motion and we have found that under physically plausible assumptions (such as uniform “local stress drop” for all the sub-events) the predictions of the various sub-event distributions are very close to the predictions of the Specific Barrier Model (which consists of equal size sub-events). This is comforting because calibration of the Specific Barrier Model to the strong motion data of a tectonic region is a relatively simple and well-established procedure.

3. **Sub-event Models**: We have made substantial progress in developing closed-form mathematical expressions of the far-field radiation of new kinematic models to represent the sub-events (see comments in the section “**Progress to date**” below). We want to extend this line of research to other models of sub-events such as *asperity models*. We thus aim at creating a “library” of models of sub-events adequate to simulate the various modes of rupture of real faults.

4. **Validation**: Any simulation method should be validated by comparing the synthetic seismograms against the recorded ones for as many earthquake events as possible. We have initiated such validation comparisons using the 1988 Saguenay earthquake event as a case study.

5. **Near-source ground motions**: In Year 5 we started addressing also the issue of near source ground motions. In particular, there are two competing physical effects that would affect near-source ground motions in ENA: Earthquake sources in ENA are characterized by higher *stress drops* and shorter *rise times* as compared to corresponding motions in California. Thus ENA near-source “killer pulses” are expected to be stronger and of higher frequency (i.e. shorter pulse duration). On the other hand, ENA earthquake sources appear to occur at greater depths and thus the source-to-station distance (and consequently geometric attenuation) is greater. It is of great practical significance to investigate which of the above two factors dominates. As we stated in our Year 5 Task Statement, our ultimate objective is to propose simple analytical functions to describe near source pulses. Such simple mathematical descriptions will be readily useful to engineers and may be included in future versions of the building code. We have accomplished this objective, i.e., we have come-up with a very simple, yet versatile, *mathematical expression* to describe near-source pulses. We have used this mathematical expression to successfully model all existing near-source records (primarily Californian records). In Year 6, we would like to use the abovementioned model to make predictions/extrapolations for near-source pulses at other tectonic environments (such as that of ENA) for which there are very few, if any, recorded motions. [Parenthetically we point out that such predictions/extrapolations are feasible only using physical models of the earthquake source, such as the Specific Barrier Model. This demonstrates the power of analytical modeling.]
Furthermore, in Year 6, we would like to develop and test a simple procedure for simulating near-source ground motions using the Specific Barrier Model (to represent the earthquake source), the Stochastic (Engineering) Approach to simulate the incoherent component of ground motion, and the above mathematical expression to represent the near-source pulses (coherent component of motion). Such a procedure would enhance the simulation tools that engineers currently have at their disposal.

(6) Site Effects: [This is a new research effort that we propose for Year 6.] This research task is feasible because of the unprecedented recorded database generated by the 1999 Chi-Chi, Taiwan, earthquake and its aftershocks. Specifically we propose to infer site Amplification Factor (AF) from the analysis of coda waves (i.e., scattered waves that can be found at the tail of a seismogram following the major phases such as body and surface waves; coda in Latin means tail) and compare it with the AF inferred from strong motion data recorded by accelerometers co-located with the seismometers that recorded the coda waves. We anticipate that the AF inferred from coda waves, $(AF)_C$, (which represents the truly linear response of sediments) will be larger than the AF inferred from strong motion data, $(AF)_S$. In fact we anticipate that $(AF)_S$ will be a function of the intensity of ground motion (traditionally in geotechnical earthquake engineering, earthquake intensity for site amplification purposes has been quantified in terms of peak acceleration). We propose to investigate/quantify the dependence of $(AF)_S$ on ground motion intensity. The result of such an investigation will provide the necessary correction factors that need to be applied to $(AF)_C$ to provide estimates of site amplification for strong ground motion. Estimation of site amplification from coda waves can be very useful from a practical point of view because coda waves are recorded by existing networks of seismometers that routinely record small earthquakes. Thus, there is an abundance of such data available for many regions of the world, including ENA. We inform the reader that a preliminary classification (in terms of site classes A, B, C, D, and E) has been done for the sites/stations of the 1999 Chi-Chi dataset that we propose to analyze, a fact that will facilitate our work considerably.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Our Task is a Center-wide overarching MCEER activity that supports multiple Thrust Areas, namely in this case Thrust Area 1 “Seismic Evaluation and Retrofit of Lifelines Networks” and Thrust Area 2 “Seismic Retrofit of Emergency Care Facilities”.

As we have stated in summaries of our research work (see Research Progress and Accomplishments: 1999-2000; 2000-2001), various earthquake source models that been proposed in the published literature [such as the Specific Barrier Model (Papageorgiou and Aki, 1983a,b; 1985; 1988) and the $\omega^2$-model (Brune, 1970; Frankel et al., 1996)]. Of all the source models, we favor the Specific Barrier Model because it provides the most complete, yet parsimonious, self-consistent description of the faulting processes that are responsible for the generation of the high frequencies, and at the same time provides a clear and unambiguous way of how to distribute the seismic moment on the fault plane. The latter requirement is necessary for the implementation of the Kinematic Modeling Approach described above as well as for simulation of near-source ground motions.
Progress to date: *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

(1) We have fully developed and implemented the Stochastic (Engineering) Approach and we have developed computer codes that may be used for the following three purposes:

(i) Simulation of strong ground motion time histories for given Magnitude, Source-to-Station Distance and Site Conditions (as specified by Site Classes defined in the NEHRP Provisions).

(ii) Prediction various measures of strong ground motion (e.g. $a_{max}$, $v_{max}$, $d_{max}$, $SA$, $PSV$ etc) using Random Vibration Theory (i.e. without having to resort to the generation of numerous realizations and subsequently to average the results).

(iii) Simulation of spectrum compatible time histories.

(2) We have created a website [http://civil.eng.buffalo.edu/engseislab/index.htm](http://civil.eng.buffalo.edu/engseislab/index.htm) which, among other things, provides access to the above codes to any one that may want to use them. Furthermore, sample time histories representative of the seismic hazard for five ENA cities (Buffalo, NY; New York City; Boston, MA; Memphis, TN; Charleston SC) have been posted on the website for the immediate use by the Users/MCEER researchers. As we have stated before, we consider our Website to be a living document that we update and improve as we produce new research results and as we try to respond to the needs and requests of the Users/MCEER researchers.

(3) We are about to complete, a comprehensive Technical Report/Monograph documenting in detail the Stochastic (Engineering) Approach used for the simulation of time histories. This Technical Report/Monograph, after being subjected to the standard MCEER review process, will be posted on the website. Thus it will be readily accessible by all the Users/MCEER researchers who can form their own opinion as to the assumptions and uncertainties involved in simulating the time histories that they use in their analyses. Posting of the Technical Report/Monograph on the website will be done in coordination with Prof. A. Reinhorn (MCEER’s User Networks) so that its access will be user friendly.

(4) We have made substantial progress in our efforts in synthesizing ground motion using the Kinematic Modeling Approach. Specifically, we have derived closed form solutions for the seismic radiation of a new class of kinematic models (asymmetrical circular and elliptical crack models) that will be used to simulate sub-events in the synthesis of strong ground motion generated by large earthquake events. These results have been recently presented in a forum consisting primarily of seismologists (“International Workshop on the Quantitative Prediction of Strong-Motion and the Physics of Earthquake Sources” held in Tsukuba, Japan, from Oct. 23 to 25, 2000) and were very well received. We present these results in four (4) journal papers, two of which are under review and the other two have already been accepted for publication and will appear in the Bulletin of the Seismological Society of America. As stated above, our work on the effects of “Variable Size Sub-events” has been completed and we are preparing a manuscript to submit for publication. Some of the results that we have obtained so far related to “Near-source Ground Motions” have been included to a journal paper that we very recently submitted to the Bulletin of the Seismological Society of America.
**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

Our Task is a Center-wide overarching MCEER activity that supports multiple Thrust Areas, namely in this case Thrust Area 1 “Seismic Evaluation and Retrofit of Lifelines Networks” and Thrust Area 2 “Seismic Retrofit of Emergency Care Facilities”.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

Our Task is a Center-wide overarching MCEER activity that supports multiple Thrust Areas, namely in this case Thrust Area 1 “Seismic Evaluation and Retrofit of Lifelines Networks” and Thrust Area 2 “Seismic Retrofit of Emergency Care Facilities”.

**Possible Technical Challenges:**

(1) Derivation of closed form mathematical expressions for the seismic radiation of *asperity models* is definitely a challenging task.

(2) Synthesis of results developed in the field of *Stochastic Seismology* with techniques for the generation of *evolutionary* stochastic processes developed in the field of *Probability Theory* is also a technically challenging task.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

- Extension of the applicability of the computer codes so that they can be used for any location in the continental Unites States (including California).
- Completion and posting on the website of the comprehensive Technical Report/Monograph documenting the Stochastic (Engineering) Approach for earthquake motion simulation.
- Computer code for synthesis of ground motion based on the Kinematic Modeling Approach.
- Development of a simple engineering approach to synthesize realistic near-source ground motions.

**Potential end-users beyond academic community:** *(IAB members and others.)*

- Seismic Evaluation and Retrofit of Lifelines Networks
- Seismic Retrofit of Emergency Care Facilities
- Loss Estimation
- Fragility Curves
Educational outcomes and deliverables, and intended audience:

The Technical Report/Monograph, documenting in detail the Stochastic (Engineering) Approach used for the simulation of time histories, is prepared in a tutorial style so as to educate engineers as to how we synthesize/simulate earthquake ground motions.

Project Schedule and Expected Milestones for the Project:  
(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

Extension of the applicability of the computer codes so that they can be used for any location in the continental Unites States (including California):
By the end of Fall 2002.

Posting on the website of the comprehensive Technical Report/Monograph documenting the Stochastic (Engineering) Approach for earthquake motion simulation:
By the end of Fall 2002.

Completion of development of the method for synthesis of near-source ground motions:
By the end of Fall 2002.

Computer code for synthesis of ground motion based on the Kinematic Modeling Approach:
Only part of the work will be complete by the end Year 6.

Site Effects:
Only part of the work will be complete by the end Year 6.

Team Members:  
(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- Dr. Gang Dong (Sr. Research Scientist)
- Mr. Benedikt Halldorsson (Graduate Research Assistant; Ph.D. candidate)
- Mr. George Mavroeidis (Graduate Research Assistant; Ph.D. candidate)
- Mr. Fangyin Zhang (Graduate Research Assistant; Ph.D. candidate)

Possible Direction of Work in Subsequent Years:

There is substantial research work that needs to be done regarding:

- the development and implementation of the Kinematic Modeling Approach;
- the development of the new approach of estimating site Amplification Factor (AF);

that will spill over beyond Year 6.
MCEER RESEARCH TASK STATEMENT

Task No. 6.0.2  Budget:  Yr 6 Assigned

Project Number:

Task Title: Definition and quantification of resilience – Development and application of center-wide system-integrated resilience measures

Investigator/
Institution:  M. Shinozuka*, University of California at Irvine $15,000
Michel Bruneau, University at Buffalo $15,000
Andrei Reinhorn, University at Buffalo $15,000
Kathleen Tierney, University of Delaware
Detlof von Winterfelt, University of Southern California $15,000
Stephanie Chang, University of Washington ***
Adam Rose, Pennsylvania State University ***
Rachel Davidson, Cornell University ***

* Indicates task leader
*** Tierney, Chang, Rose and Davidson task and funding described in separate task statement

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The objective of this overarching task is to pursue further the developments started by MCEER (in the fall of 2001) on the definition and quantification of resilience, to achieve implementation in MCEER’s Research Thrust Areas and in center-wide system-integrated tasks.

Problem Description and Research Approach of Proposed Work for Year 6: (Detailed description of research to be conducted and methodology to be used.)

MCEER’s current mission statement states:

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.

The latter sentence in this statement captures the essence of the framework proposed by MCEER to quantitatively define seismic resilience. While this framework provides a sound general basis to quantify resilience, it must be further developed and refined for the MCEER testbeds. The objective is to preserve the center-wise conceptual approach to resilience quantification, but further develop the framework to allow it to embrace the intricacies germane to each type of critical infrastructure system.

Considering that lifelines are systems of geographically distributed similar stations providing a service measurable in engineering terms, and that acute care hospitals are localized systems of
substantially different integrated systems providing complex services not measurable in simple engineering units, it is clear that the former critical infrastructure system must be used as the first step to further develop a more refined resiliency framework. However, to ensure that the resiliency framework remains center-wide and integrated across all MCEER activities, further development work on resiliency measures and definitions cannot proceed by considering a single emergency system or function. Therefore, while research will be conducted to implement the resiliency definitions and measures to the problem of integrated water and power lifelines as part of MCEER Year 6 activities, some developments will also simultaneously take place to further define the resiliency framework for the purpose of acute care facilities.

This center-wide overarching task brings together members of the MCEER Task Force that developed the original resiliency framework and MCEER Research Thrust Area coordinators to accomplish the further development of the seismic resilience framework described above. A direct implementation is accomplished for the integrated case of power and water lifelines using the LADWP as a case-study, in coordination with Rose, Chang and Davidson (see their task statement).

### Assessment of State-of-the-Art:

*Describe other relevant work being conducted within and outside of MCEER, and how this project is different.*

To the best of the investigators’ knowledge, no similar work is currently being conducted elsewhere at this time. Seismic resilience has never been quantified in the past, and the approaches proposed by MCEER are providing leadership in this endeavor.

### Progress to date:

*If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002."

The basic framework for the definition of resilience and possible innovative approaches to quantify and measure this resilience were proposed for the first time by MCEER in Fall 2001.

### Role of Proposed Task in Support of Strategic Plan:

*Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.*

Enhancing seismic resilience is at the core of MCEER’s strategic plan, and development of the general framework of resilience measures is required to achieve MCEER’s mission objective.

### Task Integration:

*Describe how the work performed interfaces with other tasks and researchers funded by MCEER.*

The definition and measures of resilience proposed by MCEER in November 2001 already have a direct impact on all researchers funded by MCEER. The further development to be accomplished as described in this task statement will continue to have such an impact, and updates on progress will therefore be periodically be provided to all researchers.

### Possible Technical Challenges:
To quantify seismic resilience in the specific terms and at a level of details required for the systems studied by MCEER is by itself a major challenge. Developing the proposed resiliency framework from its conceptual basis to a workable level for each of the systems considered, without straying from center-wide broadly applicable measures is a difficult yet important balance to maintain.

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical definitions and measures of seismic resilience that can be used to enhance this resilience in a rational comprehensive manner.</td>
<td>Utility companies (lifelines), owners of acute care facilities and the practicing engineers they hire, emergency response agencies, and all agencies or groups who can benefit from a rational approach to enhancing seismic resilience, for example to establish seismic risk reduction policies or gage the consequences and benefits from various actions.</td>
</tr>
</tbody>
</table>

**Educational outcomes and deliverables, and intended audience:**
The MCEER definitions and measures of resilience, and applications demonstrated by MCEER, could impact all earthquake engineering courses focusing on how to reduce the seismic risk.

**Project Schedule and Expected Milestones for the Project:** (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

- Updated framework with workable definitions and measures of seismic resilience that can be used with various types of emergency critical systems, yet tied to the same broad conceptual framework – September 2003.

**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

Students will conduct research with Rose, Chang and Davidson to accomplish the specific tasks described in their task statement. The other members of this overarching center-wide integrated task will contribute the experience, vision, and expertise that they possess as senior research managers with MCEER (Shinozuka, Tierney, Reinhorn and Bruneau) and continuity with the original work of the MCEER Task Force that led to the original definition and proposed measures of resilience (Winterfelt, Chang, Shinozuka, Tierney, Reinhorn and Bruneau).

**Possible Direction of Work in Subsequent Years:**

II.A-2.17


<table>
<thead>
<tr>
<th>MCEER RESEARCH TASK STATEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task No.</strong> 6.0.3</td>
</tr>
<tr>
<td><strong>Task Title:</strong></td>
</tr>
<tr>
<td>Loss Estimation and Community Resilience: Measures of Organizational and Community Resilience</td>
</tr>
<tr>
<td><strong>Investigator:</strong></td>
</tr>
<tr>
<td><strong>Institution:</strong></td>
</tr>
<tr>
<td>* indicates task leader</td>
</tr>
</tbody>
</table>

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

This project has two primary objectives: (1) to contribute to the further refinement of MCEER’s measures of organizational and community resilience by synthesizing findings from the research literature and results of earlier empirical work on resilience; and (2) to provide survey-based data on business impacts and resilience following the 1994 Northridge earthquake for incorporation into the economic loss models that will be developed for the Los Angeles integrated water and power case study. The bases of resilience in social and organizational systems are not yet well-understood, but previous MCEER work has made an important contribution to identifying and quantifying relevant measures of resilience. This task activity is one element in an overarching centerwide task encompassing all three of MCEER’s research thrust areas.

**Problem Description and Research Approach of Proposed Work for Year 6:** *(Detailed description of research to be conducted and methodology to be used.)*

With respect to the first subtask identified above, in collaboration with other MCEER investigators, the PI will continue work in Year 6 to develop conceptually sound and empirically grounded measures of resilience, with a particular emphasis on organizational and social resilience. This PI’s contribution to the larger resilience task will draw upon earlier social scientific research on resilience, as well as on the PI’s recent MCEER-funded work on organizational and community resilience in the World Trade Center attacks.

MCEER has identified the City of Los Angeles as a testbed for demonstrating both state-of-the-art loss estimation methodologies for integrated (power and water) lifeline systems and resilience-enhancing strategies, such as post-earthquake prioritization of lifeline service restoration. To accomplish this goal, MCEER will be expanding and extending the electrical power and water systems analyses and the loss estimation methodology it originally developed for the Memphis lifelines community study. As part of this effort, as indicated above, the PI will provide other PIs with whatever data and analyses are needed from a business survey conducted following the 1994 Northridge earthquake. That survey contains extensive information on business impacts following the earthquake, including those associated with lifeline service interruption, as well as data on business losses. Following methodologies developed in previous MCEER work, the business data will be used to calibrate and improve the loss estimates.
developed by other MCEER investigators. More specifically, the data will aid in the identification of resilience factors for different economic sectors and will make it possible to incorporate real-world data on business adjustments to water and power service interruption into indirect loss models. (For an illustration of this approach, see Chang, Rose, Shinozuka, Svekla, and Tierney, “Modeling Earthquake Impact on Urban Lifeline Systems: Advances and Integration,” MCEER Research Accomplishments, 1999-2000.)

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Although the concept of resilience and a related term, “disaster resistance,” are used frequently in writings on communities and their vulnerability to hazards and disasters, no methodology currently exists to measure either resilience or the contribution made (in terms of losses avoided) by various resilience-enhancing strategies, such as pre-event mitigation and post-impact response measures. MCEER’s research activities in the area of resilience constitute a pioneering approach to conceptualizing and measuring resilience for both physical and social systems. To date, MCEER investigators have made considerable progress in defining resilience and its dimensions and also in developing a general framework for quantifying resilience. That progress has been summarized in the November, 2001 document entitled “Task Force Report on Community Resilience and Prioritization of Research Tasks Based on System-Wide Model Requirements,” to which the PI contributed. Considerably more work now needs to be done to (1) further specify technical, organizational, social, and economic performance criteria for various units of analysis (e.g., lifeline systems, hospitals, communities); (2) assess the relative contributions made by different loss-reduction strategies to overall system performance; (3) collect additional data to improve modeling capability and resilience estimates; and (4) demonstrate the efficacy of these models by applying them to a specific community setting—the City of Los Angeles.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

As indicated above, work in previous years has led to the development of a conceptual framework, tools, and strategies that can now be employed to further define and measure resilience. Focusing specifically on work undertaken by this PI, in Year 5, in addition to contributing to the Task Force Report that established a definition and measures of resilience, the PI has been using the resilience concepts developed through MCEER research to characterize and analyze organizational and community response following the September 11 World Trade Center attacks. The PI and other Disaster Research Center staff have written preliminary papers and made a number of presentations on this work, including presentations at the annual meeting of the Regional Sciences Association International, the National Academy of Sciences, the Urban Land Institute, and Rutgers University. Future presentations are scheduled at the annual meeting of the American Sociological Association, the annual Natural Hazards Workshop at the University of Colorado, and the 7th U. S. National Conference on Earthquake Engineering. Year 5 work is still ongoing, but findings are expected to lead to a fuller understanding of how resilience is achieved in complex organizations and urban systems and to shed additional light on how systems can be expected to respond in major urban earthquakes.
Role of Proposed Task in Support of Strategic Plan:  *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The enhancement of community seismic resilience—characterized by reduced probability of system failures, reduced consequences due to failure, and reduced time to restore critical community systems—is central to MCEER’s mission. MCEER seeks to achieve this goal by developing knowledge, techniques, and tools that can be used to improve the resilience of facilities and organizations whose functions are essential for community well-being following earthquake disasters. Since this task and related tasks focus specifically on community resilience, they are critical for MCEER’s strategic plan. With respect to the MCEER strategic framework, as outlined in the centerwide three-plane chart, this work contributes to “Fundamental Studies on Resilience,” “Loss Modeling,” “Resilience Criteria and Measures,” and “Systems-Integrated Loss-Reduction Strategies.” Focusing on Figure 4 from the Task Force Report, “MCEER Center-wide Systems Diagram,” these task activities are most closely related to boxes 5, 8, 9, and 10.

Task Integration:  *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The PI will collaborate with other MCEER investigators who are working on the overarching resilience task and on the Los Angeles integrated lifelines testbed project, including Bruneau, Chang, Lee, O’Rourke, Reinhorn, Rose, Shinozuka, and von Winterfeldt. As in past projects, collaborative activities will include co-authoring reports, attending coordinating meetings and taking part in conference calls, and providing data as needed.

Possible Technical Challenges:

This PI and other investigators involved with the overarching resilience task face a series of significant technical challenges. With respect to conceptualizing and quantifying resilience, those challenges include developing measures that adequately capture various dimensions of resilience; developing performance criteria that are consistent across systems, dimensions of resilience, and different units of analysis; and refining MCEER’s state-of-the-art loss models to incorporate resilience-related measures and strategies. With respect to the Los Angeles community study, technical challenges include dealing with very large systems and data requirements; achieving consistency and continuity between engineering and social science models, measures, and spatial data; and resolving problems associated with uncertainty.

Anticipated Outcomes and deliverables:
*(Also indicate those of particular benefit to IAB members and other end users.)*

<table>
<thead>
<tr>
<th>Contributions to MCEER papers, reports, conferences, and workshops on resilience definition, measurement, and enhancement</th>
<th>Potential end-users beyond academic community:  <em>(IAB members and others.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Contributions to papers, reports, conferences,</td>
<td>Emergency management agencies at various governmental levels (e.g., city, county, state)</td>
</tr>
<tr>
<td></td>
<td>Utility service providers</td>
</tr>
<tr>
<td></td>
<td>Business organizations, business recovery and</td>
</tr>
</tbody>
</table>
and workshops on the World Trade Center attacks

| Contribution of data on business resilience for Los Angeles demonstration project. | contingency planners
| Risk analysts and risk managers |

**Educational outcomes and deliverables, and intended audience:**

Training experiences for postdoctoral fellow, graduate students, and undergraduates. Opportunities for postdoc and students to present papers at professional meetings and to use data for their course work.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

Since this is a collaborative activity, the overall schedule will be determined by the entire group of PIs working on this task. Resilience measurement and enhancement and the Los Angeles community study are multi-year projects. Results of PIs earlier work on resilience and on the World Trade Center case study will be summarized in papers and reports in summer and fall, 2002 and spring, 2003.

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

- Kathleen Tierney, Disaster Research Center
- James Kendra, Disaster Research Center
- Graduate and Undergraduate Students, TBA

**Possible Direction of Work in Subsequent Years:**

As indicated earlier, the activities described here are multi-year activities designed to advance the state-of-the art with respect to the conceptualization of resilience and its measurement, engineering-based and social scientific measures of resilience, and the improvement of resilience for community systems.
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Title:</th>
<th>Direct Losses, Social Impacts, and Community Resilience: Los Angeles Lifeline Study</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Investigator/</th>
<th>Stephanie Chang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institution:</td>
<td>University of Washington</td>
</tr>
</tbody>
</table>

* indicates task leader

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

This project aims to develop a loss model and related measures of community resilience for the Los Angeles lifeline study. The loss model will adapt the Memphis lifeline methodology to Los Angeles. It will expand the Memphis methodology to incorporate multiple lifeline disruption (water and power systems), add social impact evaluation, and explicitly measure changes in community resilience (social and economic). The project will focus on modeling social and economic losses. Linkages to engineering models are planned for subsequent years, when the development of the Los Angeles engineering models is complete.

**Problem Description and Research Approach of Proposed Work for Year 6:** *(Detailed description of research to be conducted and methodology to be used.)*

This project will develop a model of direct economic and social losses that can be used to evaluate the community resilience improvements afforded by the application of advanced technologies in MCEER’s Los Angeles study. It consists of two main subtasks: (1) adapting the economic loss methodology that had been previously developed in the Memphis lifeline study; and (2) expanding it to model social losses.

Adapting the Memphis methodology will involve both transferring the model to the Los Angeles context and implementing some refinements. The Memphis model is limited to the water delivery system (earlier, a separate loss model for electric power had been developed under NCEER). For Los Angeles, the model will first be restructured and reprogrammed to be able to handle multiple lifeline disruption inputs, i.e. from both water and power. This will necessitate separating the engineering from the socio-economic sub-models, since the L.A. engineering models are still under development. However, the format of the linkages between the sub-models will be clearly specified through consultation with MCEER lifeline engineering researchers, so that the sub-models can later be integrated in a seamless manner. In this consultation, it will be decided whether a change in model platform (currently FORTRAN) would also be needed. Similarly, linkages to indirect economic loss models would be specified. Transfer of the socio-economic model would further involve linking it to L.A. databases, most of which have already been gathered. The model would also be refined to evaluate not just dollar economic loss, but changes in associated community resiliency measures, as well. Outputs would be formatted for ready linkage to GIS platforms such as ArcGIS.
In the second subtask, the model will be expanded to estimate social losses from lifeline disruption. This effort will focus on estimating the population that would be displaced from their homes due to loss of water and/or electric power. Very few models exist that predict shelter and displaced population; a notable exception is the HAZUS model, which evaluates these effects for water outage. However, the effort here will also draw on the rather substantial sociological, geographical, and planning literature on populations displaced by natural disasters. It will also make use of empirical data from recent earthquake disasters which were not available when the HAZUS model was developed (especially from Kobe). Again, results will be framed in terms of impacts on community resilience, using a series of proposed resilience measures.

In addition, a networking subtask submitted separately describes the development toward a computational tool which will be made available to the Users Network of MCEER. This sub-task proposes to develop a website where details and examples of proposed measures of community resilience would be posted for review and feedback (initially among MCEER researchers and industry affiliates).

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

This project transfers MCEER’s lifeline economic loss model from Memphis to Los Angeles. To the P.I.’s knowledge, MCEER has developed the only existing models that evaluate the economic disruption impacts of electric power and/or water outage in earthquakes. In terms of expanding the scope to model displaced population, this project will build on existing models such as HAZUS by incorporating new data.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Efforts in previous years, under the Memphis Lifelines and the Loss Estimation tasks, produced an integrated engineering-economic model of losses due to water outage. This model is innovative in its treatment of uncertainty, use of GIS, incorporation of empirical data, and application to comparing pre- and post-disaster loss reduction strategies. Results have been presented and published in various venues, including MCEER’s Research Accomplishments series and, within the past year, in the journal Environment and Planning B. A paper has been accepted for presentation at the 7th National Conference on Earthquake Engineering (July 2002).

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

In terms of the 3-plane chart, this project contributes to MCEER’s “technology base” by developing a socio-economic loss model for lifelines (Thrust Area 1). This model can evaluate the community resilience impacts of loss reduction strategies, including engineering technologies, that MCEER is developing for water and power systems. It will thus contribute to the “technology integration” plane, where the resilience enhancements of these technologies is to be tested and evaluated. In terms of MCEER’s center-wide systems diagram, this project contributes to “community modeling and resilience estimation” (box 8).
**Task Integration:**  *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The socio-economic loss model developed here will eventually be integrated with engineering models of water and power outage that M. Shinozuka and T. O’Rourke are developing for Los Angeles. In consultation with these and other appropriate investigators, and based on experience in the Memphis study, this project will develop a consensus specification of the links to be made between the engineering and socio-economic models. Similar discussions with A. Rose will produce specification of the links to be made with indirect economic loss modeling.

**Possible Technical Challenges:**

Los Angeles is a much larger and more complex urban area than Memphis. It encompasses dozens of cities and involves several major lifeline providers. Challenges may include issues of data consistency and completeness, as well as computational efficiency.

### Anticipated Outcomes and deliverables:
*(Also indicate those of particular benefit to IAB members and other end users.)*

- Socio-economic loss model for L.A. lifelines (scope as indicated above).
- Specification of model linkages to be made with engineering and indirect economic models.

### Potential end-users beyond academic community:
*(IAB members and others.)*

- City of Los Angeles
- LADWP
- Emergency managers and planners
- Utility agencies

### Educational outcomes and deliverables, and intended audience:

Training of 2 graduate students.

### Project Schedule and Expected Milestones for the Project:
*(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

Notes: This schedule assumes a project period of October 2002-September 2003.

**Subtask 1: Model transfer and refinement.**

- Winter 2003 - Conduct GIS and other processing of data. Begin model development and programming.
- Spring 2003 - Complete model development and programming.
- Summer 2003 - Write up for publication.

**Subtask 2: Displaced Population Sub-model**
Fall 2002 - Review literature on displaced and shelter population in disasters.
Summer 2003 - Write up for publication.

Networking Subtask: Resilience Measures Website
Spring 2003 - Summarize model structure, links, and proposed resilience measures. Develop website and post summary. Solicit feedback via website.

Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

P.I.: S.Chang
Coordination with: M.Shinozuka, T.O’Rourke, A.Rose
Students: 2 graduate students from Geography, Economics, or Urban Planning (U.Washington)
Industrial participants: Feedback will be sought from City of LA and LADWP members of MCEER’s IAB.

Possible Direction of Work in Subsequent Years:

Integration with lifeline engineering models for L.A. study. Development of links between social and economic loss, e.g., loss of labor productivity due to earthquake disruption at the home. Assessment of social and economic resilience impacts of implementing advanced technologies.
### MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Budget:</strong></td>
<td>Yr 6 Assigned</td>
</tr>
<tr>
<td><strong>Project Number:</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Indirect Losses and Community Resilience: Los Angeles Lifeline Study

**Investigator:** Adam Rose  
**Institution:** The Pennsylvania State University

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The goal of this project is to construct a computable general equilibrium (CGE) model of the Los Angeles economy to measure community resilience in the face of earthquake threats to utility lifelines and to measure major changes in resilience in light of pre-event mitigation strategies and post-event restoration strategies. The analysis will be linked to the LA Demonstration Project on electricity and water lifelines headed by Tom O’Rourke and Masanobu Shinozuka. The CGE model will be integrated into the work of other researchers in the engineering, vulnerability assessment, GIS, mitigation technology and adoption, policy, and planning areas.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

Computable General Equilibrium (CGE) refers to a model of the entire economy based on decisions by individual producers and consumers in response to prices and markets within the limits of available capital, labor, and natural resources. It automatically incorporates non-linearities and can incorporate bounded-rationality behavior.

CGE is the state-of-the-art methodology for impact analysis at the national level, and is being more frequently used at the regional level, the appropriate geographic scope of most natural hazards. It represents a significant advance over input-output modeling, which has dominated the hazards impact literature, by overcoming limitations of linearity and mechanical response through the incorporation of nonlinearities and behavioral responses to price signals, resource limitations, and private and public sector policy considerations.

The project will capitalize on recent refinements of CGE analysis, such as the incorporation of new empirical data, the modeling of disequilibria, and separation of direct and indirect impacts.

The following tasks will be undertaken:

1. Construct a computable general equilibrium model of the LA County economy (by-products of this will be an input-output table for economic structural analysis and a social accounting matrix for distributional analysis).
2. Specify production function parameters for electricity and water on the basis of data obtained from other MCEER researchers.

3. Begin to incorporate behavioral considerations into the model from the work of MCEER decision scientists.

4. Test the model by running a trial simulation of the impacts of a system disruption to one of the lifelines.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

I am the only economist affiliated with MCEER. No other MCEER researchers are involved in regional economic analysis in general (except for Stephanie Chang’s work on direct impacts) and on CGE modeling in particular. Economists and regional scientists at other earthquake centers are not working on CGE analysis (Peter Gordon of PEER continues to work on multiregional input-output analysis, and Geoff Hewings at MAE on conjoined econometric I-O models).

Earlier attempts at adapting CGE models to natural hazards by David Brookshire at New Mexico and Dick Boisvert at Cornell have not followed through. My work has advanced on theirs by: 1) using more sophisticated production functions, 2) testing key parameters, 3) measuring individual business and community resilience measures, 4) incorporating real world data for parameter estimation, 5) being able to model adjustments when utility service prices are fixed, and 6) measuring resiliency at the community level.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

Major accomplishments in the past include:

1. Advanced the state of the art of input-output and linear programming models of indirect loss estimation for earthquakes.

2. Identified and measured capabilities of nonstructural post-event recovery measures to reduce business interruption losses from earthquakes (e.g., recontracting of suppliers and customers, rationing of scarce lifeline services).


4. Advanced the state of the art of CGE modeling for natural hazard loss estimations, including
demonstrating model capabilities in the Portland Water System Study funded by a related NSF grant.

5. During the reporting period, I made the following progress:
   a. Developed a way to incorporate real world data into the estimation of input parameters for lifeline services.
   b. Developed criteria for validating CGE models applied to natural hazard loss estimation.
   c. Made advances in modeling sectoral and community resiliency in CGE models.
   d. Made advances in incorporating adaptive nonlinear considerations, such as learning, into responses to utility service disruptions.

6. Fully converted CGE modeling capability from GAMs to the state-of-the-art MPSGE software.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This task will uniquely contribute to the MCEER objective of enhancing community resiliency to earthquakes. It calls for conceptual and empirical advances in a regional economic model, which explicitly incorporates resiliency at the individual consumer and producer levels and assesses the impacts of their decisions, together with underlying engineering system features, on the community as a whole. It focuses on the economic dimension of resiliency, but can be integrated with other dimensions. It is the only community-wide model at an advanced stage at MCEER. Moreover, the model is operational and can play a key role in the LA Demonstration Project in estimating direct and indirect business interruption losses for that community.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

My proposed research builds on the work of other MCEER researchers and will be part of an integrated, interdisciplinary loss estimation system. It will essentially yield bottom line economic loss estimates for the LA economy as a whole.

1. T. O’Rourke — modeling LA lifeline networks
2. M. Shinozuka — modeling network vulnerability/reliability
3. K. Tierney — measuring resiliency
4. S. Chang — measuring direct economic losses

**Possible Technical Challenges:**

Major challenges include:
- reconciling spatial engineering data with spatial economic data through GIS
- matching theoretical properties of the model to real world needs
- streamlining the model so that it can be incorporated into a computerized integrated assessment framework with other MCEER researchers
<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
</table>
| 1a. Construct LA I-O & SAM Models  
1b. Construct LA CGE Model  
2. Specify utility parameters  
3. Incorporate behavioral considerations  
4. Run impact simulations | 1a. LA public officials and utility managers  
1b. Other researchers & policy-makers  
2. Utility managers  
3. MCEER researchers  
4. All |

**Educational outcomes and deliverables, and intended audience:**

Completion of the following Ph.D. theses:
- Shu-Yi Liao — Summer 2002
- Gauri Guha — Winter 2003
- Ram Ranjan — Spring 2003

**Project Schedule and Expected Milestones for the Project:** (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>January 2003</td>
<td>Visual representation of LA economy</td>
</tr>
<tr>
<td>1b</td>
<td>March 2003</td>
<td>Documented model</td>
</tr>
<tr>
<td>2</td>
<td>June 2003</td>
<td>Refined model</td>
</tr>
<tr>
<td>3</td>
<td>August 2003</td>
<td>Conference paper</td>
</tr>
<tr>
<td>4</td>
<td>September 2003</td>
<td>Refereed journal article &amp; chapter of MCEER monograph</td>
</tr>
</tbody>
</table>

**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- Tom O’Rourke
- Masanobu Shinozuka
- Kathleen Tierney
- Ron Eguchi
- Stephanie Chang

**Possible Direction of Work in Subsequent Years:**

1. Incorporation of more behavioral considerations of responses by producers, consumers, and policy-makers in conjunction with MCEER decision scientists.
2. Improved conceptual and empirical modeling of individual and business resiliency.
3. Application to more aspects of LA Demonstration Project and other demonstration efforts
<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.0.6</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Number:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Restoration analysis for lifelines

**Investigator/Institution:** Rachel Davidson / Cornell University

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The objective of this task is to develop an improved model of the post-earthquake restoration processes of the electric power and water supply systems. The model will use estimates of physical damage to the systems and an understanding of the repair and recovery operations to estimate expected restoration times for each system, as well as the uncertainty surrounding those estimates. This task will be undertaken in conjunction with other work on the Los Angeles Department of Water and Power (LADWP) demonstration project.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

The rapidity dimension of electric power and water supply system resilience is a critical determinant of a community’s economic resilience. Assessment of lifeline rapidity requires quantitative measurement of expected post-earthquake restoration times. The objective of this task is to develop a model of the post-earthquake restoration processes of the electric power and water supply systems. The model will output quantitative estimates of system restoration times, which will directly support efforts to assess economic community resilience.

In Year 6, the work will concentrate on electric power systems, using the LADWP electric system as the test bed for model development. The task will include three main phases: (1) background research, (2) restoration model development, and (3) comparison of model results with documented system performance in the 1994 Northridge and 1971 San Fernando earthquakes.

First, the PI will gain the necessary background on the tasks with which this one directly interfaces—tasks that aim to estimate damage to the systems (Shinozuka and Grigoriu) will offer input for the restoration model, and tasks that aim to measure economic resilience (Chang and Rose) will use the output of the restoration model. Additional work will be done on a literature review of available post-disaster lifeline restoration modeling approaches (related to earthquakes or other hazards). Interviews with LADWP repair and emergency response personnel will be conducted to gather information about the process as well. Second, the restoration model will be designed so as to provide quantitative assessment of restoration times in a form that best supports measurement of economic resilience (e.g., including estimates of uncertainty, disaggregated spatially). The model will address the temporal and spatial variability within the restoration process, interdependencies among various lifeline infrastructure systems, and the
effects of organizational factors (e.g., repair prioritization plans, mutual aid agreements) and human interventions on the processes. It will rely on Monte Carlo simulation, and perhaps Markov modeling to capture the dynamic nature of the restoration process. It will be implemented in a Geographic Information System (GIS) environment to enable representation of the spatial sequencing of the restoration process. Third, the model will be applied in Los Angeles as part of the LADWP demonstration project. Model results will be compared to observed system performance in the 1994 Northridge and 1971 San Fernando earthquakes, and model the model will be refined as necessary.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

ATC (1992) provided an early restoration model for the U.S. water supply system based on ground shaking intensity, facility type, and region of the U.S. Ballantyne (1990) models the Seattle water supply system restoration process using several assumptions about the repair process, resources required for repairs, and availability of resources. HAZUS employs a similar approach to water system restoration (NIBS 1997). In previous MCEER work, Shinozuka et al. (1998) assume a nonlinear functional form for restoration curves for the electric power system. Chang et al. (2000) uses a resource constraint approach in which the number of repairs completed in a time period is estimated based on the availability of repair personnel, and the sequence of repairs is specified based on observations from the Kobe and Northridge earthquakes.

Previous studies such as these suggest that future restoration models should incorporate both the spatial and temporal variability inherent in the restoration process, the effect of mutual aid agreements, and the effect of interdependencies among lifelines. They also suggest that some assumptions required by models that simulate the actual repair process have not been supported by empirical evidence from recent earthquakes. A well-designed restoration model will allow assessment of the effectiveness of strategies that aim to reduce losses by shortening restoration times through mutual aid agreements, or by prioritizing the sequencing of component repairs based, for example, on their damage level, their geographic location, their function within the system, or the characteristics of the customers they serve.

Davidson et al. (forthcoming) describes the performance of the electric power distribution system in the Carolinas in recent hurricanes. Subsequent work is underway to develop a predictive model of hurricane damage and restoration. Although hurricanes and earthquakes cause very different damage patterns, the investigator’s previous research experience modeling hurricane damage to electric power systems will serve as a helpful foundation for the proposed task.


Research, State University of New York at Buffalo: Buffalo, NY.

Davidson, R., H. Liu, I. Sarpong, P. Sparks, and D. Rosowsky. Electric Power Distribution System Performance in Carolina Hurricanes. *Natural Hazards Review*. [Accepted for publication].


**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

Not applicable. This is a new task.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This task will provide a methodology to help measure the rapidity dimension of resilience for electric power and water supply systems. It will offer a direct contribution to measurement of the technical and organizational aspects of resilience, which in turn will support efforts to assess the economic and societal resilience of a community. In terms of the MCEER three-level strategic framework chart, the development of a restoration model fits in with the modeling and simulation associated with loss estimation methodologies that are part of the middle level.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The proposed work will form a critical link between the tasks that involve estimating damage to electric power and water supply systems (Shinozuka and Grigoriu) and the tasks that involve measuring the economic and societal aspects of community resilience (Chang and Rose). The restoration models will be designed to take full advantage of the estimates of physical system damage provided as input from Shinozuka and Grigoriu, and to provide as output the information required by Chang and Rose to assess the economic and societal aspects of community resilience.

**Possible Technical Challenges:**

- Restoration of the electric power and water supply systems are not independent of each other or the performance of other lifeline systems. For example, the repair of water supply pipes may be impeded by damage to the transportation network or debris in the roads if repair crews cannot gain access to the damaged area, or it may be delayed by damage to the electric power system if the electricity required to operate pumps is not available. It may be difficult to incorporate the effects of those infrastructure interdependencies.

- Even if there exist well-established earthquake response plans that dictate how a restoration is expected to proceed, the restoration processes may be heavily influenced by decisions made post-earthquake in reaction to the actual circumstances. It will be difficult to anticipate the way that repair personnel and others interact with the restoration process and to
incorporate the effect of those human interactions.

- Data required by the model (e.g., availability of repair personnel and materials; and time required for post-earthquake inspections, component repair work, and replacement of components that cannot be repaired) may be difficult to obtain.

<table>
<thead>
<tr>
<th><strong>Anticipated Outcomes and deliverables:</strong>&lt;br&gt;<em>(Also indicate those of particular benefit to IAB members and other end users.)</em></th>
<th><strong>Potential end-users beyond academic community:</strong>&lt;br&gt;<em>(IAB members and others.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Model for assessing expected post-earthquake restoration times for electric power and water supply systems.</td>
<td>LADWP</td>
</tr>
<tr>
<td>2. Estimates of restoration times for LADWP demonstration project.</td>
<td>Other electric power and water supply companies</td>
</tr>
<tr>
<td></td>
<td>Other utility companies</td>
</tr>
</tbody>
</table>

| **Educational outcomes and deliverables, and intended audience:**<br>This task will provide a multidisciplinary educational experience for a graduate research assistant who will work on the project. It will also possibly serve as a case study for discussion in the investigator’s course entitled Civil Infrastructure Systems (CEE 506). The course aims to introduce structural engineering students to the concepts and methods of the systems engineering approach through case studies relating to infrastructure systems. |

<table>
<thead>
<tr>
<th><strong>Project Schedule and Expected Milestones for the Project:</strong>&lt;br&gt;* (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Background—discussion with investigators of related tasks, literature review, interviews with LADWP personnel (Fall 2002)</td>
<td></td>
</tr>
<tr>
<td>2. Restoration model development (Spring 2003)</td>
<td></td>
</tr>
<tr>
<td>3. Comparison of model results for Los Angeles with observed performance in recent earthquakes (Summer 2003)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Team Members:</strong>&lt;br&gt;* (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A graduate student research assistant will be hired to work on the project.</td>
<td></td>
</tr>
</tbody>
</table>

| **Possible Direction of Work in Subsequent Years:**<br>Extend the model to water supply lifelines and then combine the electric and water restoration models. The combined model will account for the effect of delays in electric power restoration on reinstatement of the water delivery system. The restoration models developed in this research will be consistent with the type of approach needed for the restoration of acute care facilities and hospitals. The research products developed here for lifelines, therefore, will form the basis for hospital restoration assessment, and can be further developed for these facilities in the future. |

II.A-2.33
Thrust Area 1:

Seismic Evaluation and Retrofit

Of Lifeline Systems
**Task No.** 6.1.1  
**Budget:**  
**Yr 6 Assigned Project Number:**

**Task Title:** Electric Power Systems Network Modeling

**Investigator/ T. C. Cheng*, Xianhe Jin**  
**Institution:** University of Southern California  
* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This task involves electric power behavior analysis for the WSCC (Western Systems Coordination Council) power systems during an earthquake, correlation analysis between power and water systems under ground motions, and investigations of internal electromagnetic and electromechanical effects of high voltage power transformers during and after an earthquake with neural network applications and finite element analysis.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

After 5 years research on the LADWP (Los Angeles Department of Water and Power) power system, we continue to broaden and deepen our research work in the following aspects. From the historical seismic data of the WSCC collected during the 1994 Northridge earthquake, it is apparent that catastrophic blackouts spread electrically to a much larger geographical area, including power systems in the states of Nevada, Arizona, New Mexico, Idaho, Utah, Wyoming, Montana, as well as northern utilities all the way to Canada in addition to blackouts experienced by LADWP and Southern California Edison power systems. In year 6, we will focus on electric power behaviors of the whole WSCC power system during an earthquake or after. Special attention will be devoted to validating the methodology, as well as correlating social-economic losses incurred by disruption to the telecommunication, internet, computer, data transmission, financial, manufacturing, transportation, emergency response, national security and a host of other industries and entities. The objectives of this research are to evaluate and investigate the seismic performance of all power systems within the WSCC and recommend advanced technologies for rehabilitation measures. After the September 11, terrorist threat to America is a most critical issue. The impacts of any equipment failure will be far reaching to areas beyond the immediate location of the failure. In this context, attacking any substation in a transmission network and power plant will pose significant threats to national security. From the electrical disturbance point of view, a terrorist attack against a substation or power plant is similar to an earthquake strike. The rehabilitation methods for the WSCC power systems are quite suitable to be applied to terrorist attacks.

In addition to the system study of the WSCC power networks, we will explore correlation between water and power systems within LADWP. Power system’s degradation by an earthquake will affect water system’s operation and vice versa. Water treatment and pumping station facilities are mostly energized by electrical power. In addition, pump storage reservoirs act as storage of electric energy and thus will influence a power system’s stability and reliability. This new area of study will be collaborated with Dr. O, Rourke’s research group.

The power transformers, particularly high voltage power transformers, are easily vulnerable to ground motions both inside and outside. A bushing’s seismic performance (outside component) has been studied. Seismic behavior of internal components of a power transformer is still unknown and may have an adverse impact on its expected life expectancy. In year 6, we will investigate the effect of the seismically induced relative motions of the internal components. It could initiate partial discharges in electrical insulation which eventually result in a power transformer breakdown. Any high voltage power
transformer breakdown will cause a major blackout. We will cooperate with Dr. Feng and Dr. Saadeghvaziri and use the state-of-art technology, for instance, artificial neural network applications, base-isolation, and finite elements, to analyze internal components electromagnetically and electromechanically. It also contributes to direct and indirect economic loss analysis conducted by other research groups at MCEER.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

From our knowledge, there are no other research groups that have been conducting the same research as we do within and outside of MCEER. Our three tasks, seismic analysis for the WSCC power systems, correlation analysis between power and water systems during ground motion, and internal electromagnetic and electromechanical effects in high voltage power transformers during and after an earthquake, represent new technical areas that benefit the social and economic welfare of our community.

**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

For our project purposes, seismic data of LADWP’s power system have been collected with emphasis on damage data under the 1994 Northridge earthquake. In addition, one-line diagrams of LADWP’s receiving stations have been gathered. LADWP is invited as a participant in an end user advisory board to provide us with industrial feedback. With the collected data, substation information and the aid of software IPFLOW developed by Electric Power Research Institute (EPRI) as well as computer code developed Dr. Shinozuka’s research group, power flow analysis of LADWP’s electric power system have been performed under 47 earthquake scenarios representing the seismic hazard in Los Angeles area. The condition, under which LADWP’s power system may experience voltage drop or rise under an earthquake strike, has been categorized. The power flow and voltage changes of LADWP’s power system have been recomputed with the aid of software IPFLOW using new sets of system data.

In the past year, from April 2001 to March 2002, the fragility curves of high voltage power transformers were developed based on the seismic data in the 1994 Northridge earthquake. These fragility curves are more suitable for power transformers. A draft technical report for year 5 has been completed.

**Role of Proposed Task in Support of Strategic Plan:** (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

An electric power system is a critical system in our society. Any critical power equipment failure caused by an earthquake can disrupt telecommunication systems, the emergency response system etc. and adversely impact on national security. A terrorist attack against a substation or power plant is similar to an earthquake strike from an electrical disturbance standpoint. The rehabilitation methods developed for the WSCC power systems may be similarly applied after a terrorist attack. These tasks fit MCEER Thrust Area I which is “Seismic Retrofit of Lifeline Systems”.

**Task Integration:** (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

This project is capped under MCEER Thrust Area I – Seismic Retrofit of Lifeline Systems. The tasks are closely cooperated with Dr. Shinozuka, Dr. O,Rourke, Dr. Feng and Dr. Saadeghvaziri, and the other MCEER investigators. The outcomes from this project will substantially contribute to the project goals of other MCEER investigators. Retrofit strategy for power systems will enhance the reliability and security of those systems.
### Possible Technical Challenges:

Fully understanding seismic behaviors of a power system, correlation between water and power systems and internal electromechanical and electromagnetic effects of a high voltage power transformer under ground motion may be a major challenge.

### Anticipated Outcomes and deliverables:

(Also indicate those of particular benefit to IAB members and other end users.)

The system behavior of theWSCC power systems during an earthquake strike will be evaluated. Connections between power and water systems will be investigated. The seismic performance of internal and external components of a power transformer will be delineated, which are extremely desirable for developing an optimal rehabilitation strategy.

### Potential end-users beyond academic community: (IAB members and others.)

Direct end users for an optimal rehabilitation strategy for power systems are utilities in California and other quake prone states. In particular, LADWP, Southern California Edison, San Diego Gas & Electric and Pacific Gas & Electric and their customers will benefit. Other major users such as the telecommunication, internet, financial, manufacturing industries, etc. and national security agencies will also benefit.

### Educational outcomes and deliverables, and intended audience:

The electrical blackout study for the WSCC power systems during an earthquake is one of the most interesting topics to both graduate and undergraduate students. Technical challenges may stimulate students to get involved in different aspects of the problem. Introducing state-of-the-art technology in the classes to students will enhance their prospective academic or professional careers.

### Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

To achieve our objectives, power flow calculations in the whole WSCC power systems under an earthquake strike will be investigated. An earthquake in Southern California has a major impact on power systems of other western states and vice versa. Correlation analysis between water and power systems in cooperation with Dr. O.Rourke will be performed. The first major task is to collect inventory seismic data of the LADWP water system including electric motor failures in connection with water pumps and water service areas. The last task is to conduct a partial discharge investigation in the internal insulation of power transformers with neural networks applications. In addition, finite element calculations for an internal power transformer structure will be performed in collaboration with Dr. Feng and Dr. Saadeghvaziri. The relation between relative displacement of internal insulation components and induced partial discharges in and on these insulation components will be explored.

### Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

### Possible Direction of Work in Subsequent Years:

In year 6, we will concentrate on the inventory data collection for the WSCC power systems and the LADWP water system, power flow analysis within the WSCC based on the fragility curves we developed for power transformers, and internal components study of power transformers after an earthquake strike. After year 6, we will focus more on the impact on the WSCC power systems from other critical power equipment, such as circuit breakers, disconnect switches, capacitor banks, and electromechanical relays. Internal electromagnetic and electromechanical effects on a high voltage power transformer and internal partial discharge patterns will be investigated in detail using neural network applications.
MCEER RESEARCH TASK STATEMENT

Task No. 6.1.2  
Budget: 
Yr 6 Assigned  
Project Number: 

Task Title: Comprehensive Model for Integrated Electric Power Systems

Investigator/  
Institution: Masanobu Shinozuka, University of California, Irvine

* indicates task leader

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The goals of this project are to integrate the technologies developed by MCEER, including those to be developed concurrently with this project in Y6, for the purpose of establishing analytical procedures that permit the evaluation of seismic resilience of a community as it pertains to the seismic performance of a joint system consisting of water delivery and electric power systems accounting for their interactions. In particular, the initial version of performance criteria definition and the probabilistic analytical procedures introduced in Y5 for electric transmission systems will be further examined and extended to evaluate the joint performance of power and water systems under each earthquake as common cause. This opens up a logical avenue along which we can consider the community seismic resilience under these two and other systems combined.

Problem Description and Research Approach of Proposed Work for Year 6: (Detailed description of research to be conducted and methodology to be used.)

The proposed work is first to integrate the technologies developed by MCEER including GIS inventory data of the LADWP’s database and electric transmission systems, multiple scenario earthquakes representing the LA area seismic hazard, fragility analysis of systems, sub-systems and equipment, base-isolation techniques for transformers, systems analysis on the basis ofWSCC’s (Western Systems’ Coordinating Council’s) database and EPRI’s (Electric Power Research Institute’s) IPFLOW computer code, direct and indirect loss estimation methods, the initial version of performance criteria definition, and the probabilistic procedure introduced in Y5. The purpose of this integration is to evaluate the joint performance of power and water systems under each earthquake as common cause. The second component of this project is to establish the performance criteria that can be quantitatively mapped into the response space, not only in technological, but also in organizational, economic and social dimensions. And the third element is to develop probabilistic procedures to estimate the reliability of the seismic resilience of the community, for example, in terms of annual probability of the combined response being within an acceptable domain in the response system space (acceptable performance).
Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

MCEER’s lifeline research is unique in that the performance of lifeline systems is evaluated on the basis of network analysis. This is the only way, for example, in which interaction among the systems can be assessed quantitatively. We are also unique in proceeding forward for evaluation of the seismic resilience of the community in various dimensions integrating the performance of the systems that represent the community resilience.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Years 1 through 4

Engineering Seismology and Geotechnical: Seismologically consistent scenario earthquakes were identified to represent seismic hazards of the Los Angeles and the Memphis regions. The system analysis is then performed making use of Monte Carlo simulation techniques under these scenario earthquakes and taking the fragility curves of transformers and other equipment into consideration. The systems analysis for both LADWP and MLGW power transmission networks evaluates the average reduction in the output power in each service area, reflecting the average effect of the degradation of the system performance due to the seismic damage.

A computer code was completed and made available through a website for generation of California earthquake time histories. This was done in addition to similar computer codes made available earlier electronically for north-eastern and mid-America regions. A study on lateral spreading and other effects of liquefaction is on-going to develop liquefaction-related fragility curves for lifeline applications.

Systems Analysis: The systems analysis utilized the Western Systems Coordination Committee’s and MLGW’s database, and EPRI’s IPFLOW computer code for transmission systems. For the seismic performance of substation equipment, fragility information was developed from various sources and used in the IPFLOW code. The difference in the resulting fragility curves is currently studied from the view point of the uncertainty involved in the evaluation of ground motion intensity index such as PGA. Of equal importance is the study to determine the extent of fragility curve enhancement by rehabilitation of the bushing-transformer systems by base isolation. This was studied on the basis of the shaking table test performed at Taiwan's National Center for Research on Earthquake Engineering (NCREE) in Taipei under the MCEER-NCREE Cooperative Research Program. These test results are encouraging in that the reduction of the acceleration at the bushing-transformer interface is in the range of 50% which is consistent with the assumption made for the fragility enhancement (measured in terms of median value increase of up to 100%) in the earlier systems analysis.

Loss Estimation and Community Resilience: Scenario earthquake-based loss estimation methodologies were advanced taking into consideration the system restoration characteristics
which, among many other things, reflect earthquake disaster preparedness on the part of the lifeline owners to deal with various possible states of system-wide damage predicted by means of the systems analysis. The restoration characteristics include the duration of local as well as system-wide service outage which determines the extent of the direct economic losses in the form of economic fragility curves. This fragility curve can be combined with the seismic hazard curve to produce the annual expected direct loss. The Computable General Equilibrium (CGE) method was utilized to build an overarching framework for the estimation of the combined direct and indirect losses resulting from the damage and loss of function sustained by the lifeline system. In this respect, a breakthrough was made to deaggregate the indirect loss from the combined total losses within the framework of CGE method.

This loss estimation methodology was applied to the Memphis water delivery system for demonstration. The application to the LADWP electric power system is currently in progress. The work on seismic loss estimation for Memphis system developed and demonstrated an advanced, integrated earthquake loss estimation method for urban lifeline systems. In doing so, numerous substantive and significant refinements were introduced and added to MCEER’s knowledge base that exhibited previously. Highlights of these advances include: (1) “seamless” integration of engineering and direct economic loss models, (2) evaluation of system performance under multiple earthquake scenarios in a probabilistic risk framework; (3) implementation of advanced GIS capabilities more effectively utilizing spatially referenced data; (4) incorporation of lifeline restoration and post-disaster response parameters (5) calibration of the economic model with business impact data from the Northridge earthquake; (6) estimation of indirect loss with the new computable general equilibrium (CGE) modeling; and (7) taking into consideration model uncertainties (randomness) deriving from both engineering and economic models. More specifically, preliminary studies showed that the pumping stations are key components of the system. MLGW recently completed seismic rehabilitation of some of its pumping stations. MCEER investigators are currently studying the degree of the pumping station improvement and its impact not only on the system’s functional but also on the socio-economic performance.

MCEER strives for the enhancement of seismic resilience of communities through research, implementation, education and outreach activities. Currently, the possibility of developing of quantitative indicators for the resilience is investigated in the process of identifying various resilience enhancement measures available both for pre- and post-event settings. These measures are not only of technological but also socio-economic nature and involves strong policy issue-related points of view. At this time, this study is jointly performed with the work highlighted above in which the loss estimation methodology is developed and demonstrated for the Memphis water delivery system. Since the methodology accounts for repair and restoration characteristics in order to estimate direct and indirect losses, it is believed to provide fertile ground from which the definitions of quantitative measures of seismic resilience of communities emerge.

**Years 5**

Year 5 was a critical year in which two significant advances were made in the lifeline systems analysis. First, with respect to electric power systems, seismic performance criteria are
introduced in terms of robustness and/or restoration rapidity in technological dimension. While this is preliminary in its scope, the criteria can be extended to consider the performance in organizational, economical and social dimensions. Second, an analytical procedure to probabilistically evaluate the performance of a combined system consisting, for example, of water, and power networks on the basis of the performance criteria defined for each system on the same scale of robustness and/or restoration rapidity. These advances conceptually paved the way to combine more than two systems supporting the seismic resilience of the community such as systems of lifelines (water, power and gas), emergency response organizations, and medical care systems (a regionally designated network of acute care hospitals).

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This work plays a major role in MCEER’s Strategic Plan to develop methods and tools to enhance seismic resilience of the community. This work formulates such a process of evaluation for the resilience of a combined system consisting of water and power networks. The process is actually implemented utilizing the knowledge acquired for our testbeds, LADWP’s water and power system. This will pave the way to integrate other systems supporting the seismic resilience of the community.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This work will be tightly integrated with the effort by Grigoriu on the systems analysis of water network. The interaction of these systems from technical point of view will be investigated first. The effect of rehabilitation of water network by the use of FRC and electric power network by base-isolation is evaluated for a combined system consisting of these two networks working with O’Rouke, Saadeghvazini and Feng. The seismic resilience of this combined system in economic and social dimensions will also be attempted together with S. Chang, Rose, Tierney and Von Winterfield. Organizational dimension of the resilience will be studied with the LADWP engineers and management.

**Possible Technical Challenges:**

Quantitative evaluation of seismic resilience of the community (even of the combined water and power network) in organizational and social dimensions appears to require substantial initial and sustained effort in collecting necessary information. In addition, the specific and detailed GIS information of water, power and other lifeline systems has become very sensitive from the view point of security since the September 11th event.
# Anticipated outcomes and deliverables:
(Also indicate those of particular benefit to IAB members and other end users.)

- Preliminary development of software that allows estimation of resilience of a combined water and power network in technical and economical dimensions.

## Potential end-users beyond academic community:  
(IAB members and others.)

- LADWP
- Utility companies
- California OES
- Energy Response Community

# Educational outcomes and deliverables, and intended audience:

The subject of this task will be integrated into one of the PI’s graduate courses dealing with system simulation. Also, give lectures at electrical engineering department on the subject. All post-doctoral researchers and graduate and undergraduate students will be trained in systems analysis involving real-life large scale network, submitting reports to PI on their research. They are also required to make presentations at appropriate seminars and conferences.

# Project Schedule and Expected Milestones for the Project:  
(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

Integration of the technologies MCEER has developed will take place in Fall, quantitative performance criteria will be developed in technical and economic dimensions in Winter and Spring. Preliminary development of the performance criteria in organizational and social dimensions together with probabilistic systems analysis.

# Team Members:  
(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- Masanobu Shinozuka, Principal Investigator
- Hung-Chi Chung, Research Associate
- Hung Seok Park, Visiting Research Scholar
- Jin Hak Yi, Visiting Research Associate
- Sang Hoon Kim, Research Associate
- Wei Yang, Graduate Research Assistant

# Possible Direction of Work in Subsequent Years:

Building on the research carried out in Y6, we will study in more detail the performance of combined water and power systems in organizational and social dimensions in Y7 and beyond. Also, the integration of other systems such as systems of lifelines (water, power and gas), emergency response organizations, and medical care systems (a regionally designated network of acute care hospitals) will be carried out to evaluate the community resilience.
### MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.1.3</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task Title:</strong></td>
<td>“System Risk and Reliability for Water Supply”</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Investigator/Institution:</strong></td>
<td>Mircea Grigoriu, Cornell University</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates task leader

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

It is proposed to develop a methodology for calculating the fragility of the critical components of water supply systems. The proposed research is essential to the development of a procedure for assessing the seismic performance of water supply systems and, therefore, will contribute to the overall MCEER goal of enhancing the seismic resilience of communities.

**Problem Description and Research Approach of Proposed Work for Year 6:** *(Detailed description of research to be conducted and methodology to be used.)*

Water supply systems consist of various components such as pipelines, joints, elbows, hydrants, and, pumping stations. The integrity of these components guarantees the functionality of a water supply system. It is proposed to establish a method for calculating the probability (fragility) that the critical components of a water supply system sustain different damage levels following an earthquake. The proposed research involves:

- The development of probabilistic models for seismic hazard scenarios and soil conditions. The models will account for the uncertainty in the soil conditions and will include, for example, the number of seismic events during the design life of a water supply system, the intensity of these seismic events, and the potential for soil liquefaction.
- The identification of the critical components of a water supply system.
- The definition of the damage states. It is anticipated that the damage states will be related to the amount of water a component may leak following a seismic event. For example, there is no water flow in a component with damage level of 100%.
- The development of fragility information for components, giving the probability that a component is damaged to a given level following an earthquake.

The fragility characterization will make use of the extensive database of experimental test results obtained for MCEER at Cornell University and the University of Nevada at Reno. The work at Cornell and UNR will be combined to provide a comprehensive database for fragility characterization of water trunk and distribution piping. The database and fragility characterization will cover both external and internal FRC strengthening as well as seismically.
reinforced joints. Moreover, the methodology will apply to virtually all types of pipelines in water delivery systems, including steel, cast iron, ductile iron, and plastic.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Available analytical studies on component seismic performance are based on simplified models for soil conditions, seismic hazard and component properties. The proposed research will use realistic models for soil, earthquakes, and pipes. Also, the current damage state of the components of a water supply system at the time of the earthquake will be accounted for in the analysis. Moreover, the resulting analytical models will be validated against the data base developed at Cornell University and the University of Nevada at Reno.

**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

The PI has extensive experience in reliability analysis and application of the reliability concepts to water supply system. He is one of researchers involved in the development of the GISALLE code for evaluating the performance of the San Francisco water supply systems.

**Role of Proposed Task in Support of Strategic Plan:** (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The development of a methodology for assessing the seismic performance of a water supply system is not possible without the probabilistic characterization of the seismic performance of its critical components. The proposed task will develop fragility curves/surfaces to quantify the seismic performance of the components of water supply systems. These developments are essential for developing a quantitative measure for the seismic resilience of communities.

**Task Integration:** (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The success of the proposed research will require extensive interaction with other MCEER researchers. For example,

- The selection of the critical components of a water supply system will be based on consultations with T.D. O’Rourke and M. Shinozuka.
- The characterization of the soil conditions relevant to a water supply system will be provided by experts in geotechnical engineering.
- The component failure modes will be obtained from previous work by T.D. O’Rourke funded by MCEER and available test results.

**Possible Technical Challenges:**

- Water supply systems extend over relatively large areas so that their components are generally subjected to different seismic actions. Therefore, it is necessary to develop an accurate spatial characterization of the seismic input. The spatial characterization of the seismic action will pose
notable technical challenges.
- The development and validation of soil-component interaction models needed for fragility analysis is challenging from a mechanical viewpoint. Also, the incorporation of the uncertainty in the mechanical models poses notable difficulties.

**Anticipated Outcomes and deliverables:**
(Also indicate those of particular benefit to IAB members and other end users.)

- Methodology for the fragility analysis of the critical components of water supply systems.
- Methodology for representing the spatial variation of soil conditions and seismic actions.

**Potential end-users beyond academic community:** (IAB members and others.)

- Algorithm for component fragility analysis.
- Algorithm for generating the spatial variation of seismic actions.
- Water supply companies and engineering designers.

**Educational outcomes and deliverables, and intended audience:**

It is anticipated that an algorithm describing the spatial variation of seismic actions will be made available to the users network at MCEER.

**Project Schedule and Expected Milestones for the Project:** (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

- Spring: Methodology for representing the spatial variation of soil conditions and seismic actions.
- Summer: Methodology for the fragility analysis of components.

**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

A new graduate student is under consideration.

An undergraduate student is expected to be involved in our data collection effort.

**Possible Direction of Work in Subsequent Years:**

The component fragility information developed in this Task together with the flow analysis algorithm developed by T.D. O’Rourke in year 6 will be used to develop a methodology for evaluating the overall performance of water supply systems. These future developments will be based on the system reliability theory and will provide the framework for (1) evaluating the joint seismic performance of water, electric, and other systems and (2) developing rational strategies for enhancing the seismic resilience of communities.
MCEER RESEARCH TASK STATEMENT

Task No. 6.1.4  Budget: Yr 6 Assigned Project Number:

Task Title: Seismic Retrofit of Lifeline Systems: Shaking Table Tests for Fragility of Electric Transformers

Investigator/
Institution: Andrei M. Reinhorn*, University at Buffalo
Andrew Whittaker, University at Buffalo

* indicates task leader

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

1) Shaking table and floor testing to failure of a switching station bushing
2) Determine dynamic parameters, develop a preliminary dynamic model
3) Preliminary estimation of fragility characteristics of the bushing
4) Develop initial dynamic models and fragility of the bushing

Problem Description and Research Approach of Proposed Work for Year 6: (Detailed description of research to be conducted and methodology to be used.)

Shaking table test of a 500 kV/287 kV Victorville switching station bushing will be carried out at the Structural Engineering and Earthquake Simulator Laboratory (SEESL) at the University at Buffalo. The purpose is to determine dynamic parameters, develop a preliminary dynamic model and carry out a preliminary estimation of fragility characteristics of the bushing. In this connection, the analogue record of the acceleration time history at the Victorville switching station will be digitized. Dynamic models of the bushing will then be developed on the basis of the shaking table test for the purpose of investigating the boundary conditions for and fragility characteristics related to the gasket at the interface between the bushing and the supporting frame fixed to the shaking table.

The rubber-like, O-ring shaped gasket at the bushing and transformer interface will be modeled for the purpose of performing the fragility analysis involving oil-leakage and shifting modes of failure. The former constitutes an immediate failure of the system, while the latter, depending on the extent of the shifting, may exhibit a delayed electro-magnetic malfunction. Porcelain structure will also be modeled.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

A comprehensive series of tests, modeling and analyses of high voltage bushings were performed at PEER / University at California at Berkeley by a team of researchers including the second investigator. The series of tests and models did not cover completely the failure analysis.
of the bushing and the development of fragility curves. The current project is intended to identify the limit states for the bushing in a failure test, done after the seismic demands are identified through a series of shake table tests. The results will enable development of a finite element model verified by the shake table testing and establish and model the failure limit states. The information then will be used to determine fragility of bushing.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

This is a new project which will start in Year 6 to complement the studies for the “Seismic retrofit of lifelines systems”

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The fragility information is at the core of loss estimation methodology, which in turn is at the base of the evaluation of performance of lifelines one of the factors in the community resilience. The task is looking to derive a methodology for determining the fragility information analytically using experimentally validated information.

The results of this task will contribute to development of tools for evaluation of performance of lifelines.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The task is part of the comprehensive evaluation of electrical networks (M. Shinozuka), in which failure of transformer stations are a predominant factor. Along with development of rehabilitation techniques (Saadeghvaziri, Feng) and with the electrical functionality modeling of network (Cheng), the fragility model for the typical bushings provides the basic information for the network analysis.

**Possible Technical Challenges:**

Finite element and other numerical analysis methods will be utilized to simulate the behavior of the porcelain structure and the gasket at the interface between the bushing and transformer under earthquake ground motion. The dynamic and stress analysis models developed above for the bushing including porcelain structure, transformer and gasket will be integrated so that all the dynamic interactions can be taken into consideration as much as possible. The emphasis will be placed on numerically reproducing oil-leakage, shifting and porcelain failure of the bushing.

The modeling poses challenges due to unknown characteristics of the transformer construction and dependency of bushing behavior while connected on the network with the electric lines.
### Anticipated Outcomes and deliverables:
(Also indicate those of particular benefit to IAB members and other end users.)

1) Information on the failure of bushings connected to transformers
2) Analytical model of bushing
3) Methodology for analytical fragility evaluation

### Potential end-users beyond academic community:
(IAB members and others.)

1) Utility engineers
2) Loss estimators

### Educational outcomes and deliverables, and intended audience:

The testing techniques and associated processing will be collected and included in a module for Experimental Methods in Earthquake Engineering (CIE616) taught by the investigators at University at Buffalo.

### Project Schedule and Expected Milestones for the Project:
(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

- Spring 2003: Preparation of tests specimens and preliminary testing of bushing
- Summer 2003: Modeling of bushings and validation
- Fall 2003: Failure testing of bushings and model adjustment
- Fall 2003: Fragility modeling
- Spring 2004: Preparation of comprehensive report

Information on models will be released earlier to members Thrust 1 working on related projects

### Team Members:
(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

PhD student will be hired in Fall 2002 and prepared to undertake the project in Spring 2003

### Possible Direction of Work in Subsequent Years:

The fragility estimate for bushings connected to electric lines produce alternative modes of failure, which require detailed investigation and a more extended testing set-up. Further models development will produce more comprehensive and reliable fragility models. Under these conditions additional retrofit techniques would have to be developed.
The project goals are to 1) complete the development of technologies for seismic strengthening of critical water trunk lines, including fiber reinforced polymers (FRPs), and demonstrate their use within the Los Angeles water distribution network, 2) develop a hydraulic network model for the Los Angeles water distribution system that allows for a comprehensive evaluation of its earthquake performance, 3) initiate work on developing an integrated systems reliability model for the LADWP water and electric power networks, and 4) use the results of 1) through 3) to create a decision support platform for critical lifelines that addresses seismic resilience in its technical, organizational, societal, and economic dimensions.

The overall goals of the MCEER research thrust in lifelines is to improve the seismic resilience of communities through substantial improvements in the earthquake reliability of critical lifeline systems. The goal includes the development and demonstration of the next generation of lifelines that benefits from advanced geospatial analyses; high performance materials and manufacturing; improved loss estimation; intelligent monitoring; and advanced systems and socioeconomic modeling to assess the regional impact of lifeline operations.

The Los Angeles water and electric power distribution networks are the test beds within which advanced technologies and systems modeling are applied. Los Angeles is sufficiently complex that the products and procedures developed and proven for this community will have relevance and applicability throughout the U.S. MCEER benefits from the cooperation and involvement of LADWP. As an organization, LADWP includes both water and electric power and this integration of activities facilitates MCEER work in developing models and decision support tools that address the interdependencies between the water and electric distribution networks.

The approach taken for the proposed Year 6 work is derived from the four project goals, as follows:
1. Advanced Materials and Fabrication Technologies

MCEER researchers have developed FRP products and have proven them effective through large-scale testing. The products are able to reinforce the welded slip joints of water trunk lines and mobilize the full compressive load capacity of straight pipe sections. The products have been developed in cooperation with two specialty contractors, who are able to market and apply the products.

In the first part of Year 6, the development of advanced materials and fabrication technologies will be concluded. This work will include a through briefing of LADWP engineers and specialty contractors of the results, recommendations for best practices, and the development of model specifications that can be used by water supply utilities when commissioning future pipeline construction for either new facilities or the retrofitting of existing ones.

2. Hydraulic Network Model

A hydraulic network model will be developed for the Los Angeles water distribution system. This task will be facilitated through cooperation with LADWP. Currently, LADWP has a network model that is able to simulate system flows and pressures through its trunk lines (diameter >600mm) as well as distribution pipelines with diameters of 450 to 300 mm. This type of characterization will provide the detail needed for effective risk and reliability assessment. LADWP Planning and Management has given approval for the work to proceed, and will make its hydraulic network model available, provided that appropriate measures are taken to protect and promote the security of the DWP system.

Cornell researchers will adapt the hydraulic network model for earthquake simulation and performance under various damage states. An important part of this process will be to link the network analysis with special algorithms developed originally at Cornell that account accurately for water flow and pressure conditions in heavily damaged pipeline networks. The algorithms for the hydraulic network analysis of heavily damaged systems were embodied in the code GISALLE, written originally for the San Francisco water supply. The hydraulic network model will be validated and calibrated with respect to the observed systems performance during the 1994 Northridge earthquake. Where appropriate, the hydraulic network analysis will be calibrated with respect to special flow tests performed by LADWP.

Hydraulic network analyses will be performed for various earthquake scenarios determined in cooperation with A. Papageorgiou, who is working on seismic hazards characterization for MCEER. The effects of incorporating advanced FRP strengthening and improved fabrication processes on system performance during earthquakes will be evaluated.

Work will begin on a systems reliability model that will incorporate fragility curves and characterizations performed in collaboration with M. Grigoriu under the MCEER program, entitled System Risk and Reliability for Water Supply. Experimental work and laboratory testing results obtained at Cornell and the University of Nevada at Reno will be used in the fragility characterization.
3. Integrated Water Supply and Electric Power Systems Model

Work will begin on developing an integrated model for systems performance during and after earthquakes of the LADWP water supply and electric power systems. The work will include developing a common GIS coordinate system and database for the water and electric power systems, and demonstrating that the combined systems can be evaluated within a framework of common seismic hazards and spatial variations of strong motion. Definitions of and procedures for evaluating systems risk and reliability will be developed that are consistent for both the water and electric power networks.

4. Decision Support Platform

The overarching goal of MCEER is to create earthquake resilient communities, and one of the most important programs of MCEER is focused on defining and quantifying this resilience. The research will support MCEER efforts to define and develop performance measures for resilience. The systems model for combined water and electric power will be used to explore and quantify the technical measures of resilience. Moreover, LADWP engineers and managers will be engaged to help define the organizational issues that affect their operations and influence their planning and allocation of resources for earthquake hazards. All systems simulations will be developed in a framework that utilizes the socioeconomic models created and demonstrated by MCEER researchers for lifelines in Shelby County, TN.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Network modeling and reliability assessments for water supply and electric power systems have been subjects of research and development primarily in the U.S. and Japan. Research developments in lifeline systems performance and modeling have been summarized in two recent state-of-the-art reviews (O’Rourke, 1996; O’Rourke and Jeon, 2000). The principal investigator has been in communication with leading researchers in Japan and the U.S., including researchers at PEER and MAE.

The proposed research differs from work currently being performed with respect to the comprehensive nature of the component and geotechnical modeling that will be performed, advanced loss estimation that will be incorporated, and socioeconomic modeling that will become an integral part of the product package. Specifically, the systems modeling and reliability assessments will build on the state-of-the-art MCEER accomplishments that have used Input / Output and Computable General Equilibrium models and analytical methods for spatially distributed systems to assess the indirect economic effects of damage caused by earthquakes (Chang et al., 2000a; Chang et al., 200b; and Shinozuka, et al., 1998).

References


**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Research accomplishments during the past year include the successful execution of full-scale tests on thirteen specimens of water trunk lines fabricated by LADWP and shipped to Cornell. Testing covered compression, tension, and cyclic loading on pipelines with welded slip joints and diameter-to-thickness ratios of 50, 150, and 250. The tests span the range of pipeline geometries utilized by water supply authorities from the smallest to largest trunk lines. The tests included both as-built welded slip joints and pipelines strengthened with FRP wraps. The tests have conclusively demonstrated that the application of FRP wrap can increase the compressive capacity of welded slip joints by as much as 80 to 100%. In all test cases, the FRPs were able to increase the load capacity of welded slip joints to that of straight pipe.

The research has also resulted in advanced analytical models that are able to simulate the buckling and wrinkling behavior of straight pipelines and pipelines with welded slip joints in both their as-built and FRP-reinforced conditions. Research results provide guidance not only for FRP products, but for fabrication of the joints, alternate reinforcement procedures, internal vs. external welding, and the contribution of both the external and internal mortar linings of the pipelines.

**Role of Proposed Task in Support of Strategic Plan:** (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The proposed research will support the MCEER strategic plan by developing the next generation lifeline system, which is critical for earthquake resilient communities. Specifically, the research
will develop a systems model that will promote a comprehensive assessment of earthquake risk. The model will quantify the reduction of damage, including direct and indirect losses, so that water authorities and the communities they serve will be able to make rational decisions about the allocation of resources necessary to achieve community goals in earthquake resilience.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The work performed interfaces directly with research performed by M. Grigoriu under the task entitled Systems Risk and Reliability for Water Supply. In addition, the task interfaces with research performed for electric power systems led by Mr. Shinozuka. Developing a model for the combined water and electric power systems is an integrating effort essential for evaluating the interdependencies between different lifeline systems. Moreover, the research will make direct use of models for the regional socioeconomic effects of lifeline losses being developed by MCEER. As explained under the section of this task statement entitled Problem Description and Research Work Proposed for Year 6, the water distribution system model and combined water and electric systems simulations will be used to develop performance measures for resilience.

**Possible Technical Challenges:**

The technical and institutional challenges include:

1. Development of a fully operational hydraulic network model that covers accurately a variety of damage states, and the validation thereof by comparison with prior earthquake performance and special flow tests.

2. Development of reliability assessments that are consistent for both water and electric power and compatible with reliability procedures and resilience definition that apply to hospitals.

3. Obtaining the appropriate security clearances and cooperation of LADWP management and engineering to ensure detailed characterization of the water supply system.

4. Obtaining the appropriate security clearances and cooperation of LADWP management and engineering to develop an accurate model for combined water and electric power.

5. Creation of systems models and decision support tools that are sufficiently transparent and accessible to communities for effective planning and engagement of support from both the public and private sectors.
### Anticipated Outcomes and deliverables:
(Also indicate those of particular benefit to IAB members and other end users.)

- Successful demonstration of FRP strengthening of critical water trunk lines in Los Angeles and adoption of the technology in other systems, such as EBMUD.

- Advanced analytical models for pipeline and facilities behavior under earthquake loads.

- Improved fabrication and welding procedures for slip joints and alternate reinforcement procedures.

- Advanced hydraulic network model for LADWP.

- Combined systems model for the Los Angeles water and electric power networks.

- Decision support tools for lifeline system improvements and operations that incorporate estimates of regional socioeconomic impacts.

### Potential end-users beyond academic community: (IAB members and others.)

- Water distribution companies, such as LADWP and EBMUD.

- Water supply companies and engineering designers.

- Identification of most effective welding strategy.

- Water supply and gas distribution companies and engineering designers.

### Educational outcomes and deliverables, and intended audience:

The educational outcomes include:

- Guidance on material properties of FRP products and specifications for construction.

- Improved specifications and design procedures for water trunk lines.

- Systems model for earthquake effects on water distribution systems suitable for management decisions about operations and the implementation of advanced technologies to reduce earthquake losses.

- Use of the project to support graduate students and undergraduate research experiences.
**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

Winter 02/03: Completion and demonstration of FRP technology to strengthen water pipelines against earthquake effects.

Spring 03: Development and implementation of hydraulic network model for LADWP water supply.

Summer 03: Sensitivity studies with hydraulic network model showing the effects of various seismic hazards and earthquake scenarios.

Summer 03: Initial model for combined water and electric power networks in Los Angeles, including common GIS.

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

T.D. O’Rourke, principal Investigator  
S. Jones, Research Associate  
J. Mason, Graduate Research Assistant (GRA)  
J. Moeller, GRA  
T. Bond, Director of Cornell University’s Winter Structural Laboratory  

Undergraduate students will be engaged to assist with the hydraulic network modeling and analysis. Additional GRAs will be hired to replace J. Mason and J. Moeller, who are expected to graduate in September 02.

**Possible Direction of Work in Subsequent Years:**

In subsequent years, a combined water and electric power systems model will be developed that is capable of assessing both direct and indirect economic losses and of discerning the social impact of lifeline losses on the communities they serve. Decision support tools will be developed and demonstrated that will allow lifeline managers and engineers to create earthquake resilient systems consistent with community goals and resources.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1.6a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Project Number:**

**Task Title:** Analytical Study on Rehabilitation of Critical Electric Power System Components

**Investigator:** M. Ala Saadeghvaziri  
**Institution:** New Jersey Institute of Technology

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

Substations, key components of electric power systems, are susceptible to significant damage under seismic events. Rehabilitation of existing substations using advanced technologies and proper design of new systems will reduce the likelihood of failure and/or will enhance the probability of post-earthquake system functionality in a timely manner. Furthermore, it will ensure long-term reliability and longevity of critical equipments, which is essential in light of ever increasing dependence of modern societies on electrical power. Under this task a system approach is employed in order to evaluate the interaction among transformers, bushings and interconnecting electrical equipment. Results will contribute to the larger tasks within Thrust Area 1 that develop fragility curves. Furthermore, efforts are being made to implement the research results and findings within LADWP’s plan to rebuild the Sylmar Converter Station.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

Substation sustained significant damage and failure during past earthquakes. Substation equipment are designed and qualified for a specified level of base excitation. If the design level is exceeded or if their interaction aggravates the seismic response, as in the case of recent strong earthquakes in California and abroad, damage of the equipment is almost certain. This would result in direct and indirect loss and significantly impact the regional economy. Raising the design level is not practical, neither technologically nor economically. Furthermore, we do not understand the complicated interaction among various electrical components during the dynamic response of the entire system to an event. Therefore, raising the design level by itself might not remedy the situation even if it was feasible to do so. Thus, research is needed to (1) identify critical components in the power system, (2) develop the tools and a framework to evaluate and assess seismic performance of various components as well as their interaction in light of the system response (3) develop advanced but practical and cost-effective strategies for rehabilitation of the most critical elements, (4) design and implement practical strategies on a pilot scale, (5) monitor the performance of rehabilitated system, and (6) disseminate successful results for wider applications including improvements and expansion to IEEE 693-1997.

In light of the above objectives, this research includes both analytical and experimental studies on critical substation components to better understand their dynamic characteristics and to evaluate their seismic response in order to develop effective rehabilitation strategies. Transformers, bushings, and disconnect switches are identified as the key components in a substation. Individual behavior of transformers and bushings as well as their interaction is studied through time history analyses using 3-D finite element
models. Results indicate that transformer flexibility has a significant effect on dynamic characteristics and seismic response of the bushings. This explains the discrepancy between bushings’ good to excellent performance in laboratory (when supported on a rigid frame) compared to its poor performance during past earthquakes. Analyses of typical transformer foundations indicate that it is very difficult to design foundation capable of resisting inertia forces of a major event. New transformers tend to be even heavier (due to the need for higher voltage transmission), thus, further compounding the design of seismically adequate foundation. Shake table tests were also performed to compare the response of fixed based transformer model supporting a bushing to those when the system is isolated using Friction Pendulum System (FPS). 1-D, 2-D and 3-D excitations were conducted employing several earthquake records and different PGAs. Experimental studies were followed by parametric study using a SDOF model of typical transformer. Among parameters considered were peak ground acceleration, bi-directional motions, effect of vertical motion and isolation radius. Results point to effectiveness of base-isolation, using FPS bearings, in reducing inertia forces and bushing response. However, there are some issues, such as effect of changes in friction force due to changes in normal force, which needs further investigation. Large displacements associated with the use of base-isolation can compound interaction among transformer-bushing and interconnecting equipment. This can be addressed through proper design of conductor cables and possible modification to bushing flange design. Therefore, based on analytical and experimental results, a simplified model has been developed to further study the interaction of transformer-bushing system with interconnecting equipment. This interaction is studied parametrically for several earthquakes, isolation radii, interconnecting equipment frequencies, connecting cable stiffness and cable slacks for fixed-base and isolated cases.

Year 6 efforts will include continuation of analytical study with emphasis on the effect of vertical motion and changes in friction force on the response of bushings. Development of a new design for bushing flange to act as a fuse during extreme events will also be investigated. The proposed design envisions a yielding mechanism within the flange of the connection between the transformer/turret and the bushing. This will prevent failure of the bushing (which often happens at the gasket between the flange and the first porcelain unit) and damage to the transformer should the relative displacement exceed the amount of slack provided. During year 6, further work on issues/problems related to seismic design of foundation and anchorage system and cost-benefit analysis (vis-à-vis demand on foundation with and without base-isolation) will be performed. Effect of seismic forces on stability of internal components such as core and coil will be considered. Stability of winds is critical to proper distribution of electro-magnetic (short-circuit) forces. Similarly, effect of seismic forces on the design of anchorage between the core-coil assembly and the tank floor will be assessed. On a long-term note, the possibility of modifying FPS design to minimize or eliminate displacement at the top of the bushing will be investigated.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Experimental investigation conducted at PEER on electrical equipment relates to this task. However, they differ in that PEER has conducted experimental tests of individual bushings while here a system approach is used and it includes both analytical and experimental studies. 3-D finite element results indicate that interaction between the transformer and the bushing is important to accurate seismic assessment of the system. PEER results also support this finding and have always pointed to the need for analytical work of the type conducted under this study. Furthermore, the system approach used under this task considers the interaction among transformer-bushing and interconnecting equipment as well as problems/issues related to seismic design of anchorage and foundation. The research team has tried to develop inter-center exchange of research results with PEER and provide the unified mean for dissemination of results by both centers (e.g., see last item under Progress to Date).
Progress to date:  (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.) Note: * symbol for the bullet indicates past year progress

- Substation transformers (and bushings) have been identified as the most critical component in a complex power system.
  * 3-D finite element analyses of three (small/medium/large) actual transformers have been completed. It has been determined that flexibility of the transformer body has a significant effect on the bushing response and its frequency content. Translational modes of the transformers have the highest effect on the response of the bushing. Hence, seismic design and rehab procedures must recognize this important effect.
  * It is recommended that current qualification procedures (IEEE 693-1997) be modified to reflect the transformer-bushing interaction. For example, bushings tests should be performed on a semi-rigid stand with a frequency equal to that of the translational mode of the transformer.
- Fixed-based transformers require large amount of anchorage capacity to transfer the inertia forces to the foundation. It is usually difficult or impractical to provide strong and stiff anchorage system. The need for mobility for maintenance purposes further compounds development of an optimal anchorage design. Furthermore, the level of inertia forces point to high vulnerability of current foundation designs, especially footing foundation. This is consistent with observations made during past earthquakes including those made in Sylmar Converter Station during the events of 1971 and 1994.
- Base isolation has been identified as the most practical and effective technology for rehabilitation of transformers. In addition to alleviating problems associated with bushing response and foundation design, base-isolation will also reduce the possibility of damage to internal elements (such as core and coil). Thus, enhancing post-earthquake reliability and longevity of the system too.
- Large displacements associated with the use of base-isolation require special consideration, which can be addressed through proper design of the conductor cables and modification to bushing flange design.
- Friction pendulum System (FPS) was targeted for detailed study.
- Building upon research and practical experience gained over the past decade or so, an extensive analytical study on response of FPS bearings using SDOF models were performed. Among parameters considered are ground motion characteristics, peak ground acceleration, bi-directional motions, effect of vertical motion, and bearing radius. Results were evaluated in light of level of inertia reduction and the maximum displacement. FPS bearings are very effective for isolating transformers. They can provide as much as 60% inertia reduction compared to input PGA, and significantly more compared to fixed base situation.
- Preliminary design charts have been developed and appropriate response combination rule(s), for design purposes, have been identified.
- Close to 100 tests was conducted at NCEER in Taiwan on a transformer model supporting a bushing. Results have been processed and are in agreement with analytical results. However, they suggest the need for more detailed evaluation of the effect of vertical ground acceleration, probably due to its effect on normal force variations, which in turn affects frictional force.
  * A simplified model has been developed to study transformer-bushing interaction with interconnecting electrical equipment and to address the issue of large displacement associated with the use of base-isolation. The model will be used to determine slack design and to investigate effect of modification to bushing flange design on system response.
- Several substations, including the Sylmar HVDC Converter Station, have been visited. Various meetings with possible end-users and industry representatives have been held and will continue to ensure implementation of the results and findings.
A Ph.D. thesis entitled “Seismic Response of Transformer Bushing Systems and Their Rehabilitation Using Friction Pendulum System,” is completed. Six journal and conference papers have been published or are under review. An undergraduate student was also involved with the project for one semester (S00). Currently, an M.S. student is supported.

A session entitled “Seismic Design and Rehabilitation Strategies for Power Systems,” was organized and chaired by the PI during the 2001 Structures Congress, ASCE, Washington, DC, May 21-23, 2001. (Participants: MCEER, PEER, Bonneville Power Administration)

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

This task will contribute to MCEER overall goal of enhancing the seismic resiliency of communities by increasing seismic resiliency of substations within electric power system. This objective is achieved through application of enabling technologies to improve seismic performance of substation equipment and by performing fundamental research. The former activity builds upon vast research results available on buildings and bridges and the former activity addresses structural and functional problems unique to a substation facility.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The work conducted will be integrated into the overall loss estimation model for an entire power system under Thrust Area 1. It contributes to development and accuracy of such model by providing the knowledge base and the analytical tool for time history analysis of substations under various earthquake scenarios in order to develop fragility curves for substations (Shinozuka/Saadeghvaziri).

The work is also integrated with research conducted by Prof. Feng (working with Bridgestone) by making a recommendation on the most suitable base-isolation technique (device) for transformers considering transformer seismic response and the response of the supported bushings and interconnecting elements, as well as level of forces that need to be resisted by the foundation (Feng/Bridgestone/EPS/Saadeghvaziri).

Results will also be integrated with the work of other MCEER researchers in light of electrical design considerations to improve the reliability and longevity of transformers (Cheng/Saadeghvaziri).

Furthermore, efforts are being made to implement the research results and findings in the rebuilding of Sylmar Converter Station by LADWP (Shinozuka/Cheng/Penn/Saadeghvaziri).

Possible Technical Challenges:

Research efforts over the past years have revealed that understanding the dynamic interactions among key equipment of a substation (transformers, bushings, foundation, and interconnecting elements) is critical to proper assessment of their seismic performance, and to development of qualification and rehabilitation procedures for these equipment. A challenge to understanding such interaction is large number of equipment within a substation. Transformers, bushings, and disconnect switches are key components, however, other equipment can have significant effect on their seismic response. Another challenge is quantifying the life-cycle benefit of advanced technologies as it enhances long-term reliability and longevity of transformers by minimizing or even eliminating damage to internal components during an event. Yet a third challenge is proprietary nature of transformer design, thus, limiting access to details of internal design of transformers.

II.A-2.61
### Anticipated Outcomes and deliverables:
*(Also indicate those of particular benefit to IAB members and other end users.)*

- Quantify the effect of transformer-bushing interaction with interconnecting equipment such as disconnect switches, circuit breakers, etc. on their seismic response for both fixed and base-isolated transformers.
- Cost-benefit analysis on the use of advanced technologies in light of initial cost as well as reduced probability of failure and longevity (life-cycle basis).
- Develop resources and design guidelines for application of new technologies such as base-isolation to transformers.
- Modify current structural design of electrical equipment, internal packaging, and connections to increase robustness, resiliency, and redundancy.
- Collaborate with utility companies and manufacturers to better interpret and implement IEEE 693-1997, and to develop the knowledge base to improve and expand IEEE 693-1997.

### Potential end-users beyond academic community: *(IAB members and others.)*

- LADWP & other utility companies,
- Manufacturers of substation transformers and equipment,
- Manufacturers of base-isolation systems,
- Structural engineers, and
- Electrical engineers.

### Educational outcomes and deliverables, and intended audience:

- Availability of resources, methodologies, and tools for seismic analysis of substations and application of advanced technologies for their rehabilitation.
- Presentation of results and teaching of knowledge created within the context of: i) a new graduate course at NJIT (Topics in Structural Engineering) targeted towards practitioners, and ii) existing courses (such as Earthquake Engineering).
- Undergraduate students may also benefit from the research by directly participating in its execution or by learning about the problem and solution within the independent study course.

### Project Schedule and Expected Milestones for the Project: *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

- Continuation of analytical study on evaluating transformer-bushing interaction with interconnecting electrical equipment. Modification to design of bushing flange (Fall/Spring).
- Detailed evaluation of seismic demand on transformer foundation for both fixed and base-isolated cases. Cost-benefit analysis on the initial cost basis in light of foundation and bearing costs (Fall).
- Effect of seismic forces on the internal design of transformers – core and coil stability, anchorage of core/coil assembly to tank floor, etc. (Spring).
**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

M. Ala Saadeghvaziri, Professor, Dept. of Civil and Environ. Engrg., NJIT.

Seyed Ali H N Ashrafi, Graduate Student, Dept. of Civil and Environ. Engrg., NJIT.

**Possible Direction of Work in Subsequent Years:**

- Perform tests to assess response of bushings with modified flange.
- Modification to design of FPS bearing to minimize or eliminate displacement at the top of the bushings by fixing the articulated slider (i.e., true pendulum motion centered at, or near, the top of the bushing).
- Additional shake table tests: larger model, higher PGA especially in the vertical direction, number of bearings.
- In-field and laboratory tests to determine dynamic characteristics of interconnecting electrical equipment and assess flexible cable performance.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.1.6b</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Number:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Rehabilitation Strategies for LADWP’s Power System

**Investigator:** Maria Q. Feng  
**Institution:** University of California, Irvine  
* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

To experimentally and analytically investigate the applicability of base isolation and energy dissipation technologies for seismic protection of electrical power transformers and other facilities in power networks, and to further develop these technologies and associated design guideline for practical use.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

Damage and failure of electric power substations in recent destructive earthquakes highlighted the urgent needs for seismic upgrade and retrofit of electric transformers and other equipment. Electrical power transformer is one the most critical equipment in the power delivery network. Due to its complexity, it may take years to repair a transformer damaged by an earthquake. Post 1994 Northridge earthquake data show that earthquake shaking can significantly reduce the longevity of a transformer. Therefore, base isolation of the entire transformer/bushing system appears to be an effective measure to protect the transformer/bushing system. However, the application of the base isolation technology has not been thoroughly studied.

The primary objectives of this study are to experimentally and analytically investigate the applicability of base isolation and energy dissipation technologies for seismic protection of electrical power transformers and other equipment and facilities, and to further develop these technologies and design guidelines for their applications in facilities of electrical power networks.

In previous years, different types of base isolation systems have been analytically, numerically, and experimentally investigated to assess their applicability to electrical power transformers. In Year 6, focus will be placed on development of a simplified design procedure based on seismic design spectra, together with a prototype design guideline, for practitioners to design seismic protective systems for electrical power facilities. In order to achieve these objectives, the data collected in the shaking table tests in Year 5 will be analyzed. An analytical model for the base-isolated transformer/bushing system will be developed, which will be calibrated by the shaking...
table test results. Based on this analytical model, a simplified model for the design purposes will be derived.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

Electrical power transformer is one the most critical equipment in a power delivery network. Due to its complexity, it may take years to repair a transformer damaged by an earthquake. Post 1994 Northridge earthquake data show that earthquake shaking can significantly reduce the longevity of a transformer. Therefore, base isolation of the entire transformer/bushing system appears to be an effective measure to protect the transformer/bushing system. Although the base isolation technology has been extensively studied for the applications in buildings and bridges, their applications to the electrical power transformers and other substation facilities have not been thoroughly studied. Dynamic characteristics of a transformer/bushing system are quite different from a building or a bridge, such as the light-weight nature.

Replacement of bushings with fiber reinforced polymer composite materials is being studied outside of MCEER. However, seismic protection of the transformer itself is not being addressed.

Therefore, this project will make a unique contribution toward the implementation of the base isolation technology for seismic protection of transformers (including bushings), and other electrical power facilities.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

In Year 3, a base isolation system for electric transformers was designed and 3-D shaking table testing was performed at NCEER, Taiwan, using a large-scale transformer model equipped with a bushing. The base isolation system consists of sliding bearing to support the transformer and rubber bearings to provide restoring forces. The results verified the effectiveness of the base isolation system in reducing seismic response of the transformer and its bushing. However, some of the results indicated that effectiveness could be significantly influenced by the dynamic characteristics of the mounted bushing under 3-D ground motion.

In Year 4, the problem associated with the isolation system under 3-D ground shaking was investigated through simulation analysis. It was found that the change of the friction forces in the sliding bearing due to the vertical ground motion excited the vibration mode of the bushing, causing excessive response of the bushing. Based on this analysis, the design of the base isolation system was improved by either eliminating the sliding bearings.

In Year 5, a prototype base-isolation system was fabricated based on the improved design using high-damping rubber bearings. The challenge in design is to achieve a long isolation period
without buckling of the bearing, due to the light-weight nature of a transformer/bushing system. A multi-level structure of the bearings was designed to meet this challenge. Then, 3-D shaking table tests were performed using the same shaking table and transformer/bushing models in NCREE, Taiwan. A variety of ground motions including an artificial ground motion generated based on the IEEE design spectrum were used in the shaking table tests, in order to investigate the seismic performance of the base-isolated transformer/bushing system under ground motions with different frequency contents and intensities. As designed, the base isolation performance of this mulunter 3-D shaking was dramatically improved.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This task plays an important role in improving seismic performance of transformers and other substation facilities in LADWP’s electrical power network. LADWP’s electrical power network is one of the testbeds of MCEER’s demonstration projects. This task uniquely contributes to the enhancement of the seismic resilience of the electrical power network, and ultimately the resilience of the community.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This PI is focusing on the development of rehabilitation technologies (including base isolation and energy dissipation) suitable for seismic protection of electric power transformers. The finite element model of the transformer and bushing recently developed by Professor M. Ala Saadeghvaziri will be used in the numerical analysis and system design of this study. The results of this study will be used to assess seismic fragility of the electric power system with and without the seismic rehabilitation measures.

**Possible Technical Challenges:**

Base isolation of a transformer/bushing system presents a unique technical challenge, due to the fact that the mass of the system is much lighter compared to a building, making it difficult to elongate the isolation period without buckling the bearings.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

- A simplified design model
- Prototype design guideline

**Potential end-users beyond academic community:** *(IAB members and others.)*

- Utility industry
- Transformer manufacturers
Educational outcomes and deliverables, and intended audience:

Currently, a Ph.D. student and a few undergraduate students and MS students are working on the project. An MS thesis has been produced. A Ph.D. dissertation will be completed in the end of this project. The results of this research has been incorporated into a graduate course on “Seismic Resistant Design of Structures” which this PI is teaching.

Project Schedule and Expected Milestones for the Project: *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

Analysis of shaking table test data. By Spring, 2002

analytical models of base-isolated transformer/bushing systems. By Summer, 2002

Development of design approach and prototype guideline by Winter, 2003

MCEER technical report by Winter, 2003

Team Members: *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

Nobuo Murota, PhD Student

Yasser Salem, PhD student

Christian Casanova, MS student

Dongkyu Kim, MS student

Nicolo Vistosi, Undergraduate student

John Sun, Undergraduate student

Possible Direction of Work in Subsequent Years:
Thrust Area 2:

Seismic Retrofit of

Acute Care Facilities
<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.2.1</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Number:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Re-assessment of geotechnical issues in acute care facilities based on survey of hospitals in California

**Investigator/Institution:**
- Ricardo Dobry* - Rensselaer Polytechnic Institute, Troy, NY ($15,000)
- Marshall Lew - Law/Crandall, a division of Law Engineering & Environmental Services (a MACTEC Company), Los Angeles, CA ($65,000)
- Thomas D.O'Rourke - Cornell University, Ithaca, NY ($15,000)

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The 12-month study will provide an assessment of the main geotechnical and foundation earthquake engineering issues of hospitals based on a survey of acute care facilities in California. The main objective is to provide the basis for future decisions by MCEER on geotechnical and foundation research needed in Thrust Area 2. The centerpiece of the study will be a survey of 248 individual hospital facilities in several counties of Northern and Southern California containing a total of some 1,364 buildings. In the whole state there are approximately 470 general acute care hospital facilities including about 2,673 building; the survey will cover more than half of those facilities. The survey will mine data from reports already at OSHPD, which has offered full access and cooperation. In addition, the sites of the hospital facilities will be placed on existing state-issued seismic hazard zone maps (which include zones of liquefaction and landsliding) within a GIS format. The survey and related analysis of the data as well as the map generation will be conducted under the direction of Dr. Lew in cooperation with Drs. Dobry and O'Rourke. A report co-authored by the three PIs will contain all data, maps and analyses as well as conclusions and recommendations on hospital geotechnical issues and MCEER research. The whole report including all data will also be provided in electronic form to MCEER for further data processing and/or preparation of graphic summaries for MCEER Web page.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

Most of the work will be performed in LA by Lew at the Law/Crandall and OSHPAD offices; additional work will be performed by O'Rourke and Dobry at their universities, mainly interacting with Lew by e-mail/mail/phone in a review capacity. In addition, O'Rourke and Dobry will attend two 2-day meetings in LA at the beginning and end of the project. The work done in LA under Lew's direction will cover all hospital facility sites in the contiguous Northern California counties of San Francisco, San Mateo, Santa Clara, Contra Costa, and Alameda, and...
in the contiguous Southern California counties of Los Angeles, Orange and San Diego. The study done under Lew will consist of two main parts: (i) placing all facility sites on the State of California Seismic Hazard Zone maps within a GIS format, and (ii) mining relevant information from hospital site engineering geologic reports (which include information about the sites) and seismic evaluation reports (which include information about the buildings) available at OSHPD. OSHPD has offered full access and cooperation, including moving all relevant files from Sacramento to the LA OSHPD office and providing an area there for Lew's team to do the work. Earthquake hazards for the facility sites to be included in the survey/mapping/evaluation are: liquefaction (including settlement and lateral spreading), landsliding, tsunamis and seiches, surface fault rupture, seismically-induced flooding, and strong ground shaking (including amplification effects). Information from the individual buildings will include: number of stories, number of beds, footprint, structural type(s), foundation system(s) and other relevant information. The final report to be issued at the end of the 12-month study will be co-authored by the three PIs and will contain two parts: Part A with summaries, conclusions and recommendations for MCEER research, and Part B containing all tables, figures, maps, statistical analyses and detailed discussions. The whole report will be provided both in hard copy and electronic form.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The main motivation for this study is to base the future direction of the geotechnical and foundation MCEER research in Thrust 2 on actual needs of hospitals as concluded by the proposed study. Two of the PIs and others within MCEER (as well as outside MCEER) have conducted research on liquefaction and their effects on foundations, perceived to be relevant to hospitals. The PIs don't know of any other study similar to the one proposed here in terms of comprehensively surveying the actual hospital research needs in the geotechnical area.

**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Significant research was conducted in previous years (and it is still conducted in Year 5) by two of the PIs (Dobry and O'Rourke), on centrifuge-based evaluation of pile foundation response to lateral spreading and mitigation strategies. A comprehensive summary of the achievements of that research was included in the corresponding article in the "MCEER Research Progress and Accomplishments: 2000-2001" volume (pp. 87-101).

**Role of Proposed Task in Support of Strategic Plan:** (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The task involves a top-down approach in which 248 hospital facility sites, representing a large and statistically significant sample, are reviewed by a leading geotechnical practitioner experienced in hospital foundation assessment. The main geotechnical factors affecting hospital performance during an earthquake will be systematically evaluated, with key research needs identified. The research will provide a framework for strategic decisions on the allocation of research resources in the geotechnical/foundation area within Thrust 2. MCEER will be able to use this study to establish priorities for acute care facilities and select the most important and promising areas for its technology portfolio development.
**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

It is expected that the proposed study will naturally interface with all PIs working on geotechnical research within MCEER, especially in Thrust 2. In addition, the results of the survey and other aspects of the study will be of interest to PIs doing structural research in Thrust 2.

**Possible Technical Challenges:**

Completion of the proposed work in the short time period of 12 months.

Interactions of appropriate technical detail among Marshall Lew, Tom O'Rourke and Ricardo Dobry to collect information of desired relevance leading to conclusions and recommendations that meet MCEER objectives in the Thrust 2 area.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

Comprehensive report including Parts A and B, in both hard copy and electronic form, containing conclusions and recommendations for future MCEER geotechnical research in Thrust 2 plus supporting data.

**Potential end-users beyond academic community:** *(IAB members and others.)*

Geotechnical engineers, structural engineers, building officials regulating hospitals (including OSHPD), hospital community (including owners, administrators, and facilities managers).

**Educational outcomes and deliverables, and intended audience:**

In addition to the participation of engineering student interns in the project (see Team Members below), the knowledge produced in this project will be diffused to a broad audience through the final report itself, plus the summary and graphics materials to be placed in Year 7 at MCEER's Web site.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

The 12-month study will be conducted in five phases starting October 1, 2002 as summarized in the schedule below:

**Phase I (1 month):** Lew starts data collection, and specifically looks at 10-20 representative hospital sites and proposes to O'Rourke and Dobry a detailed format for the survey and other aspects of the project plan. The three PIs meet in LA for a kickoff meeting to decide details of survey and project plan, visit OSHPD LA office and visit 1-2 hospital sites in the LA area.

**Phase II (5 months):** Most of the mapping and survey data collection work is done in this phase by Lew and a team consisting mainly of engineering student interns from colleges in the LA area.
area. Near the end of Phase II, preliminary results, statistics and maps are submitted by Lew to O'Rourke and Dobry for review, and several iterations take place between the three PIs on how to proceed in Phase III. Possible alternatives to be discussed: To extend the survey to more counties or parts of counties? To go back to all sites/buildings already surveyed for additional information? To select a subset of sites for additional in-depth study and evaluation? To conduct additional statistical analyses and study of data already collected?

**Phase III (4 months):** In this phase, additional studies are done by Lew and his team as decided by the three PIs in Phase II, and drafts of final tables, statistics, maps and text to be included in Part B of final report are produced by Lew and circulated to Dobry and O'Rourke for review. After several iterations between the three PIs if necessary, Part B of the final report is approved.

**Phase IV (1 month):** Lew circulates a draft of Part A of final report to the other two PIs containing summaries of the results plus conclusions and recommendations to MCEER. O'Rourke and Dobry fly to LA for a final 2-day meeting with Lew where Part A is discussed, modified and approved in final form. Part B of the report is also approved in final form, including small changes to the version from Phase III if required by the discussions in the meeting.

**Phase V (1 month):** Lew produces the report containing both Parts A and B, in hard copy and electronic forms, and submits it to MCEER.

**Team Members:** (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

Only O'Rourke and Dobry will participate in the project (as PIs) from Cornell and RPI respectively.

At Law/Crandall, Marshall Lew (PI) will head a team of two engineering undergraduate student interns who will conduct much of the mapping and surveying work at the OSHPD and Law/Crandall LA offices on a part time basis, after being trained by Lew for this purpose. It is expected that one of these two interns will be a student at UCLA or USC, while the other will be a student from a local community college, possibly a minority student. In addition to collecting data these interns will participate in the analysis, report preparation, as well as in the discussions with Lew, O'Rourke and Dobry taking place in the two LA meetings, overall a valuable educational experience for them.

**Possible Direction of Work in Subsequent Years:**

The work is expected to be completely finalized within Year 6.

It is expected that in Year 7, a networking task will be implemented where the main aspects of the report including maps and other graphical material, will be placed in MCEER's Web site.

The report should influence decisions on direction of geotechnical research within Thrust 2 starting in Year 7.
Senate Bill 1953 Program Overview

Senate Bill 1953 (SB 1953) was introduced into the California State Senate on February 25, 1994, just 5 weeks after the January 17, 1994 Northridge earthquake had caused much damage to structures in Southern California, and to many hospital building and facilities in the region. The SB 1953 was signed into law on September 21, 1994 and filed by the Secretary of State on September 22, 1994. The bill was an amendment to and furtherance of the Alfred E. Alquist Hospital Seismic Safety Act of 1983 (Alquist Act). SB 1953 (Chapter 740, 1994), is now chaptered into statute in Sections 130000 through 130070 of the Alfred E. Alquist Hospital Facilities Seismic Safety Act, and part of the California Health and Safety Code. The regulations developed as a result of this statute are deemed to be emergency regulations and became effective upon approval by the California Building Standards Commission and filing with the Secretary of State on March 18, 1998.

The Alquist Act establishes a seismic safety building standards program under the jurisdiction of the State of California Office of Statewide Health Planning and Development (OSHPD) for hospitals built on or after March 7, 1973. The Alquist Act was initiated because of the loss of life incurred due to the collapse of hospitals during the Sylmar earthquake of 1971. The Alquist Act emphasizes that essential facilities such as hospitals should remain operational after an earthquake. Hospitals built in accordance with the standards of the Alquist Act resisted the January 1994 Northridge earthquake with minimal structural damage, while several facilities built prior to the act experienced major structural damage and had to be evacuated. However, certain nonstructural components of the hospitals did incur damage, even in facilities built in accordance with the structural provisions of the Alquist Act. The provisions and subsequent regulation language of SB 1953 were developed to address the issues of survivability of both nonstructural and structural components of hospital buildings after a seismic event.

Therefore, the ultimate public safety benefit of the Alquist Act is to have general acute care hospital buildings that not only are capable of remaining intact after a seismic event, but also capable of continued operation and provision of acute care medical services after a seismic event.

Hospitals as defined in Section 129725 and licensed pursuant to subdivision (a) of Section 1250 of the Health & Safety Code shall comply with the regulations developed by OSHPD as mandated by SB 1953. There are approximately 470 general acute care hospital facilities including the 2,673 hospital buildings that will be impacted by the provisions of SB 1953. If a facility is to remain a general acute care hospital facility beyond a specified date, the owner must conduct seismic evaluations, prepare both a comprehensive evaluation report and compliance plan to attain specified structural and nonstructural performance categories which must be submitted to OSHPD in accordance with these regulations.
The primary purpose of these regulations is to evaluate the potential earthquake performance of a building or building components and to place the building into specified seismic performance categories. The evaluation procedures were developed from experience gained in evaluating and seismically retrofitting deficient buildings in areas of high seismicity.

**Review of SB 1953 Comprehensive Evaluation Reports and Compliance Plans**

The comprehensive evaluation reports and compliance plans will describe the existing buildings at each hospital facility. It is anticipated that the reports will contain information describing the building structural systems and foundation systems used to support each building.

As part of the SB 1953 evaluation, an “engineering geologic report” is to be submitted as part of the comprehensive evaluation report and compliance plan. The engineering geological report is to describe the soil, rock, and groundwater conditions at the hospital facility as well as address geologic-seismic hazards that may affect the facility. These hazards include: soil liquefaction, landsliding, seismically-induced flooding, threat of tsunamis or seiches, surface fault rupture, strong ground shaking and other potential hazards. The reports may be prior reports for existing facilities, but must be found to be current and applicable to the evaluation and compliance requirements.

About 460 hospital facilities in California, covering about 2,550 hospital buildings, have submitted comprehensive evaluation reports and compliance plans to OSHPD under the requirements of SB 1953. Some of the facilities may have self-declared buildings to be in the lowest structural Seismic Category, SPC-1, and engineering geologic reports may not have been submitted for these facilities. We understand that about 1,000 buildings (about 40% of the total number of hospital buildings) have been reported to have been classified as being in the SPC-1 category. We estimate that some 300 to 350 engineering geologic reports would be available to review. For the facilities that have self declared to be SPC-1, prior engineering geologic reports may be available at OSHPD.

We propose to review the available comprehensive evaluation reports and compliance plans for those hospital facilities in the highest density urban areas in Northern and Southern California. In Northern California, the reports for the facilities in San Francisco, San Mateo, Santa Clara, Contra Costa and Alameda Counties will be reviewed; a total of 68 hospital facilities are in these five contiguous counties surrounding San Francisco Bay. In Southern California, the reports for some 190 facilities in Los Angeles, Orange, and San Diego County will be reviewed. All these 248 hospital sites in Northern and Southern California include more than 1000 hospital buildings. It is our understanding that the evaluation reports and compliance plans will be available for review in the Los Angeles office of OSHPD. The reports and plans will be reviewed and each building number of beds, footprint, number of stories, structural types and foundation systems, as well as other relevant information, will be incorporated into a database summarizing the hospital locations and basic structural information. The engineering geologic reports will be reviewed to determine the geologic and seismic hazards affecting those hospital facilities and will also be summarized and put into the hospital database.

II.A-2.76
Analysis of Data

The data from the SB 1953 required evaluation and compliance reports (especially the engineering geologic reports) will be analyzed with respect to the geologic and seismic hazards identified at each of the hospital facilities in California. The hazards to be included in the evaluation are liquefaction, landsliding, tsunamis and seiches, surface fault rupture, seismically-induced flooding, and strong ground shaking. The general soil, geologic and groundwater conditions will be identified and the Site Soil Type according to the California Building Code regulations will also be identified. A significant number of the hospital facilities in the Northern and Southern California study areas are expected to be within zones subject to liquefaction hazard and/or near active fault zones. We propose to examine the hospital sites within liquefaction hazard zones and near active fault zones in greater detail. In addition to summarizing the geologic and seismic hazards affecting the hospital facilities, the severity of the hazards affecting the site will be identified. For example, should liquefaction potential be identified at a particular hospital facility, how much liquefaction-induced settlement could occur, and/or how much lateral spreading is expected? Also, if near an active fault, what level of ground motions would be expected for code-level design?

A GIS mapping system is planned to be used to show the locations of the hospital facilities. Hospital locations have been incorporated into the base maps used in HAZUS99 and could serve as base maps for this project. Several possible uses of the maps could be used to superimpose the State of California Seismic Hazard Zone maps now being issued incrementally by the California Geological Survey (CGS). These maps show zones of potential liquefaction and landsliding hazard as determined by the CGS. The maps could be used to compare the liquefaction evaluation results in the engineering geologic reports for each facility with the mapped liquefaction hazard zones. The hospital location map could also be compared with the USGS probabilistic ground shaking hazard maps.

Usefulness of Results

The data collected from this study of the comprehensive evaluation reports and compliance plans (including the engineering geologic reports) submitted for SB 1953 compliance are expected to provide an insight into the types of seismic hazards that hospital facilities in major urban centers face. These hazards are expected to include liquefaction (and its related effects) and strong ground motion, especially near active fault zones. Other seismic hazards may be found to be significant. The evaluations in the reports should provide information on possible mitigation strategies for these hazards. This information may be useful for other areas in California and the United States with hospital facilities subject to similar seismic hazards. The data will also provide insight into the siting of hospital facilities and information that may be used in land use planning. It is also expected that conclusions can be made regarding the structural and foundation systems that may be appropriate to mitigate against seismic hazards and promote seismic safety benefit.

Marshall Lew
5/3/03 3:56:53 PM
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.2.2</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Number:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:**
Methods of Analysis of Buildings with Seismic Isolation and Damping Systems

**Investigator:** Michael C. Constantinou
**Institution:** University at Buffalo

**Statement of Project Goals:**
1) Development and verification of methods of analysis and design for buildings with seismic isolation and damping systems. This effort is primarily coordinated by committee TS12 and is linked to the development of the NEHRP Recommended Provisions.
2) Continue effort on development of a manual of examples of application of method of analysis and design of buildings with damping systems with emphasis on hospital buildings. This effort is carried out in cooperation with OSHPD of California.

**Problem Description and Research Approach of Proposed Work for Year 6:**
1) The “NEHRP 2000 Recommended Provisions for Seismic Regulations for New Building and Other Structures” contains an appendix on “Structures with Damping Systems”. This appendix represents a comprehensive effort at developing a code for the design and analysis of structures with damping systems. The appendix in NEHRP 2000 is largely the outcome of research funded by MCEER and documented in report MCEER-00-0010.

The procedures for analysis and design described in the appendix “Structures with Damping Systems” of NEHRP 2000 are recognized as in need of further development and verification. Specifically, the applicability of these procedures for near-fault excitation and for buildings on soft soil sites requires evaluation. Moreover, further design examples are needed to increase the confidence in the validity of the procedures.

We intend to work on the further development and verification of these analysis/design procedures with the specific goal of developing a revised document on “Structures with Damping Systems” for inclusion in NEHRP. The investigator leads this effort as Chair of technical subcommittee 12 charged with the development of the year 2003 NEHRP Provisions on new technologies. The effort is scheduled for completion in November 2003. We expect to have developed a comprehensive report on the planned work by the end of the calendar year 2003.

2) Earlier work funded by MCEER included the development of effective configurations of damping systems that can extend the range of applicability of damping systems. Part of this work was the development of the toggle-brace-damper system. This work is approaching closure with the student involved (Ani N. Sigaher) being in the process of finishing the writing of her dissertation and an MCEER report. This work will likely be completed in 2002 but may extend to the spring of 2003.
3) Performance-based design of important structures (e.g., hospitals) that utilize new technologies (i.e., seismic isolation and energy dissipation systems) requires that the response of the structural system and of essential non-structural components is controlled and bounded. Methods of analysis, whether simplified or sophisticated response history analysis methods, have not been verified to produce accurate results of relevance in the analysis of non-structural components. For example, nonlinear dynamic analysis computer programs that are commonly used by the profession for the dynamic analysis of buildings with seismic isolation and energy dissipation systems completely lack verification. An effort at verification of a commonly used commercial program (see MCEER report 99-0002) demonstrated that erroneous results on the response of the structural system may be produced.

Verification of the accuracy of these methods of analysis, and particularly of computer programs used for dynamic analysis of buildings with seismic isolation systems, is very important. Work supported by MCEER and industry concentrated on the generation of experimental results for seismically isolated buildings under the following conditions: (a) a range of isolation systems including highly flexible and highly damped systems (addition of viscous damping devices), (b) superstructure with flexible moment frame systems, stiff braced frame systems and asymmetrically braced frame systems, and (c) design of isolation systems for areas of very high seismicity and testing with near-fault seismic excitation. The bulk of the experimental work has been completed on a 6-story, 46-kip model structure and the results have reduced. Isolation systems tested included FPS bearings without and with viscous dampers (linear and nonlinear), Lead-Rubber bearings, elastomeric bearings without and with viscous dampers (linear and nonlinear), and combined elastomeric-sliding systems. Experimental results include global response quantities (such as accelerations, displacements, drifts and shear forces) and responses of attachments to the structure (including displacements, velocities and accelerations of attachments to the floors, and floor response spectra computed from recorded floor accelerations histories).

Preliminary analysis showed that commercially available programs could produced results on the global response and on the response of secondary systems that (i) are in good agreement with the experimental results for some systems, and (ii) are in disagreement with experimental results for other systems. Interesting is the disagreement in acceleration response of secondary systems in the high frequency range. These preliminary results indicate that the calculation of response of secondary systems may be inaccurate with the currently available models for seismic isolation and damping hardware, which have been developed to primarily accurately predict global response quantities.

We intend to continue work in this area with the following goals:

(a) Complete the comparison of analytical and experimental results using currently available commercial programs.
(b) Develop and implement in a version of program 3D-BASIS new models for isolation hardware that may better predict the high frequency response of secondary systems in isolated structures. This program may then serve as the starting point for modification of commercial programs.
(c) Write a comprehensive report on the work, including the “posting” of selected
Experimental results in electronic format on MCEER’s web page so that other investigators can utilize the results for verification of their analyses.
(d) Complete the experimental work by conducting testing of seismically isolated model structures under conditions of uplift. The model has been prepared, seismic isolation hardware is in manufacture and testing could start in the summer of 2002. This work requires the development of models for describing the behavior of the hardware.

<table>
<thead>
<tr>
<th>Assessment of State-of-the-Art:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) There is considerable research work in the area of simplified methods of analysis for buildings. It is summarized in a recent document developed by ATC under project ATC-55, Evaluation and Improvement of Inelastic Seismic Analysis Procedures. The work conducted at MCEER in the previous years and proposed for year 6 is distinguished in the following:</td>
</tr>
<tr>
<td>(a) The work concentrates on structures with damping systems.</td>
</tr>
<tr>
<td>(b) The work is performed under the direction of committee TS12 of BSSC (charged with development of NEHRP Provisions in the area of new technologies), which primarily consists of practicing engineers, therefore the results are relevant to practice.</td>
</tr>
<tr>
<td>(c) The results are directly related to the development and verification of accuracy of methods for analysis of buildings with damping systems that have been included in the 2000 NEHRP Recommended Provisions and could be included in future editions of the NEHRP Recommended Provisions.</td>
</tr>
<tr>
<td>(d) Certain part of the work (examples of application of analysis/design procedures) is conducted in cooperation with engineers from California’s OSHPD (also participating in TS 12), thus the work is truly related to hospitals.</td>
</tr>
</tbody>
</table>

2) The work on seismic isolation systems is unique and there is no similar work currently performed in the United States. Only relevant work is the experimental work on seismically isolated bridges recently completed at UC Berkeley under Caltrans funding. Since that work was carried out by Dr. Whittaker, who since then moved to Buffalo, any relevant information is directly available to us. This also includes mathematical models for isolation hardware. However, the conducted work at MCEER and the work proposed for year 6 is primarily related to secondary systems in seismically isolated buildings with emphasis on capability for accurate response prediction. Such work has not been performed in the past.

| Progress to date: | See description above |
|-------------------|

<table>
<thead>
<tr>
<th>Role of Proposed Task in Support of Strategic Plan:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The proposed work supports the MCEER strategic plan because (i) involves fundamental research in order to develop scientific knowledge, (ii) transforms this fundamental knowledge into tools for the profession (the tools are technologies for seismic hazard mitigation and tools for the analysis/ design), and (iii) involve new technologies which is the main theme of MCEER’s concentration.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Integration:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The on-going and the proposed work intend to provide practicing engineers with verified tools for the analysis and design of critical facilities for which objectives on the performance of both the structural and the non-structural systems need to be met. The work complements the main theme of MCEER for the development of a fragility-based framework for the performance-based design of hospitals. While the methodologies for this framework may be developed in a generic approach, their practical application requires the use of verified analysis and design tools. This</td>
</tr>
</tbody>
</table>

II.A-2.80
work will contribute in the development of these tools.

**Possible Technical Challenges:**
Work is ambitious but has been possible so far with contributions from practicing engineers, cooperation with other MCEER researchers (primarily Dr. A.S. Whittaker) and matching funding and support provided by industry.

**Anticipated Outcomes and deliverables:**

1) Report on Toggle-brace-damper systems.
2) Report on experimental/analytical work on seismic isolated structures with emphasis on non-structural component response.
3) Report on methods of analysis of buildings with damping systems, including manual with examples of applications.

**Potential end-users beyond academic community:**

1) Design professionals.
2) Code developing agencies (BSSC for NEHRP, ASCE-7, SEAOC).

**Educational outcomes and deliverables, and intended audience:**

1) Information/results to be published and presented at conferences.
2) Results to be presented by cooperating practicing engineers (already done by Mr. Martin Johnson of EQE in lectures organized by SEAOC).
3) Presented to students directly in courses at UB (CIE625, Seismic Isolation).

**Project Schedule and Expected Milestones for the Project**

| Fall 2002 | Conduct experimental work on seismic isolation systems under conditions of uplift. |
| Spring 2003 | Develop report on toggle-brace-damper systems. |
| Spring 2003 | Develop first report on testing and analysis of seismic isolation systems |
| Summer 2003 | Develop report on work on analysis methods for buildings with damping systems. |
| Summer 2003 | Reduce experimental data on work on seismic isolation systems subject to uplift conditions and start work on modeling. |
| Summer 2003 | Develop draft of manual with examples. |

**Team Members:**

1) Graduate students: Ani N. Sigaher, Eleni Pavlou, Panos Roussis, Eric Wolff.
2) Undergraduate student: Dan Fenz
3) Faculty collaborator: Dr. Andrew S. Whittaker.
4) TS 12 members: Martin Johnson, Charles Kircher, Robert Hanson, Tom Hale.
5) OSHPD, CA collaborator: Tom Hale.
6) Investigator: Michael C. Constantinou.

**Possible Direction of Work in Subsequent Years:**
The described work is multi-year and is intended to continue over years 7 and 8.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Advanced technologies and data for validation of integration methodologies – Displacement-based Energy Dissipation Systems - Metallic

**Investigator/Institution:** Michel Bruneau, University at Buffalo

*indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

Metallic displacement-based energy dissipation systems are studied as they may provide a satisfactory approach for the seismic retrofit of acute care facilities. Work is conducted to validate innovative energy dissipation concepts, to formulate design procedures that can be used by engineers, and to generate broader knowledge on their behavior in a format consistent with resiliency definitions and that can be integrated into the decision model tools being developed by other researchers.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

The work to be accomplished focuses on two complementary tasks: (i) The development of innovative displacement-based energy dissipation technologies, and (ii) the formulation and generation of knowledge on these systems in a format compatible with the definition of resiliency measures.

On the first of these two aspects, building on work started in Year 4, research will be conducted to establish, for various kinds of displacement-based energy dissipation systems, the range of impacts on system behavior (drifts, column and beam forces, ductility demands, stiffness). This will be accomplished through parametric studies, and use of the MCEER demonstration hospital as a case study. This review will also indirectly provide some insight into the trends and benefits of more optimal strategies, including still unstudied unconventional strategies such as perforated plates (to provide a more gradual progression of yielding and effective structural strain hardening) or plate attachment strategies that could significantly modify behavior and minimize demands on the existing structure. Consideration will be made to account for whether the energy dissipating system is used as a purely hybrid system (added to a competent moment frame able to resist alone 100% of the seismic loads) or as an integral part of the structural system likely to resist itself the totality of the applied seismic loads. Experimental validation may be required if this process identifies novel concepts as the more promising ones.

The second aspect of this project builds upon the first one, by extending these fundamental studies to provide data and case studies on how the resiliency measures can be implemented with displacement-based energy dissipation systems. Resilience being a function of reduction of...
probability of failure, consequences of failure, and time to recovery, work will focus first on quantifying reduction of probability of failure, with the implicit understanding that some proportional reduction in the other two measures ensue from the first one. Again, the MCEER demonstration hospital will play a useful role for that purpose. The methodology followed will evolve as the resiliency measures become further developed as part of the center-wide overarching task charged with this duty.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

To the best of the investigator’s knowledge, no similar work is currently being conducted in the US. However, work has been conducted in Japan and Taiwan on various types of displacement-based energy dissipation systems. Unbonded brace systems, developed in Japan have been used already in the US, but other Japanese displacement-based energy dissipation approaches have not. To date these have been only used in new buildings. As part of conventional lateral-load resisting systems, steel plate shear walls have been implemented in some new constructions in the past, often designed on a strength-basis, sometimes to provide ductile behavior. Yet, none of that work addressed the issues of minimal seismic retrofit disturbance, optimization of energy-dissipation, and quantification of performance objectives which are at the core of the research described in this task statement.

**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Use of the MCEER Demonstration Hospital as a case study revealed that relatively thin steel plates might be sufficient to provide the needed strength and stiffness for seismic retrofit. Consequently, two light gauge infill systems were fully developed/design for large-scale testing:

a) A corrugated steel plate shear wall system, using light-gauge flat plate (Specimen 1) and corrugated plate (Specimen 2) as infill to dissipate energy while minimizing demand on columns. To avoid welding fumes (undesirable and disruptive in a hospital retrofit situation), special types of industrial-strength epoxies were studied for connection of this plate to boundary frame. Specimens are ready and scheduled to be tested in May 2002.

b) A light gauge partition wall with X-bracing plates laterally restrained by cold-formed standard partition studs. Many alternatives were considered prior to selecting the final design (e.g. shape memory alloys, but connection problems and cost led to decision to postpone testing of such a specimen). Specimens is being constructed, and scheduled to be tested in June-July 2002.

Considerable efforts from April 2001 to March 2002 were invested to take the ideas from the conceptual level and achieve actual construction of the specimens. A number of schemes originally considered were discovered to be impractical during this implementation phase, and numerous adjustments were required, which in retrospect resulted in more effective and practical designs. The constructed specimens reflect these enhancements.

In addition, as part of Year 5 activities, a paper was written (under review) summarizing an innovative closed-form solution to predict the ultimate capacity of steel plate shear walls, and to
allow engineers to verify computer results and be more confident in their design. That work will also be submitted to the NEHRP Technical Subcommittee S6 in summer 2002 for review and possible inclusion in Chapter 8 of the 2003 NEHRP Provisions.

<table>
<thead>
<tr>
<th>Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The definition of seismic resilience consists of reduction of probability of failure, consequences of failure, and time to recovery. Displacement-based energy dissipation systems (as sacrificial elements) can provide a satisfactory solution at all three levels, and research will be conducted to assess how this can be best achieved.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work is conducted in parallel with efforts on displacement-based energy dissipation systems with composites (Aref) and ECC (Lee). Additionally, starting in Year 6, part of the research effort (beyond the development of new technologies) will be directed to start developing the knowledge required to quantify the behavior of displacement-based energy dissipating systems in a format compatible with the resiliency definitions (one of the center-wide overarching research task), and the integrated methodologies for which proof-of-concept results will be produced in Year 6 (work by Dargush, Grigoriu, Winterfelt, and Lee).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Possible Technical Challenges:</th>
</tr>
</thead>
<tbody>
<tr>
<td>To quantify performance in a framework to provide quantitative data in support of the resilience definitions is a major challenge. Other challenges lie in the development of innovative and cost-effective structural systems, allowing de-coupling of the energy dissipation system from the other structural systems, and meeting all other target performance goals.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New advanced technologies for the seismic retrofit of critical buildings (i.e. acute care facilities) having flexible frames.</td>
<td>Practicing engineers who will eventually design retrofit/repair systems using such strategies (many of which are MCEER IAB members).</td>
</tr>
<tr>
<td>A document outlining design concepts with worked examples (see Education outcomes below).</td>
<td>OSHPD (MCEER IAB member) who would use these tools to assist their consultants.</td>
</tr>
<tr>
<td>Both of the above outcomes are deemed to be valuable by MCEER IAB members such as OSHPD and practicing engineers involved in seismic retrofit of hospitals (such as KPFF Engineers).</td>
<td>Acute care facility owners who will be able to ensure the seismic survival and full operational critical facility following an earthquake.</td>
</tr>
</tbody>
</table>
Educational outcomes and deliverables, and intended audience:

The design procedure for steel plate shear walls developed during Years 4 and 5 as an outcome of this research is the topic of a lecture as part of the course CIE-524 Metal Structures taught at University at Buffalo.

The approaches developed through this research will be included in future professional development courses on the use of energy dissipation systems for seismic retrofit, attended by professional engineers. They will also be included in a short document outlining the retrofit design concepts, with a complete example, that will be prepared for use by practicing engineers. The California Office of Statewide Health Planning and Development (OSHPD) has already agreed to endorse and distribute such a document when available.

The systems studied within this task hold the promise that they could also be implemented in new constructions, thereby leveraging the technology transfer and outreach activities in a significant way.

Project Schedule and Expected Milestones for the Project:  
(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

Parametric Study Stage 2 – Focusing on selected systems and outcomes of Stage 1, research on innovative approaches that would meet resiliency objectives: April 1st – September 31st, 2003:

Team Members:  
(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

Currently working in this project (Year 5 research), under supervision of Michel Bruneau, are Darren Vian (Ph.D. student) and Jeff Berman (M.Sc. student), all from the Department of Civil, Structural, and Environmental Engineering at the University at Buffalo. In addition, Dr. Oguz Celik from Technical University of Istanbul (Turkey) is a visiting professor participating in this research (Aug 2001-July 2002). An REU student is expected to also assist during the summer. Mr. Vian will continue working on this project in Year 6, along with a second Ph.D. student.

Possible Direction of Work in Subsequent Years:

Development of a general design procedure for metallic energy dissipation systems, that is compatible with the refined resiliency measures produced by the Center-wide overarching task.
Developments to integrate research outcomes into decision methodologies and procedures developed by other MCEER researchers.
Development of document outlining design procedure, with fully worked-out example, for use by practicing engineers involved in seismic retrofit of acute care facilities (see educational outcomes section above).
Statement of Project Goals:

Properties of highly ductile cement-based composites and their use in varying configurations for the retrofit of flexible and rigid structures are being investigated. Specific applications in the form of ductile cement-based infill panels are being developed for the retrofit of demonstration hospital projects. The major goals of this research are to determine appropriate material constituents, panel geometries and connection details for economical implementation of this material for protecting seismically vulnerable structures and structural components. Emphasis is placed on retrofit strategies that ensure the post-earthquake function of health care facilities and on characterizing seismic performance of the retrofits for cost-benefit analyses.

Problem Description and Research Approach of Proposed Work for Year 6:

Advanced materials are continually being engineered and offer potential economical applications to the seismic retrofit of both flexible and rigid structures. Many advanced materials such as highly ductile fiber-reinforced cement-based composites (ECC*) are investigated primarily at the material level and have not yet been fully explored for their applications to larger structural problems. The variety and flexibility with which ECC may be used for retrofitting makes this material a desirable choice for investigating retrofit strategies for critical facilities, which demand particular and flexible use of space.

This research explores the applicability of ECC as an energy-dissipating infill panel system. This infill system is a material-based, passive energy dissipation solution for the retrofit of both steel and concrete structures. Assessment of the material is being made with a combination of experimental and numerical studies to verify both structural performance and constructability. In Year 6, numerous panel tests will be conducted under quasi-static lateral load. Further testing extending beyond Year 6 will involve full frame infill experiments using the proposed panels. As funding permits, shake table experiments will be conducted as well.

Additionally in Year 6, numerical studies using properties gained from material characterization, joint connection experiments and laterally loaded panel experiments will be used to analyze and evaluate the performance of this retrofit strategy in the demonstration hospital project. These numerical studies will also be used to investigate the optimal use of various panel configurations (using optimization methods developed by other MCEER researchers) and their effectiveness as a portable system within the demonstration project. The combination of experimental and numerical work, including the optimization studies will be used for cost-benefit analyses by other MCEER researchers.

Assessment of State-of-the-Art:

Within MCEER, related work is being conducted in the area of passive energy-dissipation structural retrofits for hospital structures. In particular, two other infill systems are being investigated; one system uses thin steel shear wall infills and another uses polymer matrix composite infill walls. Each system (steel, polymer composite and ECC) represents a different set of advantages and disadvantages for structural retrofits and each system has a set of challenges in the research that have some similarities and some differences from the others. A relatively unique feature of the ECC system is its flexible use within an existing frame. Being an infill system made up of individual panels that can have alternate geometries, openings in frames can be relatively easily accommodated and individual panels if damaged can be

* ECC = Engineered Cementitious Composites. See [www.engineeredcomposites.com](http://www.engineeredcomposites.com)
removed and replaced keeping the remainder of the retrofit in tact.

Outside of MCEER, there have been some studies on connections for ECC shear panels in the late 1990’s by Dr. Kanda and his colleagues in Japan. Furthermore, Prof. Kabele (Czech Republic) and his colleagues have studied ECC infill panel systems numerically. All of this work was published in the Proceedings for the 3rd International Conference on Fracture Mechanics of Concrete Structures (FraMCoS-III) held in Gifu, Japan in October, 1998. The PI has not seen further work in this area (other than that being conducted at Cornell). However she will be attending a workshop in Japan in October 2002 specifically on the topic of ECC and should learn more about Japanese, Czech and other international developments in this area.

Progress to date:
April 1, 2001 – March 31, 2002.
- Completed experimental studies of tension, compression and cyclic tension-compression tests on ECC specimens.
- Material testing results have been used to develop a constitutive model for ECC under cyclic load for larger-scale predictions of system response using ECC infill panels. The performance of two different large-scale structural component tests using ECC has been successfully simulated.
- Completed initial nonlinear analyses of bolted panel infill systems using DIANA as well as selected appropriate experimental set-up for laterally loading the panels.
- Completed three full-scale energy-dissipating infill panel tests under cyclic lateral load
- Fabricated two additional panels for testing and currently fabricating panels with alternate geometries
- Completed a series of pretensioned bolted panel connection tests in compression and shear.
- Currently conducting time-dependent bolt relaxation tests on pretensioned bolted panel connections.
- Continued testing of cyclic tension-compression specimens with alternate fiber types and aggregate additions. We have identified considerably more economical mixes with necessary ductile characteristics.
- Met with industry collaborator, Kuraray America Inc., who is donating $2,000 in material supplies to Cornell research on ECC and with whom we are in continual contact regarding improvements to ECC technology.
- Initiated discussion with other MCEER researchers on optimization algorithms and their use in assessing optimal ECC infill panel arrangements.
- In a related project at Cornell, funded by NSF, creep and shrinkage tests have been conducted to assess the time-dependent response of ECC in compression and tension

Role of Proposed Task in Support of Strategic Plan:
New retrofit strategies using advanced materials for both flexible and rigid structures are being investigated for their potential to minimize the negative social and economic impact of earthquake hazards. These retrofit strategies and in particular the investigation of their application to the demonstration hospitals will provide a major contribution to determining resilience measures of critical facilities. ECC in particular has not yet been fully explored for large-scale retrofit applications under either quasi-static or seismic load. Passive energy dissipation through the material-based solution of ECC infill panels has been identified as a promising hospital retrofit and there is industry interest in this system. The proposed investigations of ECC contribute well to MCEER’s Thrust Area 2 “Seismic Retrofit of Emergency Care Facilities”. In addition, this investigation will be one of many to provide performance information for cost-benefit analyses, and other decision-making tools as well as for the development of fragility information for critical facilities.

Task Integration:
This work contributes primarily to larger tasks in Thrust Area 2 and has contributions at all three planes of the MCEER Strategic Framework. First, the work contributes to the Fundamental Knowledge Base through technology assessment. Second, this work contributes to the Technology Base through the evaluation and validation of an advanced technology and through the development of modeling and simulation tools for this advanced technology. Finally, the work contributes to Technology Integration
through its application to hospitals and through integration with other researchers working on hospital-related projects.

More specifically, successful and promising retrofit schemes identified in this research will be used to explore their effects on the demonstration hospital project and ultimately lead to a new technology and implementation strategy. This research will then contribute to determining consensus-based performance measures and will provide part of the framework for how decision tools should be developed for the retrofit of critical facilities. Finally, numerical simulations of the experimental results of the systems will provide benchmarks for the development of fragility information for hospitals.

This work will also contribute to technology transfer through the MCEER User’s Network. A new material model for ECC will shortly be made available to the engineering community on the User’s Network along with efficient modeling strategies and benchmark simulations against which users can compare their modeling techniques.

### Possible Technical Challenges:

- Understanding the effects of different fiber types, mix designs and additional reinforcement on the pseudo-strain hardening, steady-state cracking, and cyclic energy dissipation behavior of ECC.
  
  *Understanding the effects of various reinforcements from a micro-mechanical standpoint will facilitate simpler mix designs and possible introduction of new fiber and matrix constituent options in the future. New fibers and constituent options are of interest for economy as well as for improved energy dissipation characteristics.*

- Developing appropriate panel tests to replicate performance in actual structures and conducting frame tests with complete panel infills.
  
  *This work is clearly necessary for the goals of the project and is a technical challenge in terms of time and scale of the tests to be performed.*

- Implementing a sufficiently accurate constitutive model for ECC with new fibers and reinforcement for accurate and efficient numerical modeling.
  
  *Models are needed both for accurate assessment of the retrofits in the demonstration project and for larger scale analyses for cost-benefit studies. The larger-scale studies will require new macro-models of the infill system that do not yet exist.*

- Coupling modeling tools with optimization tools developed by other MCEER researchers. These tools are necessary for optimization studies, fragility analyses and cost-benefit studies.

- Developing retrofit strategies for seismic protection of critical facilities that utilize the advantageous properties of ECC and that minimize the amount of time building operations need to be down while the retrofit is put in place and once it is in place.

- Developing retrofit strategies that are flexible in use and can potentially be transferred to different locations within a structure (full-portability).

### Anticipated Outcomes and Deliverables:

- Mix designs including fiber and other types of reinforcement as well as aggregate additions for the economical and efficient use of ECC materials for seismic infill panel applications.

- New constitutive models for ECC materials under cyclic load with unique energy-absorbing characteristics. Models for both detailed nonlinear finite element analyses and macro-models for large-scale nonlinear analyses will be developed.

- Guidelines for feasible panel-to-panel and panel-to-frame connection details.

### Potential End-users Beyond Academic Community:

- Researchers, IAB members and other engineers, material suppliers

- IAB members and other engineers in consulting firms, researchers

- IAB members and other engineers in consulting firms, researchers
Guidelines for optimal use and potential for portability of various retrofit strategies for critical facilities.

IAB members and other engineers in consulting firms, hospital owners, architects and other building professionals

**Educational outcomes and deliverables, and intended audience:**

An important advanced technology that of ECC materials, will be developed for practical and economical applications for earthquake hazard mitigation. ECC represents a new type of concrete that can be engineered and tailored based on micro-mechanical principles including fracture mechanics. This approach to mix design will be new to many practicing engineers and will therefore require clear, educational guidelines to improve the speed at which the material may be used. Therefore a major goal of these investigations is to provide guidance for engineers to develop their own engineered materials for specific applications.

Audiences for this research include practicing engineers as well as building owners who desire to have a structural retrofit system that is flexible in use (i.e. portable). For the infill panel strategies being investigated, attention is given to the transport and removal/replacement possibilities for the system.

Other educational outcomes include the education of students who will work on this project. There is currently one Ph.D. student being funded through this project. One post-doctoral candidate was partially funded by this project in the past to develop the ECC constitutive model. In addition, a number of undergraduate researchers have worked or are currently working on this project funded through Cornell University. An additional PhD student, currently on an NSF Graduate Fellowship will begin (Summer ‘02) to conduct research related to this MCEER project. Finally, many of the test set-ups developed for investigating this new material and the developed models for ECC serve as demonstration tests and models for an undergraduate course taught in the Spring by Dr. Billington. This course is titled “Physical and Computational Material Simulation” and involves laboratory exercises combining hands-on experimentation with computer simulation of experiments. To date, the ECC compression, tension and flexural tests have been used for class laboratories and independent course projects.

**Project Schedule and Expected Milestones for the Project:**

**Through Fall ‘02:**
- Physical testing of single and double-height panels with bolted connections.
- Evaluate alternate panel geometries and arrangements
- Begin developing large-scale modeling techniques for simulation of panels in demonstration hospital (continued through Spring and Summer ’02)

**Through Spring/Summer ‘03:**
- Work with developers of optimization algorithms on implementing ECC analyses to study optimal retrofit schemes.
- Develop test set-up for full-frame infill-panel tests under quasi-static load.
- Consult with social scientists and other researchers on acceptable retrofit performance and performance metrics needed for optimization studies and for decision analysis tools.
- As funding permits, develop a shake-table experiment of a full frame with infill panels.

**Team Members:**
- Prof. Sarah Billington (Cornell, PI)
- Mr. Keith Kesner (Cornell, PhD candidate)
- Mr. Kyle Douglas (Cornell, PhD candidate)
- Mr. Ghim Hua Lian (Cornell, undergraduate researcher)
- Kuraray-America, Inc. (fiber supplier from Japan)
- Dr. Tong-Seok Han (former Post-doc at Cornell, currently Lecturer in Korea, continuing minor refinements to ECC constitutive model)
Possible Direction of Work in Subsequent Years:
Projected work beyond Year 6 includes:

• Continue physical testing of infill panels in large-scale steel frames. Possible development of shake table experiments to begin in Summer ‘03.
• Refine large-scale analyses, constitutive models, and macro-models for simulating alternate ECC panels and connections for hospital retrofits.
• Further participation in new optimization studies and cost-benefit analyses with other MCEER researchers considering retrofit aspects such as number and size of panels, number of connections, potential changes in building strength, stiffness or ductility, cost of fabrication, installation methods and time, and loss of space due to in-place retrofits.
• Develop guidelines for the practical application of ECC materials as panel retrofits for steel and concrete hospitals – based on studies conducted to date. Specific attention will be placed on how to engineer the material and the retrofit configuration to achieve desired performance for the critical facility under consideration.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.2.5</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
<th>Project Number:</th>
</tr>
</thead>
</table>

**Task Title:** Energy dissipation systems using Composites - Advanced Technologies and Data for Validation of Integration Methodologies

**Investigator/Institution:** Amjad Aref/University at Buffalo

* indicates task leader

**Statement of Project Goals:**
The objectives are:
1. Introduction of conceptual energy dissipating polymer matrix composite systems
2. Establishing a framework for rigorous and simplified analysis tools
3. Establishing a framework for simplified design procedures
4. Addressing constructability and manufacturing issues
5. Integration of the composite energy dissipation systems within benchmark models of hospital structures to compare and validate their effectiveness and limitations.

**Problem Description and Research Approach of Proposed Work for Year 6:**

*In addressing the conceptual design objective,* two systems are considered. The two systems will contain a combination of solid visco-elastic material and honeycomb polymeric material. The two concepts differ in (1) the geometrical configuration of the wall systems and (2) the distribution of the energy dissipating materials within each system. Thus, by introducing these two systems we are trying to create a spectrum of energy dissipating systems ranging from very flexible to stiff infill walls. One system has been designed and plans are underway to design the second panel. The following step will aim at manufacturing the panels and performing the experimental validation.

*In addressing the rigorous and simplified analysis tools,* we continue to use finite element analysis (ABAQUS) to model the steel frame with the proposed infill walls. In addition, for every conceptual design we are devising simplified analysis procedures.

*In addressing Simplified Design procedures,* the data provided by testing and rigorous analyses procedures will be primarily used to propose simplified design procedures for both systems.

*In addressing constructability and manufacturing issues,* we focus on the creation of modular infill panels for new construction as well as subassemblies that can be brought into an exiting structure. Therefore, for an exiting building, limitations imposed on the mobilization of the subassemblies in various spaces within the structure ought to be considered carefully. This consideration of sub-assemblies will warrant devising effective connections to install the panels in the field. We are working with the manufacturer of the panels to come up with practical and reliable connection details.
Finally, the integration of the composite energy dissipation systems within benchmark models produced by other tasks will provide the assessment tool as to the effectiveness of the proposed composite systems. The assessment and comparison of the composite systems will reveal (1) the limitations of the composite systems, (2) the range of applications that these systems may be effective, and (3) an insight as to the possibility of complementing these systems with other concepts. Therefore, hybrid strategies might emerge to enhance the applicability range of different energy dissipating strategies among MCEER’s research tasks. For example, the integration of composite infill system with steel infill systems, or engineered cementitious composite (ECC) panels may provide unique hybrid systems that suit special applications.

**Assessment of State-of-the-Art:**
Based on searching archival sources, the systems proposed by this task are unique in terms of the use of polymeric material as well as the novel concepts. However, other novel energy dissipating strategies exist within MCEER’s projects.

**Progress to date:**
During the year 2 and 3, extensive material testing and selection of constituents were performed. In year 3, the first conceptual design of an infill wall was analyzed, designed and manufactured. Also, two experiments were carried out to validate the response of the first infill panel system. One test focused on the performance of the system without any connections to the steel frame, and the second test focused on strategies for connecting the infill wall with the steel frame. In the past year, we devised a novel combination of solid and honeycomb visco-elastic materials to be used in the panels proposed in this task. To investigate the combination of damping materials, extensive testing of these materials was conducted and conclusions about the optimal combination that maximizes the energy dissipation was reached. In addition, the analysis and design of one of the two systems proposed in this task were completed.

**Role of Proposed Task in Support of Strategic Plan:**
This task mainly contributes to the advancement of passive energy dissipation systems. The use of advanced polymeric materials provides a new dimension and complements other seismic protective systems being considered within the technology portfolio. Thereby, this research task proposes a spectrum of solutions for seismic retrofitting. In addition, there is a great potential of coordinating the outcome of this research with other similar tasks to come up with hybrid retrofitting strategies. Thus, this interaction within MCEER’s tasks coupled with interaction with the ongoing industrial partners is in accord with the spirit and strategic plan of MCEER.

**Task Integration:**
The integration of this task with other tasks entail the following:
(1) The conceptual designs under investigation in this task can be combined with other researchers’ proposed systems to produce a spectrum of hybrid energy dissipation strategies that a single system cannot satisfy.
(2) In addressing the cost issue when dealing with composite materials, finding an optimal energy dissipating strategy with other systems would require proper interface mechanism and design parameters that can be used to produce a desirable solution.
Possible Technical Challenges:
The technical challenges include:
(1) Connection details for sub-assemblies of infill panels, and the connection details with the steel frame.
(2) Bringing the cost of the composite panels to a competitive level to compete with traditional materials used in other concepts.
(3) The lack of standards for design and methodologies for material selection.
(4) Fire protection

Anticipated Outcomes and deliverables:
(Also indicate those of particular benefit to IAB members and other end users.)

1) A number of conceptual energy dissipating infill wall systems.
2) Simplified analysis and design procedures for the proposed conceptual designs tailored for use by practicing engineers.
3) Publication of an MCEER report to document the findings of this research project.
4) Dissemination of findings in archival journal and conferences.

Potential end-users beyond academic community: (IAB members and others.)
Results of using high performance materials for infill walls for seismic resistance, after being tested in the laboratory and design challenges are resolved can be utilized in the demonstration project (a hospital or other critical facility). Although laboratory size structures can be manufactured and then tested in the existing facilities available in the Department, utilizing the expertise of industries that already manufacture large-scale PMC structures is necessary. Therefore, a PMC material supplier and manufacturer have been working with the investigator and his student to produce the required panels for this research. Upon completion of this research, there exists a great potential for commercial applications of the infill panels for seismic retrofit.
**Educational outcomes and deliverables, and intended audience:**

The findings of the research dealing with analysis and design procedures will be used in a graduate course at UB (CIE528 composite structures). Integration of the findings of this research in a graduate course will facilitate and promote the use of such systems, thus accelerating the transfer of research into industrial applications.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

- **Fall:** The design of the second panel introduced in this task will be finished and the manufacture and testing of the first panel will be carried out.
- **Spring:** Manufacture of second panel and testing. Starting the synthesis of data collected from both experiments to propose simplified analysis and design procedures.
- **Summer:** Verify and validate the proposed analysis and design procedures with efforts to consult with practicing engineers to enhance the quality of the design tools so as to meet the expectations of the engineering community.

**Team Members:**

WooYoung Jung, Ph.D. Candidate in the Dept. of Civil, Structural and Env. Engineering, UB

**Possible Direction of Work in Subsequent Years:**

At the end of year 6, this research would have produced three energy dissipating infill wall systems (one system in year 3 and two systems in years 5 and 6). Based on these systems and using validated simplified and rigorous analysis procedures, parametric studies to deal with various geometric and material architecture issues would be needed. In addition, combining these systems with other energy dissipating strategies produced by other MCEER researchers is of paramount importance. In fact this kind of interaction is one aspect that makes MCEER research more valuable and unique.

Finally, the goal of this research is to transfer this technology to practice and eventually provide all necessary design and analysis procedures to promote mass production of these systems. Therefore, working with industrial partners will be pivotal in achieving this goal. Consequently, efforts will be made to address and solve any impeding factors in order to accelerate the transfer of this technology from academe to industrial applications.
## MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Advanced technologies and data for validation of integration methodologies – Localized velocity-based energy dissipation systems.

**Investigator/**
**Institution:** Andrei M. Reinhorn*, University at Buffalo  
* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

1. Proof of concept testing of energy dissipation system in hybrid structures with independent lateral and vertical load resisting systems
2. Development of analytical tools for evaluation of fragility of hybrid structures
3. Evaluation of sensitivity of fragility in hybrid structures with energy dissipation systems
4. Evaluation of retrofit of WC70 hospital structure using hybrid approach

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

Each of the four goals listed above are discussed below:

Decoupling the lateral and vertical load resisting systems in structures can improve the reliability of the structure to sustain both gravity and lateral seismic forces without, or with substantially reduced, damage. In structures with independent gravity and lateral load resisting, it is possible to allow the gravity system to behave as a mechanism, without damage during earthquakes, while an independent lateral load resisting system stabilizes the mechanism and maintain lateral sways to a minimum. Additionally, existing structures with strong lateral systems, but without sufficient ductility, may be weakened modifying the lateral system but controlling the lateral sway with energy dissipation devices. Energy dissipation systems as connectors without, or with, amplification mechanisms can be added to control the lateral deformations. This project will attempt to use fluid viscous devices, and possibly metal hysteretic devices, to reduce the lateral sway of such hybrid structures. The devices for this proof of concept experiment will be obtained from Taylor Devices (or similar). Component tests will be performed and a shake table study will be carried out using a sacrificial-scaled model developed in a previous research.

The system will be evaluated for damage development and fragility changes using a computational tool based on IDARC3D program developed by the proposer. The analytical development will include specific modeling of fluid and hysteretic devices, which will be validated using the experimental data obtained from the component tests and shake table experiments.
With the completion of the development of the above analytical tool, an evaluation of fragility changes in the hybrid structures with energy dissipation will be performed. The methodology will be useful for the evaluation of hospitals and their retrofit.

The typical California hospital WC70 will be used for verification of the hybrid concept described above in which energy dissipation systems are added along with the modification of the main lateral structural system. The method may be suitable for the protection of both structural and non-structural system. The evaluation obtained in terms of fragility will be coordinated with the developments of performance evaluation tools (see task by Whittaker, University at Buffalo)

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

The decoupling of lateral and vertical system is common practice in design of new buildings. However the practice does not produce the intended products, which in the past sustained severe damage in buildings and bridges (Northridge 1994). Recently, Mander et al (2000) studied at MCEER bridges with rocking columns, which are primarily designed to sustain vertical loads without damage. The proposer performed a study of hybrid structures and developed a multipurpose model with sacrificial elements for study of structures near collapse. A model with separated lateral and vertical systems was built and tested to “near” collapse on shake table (see below Progress to Date). The proposer is not aware of available information on the proposed subject; therefore a literature search will be also performed along with the experimentation and computational effort. The proposed work will develop a method which allows control of deformations in such hybrid structures, which may allow to use the proposed method for retrofit through weakening the structural system and controlling the deformations using energy dissipation.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

The proposer has constructed and studied behavior of irregular structures near collapse using a structural scaled model having independent lateral and vertical load resisting systems. The model was tested on shake table. The results from this work are currently being processed (by PhD candidate Ms Dyah Kusumastuti scheduled to complete program in summer 2002)). The lateral system of the model was damaged without collapse based on the concept outlined above. The deformations where large and lead to the severe damage, near collapse. The analytical platform, IDARC3D, was modified (by Sivaselvan Mettupalayam, PhD Candidate) to be able to handle semi–rigid connections that were prevalent in the scaled model, and in many of the hospital structures, The above computer platform was then used to evaluate the experiments.

The proposer and a visiting postdoctoral associate Dr Stefania Viti from University of Florence (Italy) evaluated the WC70 hospital damaged in Northridge earthquake using the above analytical tool. They developed the fragility curves for the existing health care facility, which was used for evaluation of the benchmark retrofit scheme, resulting from the proposed work.
Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The proposed work will develop: (i) a possible strategy for response modification using an advanced technology suitable for retrofit of health care facilities and other structures; (ii) a methodology to evaluate the response modification based on fragility evaluation and its sensitivity and (iii) an enhanced computational tool (IDARC3D) to evaluate performance of complex hybrid structures with energy dissipation systems. The resulting methodology will enable modification of performance and improvement of resilience of structures and communities.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

This work will be integrated with the development of tools for performance evaluation of health care facilities (Whittaker) and with the development of strategies for response modification (M. C. Constantinou) The evaluation methodology described above and an associated sensitivity analysis will be complementary to work done by M. Grigoriu for global evaluation of fragility and on sensitivity for primary and secondary systems.

Possible Technical Challenges:

The proposed technique utilizes multiple devices with small deformations and velocities. The velocities and deformations may not be sufficient to develop the desired energy dissipation and control. Alternative techniques will be explored first analytically and then experimentally. Such solutions may include amplification systems, hysteretic yielding of friction systems.

Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)

1) A retrofit strategy for structures
2) A computational tool for evaluation of structures with response modification systems
3) A methodology for performance evaluation based on fragility

Potential end-users beyond academic community: (IAB members and others.)

1) Engineering community involved in protection of structures
2) Developers of commercial software for engineering evaluations

Educational outcomes and deliverables, and intended audience:

Information / deliverable will be included in the UB graduate class on earthquake engineering (CIE 619). Intended audience graduate students.
**Project Schedule and Expected Milestones for the Project:**  (*Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.*)

<table>
<thead>
<tr>
<th>Time</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2003</td>
<td>testing of components and devices for energy dissipation</td>
</tr>
<tr>
<td>Spring 2003</td>
<td>design of experiment and preparation of interfaces</td>
</tr>
<tr>
<td>Summer 2003</td>
<td>testing of assembly with most appropriate method.</td>
</tr>
<tr>
<td>Summer 2003</td>
<td>analytical work for modification of computational platform</td>
</tr>
<tr>
<td>Fall 2003</td>
<td>evaluation of retrofit strategy for the WC70 health care facility</td>
</tr>
<tr>
<td>Fall 2003</td>
<td>summary report on feasibility and sensitivity of proposed strategy</td>
</tr>
</tbody>
</table>

**Team Members:**  (*If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.*)

All team members for this project will be hired in the Fall 2002.

Some work will be performed by Mr. Sivaselvan Mettupalayam after completion of his current PhD Program

**Possible Direction of Work in Subsequent Years:**

Alternative techniques for control of deformation of weakened structures will be developed using semi active strategy in particular directed to survivability of structures near faults. Control (active or semi active) of inelastic structures has not been studied yet due to complexity of problem. Such systems may be suitable for control of damaged structures
## MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.2.7</th>
<th>Budget:</th>
<th>Yr 6 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Semi-active response reduction technologies and their implementation in buildings and non-structural components.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigator/</td>
<td>George C. Lee and Mai Tong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institution:</td>
<td>University at Buffalo</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates task leader

### Statement of Project Goals:
(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The goals of this research task is to develop hybrid semi-active and passive response control systems for buildings and/or critical non-structural components so that the range of response reduction of the passive systems is extended to cover from small to large earthquakes and a fail-safe feature of the structure-device system is provided. The research task will seek optimized design of semi-active systems to balance the energy dissipation effect of passive damping devices and lateral resistance capacity enhancement of strength based control mechanism.

### Problem Description and Research Approach of Proposed Work for Year 6:
(Detailed description of research to be conducted and methodology to be used.)

The basic objective of this research task is to carryout studies on semi-active control technologies and their applications in seismic protection of health care facilities and other critical structures. The specific focus is to use the semi-active control mechanism to extend the capacities of available passive control devices (tuned mass dampers, base isolators, energy dissipation devices, etc) to cover the different seismic requirements (energy dissipation and lateral resistance enhancement) under small to large earthquakes.

During the past six years, the co-PIs have been engaged in developing and perfecting a semi-active structural control system. This semi-active system is referred to as “Real-time Structural Parameter Modification” (RSPM) technology. Through the control of the orifice of the viscous fluid of a damper by “switching” actions, RSPM can add or delete an amount of stiffness and damping to a passive device in real time. During year 5, this concept was applied to address the possible pounding problem of two adjacent buildings on the UCLA campus through computer simulations with satisfactory results.

In year 6 we will focus on the development of a hybrid system consisting of passive viscous dampers with a variable stiffness based semi-active element. Specific efforts include

1. Theoretical work to show that such a system can cover the entire elastic and inelastic range of a typical building structure.
The system will only perform passively for small to medium levels of building responses (including floor responses for equipment and non-structural components). When the structure experiences large inelastic responses, the semi-active element will be activated automatically to add stiffness to the system to reduce or limit the displacement responses. This concept is compatible with the standard ductility based design approach.

A hybrid RSPM-passive viscous damper system will be developed for the Northridge hospital building for various levels of input ground motions.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

The concept of semi-active structural control was introduced by Kobori in 1993 for earthquake protection of buildings. Since that time the major advancement in semi-active control has been in the area of using smart (rheological) fluids. Besides the development of RSPM by the co-PIs, there are very few new developments. This research task is believed to be the first attempt to add/drop stiffness to a passive viscous damper to extend the range and capacity of the passive system.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

As noted in the problem descriptions, the basic concept was developed in year 4 and a computer simulation was carried out for a building in LA. Year 6 will be the first time to develop a variable stiffness viscous damper system for the Northridge hospital building.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This task can result in a cost effective approach to reduce the floor responses for the Northridge hospital building. It represents an advanced technology development for structural retrofit in general. This task will also result in a method for analyzing hospital buildings implemented with semi-active devices.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

We will interface with two sets of research tasks. The first are those working on passive devices (e.g. Whittaker, Constantinou). The second are those working on FE analysis procedures (e.g. Dargush, Reinhorn). In addition, the PI is responsible to coordinate with the developments of protective systems of the FHWA project.
### Possible Technical Challenges:

The most difficult area in this task is to develop a FE model for predicting the behavior and design of hospital building structures when such semi-active control system is installed. It is in the area of fundamental structural dynamics. When approximations are made, as they have to be, we must know to what extent the accuracy is compromised in order to know the safety margins of the design.

### Anticipated Outcomes and deliverables:

(Also indicate those of particular benefit to IAB members and other end users.)

Computer simulation of a variable stiffness viscous damping system that can be implemented in the Northridge hospital.

### Potential end-users beyond academic community: (IAB members and others.)

Possibly manufacturers of viscous dampers.

### Educational outcomes and deliverables, and intended audience:

Training of graduate student and part time post doctoral fellow.

### Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

- **Fall 2002:** Theoretically prove that this hybrid semi-active stiffness and viscous damper can be applied to elastic and inelastic ranges.
- **Summer 2003:** Complete the development of the hybrid system and apply it to the Northridge hospital building structure.

### Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

- George Lee – project leader
- Mai Tong – project co-PI
- Others – students

### Possible Direction of Work in Subsequent Years:

Extending the approach to other passive control devices (base isolators, other energy dissipators). Consider other semi-active elements when they are available (e.g. rheological fluids).
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:**
“Advanced technologies and data for validation of integration methodologies – Experimental data for performance of piping distribution systems”.

**Investigator/** Emmanuel “Manos” Maragakis*, Ahmad Itani  
**Institution:** University of Nevada, Reno.

* indicates task leader

**Statement of Project Goals:** *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

The main goal of the proposed research is to initiate the performance of shake table tests of a hospital piping distribution system, which was designed in collaboration with OSHPD in year 5. The objectives of the tests are the identification of the capacity characteristics of the system as well as its weak points and failure modes. The system will be tested with and without bracing or other devices that can be used to improve its seismic performance, in order to assess their effectiveness. The results will also be used for the identification of critical components and to provide information to the researchers of a parallel Task, who are performing analytical studies and are developing the fragility information for these systems.

**Problem Description and Research Approach of Proposed Work for Year 6:** *(Detailed description of research to be conducted and methodology to be used.)*

Functioning of a complex critical facility, such as a hospital, after an earthquake, relies heavily on proper functioning of its non-structural components such as fire suppression and water distribution systems, elevators and critical medical equipment. In recent earthquakes hospital piping systems suffered significant damage, which resulted in significant reduction of the functionality of the facilities.

A typical hospital piping distribution system is a geometrically complex network including several straight or angled pipe connections, connections of pipes to rigid elements such as water heaters, heat exchangers, pumps and sprinkler heads as well as several pipe floor crossings. The network consists of vertical piping systems running across hospital floors and horizontal systems, which run primarily in the plane of a floor. The pipes are suspended by the frame of the structure. Due to the complexity of these systems there are many unknown aspects of their behavior during an earthquake and many coupled parameters that control their response. Furthermore, the effectiveness of proposed retrofitting methodologies such as bracing is unknown. To answer these questions and improve our understanding on the seismic response of these systems, a series of analytical and experimental studies need to be conducted.

The main objective of the proposed research project will be to conduct a first of a series of shake table experiments of hospital piping sub-systems. The following approach will be followed:

II.A-2.102
- Meet with consultants, OSHPD Engineers and contractors with experience in the area of hospital non-structural systems in order to finalize the geometry of a hospital piping sub-system that has already been identified and designed.
- Design the final shake table experimental set-up.
- Perform a finite element analysis of the experimental set up in order to obtain preliminary analytical response and failure data and finalize instrumentation and selection of input motion.
- Construct the specimen including a rigid frame from which the pipes of the system will be suspended. The specimen will include actual field plumbing details around elements such as valves, water heaters and heat exchangers. The pipes will contain water under pressure.
- Perform the experiments without using any bracing. The specimen will be subjected to incrementally increasing excitation levels until significant damage, water leakage or failure are observed.
- Repeat the experiments with a bracing system.
- Perform an initial analysis of the data and obtain capacity information and evaluate the effectiveness of pipe bracing on the seismic response of the tested piping systems.
- Meet with OSHPD engineers and other researchers, discuss the results and identify needs for further experiments.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

Recent earthquakes exposed the vulnerability of piping systems in California hospitals. The investigation reports by the Office of Statewide Health Planning and Development (OSHPD) reported that most damage to California hospitals was due to failure of nonstructural components. In fact, the Earthquake Engineering Research Institute (EERI) reported the availability of 1750 beds in intensive care units in Los Angeles County before the 1994 Northridge earthquake. However, after the earthquake only about 200 of these beds were available. Most of this significant loss was due to failure of mechanical systems such as pipe networks and connections. This unforeseen nonstructural damage limited the serviceability of several hospitals in the LA County.

Experimental testing of mechanical systems has been limited to component testing of pipes. These component tests were conducted on small-scale pipes and few connection details. Recent earthquake such as the Northridge earthquake showed that the seismic response of piping systems is complex since there is an interaction between the structural frame response, the pipes and the type of bracing details. Component testing cannot capture this interaction. No results from experiment of piping distribution systems have been reported at this time.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

This is a relatively new task and, therefore, there are no significant accomplishments at this point. In year five, in consultation with OSPD engineers and consultants, a piping sub-system
was identified. After several iterations the experimental specimen representing the system has been designed. A design of the experimental set up including a rigid frame from which the pipes will be suspended is in progress. Brace manufacturers have been contacted to design the bracing system. Contractors have been contacted for the construction of all the components of the experimental set up when it is finalized.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

Since no other shake-table tests of piping distribution systems have taken place in the past, the proposed first of a series of tests is a fundamental research experiment contributing to the basic understanding of the seismic behavior of these complex systems. They will also allow the assessment of the effectiveness of seismic strengthening methods, such as bracing or other techniques that will be tested in up-coming years. This assessment is necessary for the implementation of these loss-reduction technologies. Furthermore, the results of the proposed experiments will be used for the calibration and validation of analytical tools aiming at the development of fragility information of hospital piping distribution systems. This fragility information is necessary for the assessment of the seismic risk and the development of seismic strengthening methodologies of a critical facility such as a hospital.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The experimental results will be used for the calibration of analytical fragility models that will be developed by researchers working on the analysis of hospital piping systems. The project will also contribute to the Task on the Networking Experimental Facilities.

**Possible Technical Challenges:**

1. Fabricate the piping specimen including realistic plumbing details. Most of the fabrication will take place in on-site the UNR Large-Scale Structures Laboratory.
2. Develop shake table motions that can represent realistically the pipe excitation from the structural frame of the building.
3. Suspension of the piping system from the frame and installation of bracing.
4. Modeling the system before the experiment in a simple manner with the expectation to identify the areas where damage is expected and develop an effective instrumentation plan.
5. Definition/identification of failure (other than water leakage)

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

<table>
<thead>
<tr>
<th>Potential end-users beyond academic community: <em>(IAB members and others.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Final design of a hospital piping sub-system.</td>
</tr>
<tr>
<td>Development of an experimental protocol for</td>
</tr>
</tbody>
</table>
the shake table test of a piping system.

- Information on the dynamic response of hospital piping sub-systems.
- Information on the effectiveness of bracing on the seismic response of piping systems.
- MCEER researchers working on development of fragility curves – other researchers, consultants and state engineer working on hospital piping systems
- Researchers, consultants and state engineers

**Educational outcomes and deliverables, and intended audience:**

Contribution to the general educational goals of the overall Thrust Area 2.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

**Task 1:** Finalize the design of the shake table experiment for the piping sub-system, which includes a hot water heater tank, a heat exchanger and pumps. In such an experiment the pipes will contain water under pressure. The test set-up will include a rigid frame from which the pipes will be suspended and braced simulating the actual as-built conditions (Fall 2002).

**Task 2:** Analyze the designed piping system (specimen) and identify necessary modifications (Winter 2002/2003).

**Task 3:** Meet with consultants and OSHPD engineers to discuss the design and analysis of the experiment and implement necessary modifications (Winter 2002/2003).

**Task 4:** Fabricate the specimen after contacting several manufacturers who could donate materials such as pipes, couplers, bracings etc. (Winter/Spring 2003)

**Task 5:** Perform the shake table tests of the sub-system identified in tasks1-4 (Spring 2003).

**Task 6:** Perform a fundamental analysis of the results and discuss them with other researchers of Thrust Area 2, consultants and OSHPD engineers (Spring /Summer2003).

**Task 7:** Identify critical components that will have to be individually tested in subsequent years (Summer 2003).

**Task 8:** Work with consultants and OSHPD engineers to design future sub-system and a large system hospital piping experiments by using the multi-table facility at the University of Nevada, Reno (Summer/Fall 2003).
<table>
<thead>
<tr>
<th>Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The project will be under the leadership of Dr. Manos Maragakis, professor of Civil Engineering at the University of Nevada, Reno. Dr. Ahmad Itani, an Associate Professor of Civil Engineering, will be a co-principal investigator. A graduate student (preferably pursuing a Ph.D.) will be hired on the project.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Possible Direction of Work in Subsequent Years:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Testing critical component details of hospital piping systems in coordination with the needs of other researchers in Thrust Area 2 as needed for the fragility analysis.</td>
</tr>
<tr>
<td>2. Design and conduct experiments of more critical piping sub-systems.</td>
</tr>
<tr>
<td>3. Design and conduct experiments of a large hospital piping system, by using the multi-table facility at the University of Nevada, Reno. Such an experiment, as well as and the experiments of the sub-systems can be used for the evaluation of the effectiveness of seismic bracing and other technologies can be used to improve the seismic performance of hospital piping systems.</td>
</tr>
</tbody>
</table>
## MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Advanced Technologies and Data for Validation of Integration Methodologies: Developing Acute Care Hospital Decision Parameters into Integrated Methodologies

**Investigator:** William J. Petak*
**Institution:** University of Southern California

**Investigator:** Daniel J. Alesch
**Institution:** Professor Emeritus, University of Wisconsin-Green Bay

*indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

We propose to conceptualize a hospital decision-making model, based on the California experience and our work during Years 4 and 5. We would focus on hospital decision-making for capital investments in seismic safety. We will work collaboratively with MCEER engineering investigators to provide them with organizational decision rules to learn if the two bodies of knowledge (engineering and organizational decision making) can be bridged by incorporating other decision-making rules into their models. If successful in creating a working model, we will contribute significantly to an integration of the disciplines and more resilient communities because we will have available, for engineers and other seismic safety advocates, a practical tool for facilitating the development of seismic safety proposals that meet the standards of engineers and regulators and the needs of owners. The goal, during Year 6, is to complete a proof-of-concept test.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

Hospital decision makers and engineers use different decision rules to evaluate proposed investments in seismic safety. Like most other business executives, hospital decision makers ask a different set of questions. Unlike the engineer, they cannot evaluate structural investment choices with respect only to enhanced seismic safety. They have to trade off among many interests competing for limited resources. Our interviews with hospital executives indicate that they trade seismic safety off against other investments that would yield a more likely, more immediate, and higher return and that decisions would positively affect the organization’s operating gain or loss, attainment of its service mission, and success in their chosen market niche or area.

We have developed what we think is a good understanding of the decision criteria and processes used by hospital policy makers in California concerning investments in enhanced seismic safety. Relatively high standards for new construction and for retrofit of existing structures have been imposed there by legislation. We do not yet have conceptual models for hospital decision-making in states with relatively low seismic standards for buildings.
MCEER investigators have been developing greater understanding of how to improve structural performance. At the same time, other MCEER investigators have made headway on decision making with respect to seismic safety, but the two bodies of knowledge have not been linked operationally. For MCEER to succeed in its mission, it will be necessary to bridge the two bodies of knowledge, creating connections and networks so they can be used together to improve implementation of improved seismic design. That way, design professionals can incorporate better understanding of owners’ decision-making process and incorporate decision-related parameters into their design proposals. The proposed effort is focused on creating the bridges, connections, and networks.

During Year 6, we will:

1) Develop a conceptual model, based on our California research, of decision making processes and criteria for hospital policy makers concerning capital investment in enhancing seismic safety under several fundamental sets of circumstances, such as ownership and mission, organizational financial condition, prevailing seismic regulations in the state or locality, organizational culture, and activities of peer organizations and competitors;
2) Work collaboratively with other MCEER investigators to learn how best to integrate the organizational models into building bridges, connections, and networks with MCEER’s engineering and geotechnical design professionals;
3) Provide the conceptual model and appropriate related information to investigators so they can devise means for performing proof of concept testing using elements from the conceptual model.
4) Prepare a written report documenting the empirically-based conceptual models

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Thus far, the investigators have completed an extensive literature review of obstacles to enhanced seismic safety and published it as an MCEER working paper. During Year 4, a case study of California’s SB 1953 was completed. It included a focus on both the development of the policy and on responses to the regulations associated with the legislation by various hospital organizations. They completed, in each year, all the tasks funded for that period.

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

MCEER is working to develop means to reduce seismic risk by increasing community resiliency, thus enhancing seismic safety nationally. Designing new buildings and retrofit strategies is necessary, but not sufficient to meet the objective. Those designs must be acceptable to the organizational decision makers who will have to implement and pay for the improved safety. Nor is it sufficient to induce legislative bodies to adopt higher standards; the standards must be consistent with the contextual factors constraining decision-making. The costs of enhanced safety, both for new and for retrofit buildings cannot exceed willingness or
ability to pay. If the costs significantly exceed what a critical mass of owners and operators view as acceptable, the affected parties will launch political efforts to lower or defer the standards. If the political efforts are ineffective, then the availability of buildings in the regulated community will decline. The MCEER challenge is to develop approaches for developing and evaluating new construction and retrofit designs that meet both the standards of engineering and design professionals, the objectives of public officials for public safety, and the needs of the organizations that own and operate the buildings.

Today, the match between the design and the organization’s needs, when there is no legislative mandate for seismic retrofit, is usually accomplished iteratively on a limited number of design alternatives. Discussions are held between the client and the design team concerning alternative approaches for achieving an acceptable level of safety at an acceptable cost. The design team works with the organization to learn the constraints it places on the new design or the retrofit. The designer then designs to the envelope of engineering and organizational requirements.

A different approach to devising a solution is to create a model to help structure a procedure and process for evaluating many alternative design concepts to learn which of those designs fall within the “envelope” that meets the needs of the organization, reduces the risk of the losses from potential seismic events, meets the standards of the engineering and design professions, and satisfies the public interest. If such a model can be devised, then engineers can explore and evaluate the relative effectiveness of a wide range of design concepts or alternatives that fit the decision envelope. And, those evaluations can be conducted at relatively low cost. This approach affords the opportunity to devise and test more alternative approaches to the problem than does the current approach and, at the same time, is particularly amenable to performance-based seismic design.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

This task supports efforts by seismic design professionals and others in the MCEER research community to develop computer-supported models for devising and testing alternative designs for enhancing seismic safety in new and existing buildings. The proposed effort is intended to help build a linkage between engineering and behavioral decision making models. The efforts are intended to help modelers test the efficacy of models that incorporate both decision-making and technical criteria in designs to improve seismic safety.

Possible Technical Challenges:
Based on our research, we believe that hospital decision makers appear to employ slightly different criteria in their choices about investments in seismic decision-making depending on the hospital corporation’s circumstances. Our challenge will be to conceptualize a model that accounts for variations in hospital circumstances and that can be incorporated into relatively simple algorithms for incorporation into computer-driven models. We are confident in our ability to overcome the challenge at least at the conceptual level. Operationalizing the model will be more challenging.
### Anticipated Outcomes and deliverables:
*(Also indicate those of particular benefit to IAB members and other end users.)*

1. Conceptual model of hospital decision-making concerning investments in structural enhancements to seismic safety, as applied to California.
2. Operationalized decision rules for application in test of concept models to bridge behavioral and technical considerations in seismic design.
3. A completed report on the conceptual model.

### Potential end-users beyond academic community: *(IAB members and others.)*

Should the proof of concept model provide the basis for one or more working models, we expect to contribute to a model that structural engineers can employ to help create designs that are more robust in terms of their acceptability to clients. Second, we expect the model to be useful to regulatory bodies in their development of seismic policies and regulations.

### Educational outcomes and deliverables, and intended audience:

### Project Schedule and Expected Milestones for the Project: *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

1. **1st Quarter:** Work with MCEER investigators to specify model requirements and appropriate algorithms.
2. **2nd Quarter:** Conceptualize basic decision-making model for California Hospital policy makers.
3. **3rd Quarter:** Work with MCEER investigators to provide information on proof of concept tests.
4. **4th Quarter:** Complete technical report on conceptual models.

### Team Members: *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

Professors William J. Petak (Project Leader) and Daniel J. Alesch. At this time, we do not expect that a student will be supported by grant funds.

### Possible Direction of Work in Subsequent Years:

If the Year 6 tests prove instructive and encouraging, then Year 7 would be devoted to expanding, improving, and making our decision making model more robust and more generally applicable. We would propose to develop hospital case studies in places such as the Seattle, Memphis, and New York areas. Such studies would be essential to develop the necessary understanding for a generally applicable model or models. California is a special case because of the frequency of seismic activity and extensive state regulation concerning seismic safety. It is important to understand organizational decision making about seismic safety in states without such regulations and in areas that experience fewer seismic events, but that still have significant seismic hazards. We believe this to be particularly important, given the growing concern with seismic effects outside California.

II.A-2.110
<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.2.10</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
<th>Project Number:</th>
</tr>
</thead>
</table>

**Task Title:**  
“Integrated Approaches for Decision Support-Fragility Based Methodology”

**Investigator/**  
Institution: Mircea Grigoriu/Cornell University

* indicates task leader

**Statement of Project Goals:**  
*(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

A main objective of the project is the development of a methodology for evaluating the seismic performance of individual health care facilities. The methodology will be applied to a demonstration project and will be extended in the future to assess the seismic performance of the collection of health care facilities serving a community. The proposed research contributes in an essential way to the overall MCEER goal of enhancing the seismic resilience of communities.

**Problem Description and Research Approach of Proposed Work for Year 6:**  
*(Detailed description of research to be conducted and methodology to be used.)*

It is proposed to develop a methodology for assessing the seismic performance of a health care facility during a specified time interval. The methodology will also include a preliminary life cycle cost-benefit analysis for an existing facility under several retrofitting strategies. The proposed work will:

- Develop a life cycle seismic hazard scenario. Each scenario gives the earthquake arrival times during the projected life of a facility and the ground acceleration history for these earthquakes. Both the number of earthquakes and their time histories are random.
- Develop a methodology for the fragility analysis for both structural and non-structural systems. Fragility surfaces depending on the earthquake magnitude and seismic source to site distance, rather than fragility curves depending on PGA or similar parameters, will be developed.
- Develop a methodology for evaluating system performance based on a preliminary cost-benefit analysis. Histograms will be used to assess the variability of losses calculated under various design/retrofitting strategies and life cycle seismic hazard scenarios. The histograms can be used to identify optimal actions under cost constraints.
**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

Current seismic performance studies are based on fragility curves and, for example, the maximum Peak Ground Acceleration at a site over a 50 year period.

We believe that fragility surfaces provide a more accurate measure for the seismic performance of structural and non-structural systems than fragility curves. Also, the use of maximum earthquake in the lifetime of a system may be adequate for safety but provides limited information if the objective is the improvement of earthquake resilience under cost constraints.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

Preliminary results have been obtained on

- The generation of life cycle seismic hazard scenarios and
- The development of fragility surfaces

Previous work focus was on the development of sensitivity equations (Dr. C. Roth). These developments are expected to be used in the selection of an optimal strategy for seismic rehabilitation of structural / non-structural systems.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The proposed task is essential for the MCEER objective of enhancing earthquake resilience of communities. A main objective of the task is the reduction of the probability of failure for health care facilities during seismic events, where failure means that the facility cannot fulfill its function following an earthquake. Also, the research is most relevant to advanced technologies (e.g., it can be used to find optimal locations for dampers and other devices in structural systems), provides the framework for assessing potential economic and other losses, and is useful for the development of rational recovery strategies.
Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The interaction with other tasks funded by MCEER is expected to be significant. For example,

- The generation of the life cycle seismic hazard scenarios uses a probabilistic model developed by Papageorgiou which delivers the spectral density of the ground acceleration process at the site. Also, the generation accounts for soil conditions to be obtained from the experts in geotechnical engineering.

- The preliminary cost-benefit analysis will be performed in direct communication with experts in economics. We will interact with Detlof von Winterfeldt in this task.

- The definition of fragility surfaces will use limit states based on suggestions from social scientists.

Possible Technical Challenges:

- The incorporation of soil conditions in analysis via soil fragility surfaces or soil-structure interaction because of the significant uncertainty in and the limited information on soil properties.

- The development of efficient algorithms for developing fragility surfaces and assessing seismic performance.

- The selection of representative structural and non-structural systems for demonstrating the methodology.

- The derivation of simple measures that can be used in practice to quantify the seismic resilience.

Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)

- Methodology for generating life cycle seismic hazard scenarios.

- Methodology for calculating fragility surfaces for specified systems and limit states.

Potential end-users beyond academic community: (IAB members and others.)

- Algorithm for generating life cycle seismic hazard scenarios.

- Demonstration project.

- Retrofitting strategies for health care facilities.
Educational outcomes and deliverables, and intended audience:

- An algorithm for generating life cycle seismic hazard scenarios will be made available for the users network of MCEER

- Preliminary results are currently used in my courses on Earthquake Engineering (CEE 779) at Cornell

**Project Schedule and Expected Milestones for the Project:** (*Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.*)

- Fall: Methodology for generating life cycle seismic hazard scenarios.

- Spring: Methodology for generating fragility surfaces for specified systems and limit states.

- Summer: Preliminary cost-benefit analysis

**Team Members:** (*If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.*)

Ehab Mostafa, Ph.D. student

Cagdas Kafali, Ph.D. student (Not funded at present but will be supported if the task is funded.)

**Possible Direction of Work in Subsequent Years:**

- Apply the proposed methodology to a demonstration project using realistic soil-structure, non-structural, and economical models.

- Extend the proposed methodology to a collection of health care facilities serving a community. The extension will allow to find, for example, the probability that 80% of this collection of health care facilities operates at 90% capacity within 5 days. This extension is essential for achieving a major MCEER goal of earthquake resilient communities, and will involve extensive interaction with virtually all research groups at MCEER.
MCEER RESEARCH TASK STATEMENT

Task No.  6.2.11   Project Number:  

Budget:  
Yr 6 Assigned  

Task Title:  Evolutionary Methodologies for Decision Support  

Investigator/  
Institution:  G.F. Dargush, University at Buffalo  

Statement of Project Goals:  (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)  

The primary objective is to develop new approaches and related software, based upon an evolutionary methodology, for decision support toward earthquake resilient communities. Previous work focused on developing an automated approach for evolutionary aseismic design and retrofit (EADR) of passively damped structural systems within an uncertain environment. Year 6 effort will continue with the development of an interactive parallel version of the software, along with the inclusion of dissipative panels and semi-active elements. New collaborative work will also be initiated to develop evolutionary methods for more general socioeconomic decision support with an initial focus on a water supply system.  

Problem Description and Research Approach of Proposed Work for Year 6:  (Detailed description of research to be conducted and methodology to be used.)  

Over the past two years, MCEER has supported the development of an evolutionary optimization approach for the aseismic design and retrofit of passively damped structures. Significant progress has been made and the current automated version is quite promising. Consequently, a proposed Year 6 Networking Subtask is directed toward the release of an initial beta-version of the software (eadr_1.0) for use by MCEER researchers and industry partners. This will include development of a graphical user interface (GUI) within a geographical information system (GIS) to display evolving structures, along with associated ground motions and the resulting performance.  

In order to more fully realize the potential benefits, there is also a need to accommodate more realistic two and three-dimensional structural models, to incorporate additional types of structural control elements and to utilize a pre-selected initial population. The first issue will be addressed by developing a parallel version of the evolutionary algorithm and software for use within the UB CCR facilities. The proposed new element types will involve the development of macro-models for ECC dissipating panels and semi-active dampers.  

With these additions, one can envision a very powerful design tool. What are the limitations of such an artificial system? Given sufficient computing cycles, will it be capable of innovation? Can an experienced design engineer enhance or accelerate the evolution of robust structures? Can a software tool help inexperienced design engineers develop structural intuition? In order to
address these issues, we propose the development of an interactive design system formed by combining the GUI and the parallel version of the evolutionary algorithm. With this approach, the design engineer can help guide the evolutionary process by interactively modifying the population of candidate structures. Good suggestions from the design engineer will then be propagated through the evolving population, while poor suggestions will become extinct. An initial version of this approach will be developed during Year 6, utilizing simple structural models in order to achieve the feedback necessary for effective interaction.

Evolutionary algorithms are applicable to a wide range of difficult optimization problems. As a final subtask, we propose to investigate the application of this approach for more general socioeconomic decision support by working closely with Professors Alesch and Petak to formulate and solve a particular example. Initial discussion suggests that the investigation of a water supply system may provide a good starting point.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

Our research conducted over the past two years and that proposed for the next several years, attempts to make contributions at an applied level within the field of earthquake engineering and at a basic level within the disciplines of complex adaptive systems (CAS) and evolutionary algorithms. Evolutionary methods, in general, and genetic algorithms, in particular, have been employed in many fields over the last few decades, beginning with the pioneering work by Holland (1975). The books by Holland (1992), Goldberg (1989) and Mitchell (1996) provide good overviews of the subject. Applications of genetic algorithms (GA) within earthquake engineering have recently appeared, including the work by Singh and Moreschi (1999, 2000, 2001) and Li et al. (2001). Our research differs from those above by including multiple damper types, along with nonlinear structural and passive damper models. More fundamentally, our work also differs by addressing the inherent uncertainty of the seismic environment, by introducing new knowledge-based algorithms and by proposing the concept of interactive evolutionary design. Furthermore, in a practical sense, the MCEER work will produce software that can be used by researchers and industry partners to promote the development of earthquake resilient communities.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

In previous years, MCEER support led to the development of continuum level models for a number of control devices including a viscoelastic (VE) damper, a metallic plate damper, and an E-damper component for seismic isolation systems. Each case involved development of appropriate constitutive models. For example, a temperature and frequency dependent model was developed for VE materials and correlated with experimental data, and a two-surface plasticity model was developed for cyclic response of structural steel. Both were implemented as subroutines within the general-purpose finite element code ABAQUS. During this past year, macro-models were also developed for each device to enable efficient overall structural analysis.
Furthermore, the framework for Evolutionary Aseismic Design and Retrofit (EADR) was established and successfully applied to a series of multistory steel moment frame retrofit examples, incorporating metallic, viscous and viscoelastic dampers. The current version runs on a single processor in a sequential mode utilizing a genetic algorithm for discrete optimization under uncertain ground motion time histories. Each structural evaluation is performed via a nonlinear transient dynamic analysis utilizing the above-mentioned models. At present, EADR may utilize either ABAQUS or an in-house state-space explicit transient dynamic code. During the past year, effort was directed toward enhancing the functionality, robustness and efficiency of this evolutionary approach. In particular, a knowledge base is now generated to accumulate information and automatically adapt the environment during the evolutionary process. The result is an efficient algorithm with practical applicability for aseismic design and retrofit, and a methodology appropriate for application to more general problems of decision support.

**Role of Proposed Task in Support of Strategic Plan:** (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The development of evolutionary methods and software for decision support contributes directly to the central theme of the MCEER strategic plan. These methods have the potential to assist in the development of earthquake resilient communities.

**Task Integration:** (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

In Year 6, the proposed research activities defined above will interface with several other ongoing projects by MCEER-funded researchers. The ECC dissipating panel macro-model development and subsequent evolutionary optimization will be conducted in conjunction with Professor Billington. Work on the definition of advantageous initial populations will be performed jointly with Professor Reinhorn. The extension of the evolutionary algorithms for more general socioeconomic decision support will require close cooperation with Professors Alesch and Petak.

**Possible Technical Challenges:**

In general, the primary technical challenge in the development of these evolutionary methods will be to maintain robustness and computational efficiency. The introduction of a knowledge base in Year 5 to accumulate information and to adapt the environment improved the situation considerably, however additional enhancements and the establishment of a firm theoretical base would still be beneficial.

The application of the evolutionary methods to socioeconomic problems of decision support will no doubt provide many challenges related to problem definition, parameter estimates and algorithm control.

Another significant challenge remains concerning the reduction of the computational complexity for nonlinear transient dynamic structural analysis. However, this will not be confronted during Year 6, but will instead be proposed as a Year 7 Subtask.
<table>
<thead>
<tr>
<th><strong>Anticipated Outcomes and deliverables:</strong> (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th><strong>Potential end-users beyond academic community:</strong> (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evolutionary Aseismic Design and Retrofit software. An initial beta-version will be made available on the MCEER Networking Website for MCEER researchers and IAB members. Interactive parallel version of the software will be developed on the UB CCR computing platform. An initial formulation for the socioeconomic optimization of a water supply system. Conference and journal papers documenting progress.</td>
<td>IAB members and other practicing engineers interested in the design and retrofit of structures with protective systems. Ultimately, assuming the extension to socioeconomic problems is successful, all those interested in developing earthquake resilient communities.</td>
</tr>
</tbody>
</table>

**Educational outcomes and deliverables, and intended audience:**

A significant portion of our previous MCEER research has found its way into the graduate level courses taught by the PI. In particular, the course on Advanced Finite Element Analysis contains a significant seismic component. That course is also available to distance learners via the UB EngiNet program.

Two doctoral students (Q. Yu and R. Sant) will have completed their degrees during Year 5. The former student was supported throughout by MCEER, while the latter received partial support. During Year 6, we propose to provide full support for two additional doctoral students and partial support for one post-doctoral researcher.

The software developed under MCEER support will be made available through the MCEER Networking Website. Naturally, this software can be used for educational purposes, as well as for research and development. The interactive version, in particular, could provide a very effective education tool for both graduate students and practicing engineers.

**Project Schedule and Expected Milestones for the Project:** (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

The four Subtasks discussed above will be developed concurrently. The goal is to release the beta version of the software (eadr_1.0), along with the necessary documentation by Spring 2003. The remaining tasks involving the development of new device macro-models, the interactive parallel version of the software and the initial socioeconomic formulation will not be completed until the end of Summer 2003.
**Team Members:**  *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

Gary F. Dargush, Associate Professor; Mark L. Green, Research Assistant Professor; Ali R. Hadjesfandiari, Postdoctoral Associate; Yunli Wang, Ph.D. Candidate; One additional first year doctoral student

**Possible Direction of Work in Subsequent Years:**

The development of these new evolutionary methods for decision support is clearly a multiyear research program. Work in subsequent years will continue toward the development of the interactive evolutionary design concept and on the extension to other socioeconomic decision support functions. Additional applications of the evolutionary algorithms in crisis decision-making and recovery management may be appropriate.

One of the key issues in evolutionary structural design concerns the computational requirements associated with nonlinear transient dynamic analysis. Consequently, we will propose the development of new multiscale methods to dramatically reduce the computational complexity of those required analyses.
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.2.12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget:</td>
<td>Yr 6 Assigned</td>
</tr>
<tr>
<td>Project Number:</td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Rehabilitation Decision Analysis

**Investigator/Institution:** Detlof von Winterfeldt/University of Southern California

*indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

To develop and implement a decision analysis framework for evaluating rehabilitation strategies and to apply this framework to a major rehabilitation decision of a hospital. This framework will further operationalize the concept of resilience and apply it in the hospital context to improve decision-making.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

During the previous years a decision analysis framework was developed to evaluate seismic rehabilitation decisions. This framework consists of a combined decision tree/simulation approach. It has a seismic component (risk analysis of shaking intensities at a given location), an engineering component (fragility curves for a given structure), and a socioeconomic component (a multi-objective evaluation of various resilience measures and costs). The model has been applied to hillside homes and to apartment buildings with tuckunder parking structures. These applications have shown, among other things, the importance of the financial model for rehabilitation costs.

In year 5, we started to apply this framework to a hospital rehabilitation problem and we began by examining a specific rehabilitation problem that Degenkolb Engineers had worked on for a Kaiser hospital in Northern California. However, the NSF review and the subsequent activities to respond to it used up most of our remaining time in year 5. On the positive side, we believe to have contributed significantly to define and operationalize “resilience” as a key guiding concept of the MCEER program. The year 6 effort of this task will benefit from this effort in that we can focus our attention on better defining resilience in the hospital context.

In the remainder of year 5 and in year 6 we will focus on the hospital application. We will develop resilience measures for hospitals as part of the socio-economic model and we will apply the decision analysis framework to a specific hospital rehabilitation decision.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The Cornell team under the leadership of Mircea Grigoriu is developing a similar decision analysis approach, primarily based on simulation. We have and will continue to coordinate with
the Cornell team and hope to eventually create a joint MCEER framework.

There have been some efforts in the past to apply decision analysis to earthquake problems, but we believe that the efforts currently developed at MCEER (Dargush, Giorgiu, our project) are truly state-of-the-art.

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

In the past year we did four things:

1. Completed the decision tree model for the apartment building application (paper submitted to Natural Hazards Review)
2. Developed a simulation model for the decision analysis and applied it to the apartment building application (model and analysis completed, paper in preparation)
3. Collaborated with Jay Love of Degenkolb to initiate the hospital application
4. Most of all, worked on the task force to respond to the NSF review

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

1. This task will be one of the first to use and implement the MCEER resilience concept and definitions in a concrete decision making context.
2. We will develop operational resilience measures for hospitals as part of this project.
3. We will help integrate seismic, engineering, and socio-economic models in a specific decision making context.
4. We hope to make contributions to helping real decision makers in hospitals and to link both industry, engineering consulting firms, and MCEER teams by doing so.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This task contributes primarily to the integration of the engineering and social science tasks in Thrust Area 2. By focusing on a major hospital rehabilitation decision, this task will require collaboration from seismologists, engineers, and social scientists. The decision focus and the focus on a specific hospital rehabilitation problem will serve to integrate disciplines. In particular, we expect to work closely with the Cornell group and Degenkolb Engineers.

**Possible Technical Challenges:**

A major challenge is to define and operationalize the concept of resilience in the hospital setting. This will be the key element on developing our socio-economic model. Another challenge is to integrate seismic, engineering, and social science. We now have a fairly good seismic model, but we think that it can be improved by using the Cornell team’s methodology of using time
series of earthquake events. Also, so far we have worked with fairly straightforward engineering issues (fragilities of hillside homes and apartment buildings). This will be much more complex in the hospital setting. Finally, after the two previous applications of the decision analysis framework (to hillside homes and apartment buildings), we now realize the importance of the financial model for evaluating rehabilitation decisions. This will be an especially important challenge in the hospital context, since the financial models will differ significantly between non-profits, public, and private hospitals.

### Anticipated Outcomes and deliverables:

(Also indicate those of particular benefit to IAB members and other end users.)

1. Resilience measures for hospitals
2. Prototype analysis for a specific hospital rehabilitation problem

### Potential end-users beyond academic community: (IAB members and others.)

1. Hospital administrators and decision makers
2. Planning agencies concerned with seismic risks (e.g., OSHPD)
3. Engineering firms analyzing and evaluating rehabilitation alternatives

### Educational outcomes and deliverables, and intended audience:

The decision analysis framework, the software associated with it, and the application to hospital rehabilitation decisions will provide many insights in the concept of resilience, in structuring hospital rehabilitation decisions, and it can serve as a prototype for engineers and hospital administrators to analyze their own rehabilitation decisions.

### Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

1. Fall, 2002: Complete framing of the hospital rehabilitation problem (location, risks, resilience measures, etc.)
2. Spring, 2003: Complete prototype decision analysis for the hospital problem

### Team Members:  (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

1. Mark Benthien, Research Assistant, Master of Public Administration student
2. TBD, Research Assistant, Ph.D. in Planning student

### Possible Direction of Work in Subsequent Years:

1. Further develop the resilience concept as a cross-cutting concept across the three MCEER programs.
2. Develop additional decision support tools for earthquake rehabilitation
3. Facilitate integration across MCEER teams by providing a decision focus.
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>6.2.13</th>
<th>Task Title:</th>
<th>NYS Hospitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget:</td>
<td></td>
<td>Investigators</td>
<td>George C. Lee and Mai Tong</td>
</tr>
<tr>
<td>Yr 6 Assigned</td>
<td></td>
<td>Institution:</td>
<td>University at Buffalo</td>
</tr>
</tbody>
</table>

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The goal of this research task is to develop a measurement and evaluation platform of seismic resiliency of hospital, and to provide general procedures for the owners to assess the seismic risk of structure and non-structural systems and to consider possible retrofit approaches that are economically justifiable for areas of low to medium seismic hazard but high damage risks.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

This research task deals with urban regions of low to medium seismic hazard but high damage consequences, where little or no seismic design requirements for most of the hospital structures exist. This is typical in many metropolitan areas in the central and eastern US. NYS has recently adopted IBC 2000. Hospitals now need to pay some attention to seismic resistance of buildings and critical non-structural components. The purpose of this research task is to provide information for NYS hospitals to assess their seismic risks and to make informed decisions on retrofitting.

We will be working with two or more NYS hospitals.

1. Obtain information and necessary data of the physical systems (buildings, lifelines, equipment, etc.) as well as their operations (some information already obtained during last two years).

2. Establish FE models to examine the seismic safety of the building structures based on current code requirements and the dynamic responses of the structures (some of them already accomplished during the last two years).

3. Establish measurement requirements for seismic resiliency of hospitals, and develop evaluation platform and procedures to assess the seismic risks of selected lifeline systems (water and electric power). Determine quantitative basis for evaluation of benefits of seismic retrofit for the lifeline systems.

4. Establish integrated sample study cases of evaluations for typical NYS hospitals.
Assessment of State-of-the-Art:  (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The major thrust of the MCEER hospital project is related to development of advanced technologies for retrofit through the Northridge hospital as the test bed. This task is concerned with the development of a system evaluation model for non-structural components based on a patient in – patient out model of hospital medical functions. At present only the water supply system and the electric power system in the hospital are considered, based on information of two NYS hospitals. In the future (2-3 years), this task should merge with the studies of the Northridge hospital.

Progress to date:  (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Progress made since April 1, 2001 includes the cooperative agreement with the Bassett Hospital (near Albany, NY) and the collection of data for the hospital building and the development of a FE computer model for the hospital building.

Role of Proposed Task in Support of Strategic Plan:  (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

To realize the vision of MCEER, the earthquake resiliency of a community should have measurable increase. This can be determined by the relative loss of medical services or functions after a destructive earthquake as compared to the reduced loss of medical function if the physical systems are retrofitted. In low to medium seismic hazard and high damage risk regions, the decision to retrofit is a very complex issue. This task is focused on developing quantitative measures for hospital owners to make informed decision on whether or not to retrofit. (For the tasks related to the Northridge hospital, retrofitting is required by law.) This task is thus complementary to the tasks for the Northridge hospital. When combined, they provide a more comprehensive approach to develop earthquake resilient communities.

Task Integration:  (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

The natural extension of this task (concerning evaluation of selected lifeline systems in NYS hospitals) is to develop medical capacities in an urban region after a destructive earthquake. This would involve transportation network analysis for moving patients. It is more realistic for low to medium hazard but high damage risk regions. In the future, regional lifeline systems (research thrust area 1) will be linked to the regional medical services.

Possible Technical Challenges:

The immediate challenges are to develop cooperative working relationships with NYS hospitals, because they do not consider earthquake mitigation and preparedness as high priority action items for their limited budget. As a result, the collection of related data and information is not an easy task. So far, we have developed working relationships with three NYS hospitals.
**Anticipated Outcomes and deliverables:**
(Also indicate those of particular benefit to IAB members and other end users.)

In the long run (4-5 years) we expect to prepare general procedures for evaluation of seismic risk of structures and related lifeline systems in NYS hospitals, and to produce guidelines for NYS to consider seismic and multi hazard retrofitting of the structural and critical nonstructural components based on IBC 2000 requirements.

**Potential end-users beyond academic community:**
(IAB members and others.)

Hospital administrators and facilities managers.
State health care officials.

<table>
<thead>
<tr>
<th><strong>Educational outcomes and deliverables, and intended audience:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Graduate and post-doctoral student training</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Project Schedule and Expected Milestones for the Project:</strong> (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2002, complete data collection for two hospitals (ECMC and Bassett hospital) and complete the FE model of the Bassett hospital building (ECMC FE model completed in 2000)</td>
</tr>
<tr>
<td>Summer 2003, complete the development of the lifeline systems evaluation model for a hospital, and to demonstrate this system by assessing seismic risks of the non-structural lifeline systems (water or electric power) and evaluating the benefit of retrofitting.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Team Members:</strong> (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>George C. Lee – PI</td>
</tr>
<tr>
<td>Mai Tong – Co-PI</td>
</tr>
<tr>
<td>Other MCEER Researchers:</td>
</tr>
<tr>
<td>A. Papageorgiou</td>
</tr>
<tr>
<td>M. Shinozuka</td>
</tr>
<tr>
<td>Industry Partners:</td>
</tr>
<tr>
<td>M. Ettouney (Weidlinger Associates.)</td>
</tr>
<tr>
<td>Graduate and postdoctoral students</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Possible Direction of Work in Subsequent Years:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanding this task into a regional basis, so that the water and electric power systems in a region can be evaluated and the regional medical service functions can be assessed under various seismic and other hazard conditions. This effort would consider transportation network for moving patients. Furthermore, this task will be directed to develop integrated measurement of seismic resiliency for hospitals and evaluation procedures/ guidelines for retrofitting of structural system and non-structural components to resist multi-hazards including earthquake ground motion and blast loading conditions.</td>
</tr>
</tbody>
</table>

II.A-2.125
MCEER RESEARCH TASK STATEMENT

Task No. 6.2.14  
Budget:  
Yr 6 Assigned Project Number:  

Task Title:

Emergency care facility performance evaluation using deterministic integration of structural and non-structural component response data.

Demonstration emergency care facility coordinator

Investigator/Institution: Andrew Whittaker, University at Buffalo

Statement of Project Goals:

The following items are the goals of this Year 6 project.

3. Test preliminary strategy of Goal 2 above using WC60 retrofitted by seismic isolation.
4. Development of a database for emergency-care-facility models together with a damage-evaluation system.

A networking subtask that will be submitted separately describes the development of a database and an associated computational tool that will be made available to the Users Network of MCEER.

Problem Description and Research Approach of Proposed Work for Year 6:

Each of the four goals listed above is discussed in turn below.

The vulnerability of non-structural components rather than structural components will often determine whether a hospital or emergency care facility remains operational after moderate-to-severe earthquake shaking. As such, robust characterization of the vulnerability of key non-structural components is needed. The fragility approach will be used for such characterization. The first step in the process is to confirm and prioritize those components whose on-going function is vital in an emergency-care facility: a step that will involve expert MCEER researchers (led by Professor Soong) and engineers at OSHPD in California. Such work will be accomplished in Year 5. Once those components are confirmed and prioritized, fragility data for the key components will be assembled. The datasets of Professor Soong will be studied carefully. (Where data do not exist, selected manufacturers will be contacted to solicit materials and funds for fragility testing.) Data will be collected and synthesized and gaps in the datasets will be identified. Fragility curves will then be prepared and published using a common format for use in this project and by other researchers in Thrust Area 2. This work will be started in Year 5 and completed in Year 6.

A fragility-based framework is one technically viable approach for the performance-based design of new and retrofit construction of emergency care facilities. Such a framework can also be adapted or extended...
for use by those tasked with making financial decisions regarding such facilities. The Investigator and Professor Bruneau mapped out a preliminary framework at the last meeting of the Thrust Area 2 research team at the University at Buffalo. Meetings will be held at the end of the Year 5 effort with selected experts (Professors Bruneau, Constantinou, Grigoriu, and Reinhorn) to further develop the fragility framework. The results of those discussions will provide the springboard for the Year 6 studies, which will seek to bring the framework to the point of trial implementation.

To test the fragility framework noted above, one of the three MCEER demonstration hospitals (WC60) will be retrofitted with seismic isolation hardware. Multiple isolation solutions will be developed. The isolation systems will be designed per the upcoming requirements of the 2003 NEHRP Recommended Provisions (as given by the TS12 committee that Professor Constantinou and the Investigator co-chair) and analyzed using response-history analysis to determine fragility curves.

To maximize the benefit of the work conducted by individual MCEER investigators and to best serve the stated need for program integration, a database of information and knowledge related to emergency-care-facilities and mathematical models (on a variety of platforms) will be established in close consultation with Professor Reinhorn. The database and its evaluation tools will be developed, published, and distributed through the MCEER Users Network. A beta version of the database will be available in late Spring 2003.

**Assessment of State-of-the-Art:**

Much fragility data for non-structural components in emergency care facilities are available but not all of these data have been processed in a common format and not all are readily available for use by the MCEER research team and members of the MCEER IAB. *(The proposed work will collect and process the available data and make plans for collecting new data as needed.)*

Performance-based earthquake engineering (PBEE) of building structures is generally undertaken using documents such as FEMA 273/274/356. These documents make use of discrete performance levels and hazard levels that are married to form performance objectives. Performance levels for structural components are established at the component level rather than the system level and median estimates of the hazard are generally used. Performance levels for non-structural components are somewhat ambiguous and are given for broad classes of components rather than manufacturer specific components. The reliability of a system design that nominally meets the stated performance objective is unknown. *(The proposed work will focus attention on emergency care facilities for which the limit states of response for structural and non-structural components can be accurately defined and develop a system fragility framework around those limits states.)*

**Progress to date:**

Three demonstration hospital structures have been designed and data are now available at the MCEER website. Included in the materials at the web site are (a) an 80-page report describing the analysis and design of the three separate buildings (WC70, WC60, and EC70), (b) the SAP2000NL input files that can be used for the analysis of the three buildings, and (c) drawings of the three buildings in AutoCAD. All of these files can be downloaded.
**Role of Proposed Task in Support of Strategic Plan:**

The proposed task supports the MCEER strategic plan and will operate at the lower two levels of the new MCEER 3-plane chart in Year 6, namely, (1) part of the work will develop valid and applicable scientific knowledge based on fundamental research, and (2) part of the work will integrate fundamental knowledge into testable technologies and tools. The work will provide the springboard in later years for the development of financially oriented decision-making tools that can be used by owners and administrators tasked with making decisions about the requisite resilience of new and retrofit construction of emergency care facilities.

**Task Integration:**

The proposed work serves to integrate work already completed in Thrust Area 2 (Year 5) through the development of both an MCEER database and a fragility-based framework for the performance-based earthquake engineering of hospitals. The proposed work also provides a framework for the acquisition and synthesis of new knowledge on the behavior of structural systems and non-structural components in emergency care facilities.

**Possible Technical Challenges:**

1. Integration of fragility data for structural and non-structural components.
2. Insufficient fragility data on selected non-structural components in emergency care facilities.

**Anticipated Outcomes and Deliverables:**

1. Sample fragility data for non-structural components presented in both written and database formats.
2. Database for emergency care facility information and models.
3. Integrated fragility framework for performance-based earthquake engineering of emergency care facilities.
4. Decision making tools (following further development).

**Potential end-users beyond academic community:**

1. Design professional community and facility administrators for use in performance-based earthquake engineering of hospitals (following further development and deployment in Yrs 7 and 8).

**Educational outcomes and deliverables, and intended audience:**

Information/deliverables to be included in the UB graduate class in earthquake engineering (CIE 619). Intended academic audience is graduate students.

**Project Schedule and Expected Milestones for the Project:**

*Spring 2003:* Initial deployment of database for trial use by MCEER researchers.

*Spring 2003:* Seismic isolation solutions for WC60

*Summer 2003:* Summary report on fragility of selected non-structural components in hospitals.

*Summer 2003:* Fragility data for performance of isolated versions of WC60
**Fall 2003: Summary report on fragility framework for emergency care facilities**

<table>
<thead>
<tr>
<th>Team Members:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The graduate student hired for the Year 5 work will continue in Year 6. Another student will be hired to develop and maintain the database for emergency-care-facility models and a damage evaluation system. Close collaboration with Professors Constantinou (seismic isolation), Grigoriu (fragility strategy), and Reinhorn (fragility strategy) is anticipated.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Possible Direction of Work in Subsequent Years:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work following Year 6 will see on-going development of the fragility framework and the development of tools for decision-making (by administrators etc) using the fragility framework.</td>
</tr>
<tr>
<td>On-going development and maintenance of the database for emergency-care-facility models and damage evaluation system.</td>
</tr>
</tbody>
</table>
Thrust Area 3:

Earthquake Response and Recovery
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Advanced Technologies for Loss Estimation, Development of Damage Functions using Remotely Sensed Data and Real-Time Decision Support Systems

**Investigator:** Ronald T. Eguchi*/ImageCat, Inc.
**Institution:** Bijan Houshmand/Consultant
M. Shinozuka/University of California, Irvine
Apostolos Papageogiou/SUNY

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This task focuses on the development and application of remote sensing technologies for building inventory development, real-time earthquake loss estimation, and post-earthquake damage detection. In addition, a new task - added for the first time this year - focuses on the use of wireless, broadband communication systems in crisis response. Ultimately, these technologies will be adapted for real-time decision support systems. In order to validate the methodologies, we are using data from several recent earthquakes, including the 1994 Northridge, the 1995 Kobe, the 1999 Turkey and 1999 Taiwan earthquakes. A new task under this program is the creation of a catalog of satellite images to be housed on the MCEER website.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

Advanced technologies, such as remote sensing technologies, are beginning to emerge as useful post-earthquake evaluation tools. Recent studies in Japan and in the U.S. have shown that satellite-based imagery can, in fact, identify broad zones of damage after significant earthquakes. In some cases, damage caused by widespread liquefaction and fire-following effects can be determined from low-resolution, remotely sensed data (Kobe earthquake). In the long-term, it is expected that use of remote sensed data would help to facilitate many post-earthquake response decisions and ultimately, improve overall response. This particular task involves the use of advanced technologies in real-time decision support systems. We will investigate the application of these technologies during the immediate response period (first few days after a large earthquake), during the early recovery period (first several weeks following the earthquake) and as part of longer-range mitigation programs. Our approach will be based on studying what methods or procedures are currently being used to make decisions during each of these disaster periods and to identify ways in which these decisions (or the timeframe under which these decisions are made) can be improved through the application of advanced technologies. Special attention will be placed on identifying ways in which remote sensing technologies can be used.
Specific Year 6 assignments by investigator are:

**Eguchi** – Integration of remote sensing damage detection methodologies with near real-time loss estimation tools (HAZUS, EPEDAT), and application of remote sensing damage detection models to 1999 Chi-Chi, Taiwan earthquake, and creation of remote sensing catalog for MCEER networking task. As part of the networking task, ImageCat will be creating a satellite imagery catalog that can be accessed through MCEER’s website. In addition, we will be working with MCEER to negotiate MOUs with satellite data providers.

**Houshmand** – Development of more efficient, wireless broadband communication systems for crisis response.

**Shinozuka** – Adaptation of SAR simulation techniques for calibrating damage detection models; use of SAR imagery to detect damage to underground water pipelines.


---

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The research that MCEER is performing is unique in the U.S. Considerable research on using remote sensing technologies for post-event damage detection is being conducted in Japan by the Earthquake Disaster Mitigation Research Center (EDM) in Miki, Japan. We are working closely with EDM on several recent earthquakes, e.g., 1994 Northridge earthquake, 1994 Kobe Earthquake, 1999 Marmara, Turkey Earthquake, and the 1999 Chi-Chi, Taiwan Earthquake. Current research on SAR interferometry is being performed by a number of geophysical groups in the U.S. and in Europe. This research, however, is focused exclusively on measuring the displacement or strain fields around large magnitude earthquakes where the rupture plane has broken the surface. Current efforts are now being launched by several other federal agencies, including DOT and NASA to develop methodologies to use remotely sensed data for disaster response. These programs are in the “truth of concept” phase. MCEER researchers are actively involved with some of these programs.

**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

In the first five years, we have concentrated on (1) modeling urban areas using synthetic aperture radar technology, (2) exploring the use of other remote sensing technologies – optical imagery, aerial photography – to separate the urban environment from natural surroundings, and (3) developing a framework from which to assess post-earthquake damage using interferometric synthetic aperture radar (IFSAR). Based on airborne SAR data for Los Angeles, we have successfully characterized residential, commercial, and industrial areas using “building height signatures.” Building height signatures are constructed by summing total building footprint areas (as determined through multi-spectral analysis of visible and infrared imagery data) across various story height categories. An analysis of three different areas in Los Angeles indicates that these signatures vary in terms of slope and intercept (i.e., the parameters of a building height signature curve) and maximum story height depending upon type of development. The main use of these models is in the development of total floor area, which, in turn, is used to estimate the
In the last year, we have been working on using IFSAR to detect earthquake damage after major earthquakes. Some work has been completed on the 1999 Marmara, Turkey earthquake. Preliminary findings show that comparisons of “before” and “after” satellite imagery can, in fact, detect significant damage to buildings. The project team has used various change detection indices to describe the extent of these changes, including intensity difference, correlation, coherence, and cross power. These change indices have been compared to “ground-truth” data for the town of Golcuk, Turkey. In these comparisons, the magnitude of the change detected in satellite images was directly proportional to the amount of observed building damage. Optical data (e.g., SPOT) show the best results in these comparisons. This is due in large part to the higher resolution of that data.

In Year Five, we compared displacement and strain field maps derived from GPS measurements with those developed from SAR interferometry. The research challenge that we were exploring in Year 5 was whether we could discern damage to the urban environment by merging data from different sources and technologies. We plan on extending this analysis to the Chi-Chi, Taiwan Earthquake.

Role of Proposed Task in Support of Strategic Plan:
(Describe how the effort will make a unique, usable contribution to the MCEER strategic plan.)

Development of new technologies that help to quantify post-earthquake damage in near real-time is a critical task in improving current response and recovery procedures. As an element in Thrust Area 3, these technologies will improve community resilience by 1) helping emergency officials identify severely impacted areas in near real-time, 2) contributing to decision support systems that must prioritize response activities based on need, opportunity and available resources, and 3) helping with communication of critical response information using wireless technologies. As part of our networking task, we will be recruiting new members to MCEER’s Industrial Affiliates Program.

Task Integration:
(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

This task focuses on the development and use of advanced technologies for emergency response and recovery. In order to improve our ability to respond more reliably and quickly after major disasters, we will need new tools and more comprehensive databases on our urban environment. Program 3 will result in better tools for emergency planners and officials. As a result of our research, we anticipate that planners will have access to better information on exposed assets, more reliable methodologies to project future earthquake losses, and real-time decision support systems that will identify post-earthquake damage within a matter of hours. Critical in this development will be the integration of a whole new set of remote sensing technologies including synthetic aperture radar, high-resolution optical satellite imagery, GPS-based tools, high-powered geographic information systems (GIS), and improved database management systems. In addition, we also focus on more efficient procedures and technologies for transferring large datasets and files during a post-earthquake crisis period, e.g., wireless and broadband communication technologies. In addition, as part of the Networking task, we will be working with MCEER to negotiate MOUs with satellite data providers.
**Possible Technical Challenges:**
The technical challenges associated with the testing and validation of new technologies are considerable. Not only are we dealing with limited data sets, but to demonstrate the efficacy of these new technologies as compared to conventional and perhaps, more accessible methodologies, could pose some challenging implementation problems. If successful, however, the potential for more accurate and timely post-event loss estimates is extremely high.

**Anticipated Outcomes and deliverables:**
*(Also indicate those of particular benefit to IAB members and other end users.)*
- Report documenting methodology and models for post-event damage detection.
- Catalog of satellite images on MCEER website.
- Case studies involving U.S. and foreign earthquakes.
- Possible collaboration between several government agencies (LA City and CA OES) and MCEER in pilot studies.

**Potential end-users beyond academic community:** *(IAB members and others.)*
- Government Agencies: LA City, LA County, California Governor’s Office of Emergency Services, Federal Emergency Management Agency, DOT, NASA.

**Educational outcomes and deliverables, and intended audience:**
Special seminars on the use of advanced technologies for post-earthquake damage detection; intended audience: students, industry representatives.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*
- Report on Damage Detection Methodologies, Spring 2003
- Catalog of Satellite Images, Spring 2003
- Report on Opportunities to Improve Crisis Response using Wireless Communication technologies, Summer 2003

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*
- Ronald T. Eguchi, ImageCat, Inc., Team Leader
- Bijan Houshmand, Consultant
- M. Shinozuka, UCI
- A. Papageogiou, SUNY

**Possible Direction of Work in Subsequent Years:**
- Integration of remote sensing with decision support systems, including near real-time loss estimation programs, e.g., HAZUS, EPEDAT
- Leveraging Information Technologies for Crisis Response (Data Fusion, Mining, etc.)
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Task Title: Urban Damage Assessment Using Remote Sensing Technology and Real-time Decision Support

**Investigator/Institution:** *M. Shinozuka/University of California, Irvine*

*indicates task leader

## Statement of Project Goals:

(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This project primarily focuses on development of implementable real-time remote sensing technologies to identify the extent, location and mode of seismic damage sustained by urban built environment. Post and pre-event digital (SAR, optical and possibly LIDAR (light detection and ranging)) images obtained from ground, aerial and satellite platforms are used for damage identification. The technical basis of this project is built on the digital image processing techniques, and in this context, we will further improve the correlational analysis, principal component analysis, and Markov random field approach which have been developed at MCEER from the view point of pattern recognition technology.

## Problem Description and Research Approach of Proposed Work for Year 6:

(Detailed description of research to be conducted and methodology to be used.)

This study will develop and improve methods of digital image processing pertaining to urban seismic damage assessment and detection of more specific structural damage. For this purpose, pre-and post-disaster images will be used. Building on the successes in utilization of the correlation analysis, PCA (principal component analysis) methods with optical data and the coherence analysis method, Bayesian-based Markov random field approach with the SAR data, we intend in Year 6 to further expand our horizon by investigating other methods of damage identification which are potentially more useful and/or more easily implementable for post-disaster decision making. These methods will include pattern recognition technology utilizing wavelet formulation, and usage of ARC/VIEW software for damage identification and characterization. In Year 6, we initiate an effort to measure ground surface strain caused by an earthquake with available GPS data to calibrate the measurement. In addition to the exploration of these new methods, the technologies developed up to Year 5 will be summarized in Year 6 in the form that can support the post-earthquake decision-making.
Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

SAR interferogram can be obtained either by repeat-pass scheme (single antenna on board) or by single-pass approach (two antenna connected together with a rigid baseline). SAR high altitude satellite systems have one antenna on board and make the repeat-pass interferometry implementation feasible. ERS-1 and ERS-2 (European Remote Sensing Satellites) and RadarSat1 (Canadian satellite) are high altitude SAR satellite systems that provide global coverage continuously. JERS-1 and JERS-2 (Japanese Earth Resource Satellites) were other platforms that mapped the earth in the microwave region of electromagnetic spectrum during their operations. These satellites provide an approximated ground resolution of about 20 meters (RadarSat-1 can provide 10 meter resolution in the Fine Mode) suitable for regional monitoring and change detection. The launch of RadarSat2 is being planned for the year 2003. This SAR system will provide an additional Ultra Fine Mode that will deliver data with 3 meters ground resolution. However, this project is unique in that we acquire SAR satellite data of before and after the earthquakes for the Los Angeles area, develop suitable algorithms for differential interferometric studies, and calculate remotely sensed displacement field related to the seismic activities or ground activities which will be correlated to urban seismic damage. Furthermore, we intend to calibrate the remotely sensed displacement field with the use of GPS data. The calibration will involve the interpretation of the difference and the modification of the algorithms.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

In Years 1 and 2, the study pursued the development of methods to identify the extent and mode of structural damage due to earthquake by means of satellite- or air-borne SAR images of each structure before and after the seismic event. The simulation of SAR image of structures was demonstrated to be a useful tool. The resulting technical paper was published in Journal of Engineering Mechanics, ASCE. In Year 3, applications of optical images were attempted for damage identification with an emphasis on reconstruction of 3-D models. Also, in Year 3, Babak Mansouri, a graduate student working on SAR imaging, received a Telecommunications Advancement Research Fellowship from the Telecommunications Advancement Organization of Japan to spend two months (February 1- March 31, 2000) at the Hamamatsu Lifeline Research Center in Hamamatsu, Japan. There, he studied a wireless data collection system from monitoring and control of city lifelines. The technical accomplishments in Year 3 and the first half of Year 4 were published in a total of 6 papers published in the proceedings of the 7th and 8th Annual International Symposium of SPIE on Smart structures and Materials. Three Ph.D dissertations were completed by Hung-Chi Chung, “Digital Image Processing for System Identification”, Babak Mansouri, “Remote Sensing: Feasibility of Change/Damage Detection in Urban Areas and Structures by Synthetic Aperture Radar (SAR) Imagery” and Ali Rejai, “Unsupervised Change Detection in Remotely Sensed Images”.

II.A-2.138
**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

This task is carried out as part of MCEER’s effort to provide decision support tools for post-earthquake disaster mitigation. The MCEER research team demonstrated, through a number of publications including a report of its own reconnaissance experience, the usefulness of remote assessing techniques in identifying the location of extensive seismic damage in urban areas in relation to the 1999 Marmara Earthquake in Turkey. To develop real-time post-disaster decision support tools for earthquake emergency response is MCEER’s strategic plan to mitigate seismic disaster and to enhance seismic resilience of the community, and in this context, this project plays a significant role.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

With R. Eguchi serving as group leader, this task is closely coordinated with the research being carried out by R. Eguchi, A. Papageorgiu and B. Houshmand, and will be, integrated into the effort by MCEER’s response and restoration group to provide technical support for post-earthquake decision making at various levels.

**Possible Technical Challenges:**

Availability of affordable super-high resolution satellite-borne optical images for civilian applications remains to be somewhat uncertain. Ikonos optical satellite images with resolution of 1 m range and LIDAR images also with high resolution will be highly useful, but appear to be expensive to acquire at this time. Integration of the technologies developed under this task with the effort expended in other MCEER tasks for the purpose of urban seismic damage evaluation also requires some effort.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

- Computer codes for practical damage detection using SAR and optical images
- Analytical method to estimate ground surface strain seismically induced on the basis of SAR interferometric.

<table>
<thead>
<tr>
<th>Potential end-users beyond academic community: <em>(IAB members and others.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Researchers, government agencies and emergency response profession</td>
</tr>
</tbody>
</table>

II.A-2.139
Educational outcomes and deliverables, and intended audience:

A number of undergraduate and graduate students will be recruited and work with post-doctoral researches. They will be trained as researcher in the remote sensing area with the depth and breadth of understanding of that technology needed for urban damage estimation purposes. The deliverables include technical reports, their MS and Ph.D. dissertations, and poster-session materials in the MCEER and/or EERI conferences.

Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

Summarizing the research results up to Year 5 in fall, preliminary studies for new methods in winter, and research on selected new methods in spring and summer.

Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)

M. Shinozuka, Principal Investigator
S. Kim, Research Associate
H. Chung, Research Associate
X. Dong, Graduate Research Assistant

Undergraduate students will be recruited to work with the team providing assistance for computer codes development and numerical analysis.

Possible Direction of Work in Subsequent Years:

In Year 7 and beyond, GPS-compatible GIS applications will continue to be developed for rapid regional damage assessment. Use of optical, SAR and possibly LIDAR images of super-high resolution will provide near ground truth verification in near real-time, and this capability in turn will support search/rescue and other emergency response activities and related decision making.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Task Title: Comprehensive Community Recovery Modeling

Investigator/ Project Number: Stephanie Chang

Institution: University of Washington

* indicates task leader

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

This project aims to further refine and calibrate the prototype simulation model of community recovery that has been developed in previous years. Important model refinements include incorporating internal migration, quantifying outputs in terms of resilience measures, and improving specification of decision and policy variables. A demonstration version of the model will be used to solicit feedback from MCEER industry members and other potential users. Continued efforts at calibration will target key functions and parameters in the model (e.g., lifeline restoration functions). Empirical data for these model elements will be assembled and disseminated as an electronic data library.

Problem Description and Research Approach of Proposed Work for Year 6: (Detailed description of research to be conducted and methodology to be used.)

This project will improve the prototype comprehensive model of community recovery that has been developed in previous years. In contrast to loss estimation models, this model places much greater emphasis on the timepaths by which a community recovers from disaster. It seeks to capture how economic disruption losses accumulate over time, depend on interactions within the neighborhood and community, and are influenced by response and recovery decisions. Such a model of the urban disaster recovery process can provide a means for informing and evaluating public decisions that can facilitate recovery. The project consists of two subtasks: (1) model refinement, and (2) model calibration.

The objective of model refinement will be to develop a demonstration version of the model that can be used to solicit feedback from potential end users, particularly members of MCEER’s IAB. One important refinement will be to better model how migration and relocation are handled in the model. Currently, households and businesses are allowed to remain in their original neighborhoods or “exit” via out-migration from the region or business failure. The model should be refined to allow for temporary and permanent internal migration in the urban area, particularly as it relates to disaster housing policy. In addition, the model’s outputs will be refined to include proposed measures of community resilience. With these refinements, a demonstration version of the model will be developed and used to solicit feedback from potential end users. Based on this feedback, the selection and representation of decision variables in the model will be revised and refined.

The second subtask will continue efforts at calibrating and validating the model. In

II.A-2.141
previous years, efforts in this direction have been focused on validating broad outcomes of the model. In particular, the model is being validated against the Kobe earthquake for outcomes related to neighborhood recovery disparities and overall recovery timeframes. Here, similar validation analysis will be conducted for less catastrophic disasters. Further efforts will also be made to calibrate key equations and parameters in the model, especially those related to lifeline systems. As the calibration data are gathered and systematized, they will be stored in an electronic data library that will be made publicly available.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

While a number of earthquake loss estimation models exist and are being developed, both within and outside of MCEER, none emphasize the dynamics of the recovery process. The simulation model being developed here is unique in its attempts to capture the full picture of community recovery – particularly in terms of interaction effects across space, time, and community sectors, and in its consideration of a broad range of pre- and post-disaster decision variables.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

A prototype simulation model has been developed and implemented in Matlab. In the last year, this prototype has been expanded to represent a hypothetical urban area with 4 neighborhoods and 100 businesses and 100 households in each neighborhood. Preliminary sensitivity analysis has been conducted. A concerted effort has been made to develop a validation framework based on detailed data analysis of impacts and recovery in the Kobe earthquake. This has involved estimating the net impact of the disaster on businesses and households at the small-area level (i.e., forecasting without-earthquake time series and comparing these to actual post-earthquake data). Current efforts are focused on using the Kobe data to implement model validation in terms of broad model outcomes. A book chapter has been accepted for *Modeling Spatial Economic Impacts of Natural Disasters*, eds. Y. Okuyama and S. Chang (forthcoming from Springer-Verlag).

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

In terms of the 3-plane chart, this project contributes to MCEER’s “technology base” by developing a prototype simulation model of community recovery from earthquakes. It is particularly relevant to Thrust Area 3, Response and Recovery, but is also applicable to Thrust Area 1, Lifelines. The model developed from this project may contribute eventually to Thrust Area 3 demonstration projects, as well as integration of Thrust Areas 1 and 3 in future years. In terms of MCEER’s center-wide systems diagram, this project contributes to “community modeling and resilience estimation” (box 8).
**Task Integration:**  (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

This work provides a basis for implementing and testing community resilience measures being developed by other MCEER researchers, inc. K. Tierney. It can help determine inputs and calibration points for CGE modeling of indirect economic impacts by A. Rose. It will benefit from work on decision variables, loss reduction strategies, and their effectiveness that is being conducted by W. Petak and D. von Winterfeldt.

**Possible Technical Challenges:**

Modeling internal migration or relocation will be a challenge, given the model structure, and may involve tradeoffs with computational efficiency. Model calibration and validation remain challenges since empirical data are sparse and complex to interpret for this purpose.

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refined community recovery model, including demonstration version.</td>
<td>Emergency managers and planners. Utility agencies.</td>
</tr>
<tr>
<td>Electronic data library of recovery-related information (e.g., lifeline restoration times in previous earthquakes).</td>
<td></td>
</tr>
</tbody>
</table>

**Educational outcomes and deliverables, and intended audience:**

Training of 2 graduate students.

**Project Schedule and Expected Milestones for the Project:**  (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)

Notes: This schedule assumes a project period of October 2002-September 2003.

*Subtask 1: Model refinement.*
- Fall 2002 - Refine model for community resilience measures and migration/relocation.
- Winter 2003 - Develop demonstration version of model.
- Spring 2003 - Solicit feedback from selected IAB members and possibly other end users. Revise decision variables in model as appropriate, based on feedback.
- Summer 2003 – Write up for publication.

*Subtask 2: Model calibration and validation.*
- Winter 2003 - Validate broad model outcomes for moderate disasters (e.g., Northridge).

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

P.I.: S.Chang
Coordination with: K.Tierney, A.Rose, and other MCEER social science investigators.
Students: S.Miles (Geography Ph.D.) and 1 other graduate student from Geography, Economics, or Urban Planning at U. of Washington
Industrial participants: Feedback will be sought from members of MCEER’s IAB, probably including City of LA and LADWP.

**Possible Direction of Work in Subsequent Years:**

Application of prototype model to an actual urban area, e.g. Los Angeles. Assessment of community resilience impacts of advanced technologies and methodologies for lifelines and in response and recovery.
User Networks for Seismic Assessment and
Retrofit of Critical Facilities
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Coordination and Development of Networking Infrastructure

**Investigator/ Institution:** Andrei M. Reinhorn*, University at Buffalo  
* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

1) Coordinate the development and execution of Networking Subtasks (see separate Statement)  
2) Develop and integrate subtasks in the MCEER Users Network  
3) Develop infrastructure for collaboration through Internet media  
4) Develop educational support for student activities and engineering community  
5) Develop a new innovative database management for experimental and analytical information

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

The above tasks are detailed in the following:

1) Subtasks for networking of research in progress and results have been suggested for seven (7) chosen tasks in each of the Thrust areas (see separate task statement). The coordinator of all tasks (within this task) will help prepare guidelines specific to each subtask, identify suitable procedures for networking and assist with advise in data organization. The coordinator will continue to “scout” additional projects for future inclusion in the networking program

2) The results of the work in the subtasks will be connected to the MCEER Users Network, a website which will be continuously updated to include the incoming information. Automated update links will be developed and maintained for ease of operations.

3) The Networking program assists all MCEER activities with connectivity for conferencing, webcast streaming of information, laboratory connectivity, on line teleoperations. New developments are required to allow for links and transfers of video, voice, data and real time presentations. Hardware and software are linked in some cases with readily available software, or newly developed communication platforms have to be connected. This task will provide the hardware infrastructure and the organization to enable communications through Internet (networks or webs). This task includes development of connectivity with Florida A&M University, CUNY and NJIT (Minority Institutions) for educational and student activities.

4) The networking program is at the base of student connectivity. The program assists the SLC with conferencing capabilities and organization. Infrastructure will be prepared to enable independent use of resources. Manuals and instructions are being thought. Moreover, the
program intends to provide recording and streaming of information form special classes to develop a series of instructional modules for training in the laboratory, or developing design skills.

5) The program developed in the past a new concept for experimental and computational data organization using Multi-dimensional Geometric Information System (M-GIS). The concept was developed using three dimensional generic database developments. The proposer identified possibilities to adapt the ArcInfo and ArcView GIS products to incorporate and integrate data and metadata for easy logical retrieval and transfer. This subtask will attempt to develop a prototype based on the above platforms in connection with shake table experiments and computational information. An expert in GIS and programming will assist the PI in this subtask. When successful the platform will allow to integrate, visual database in all areas of computing and experimentation.

Assessment of State-of-the-Art: (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

Although many of the components related to integration of multimedia information are not new, the applications proposed herein pioneer networking and collaboration, which is not yet available. Network base operations of equipment and computing assistance of other institutions using real time networked based sessions are new although are based on application sharing technology (well known in the collaboration areas).

The innovation included in this task is the development of the M-GIS. Although GIS is a well-established technology in Geographic related database information, the extension to generalized geometric information has not been done yet. Moreover, the new NEES developments of the System Integrator do not seem to have the resources and will to develop this approach, although many of the Equipment Sites approved by NSF expressed their interest and confidence in such approach.

Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

The PI served as the coordinator for the previous networking activities, which resulted in a Users Network with information from work in progress and research results (see Users Network website). In addition the coordinator developed Intenet connectivity used in all areas of Center operations from Laboratories to Computational Facilities to Webcast Seminars, Video Teleconferences of Executive Committee etc.

The concept of M-GIS was developed and presented to a wide audience and further developments were identified.
Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

The proposed task will facilitate collaboration through the electronic media, with resulting procedures available to researchers, students and industry partners. The information published through the Network will allow easier distribution of Research products as indicated in the Strategic plan. The development of the M-GIS concept will allow new ways of comprehensive and yet standardized collaboration platform.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

This task is interconnected with the sub-tasks and all the thrust areas:
1. S. Chang, "Direct Losses, Social Impacts, and Community Resilience: Los Angeles Lifeline Study" (Subtask of Thrust 1)
2. R. Eguchi, "Catalog of Satellite Images for MCEER Webpage and Efficient Procedures for Transferring Large Datasets (Subtask of Thrust Area 3)
3. M. Grigoriu, “System Risk and Reliability for Water Supply” (Subtask of Thrust 2 and 1)
4. Tom O’Rourke, “Seismic Strengthening Water Trunk And Transmission Pipelines”, (Subtask of Thrust 1)
5. A. S. Whittaker, “Emergency care facility performance evaluation using deterministic integration of structural and non-structural component response data;” (SubTask of Thrust 2)
6. G. Dargush, “Evolutionary Structural Optimization” (Subtask of Thrust 2)
7. G. C. Lee, “NY State Hospital Project” (Subtask of Thrust 2)

Possible Technical Challenges:

Each of the subtasks have challenges related to integration of hardware and software for communication with specialized engineering software. The subtask on M-GIS will be challenged by the interface of proprietary software with engineering needs a barrier to distribution. However this barrier can be overcome in multiple ways and solutions will be searched.

Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)

1) Users Network with engineering products
2) Communication Infrastructure for education and student collaboration
3) New platform for database management of experimental and computational information

Potential end-users beyond academic community: (IAB members and others.)

1) Industry partners
2) Other research centers
**Educational outcomes and deliverables, and intended audience:**

The M-GIS platform can be developed for use in the Experimental Methods in Earthquake Engineering (CIE 616) at University at Buffalo. Additional modules for same class will be shared with the programs in the Minority Institutions indicated in the subtask (4) of this task.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

<table>
<thead>
<tr>
<th>Time</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2003</td>
<td>Coordination of new Networking subtasks for year 7 of MCEER Program</td>
</tr>
<tr>
<td>Spring 2003</td>
<td>Connectivity with Minority Institutions and delivery of experimental course</td>
</tr>
<tr>
<td>Summer 2003</td>
<td>Prototype of M-GIS distributed for testing in laboratory operations</td>
</tr>
<tr>
<td>Fall 2003</td>
<td>Networking products from sub-tasks on the Users Network verified and completed.</td>
</tr>
<tr>
<td>Fall 2003</td>
<td>Prototype of M-GIS platform</td>
</tr>
</tbody>
</table>

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

- Dr. Mark Green, Post Doctoral Associate (University at Buffalo) expert in GIS and high-level programming.
- Mr. Jason Hanley, (or equivalent), graduate student, computer science and networking expert

**Possible Direction of Work in Subsequent Years:**

Expansion of successful components of this program
## MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned Project Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Task Title:
Development of templates for networking of experimental databases and methodologies for networking of experimental facilities.

### Investigator:
M. Maragakis* and S. Elfass

### Institution:
University of Nevada, Reno

* indicates task leader

### Statement of Project Goals:
(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

Enhance the current network system to allow a better interaction among the experimental facilities and laboratories of the participating institutions in MCEER as well as laboratories of other institutions from around the world through the Internet. Such an interaction includes, but not limited to, sharing up-to-date information of available experimental databases as well as providing a virtual presence via video teleconference and webcasting.

### Problem Description and Research Approach of Proposed Work for Year 6:
(Detailed description of research to be conducted and methodology to be used.)

The objective of this proposal is to continue the steps taken towards the development of a large-scale network system for the purpose of networking of experimental facilities through the Internet. This network system will allow researchers and engineers from around the world to share the up-to-date information about the laboratory experimental facilities and research achievements and activities performed by different institutions. Two major issues are needed to be addressed in order to complete the framework for such a network system. The first one is how to ease the goal of sharing up-to-date information among other facilities, while the other issue is where to look for such information and how easy to find it. While steps have been taken already offering solutions for the above-mentioned issues in year 5, it is necessary to complete and test such solutions. Consequently, the goals of this task are to:

- Finalize and test the new state-of-the-art network protocol for live dissemination of experimental test results through the Internet to be networked among researchers from different institutes.
- Finalize and test the advanced searchable web-based database of most recent technical publications with information about up-to-date research achievements and activities performed at UNR.
- Initiate the framework of an advanced searchable web-based database of most recent technical publications with information about up-to-date research achievements and activities performed at other agencies.
- Continuously update and maintain the current available experimental networking services such as the up-to-date technical publications on several research topics performed at UNR, the information about the experimental facilities at UNR (including detailed list of lab equipment, their specifications, and photos), etc.
Assessment of State-of-the-Art:  (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

There is an ongoing effort through NEES, sponsored by NSF, to employ the Internet technology to link various Earthquake Engineering research facilities. The main goal of this effort is to provide remote users from different universities with telepresence and teleoperation capabilities. The project proposed in this proposal includes activities complimentary to NEES. The focus of this project is the development of protocols for live dissemination of experimental test results through the Internet to be networked among researchers from different institutes.

Progress to date:  (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

The following is a summary of the achievements towards the objectives of Task 4.1 through the web site of the Bridge Research and Information Center (BRIC), which is headquartered at the University of Nevada, Reno: (i) an advanced network system has been employed for Internet “Live Webcast” of the experimental events performed at UNR using RealNetworks technology, (ii) an online protocol for sharing information about previous experimental activities including achievements and test procedures that could be used as a guideline for future tests has been developed. This protocol also includes dissemination of experimental test results, photos, and video clips. A sample of the protocol is published on BRIC web site, (iii) an advanced video teleconference equipment has been purchased and is currently being utilized for live interaction through the Internet, (iv) development of an online detailed inventory providing up-to-date information about the experimental facilities of the structures laboratory at UNR as well as a detailed listing showing number, models, and specifications of the available equipment to be used for experimental facilities networking purposes among different institutes, (v) a complete list of technical reports that were published by the Department of Civil Engineering at UNR has been developed including abstracts and photos and video clips of several experimental tests. This can be used for sharing the most recent research findings and achievements of research studies performed at UNR with other researchers and engineers from different institutions, (vi) two web pages have been developed, one linking to several institutions and research centers (such as MCEER, EERC, etc.) and the other linking to several online databases (such as MCEER, ASCE, etc.) with information about technical publications in the field of civil engineering. These links will provide the web site visitors with up-to-date information about research activities and publications by other institutions and agencies.

Role of Proposed Task in Support of Strategic Plan:  (Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)

All the objectives of this proposal are related to networking experimental facilities, sharing data and disseminating effectively research results. These efforts contribute not only to enhancing the efficiency of research performed at MCEER, but also to more efficient dissemination of the results to other researchers, practicing engineers and the community in general.
**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The techniques developed in this project will be applied for the dissemination of the experimental results of experiments performed in Thrust Areas 1 and 2. For example all of the results, pictures, and video of the piping distribution systems tests that will be performed at UNR as part of Thrust Area 2, will become available using the protocol that will be developed in this task.

**Possible Technical Challenges:**

An important challenge would be designing a protocol for live and pre-recorded dissemination of experimental tests data in several formats and video clips. This task requires using advanced Internet programming techniques such as Java Script/cgi programming, and multimedia development tools to develop a web page serving this task. Another challenge is developing a web-based database, which requires using advanced Visual Basic and SQL programming for developing the database and using ASP Internet technology and VB Script programming for designing the connectivity between the web page and the server.

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: <em>(Also indicate those of particular benefit to IAB members and other end users.)</em></th>
<th>Potential end-users beyond academic community: <em>(IAB members and others.)</em></th>
</tr>
</thead>
</table>
| • A protocol using a state-of-the-art network system for live dissemination of experimental data through the Internet.  
• A web-based database containing the most recent information of research projects performed at UNR.  
• A preliminary frame work for a web-based database containing the most recent publications and research achievements performed by other agencies. | • MCEER researchers, other researchers and practicing engineers.  
• MCEER researchers, other researchers and practicing engineers.  
• When completed, MCEER researchers, other researchers and practicing engineers. |

**Educational outcomes and deliverables, and intended audience:**

All the tools developed in this project are related to the networking of experimental facilities of MCEER and the availability of research results, pictures and videos on the Internet. Furthermore, web casts of tests and exchange of test results, videos and photographs will become available on a routinely basis. Therefore, these tools and the web available information can be used in the educational activities of MCEER.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*
**Task 1:**
Finalize and test the protocol which uses the state-of-the-art network system for live electronic dissemination of experimental test results through the Internet. *(Fall 2002)*

**Task 2:**
Finalize and test the online database which will provide the engineering community with information about the most recent research activities, findings, and publications at UNR through the World Wide Web. *(Spring 2003)*

**Task 3:**
Initialize the framework for the online database using the latest Internet programming techniques to provide the engineering community with information about the most recent research activities, findings, and publications at other agencies through the World Wide Web. *(Summer 2003)*

**Task 4:**
Continuous efforts for updating, implementing and maintaining the currently available experimental networking services will be made. This includes updating the information about the experimental laboratory facilities and capabilities at UNR, the detailed list of lab equipment and their specifications, the most recent publications containing information about findings and achievements of experimental research activities performed at UNR, the experimental protocols and others. *(Throughout the year)*

**Team Members:** *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

The project will be under the directions of Emmanuel “Manos” Maragakis, professor and chair of civil engineering department at the University of Nevada, Reno. Dr. Sherif Elfass, information manager, will be the co-principal investigator for this project.

**Possible Direction of Work in Subsequent Years:**

The following are the projections for future years: (i) Finalizing the web-based database of most recent technical publications with information about up-to-date research achievements and activities performed at other agencies. (ii) Enhancing the current “Live Video Webcast” system by implementing new technologies that would allow an interactive classroom type of presentation through the Internet for networking of experimental activities, seminars, and online classes among researchers, engineers, and students from different institutions, (iii) Using the developed template for reporting results of experimental research studies performed at UNR or by MCEER researchers as well as researchers and engineers from other institutions, and (iv) Continuously updating, implementing and maintaining the current provided experimental networking services to the civil engineering community.
MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task Title:</th>
<th>Networking SubTasks</th>
</tr>
</thead>
</table>
| Investigator/Institution: | A. M Reinhorn*, University at Buffalo  
S. Chang, U. of Washington  
R. Eguchi, ImageCat, Inc  
M. Grigoriu, Cornell University  
T. O’Rourke, Cornell University  
A. S. Whittaker, University at Buffalo  
G. Dargush, University at Buffalo  
G. C. Lee, University at Buffalo |

*indicates task leader

Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

1. S. Chang, "Direct Losses, Social Impacts, and Community Resilience: Los Angeles Lifeline Study" (Subtask of Thrust 1)
2. R. Eguchi,"Catalog of Satellite Images for MCEER Webpage and Efficient Procedures for Transferring Large Datasets (Subtask of Thrust Area 3)
3. M. Grigoriu. “System Risk and Reliability for Water Supply” (Subtask of Thrust 2 (and 1)
4. Tom O’Rourke; “Seismic Strengthening Water Trunk And Transmission Pipelines”, (Subtask of Thrust 1)
5. A. S. Whittaker, “Emergency care facility performance evaluation using deterministic integration of structural and non-structural component response data;” (SubTask of Thrust 2)
6. G. Dargush, “Evolutionary Structural Optimization” (Subtask of Thrust 2)
7. G. C. Lee. “NY State Hospital Project” (Subtask of Thrust 2)

Problem Description and Research Approach of Proposed Work for Year 6: (Detailed description of research to be conducted and methodology to be used.)

S. Chang "Direct Losses, Social Impacts, and Community Resilience: Los Angeles Lifeline Study" (Subtask of Thrust 1)

In MCEER's new systems approach, the quantitative measurement of resilience is a central area of new research. The resilience measures that are developed will be used to evaluate MCEER's advanced technologies and methodologies for earthquake loss reduction. It is therefore essential that proposed measures of resilience be subjected to review, criticism, and debate - initially among MCEER leadership, researchers, and industry affiliates, but eventually also by the professional earthquake community at large.

In this networking subtask, I propose to develop a website where examples of proposed resilience measures will be posted for review and feedback. This website will feature the following elements: (1) a sketch model of social and economic loss from lifeline disruption in
earthquakes, with example outputs; (2) proposed resilience measures that are linked to the model's outputs, with emphasis on social and economic resilience; and (3) online features for collecting and reporting feedback on the model and measures. The sketch model will not be functional, but merely illustrative of data inputs, result outputs, and key model links. It will capture the essence of the loss model being developed in the main task for water and power disruption in Los Angeles. The example outputs and associated resilience results will demonstrate how changing given inputs, such as implementation of advanced retrofit technologies, might enhance social and economic resilience. Online feedback features may include polling, commentary, or discussion platforms.

R. Eguchi: “Catalog of Satellite Images for MCEER Webpage and Efficient Procedures for Transferring Large Datasets” (Subtask of Damage Detection using Remote Sensing Technologies, Thrust Area 3)

This task will explore the feasibility of creating an on-line catalog of aerial and satellite images of recent disasters. The focus will be on post-event imagery and will include images from recent earthquakes, floods, hurricanes and fires. As part of this task, we will approach various satellite companies and agencies to discuss possible Memorandum of Understandings (MOU) with MCEER.

To date, there is no efficient way for MCEER investigators to share and transfer large files on remotely sensed data. Typically, these files are on the order of several ten’s of megabytes, thus rendering their transfer via conventional methods (as attachments to email messages) impossible. Also, disseminating the results of our research has been problematic because of the size of these files. In order to “market” this aspect of MCEER’s research program, it will be necessary to develop and maintain a page on the MCEER website where images could be downloaded or retrieved – perhaps for a publication fee.

The following approach is proposed:
1. Identify current images in MCEER’s project file (start with disaster/events listed on our current datafiles)
2. Work with MCEER’s information services manager to develop a protocol to access images on MCEER’s website.
3. Begin effort to develop MOUs with satellite data providers, e.g., USGS, Space Imaging, European Space Agency, SPOT, Intermap, and others
4. Create a mechanism where MCEER investigators can transfer and share large datafiles.
5. Explore feasibility of marketing and “selling” processed images
6. Work with other Thrust Area 3 investigators to identify information transfer needs, particularly with respect to post-event decision support systems.

M. Grigoriu, “System Risk and Reliability for Water Supply” (Subtask of Thrust 2 (and 1))
1. Finite Element mesh for piping systems a MATLAB program with graphical user interface for automatic generation of FE mesh will be delivered. The input is the geometry of piping centerlines and parameters describing the mesh. The output is a data file ready to run with major structural analysis software (e.g. DIANA and SAP2000). Main features of the program include general 3D modeling capability, automatic generation of beam-shell FE interface, optimal FE aspect ratio at T-sections, automatic modeling of boundary conditions, and input data verification. A simple example illustrating the use of the program and its graphics capabilities will be made available. The program will be also include a user's manual.
2. Life cycle seismic hazard scenarios A MATLAB program will be delivered for generating random samples of seismic hazard scenarios at a site. Each scenario consists of (1) number of earthquakes during a specified time interval and (2) the acceleration time histories of these earthquakes. Both the number of earthquakes and the ground acceleration time histories are random. The number of earthquakes is based on seismicity of the site while the properties of individual earthquakes are based on Prof. Papageorgiou model.

The programs will be integrated in typical MCEER Networking templates with links to major computational platforms, ground motion sources and feedback information.

Tom O’Rourke; “Seismic Strengthening Water Trunk And Transmission Pipelines”, (Subtask of Thrust 1)

Researchers at MCEER have developed in collaboration with industry a suite of technologies for strengthening the welded slip joints of critical water trunk and transmission pipelines. Welded slip joints are the preferred means of joining adjacent sections of steel pipelines in water supplies, but are vulnerable to compressive forces generated by both permanent and transient ground deformation during earthquakes. The technologies include fiber-reinforced polymer (FRP) wraps to confine slip joints against outward buckling, model-based welding and fabrication processes, and supplemental steel reinforcements. The research has resulted in advanced computational models, validated by full-scale laboratory experiments, that can simulate accurately the performance of straight pipe, internally and externally welded slip joints, and slip joints reinforced with FRP wraps and supplemental steel components.

In Year 6, Cornell researchers will provide web-based guidance and access to computational tools for modeling welded slip joint performance during earthquakes and various other severe loading conditions. They will develop a web site, linked to the MCEER Users Network, that will provide guidance for the computational modeling of welded slip response to compressive, tensile, and cyclic loads, including databases comparing computational simulations with full-scale load response measured during experiments at MCEER experimental facilities. The web site will include guidelines on the composition and application of FRP products for strengthening water trunk and transmission pipelines, including a database on the key material properties of the polymers and carbon fibers used in the FRPs. Model specifications for the selection, qualification, installation, and quality control of FRP wraps will be provided.

A.S.Whittaker: “Emergency care facility performance evaluation using deterministic integration of structural and non-structural component response data;” (SubTask of Thrust 2)

The scope of this subtask is to develop, publish, and distribute a database and the associated knowledge tools for use by the Users Network of MCEER. The database will include (a) mathematical models of MCEER-studied emergency care facilities, including models of the three demonstration hospitals [others will be responsible for the accuracy of the models], (b) results of the analysis of the models by MCEER researchers, and (c) fragility data for non-structural components that are commonly found in hospitals. Sample analysis results from some of the models will be available to the Users Network with a Users Guide.

George C. Lee “New York State Hospital Project” (Subtask of Thrust 2)

The NY State hospital project will prepare all the information for the selected hospitals involved in pilot demonstration including FE models, design drawings, non-structural element
configurations and the pilot evaluation platform in digital format for network access. Reports of study will also be available in digital format for network access if desired. The format of the information will comply with MCEER Network project standards. Interface will be developed to provide the proper integration to MCEER research network.

**Assessment of State-of-the-Art:** *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

This is a generic activity of MCEER

**Progress to date:** *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)*

The MCEER Users Network already includes information of Work in Progress made available to the Center’s investigators

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The above tasks will provide the computational tools and methodologies for potential users on the MCEER UsersNetwork to support

1. Research by all MCEER investigators
2. Applications for practicing professionals where applicable
3. Educational material

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

The work in this task is derived from various Center’s tasks and provide the base for distribution of information to the other tasks. Moreover facilitate transfer of information to the other projects in the other Engineering Research Centers

**Possible Technical Challenges:**

Development of templates for common use by subtask developers.

**Anticipated Outcomes and deliverables:** *(Also indicate those of particular benefit to IAB members and other end users.)*

1. Websites linked in the MCEER Users Network
2. Computational Tools for Loss evaluation, pipe analysis, hospital buildings evaluations, etc

**Potential end-users beyond academic community:** *(IAB members and others.)*

1) Lifelines Utilities
2) Engineering Consultants
## Educational outcomes and deliverables, and intended audience:

All materials are raw materials for earthquake engineering applications and would be integrated in class modules where applicable.

## Project Schedule and Expected Milestones for the Project:  
*(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

See task description

## Team Members:  
*(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

See List of Investigators

## Possible Direction of Work in Subsequent Years:

Further Enhancement of Users Network
<table>
<thead>
<tr>
<th>Investigator</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. Maragakis</td>
<td>Development of Networking Templates for Experimental and Computational Facilities</td>
</tr>
<tr>
<td>A.M. Reinhorn</td>
<td>Coordination and Development of Networking Infrastructure</td>
</tr>
<tr>
<td>S. Chang</td>
<td>Direct Losses, Social Impacts, and Community Resilience: Los Angeles Lifeline Study (Subtask of Thrust 1)</td>
</tr>
<tr>
<td>R. Eguchi</td>
<td>Catalog of Satellite Images for MCEER Webpage and Efficient Procedures for Transferring Large Datasets (Subtask of Damage Detection using Remote Sensing Technologies, Thrust Area 3)</td>
</tr>
<tr>
<td>M. Grigoriu</td>
<td>System Risk and Reliability for Water Supply</td>
</tr>
<tr>
<td>T. O’Rourke</td>
<td>Seismic Strengthening Water Trunk And Transmission Pipelines (Subtask of Thrust 1)</td>
</tr>
<tr>
<td>G. Dargush</td>
<td>Evolutionary Structural Optimization</td>
</tr>
<tr>
<td>G.C. Lee</td>
<td>New York State Hospital Project</td>
</tr>
</tbody>
</table>
Education
# MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Task Title:** Educational Developments

**Investigator/Institution:** Andrea Dargush/MCEER

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The purpose of this effort is to develop activities and materials which can be used by precollege students and teachers to increase their awareness of earthquakes, their understanding of physical science and social science concepts associated with earthquake phenomena, and to encourage professional interest in earthquake engineering and related fields.

**Problem Description and Research Approach of Proposed Work for Year 5:** (Detailed description of research to be conducted and methodology to be used.)

The activities conducted will support existing goals of science standards and curricula, so that learning modules and tools can be easily integrated into middle or high school level classes. The intent will also be to assist teachers without training in earth science or physics to master earthquake content that they may be required to address. This will be carried out in the form of teacher training sessions, which will expose participants to earthquake and engineering concepts, and to the earthquake research environment, while working interactively with MCEER staff and researchers to develop thematic materials which can be used in the classroom. Assessments of learning tools will be carried out to assure accuracy and applicability. Use of new learning technologies will also be applied as pedagogically appropriate.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

The task parallels similar ongoing initiatives within NSF to provide needed training and support to precollege teachers. The MCEER effort is intended to develop a needed two-way exchange between teachers, earth scientists, engineers and academic researchers to further understanding of precollege education goals and needs. Educational tools which are developed as a consequence are likely to be more effective in the classroom. This type of focused interaction between educators and scientists is an essential part of the teacher training activity, and is somewhat unique to MCEER.

**Progress to date:** (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Similar teacher training courses have been offered by MCEER in past years. These have been smaller in scope, but one in expanded format is planned as part of the Year 5 task, and will be held in Fall, 2002. Throughout year 5, the MCEER education coordinator has been working...
with teachers in smaller groups, as well as directly in the classroom with middle and high school level students.

**Role of Proposed Task in Support of Strategic Plan:** *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The mission of MCEER is to help build more disaster-resilient communities. Education plays a key role in creating an awareness of the seismic hazard, the potential for risk, and the possible approaches and solutions which can be applied. The model and approach being used for this educational effort is also transferrable. Many of the educational activities which are being conducted and developed can be made effective for broader audiences, such as the public-at-large, media and decision-makers. In addition, many of the activities incorporate unique information about advanced technologies which are explored as part of the MCEER research plan.

**Task Integration:** *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This task is integrated with the other educational tasks funded by MCEER, each of which addresses a different specific target audience. The educational activities are also closely linked with the Networking effort, as new applications of information technology and educational methodologies are examined.

**Possible Technical Challenges:**

<table>
<thead>
<tr>
<th>Anticipated Outcomes and deliverables: (Also indicate those of particular benefit to IAB members and other end users.)</th>
<th>Potential end-users beyond academic community: (IAB members and others.)</th>
</tr>
</thead>
</table>

**Educational outcomes and deliverables, and intended audience:** The outcomes will be additional earthquake education resources which can be used in the precollege classroom. It is anticipated that these will be made broadly available through the web or on CD-ROM after careful evaluation. The initial audience will be middle school earth/physical science teachers, with extension to physics and technology teachers at the high school level.

**Project Schedule and Expected Milestones for the Project:** *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

A year 6 training session will be initiated in the Spring of 2003, with a broader program planned for summer of 2003, which will also involve the participation of undergraduate interns in the NSF-funded REU program.
<table>
<thead>
<tr>
<th><strong>Team Members:</strong>  (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>George Lee</td>
</tr>
<tr>
<td>Andrea Dargush</td>
</tr>
<tr>
<td>Dorothy Tao</td>
</tr>
<tr>
<td>Shari Salisbury</td>
</tr>
<tr>
<td>Andrei Reinhorn</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Possible Direction of Work in Subsequent Years:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>It is anticipated that networking using the internet will play a much larger role in future training and will expand the possible audiences which can be reached.</td>
</tr>
</tbody>
</table>
Task No. Budget: Yr 6 Assigned
Project Number: 03/5.2

Task Title: Earthquake Analysis of an Existing Structure in the Southeast Region:
A Case Study YR6

Investigator/ Institution: Makola M. Abdullah / Florida A & M University

* indicates task leader

Scope: (100 words or less - description for contract purposes)

To produce a detailed earthquake analysis of an existing structure in the southeast region as a case study. The structure would be subjected to the current earthquake hazard in the southeast. Specific geographic regions include South Carolina.

Problem and Approach:

The Tasks for completing the project include, but are not limited to:

Identification of Structure

Modeling of Structure
  • Foundation and Soil Type
  • Structural Materials
  • Structural Framing
  • Structural Connections
  • Interior and Exterior Non-Structural Components

Structural Response of Structure
  • Calculation of building response from earthquake

Estimation of Damage
  • Estimated value of structure and contents
  • Estimated economic value of products and/or services related to the structure
  • Review of Damage from similar buildings from past hazards
  • Effect of building response on structural, lifeline and non-structural components
  • Estimated cost of repairs to structural, lifeline and non-structural components
  • Estimated time of repairs to structural, lifeline and non-structural components
  • Estimated economic value lost from building downtime due to repairs

Design Recommendations
  • Design methods that could have been used to improve building response and reduce estimated damage from hazards.
Effects of advanced technologies

**Justification:** *Describe how the effort will make a unique, useable contribution to the MCEER strategic plan and earthquake hazards mitigation.*

This effort will produce a case study that can be used by educators to show the importance of earthquake hazard mitigation in the Southeast Region of the United States.

**Progress to date:** (if ongoing effort)

To date, we have completed several of the tasks. One of the more interesting was estimating the effects of advanced technologies on the reduction of estimated damage. This work is very preliminary, but has significant promise.

Currently, we have been working with schoolteachers to develop earthquake and hurricane curriculum additions to be used in the schools. Implementation should take place in this calendar year.

**Possible Technical Challenges:**

<table>
<thead>
<tr>
<th>Anticipated outcomes/ deliverables:</th>
<th>Potential end-users beyond academic community:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A written document suitable for distribution to be used for educational purposes.</td>
<td>The case study will be geared towards the practicing structural engineer. It is also anticipated that some of the materials will be interesting and appropriate for 9-12 students</td>
</tr>
<tr>
<td>A CD-ROM supplement that includes all applicable materials used to produce the study.</td>
<td></td>
</tr>
<tr>
<td>A web page that can be used to access information related to the study.</td>
<td></td>
</tr>
</tbody>
</table>

**Educational outcomes and deliverables, and intended audience:**

The three deliverables will be:

1) A written document suitable for distribution to be used for educational purposes.

2) A CD-ROM supplement that includes all applicable materials used to produce the study.

3) A web page that can be used to access information related to the study.

The intended audience will be advanced undergraduate students, graduate students and practicing structural engineers. It is also anticipated that some of the materials will be interesting and appropriate for 9-12 and lower-level undergraduate students.
### Project Schedule:  
*(milestones and estimated time of achievement; e.g. Fall, Spring Summer)*

<table>
<thead>
<tr>
<th>Task</th>
<th>Estimated Semester of Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification of Structure</td>
<td>Fall 2001</td>
</tr>
<tr>
<td>Modeling of Structure</td>
<td>Fall 2001</td>
</tr>
<tr>
<td>Structural Response of Structure</td>
<td>Spring 2002, Fall 2002</td>
</tr>
<tr>
<td>Estimation of Damage</td>
<td>Fall 2002</td>
</tr>
<tr>
<td>Design Recommendations</td>
<td>Fall 2003</td>
</tr>
</tbody>
</table>

### Task Integration:  
Describe how the work performed contributes to a larger task within the program; what contributions are anticipated.

### Projected future work:
**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Task No.</th>
<th>5.3</th>
<th>Budget:</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task Title:</strong></td>
<td>Application of Response Modification Technologies for Performance –Based Seismic Design of a Multi Story Building</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Project Number:</strong></td>
<td>03/5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Investigator:</strong></td>
<td>Rupa Purasinghe</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Institution:</strong></td>
<td>California State University at Los Angeles</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates task leader

**Scope:** (100 words or less - description for contract purposes)

his research involves practical aspect of application of passive energy devices for retrofit of a multistory building in the context of performance based seismic design. This will be based on the push over analysis results of year 5 (third year for this project). Training students in the latest response modification technologies for performance-based design will accomplish this.

**Abstract:** (500 words or less - summary of activity and outcome)

A 3-D model of the multistory building with alternative schemes of dampers will be subjected to time history earthquake loading, as part of a retrofit strategy. The response modifications obtained will be analyzed and optimum scheme will be identified.

**Task Integration:** Describe how the work performed contributes to a larger task within the program; what contributions are anticipated.

The proposed project will help apply response modification technologies to a multi story building. This will be based on the Year 5 (second year for this project) results of the non-linear push over analysis. Also this activity will help educating students for careers in earthquake engineering, thereby contributing to the educational interface program of the MCEER.

**Justification:** Describe how the effort will make a unique, useable contribution to the MCEER strategic plan and earthquake hazards mitigation.

A response modification technology in seismic design is a relatively new phenomenon, which has entered the design codes such as FEMA 273/351, and ATC 40. As such this research will provide a latest application technique in earthquake hazard mitigation.

This project will train students in latest practice based technology in earthquake hazard mitigation, and hence enhance the Educational Interface Program of the MCEER.
**Problem and Approach:**

The project seeks to study application of response modification technologies for performance based seismic design of a multi story building. The approach used will be structural simulation using passive dampers in a time history dynamic analysis as per FEMA 273/351 and ATC 40. 3-D models of SAP 2000/ETABS programs will be used.

**Progress to date:** (if ongoing effort)

With the year 5 funding (second year for this project), a non-linear push over analysis has been done and building performance levels has been determined. This is by using 2-D and 3-D models of SAP2000/ETABS and Perform 2D structural simulation programs.

**Possible Technical Challenges:**

i) Accurate non-linear modeling of 3-D building for response modification.
ii) Interpretation of simulated results.

**Anticipated outcomes/deliverables:**

<table>
<thead>
<tr>
<th>Potential end-users beyond academic community:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practicing Engineers in Earthquake Engineering</td>
</tr>
</tbody>
</table>

As this is a practice-oriented project, practicing engineers will benefit from the outcome of the project.

**Project Schedule: (milestones and estimated time of achievement; e.g. Fall, Spring Summer)**

| i) 3-D modeling of the multistory building with passive energy dissipation divices (Fall 2002) |
| ii) Time history analysis with different alternatives(Winter 2003) |
| iii) Retrofit recommendations (summer 2003) |

**Educational outcomes and deliverables, and intended audience:**

i) Response modification technology Models of a multistory building
ii) Training students in advanced technologies in earthquake engineering

**Projected future work:**

Advanced Control Strategies for Control of buildings
## MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>03/5.5</th>
<th>Budget: NSF</th>
<th>Yr 6 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Number:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task Title:</td>
<td>Graduate Modules</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigator/Institution:</td>
<td>Billie F. Spencer, Jr.*/University of Illinois at Urbana-Champaign</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates task leader

**Statement of Project Goals:** (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)

The objective of this effort is to develop web-based modules to support earthquake engineering research and education ranging from graduate to the professional level. Module development will be primarily Java-based so as to be broadly accessible via the World Wide Web. These efforts have an overall goal of providing increased awareness and interest in earthquake engineering for the public and students of all levels, as well as practitioners. Additionally, the PI will represent MCEER in center to center coordination for the development of graduate level educational modules, which is a continuation of previous year’s efforts.

**Problem Description and Research Approach of Proposed Work for Year 6:** (Detailed description of research to be conducted and methodology to be used.)

To develop a suite of educational modules that will provide an interactive means for students to gain fundamental understanding and intuition regarding topics in earthquake engineering via the World Wide Web. At the graduate/professional level, virtual laboratory (VL) experiments will be developed based on the platform independent Java programming language and will be integrated into the framework of the MCEER member-institution coordinated graduate professional educational program in earthquake engineering. Current modules for the nonlinear response of structures are limited to two degree-of-freedom systems. One of the focuses of this year’s effort will be the development of modules that can portray the behavior of $n$-degree-of-freedom nonlinear structures. An additional feature will be the ability to include various types of supplemental damping devices in the analysis (e.g., linear and nonlinear viscous dampers, yielding hysteretic dampers, etc.). At the undergraduate level, educational modules should focus on enhancing the existing curriculum through appropriate web-based tools. These tools could introduce earthquake hazard mitigation as an exciting multidisciplinary area of research, and will compliment ongoing activities of the other Earthquake Engineering Research Centers and professional engineering organizations. These efforts are essential to developing the next generation of earthquake engineers.

**Assessment of State-of-the-Art:** (Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)

This project is a unique educational effort in the earthquake engineering community.
Progress to date: (If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2001, to March 31, 2002.)

Since this educational effort was initiated, the following activities have been achieved: (a) Development of a modular and systematic framework for the overall effort, allowing VL modules to be tightly integrated and provide for uniformity of operation, look and feel. (b) Development of basic Java-based applets for building VLEE modules, including numerical integration applets and various graphics applets. (c) Development of the VLEE supervisory program located at the url: http://cee.uiuc.edu/sstl/java/ (note that version 4.0 or higher of either Netscape Navigator and Internet Explorer is required). (d) Development of a “Structural Control using TMDs and AMDs” VLEE module located at the url: http://cee.uiuc.edu/sstl/java/sin.html. This module considers a single-degree-of-freedom building model subjected to various historical earthquake records. The module allows browsers to change system parameters and design TMD and HMD for response mitigation to seismic excitations. (e) Development of a “Nonlinear Base Isolation” VLEE module located at the url: http://cee.uiuc.edu/sstl/java/nonlinear/index.html. This module considers a two-degree-of-freedom building model (with base) subjected to various historical earthquake records. The structure is modeled as a linear one-degree-of freedom system, while different models including linear and nonlinear models are used to represent the behavior of the base isolation. This module allows browsers to change system parameters and design different base isolators for response mitigation to seismic excitations. (f) Developed a “Nonlinear Response of Structures” module VLEE located at the url: http://cee.uiuc.edu/sstl/java/twostory/animation.html. This module, the main focus of the previous year’s efforts, considers a nonlinear two-degree-of-freedom building model subjected to different earthquake loading. This two-degree-of-freedom building can behave either linearly or nonlinearly. The users are allowed to change the system parameters and to consider different structural models to mitigate the response of earthquake loading. (g) Development of documentation/help pages for the VLEE modules in both English and Japanese.

Role of Proposed Task in Support of Strategic Plan: (Describe how the effort will make a unique, usable contribution to the MCEER strategic plan.)

We must always strive to better prepare the next generation of structural engineers who can understand and effectively deal with the design of earthquake resistant structures so as to reduce the associated human and financial losses. The main goal of these educational modules is to provide practitioners and students at all levels with a means to interactively develop fundamental understanding and intuition regarding a wide range of topics in earthquake engineering via the World Wide Web. To allow for universal access, the educational modules will be primarily built using Sun’s Java Programming Language. Note that the Java platform provides for minimization of administrative overhead associated with maintenance of the VL.

Task Integration: (Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)

This task supports the overall goal of providing training for earthquake engineering students, researchers and practitioners, and of increasing public awareness of critical issues in earthquake hazard mitigation.

Possible Technical Challenges:
None anticipated.
### Anticipated Outcomes and deliverables:
(Also indicate those of particular benefit to IAB members and other end users.)
This effort will produce new educational modules, including a VL module that can portray the behavior of $n$-degree-of-freedom nonlinear structures. The module will include various types of supplemental damping devices in the analysis (e.g., linear and nonlinear viscous dampers, yielding hysteretic dampers, etc.).

### Potential end-users beyond academic community:
(IAB members and others.)
Earthquake engineering students and practitioners throughout the world.

### Educational outcomes and deliverables, and intended audience:
The educational modules are intended for earthquake engineering students, researchers and practitioners throughout the world. The modules that have already been established still receive approximately 500 visitors per month. The proposed effort will develop modules at several levels, including a VL module for the nonlinear response of MDOF structures. With the addition of the proposed modules, an even larger number of individuals can be reached.

### Project Schedule and Expected Milestones for the Project: (Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)
Develop web-based tools and applets to allow for: nonlinear analysis of dynamical systems. This task will involve:
- extend the Java based Newmark-beta and alpha numerical integration schemes to MODF systems, spring 2003
- development of Java applet to include supplemental damping devices, spring 2003
- initiate coordination and development of MCEER graduate educational modules among the three earthquake centers, spring 2003
- programming of graphical user interface for educational modules, summer 2003
- writing appropriate documentation and user’s manuals, fall 2003

### Team Members: (If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)
B.F. Spencer, Jr. (PI), Professor, University of Illinois at Urbana-Champaign
Yong Gao, Doctoral Candidate, University of Illinois at Urbana-Champaign
Diana Brinkmann, M.S. Candidate, University of Illinois at Urbana-Champaign
George C. Lee, Professor and Director of MCEER, State University of New York at Buffalo
Andrea S. Dargush, Assistant Director of MCEER, State University of New York at Buffalo

### Possible Direction of Work in Subsequent Years:
Continued development of new educational modules, along with integrations of these efforts with those of the other earthquake engineering research centers.
Section B:

Bibliography of Publications
Bibliography of Year 6 Publications

The publications listed in this section resulted from MCEER-sponsored research for project year 6. The list is arranged by MCEER thrust area, and further grouped by journal articles, workshop and conference proceedings, and books, book chapters and technical reports. There are 148 citations provided in this listing.

Research Program – Organized by Thrust Areas

Overarching Center-wide Cross Program Research Activities

Journal Articles


Workshop and Conference Proceedings


Thrust Area 1: Seismic Evaluation and Retrofit of Lifeline Systems

Journal Articles


Workshop and Conference Proceedings


**Books, Book Chapters and Technical Reports**

Thrust Area 2: Seismic Retrofit of Acute Care Facilities

Journal Articles


Workshop and Conference Proceedings


Dargush, G.F. and Sant, R.S., Computational Aseismic Design and Retrofit with Application to Passively Damped Structures, Seventh National Conference on Earthquake Engineering, Boston, MA, July 21-25, 2002, on CD-ROM.


Books, Book Chapters and Technical Reports


Thrust Area 3: Emergency Response and Recovery

Journal Articles


Workshop and Conference Proceedings


Books, Book Chapters and Technical Reports


**User Networks for Seismic Assessment and Retrofit of Critical Facilities**

**Workshop and Conference Proceedings**

Supplementary Research Activities

Workshop and Conference Proceedings


Books, Book Chapters and Technical Reports


**Education Program**

**Workshop and Conference Proceedings**


**Books, Book Chapters and Technical Reports**


Industry/Practitioner Collaboration and Technology Transfer

Workshop and Conference Proceedings

Section C:

Biographical Sketches
TAREK ABDOUN
Research Assistant Professor & Manager,
Geotechnical Centrifuge Research Center at RPI
Rensselaer Polytechnic Institute
Troy, NY 12180-3590
Phone: 518-276-6544
Fax: 518-276 4833
e-mail: abdout@rpi.edu

EDUCATION
Ph.D., Civil Engineering, Rensselaer Polytechnic Institute, Troy, NY, May 97 (Geotechnical Engineering) Dissertation: Centrifuge Modeling of Seismically Induced Lateral Spreading and Its Effect on Pile Foundation.
MS., Civil Engineering, Rensselaer Polytechnic Institute, Troy, NY, May 94 (Geotechnical Engineering) Thesis: Prediction of Soil Deformation Due to Seismically Induced Liquefaction.
B.S., Civil Engineering, Cairo University, Cairo, Egypt, June 91 (Structural Engineering).

ACADEMIC/PROFESSIONAL EXPERIENCE
Research Assistant Professor and Manager, RPI's Geotechnical Centrifuge Research Center, Rensselaer Polytechnic Institute, Department of Civil Engineering, Oct. 98-present.
Post Doctoral Research Associate & Technical Manager, Geotechnical Centrifuge Center, Rensselaer Polytechnic Institute, Department of Civil Engineering, Sept. 97-Aug. 98.
Research Assistant, Rensselaer Polytechnic Institute, Department of Civil Engineering, May 96-Aug.97.
Teaching Assistant, Rensselaer Polytechnic Institute, Department of Civil Engineering, Aug. 94-May 96.
Laboratory Engineer, Cairo University, Egypt, Department of Civil Engineering, Oct. 91-Dec. 92.
Engineer Trainee, Achen University, Achen, Germany, June 90-Aug. 90.

HONORS/STATE-OF-THE-ART PRESENTATIONS

RELEVANT PUBLICATIONS
1. "Soil-Pile Interaction during Lateral Spread." Goh, S.H., O'Rourke, T.D., Abdoun, T., and


MAKOLA M. ABDULLAH
Assistant Professor
Department of Civil Engineering
Florida A & M University
2525 Pottsdamer St.
Tallahassee, FL  32310
Phone:  850-410-6386
Email:  Abdullah@eng.fsu.edu

EDUCATION
1/92-6/94  Northwestern University, Evanston, IL, Doctor of Philosophy, Civil Engineering (Structural), Dissertation Title: Optimal Output Feedback Control of Civil Structures
9/90-12/91 Northwestern University, Evanston, IL, Master of Science, Civil Engineering (Structural) Thesis Title: Active Control of Tall Buildings
8/86-5/90  Howard University, Washington, DC, Bachelor of Science, Civil Engineering Magna Cum Laude

ACADEMIC EXPERIENCE
8/96-present Assistant Professor, Department of Civil Engineering, FAMU/FSU College of Civil Engineering, Florida Agricultural & Mechanical University, Tallahassee, FL
9/94-5/96  Adjunct Professor, Department of Chemistry & Physics, Department of Engineering Studies, Chicago State University, Chicago, IL
7/94-8/94  Mathematics Instructor, Pre-College Engineering Program (PREP), Chicago State University, Chicago, IL
7/90-6/94  Research Assistant, Department of Civil Engineering, Northwestern University, Evanston, IL

PROFESSIONAL EXPERIENCE
9/94-7/96 Jackson & Tull, Chartered Engineers, Chicago, IL, Engineer. Participated in the design process for the reconstruction of highway bridges. Also responsible for preparing reports and invoices.
5/88-8/88 Los Angeles Department of Water & Power, Los Angeles, CA., Associate Engineer. Inspected underground and above ground power transformer station for oil containment safety.
5/87-8/87 Illinois Department of Transportation, Shaumburg, CA, Assistant Engineer. Supervised construction work on Calumet Expressway bridge decks.

REFEREED PUBLICATIONS

COLLABORATORS & OTHER AFFILIATIONS
Yassir Abdelrazig, Ph.D., Dept. of Civil Engineering, FAMU-FSU College of Engineering; Emmanuel Collins, Ph.D., Dept. of Mechanical Engineering, FAMU-FSU College of Engineering; Shirley Dyke, Ph.D., Dept. of Civil Engineering, Washington University; Dale Wesson, Ph.D., Dept. of Chemical Engineering, FAMU-FSU College of Engineering.

GRADUATE ADVISOR
Takeru Igusa, Johns Hopkins University

THESES AND DISSERTATION ADVISOR
Ph.D. Dissertation (Committee Chairman):
Andy Richardson, Florida A&M University
Claudia Wilson, Florida State University
Ph.D. Dissertation (Committee Member):
Rafal Wuttrich, Florida State University
Tanya Green, Florida State University
Masters Thesis (Committee Chairman):
Jameel Hanif, Florida A&M University
Andy Richardson, Florida A&M University
Ken Walsh, Florida A&M University
Terri Norton, Florida A&M University
Shealy Gross, Florida A&M University

Masters Thesis (Committee Member):
Kevin Brinson, Florida State University
Eric Johnson, Florida State University
ANIL KUMAR AGRAWAL
Assistant Professor
The City College of the City University of New York
Department of Civil Engineering
Steinman Hall, Room 121
Convent Avenue at 140th Street
New York, NY 10031
Phone: 212-650-8442
Fax: 212-650-6965
Email: anil@ce-mail.engr.ccny.cuny.edu

PROFESSIONAL PREPARATION

Indian Institute of Technology, Kanpur (India), Civil Engineering, B.Tech., 1988.
University of Tokyo, Tokyo, Japan, Civil Engineering, M.Eng., 1991.
University of California, Irvine, CA, Civil Engineering, Ph.D., 1997.
University of California, Irvine, Structural Control, August 1997 to August 1998 (Post-Doctoral Fellow).

APPOINTMENTS

Associate Professor, City College of the City Univ. of New York, Jan. 2003 to Present.
Assistant Professor, City College of the City Univ. of New York, Sep. 1998 to Dec. 2002.
Post-doctoral Fellow, University of California, Irvine, CA, August 1997-to August 1998.

PUBLICATIONS

Most significant Publications

Other Significant Publications


SYNERGISTIC ACTIVITIES

Development of innovative algorithms for semi-active control of structures
Participation of undergraduate and graduate minority and underrepresented students in research
Research Experience for Undergraduates at the CCNY and in Japan
Service to the profession and Society through sessions organization.
Teaching improvement through integration of laboratory into courses

COLLABORATORS & OTHER AFFILIATIONS

Collaborators/Graduate and Postdoctoral Advisors

Professor J.N. Yang
Department of Civil Engineering
University of California, Irvine
Irvine, CA 92697

THESIS ADVISOR AND POSTGRADUATE-SCHOLAR SPONSOR

Dr. He, Wanlong [Ph.D. Student]
Engineer, RSD Engineering, P.C.
50 Broadway, New York, NY

CURRENT PH.D. STUDENTS: Three
DANIEL J. ALESCH
Professor
Community Sciences
University of Wisconsin Green Bay
2420 Nicolet Drive
Green Bay, WI  54311-7001
Phone:  920-465-2791
Email:  dalesch@new.rr.com

PROFESSIONAL PREPARATION
Doctor of Philosophy, Political Science, University of California, Los Angeles.  Fields of Study: Public Administration, Socio-technical Systems (Graduate School of Business), State and Local Government, and Comparative Administration. 1970.

Master of Arts, Political Science, University of California, Los Angeles. 1969.

Graduate School of Public Affairs, State University of New York at Albany, Graduate School of Public Affairs, Political Economics.  Course work in economics, econometrics, mathematics, and fiscal policy.  Withdrew to accept position at the University of Southern California. 1966-68.

Master of Science, Urban and Regional Planning, University of Wisconsin, Madison. 1964.

Bachelor of Science, University of Wisconsin, Madison, Political Science. Public Administration emphasis, Economics minor. 1962.

APPOINTMENTS
Professor of Public Administration and Administrative Science. University of Wisconsin-Green Bay. 1979 to present.

Senior Social Scientist, The Rand Corporation, Santa Monica, California; 1968-79.

Member, Research Staff, School of Public Administration, University of Southern California. 1967 - 68.


PUBLICATIONS


**SYNERGISTIC ACTIVITIES**
Currently, Principle Investigator on $307,000 grant from Public Entity Risk Institute to develop empirical models of small organization survival or failure following natural hazard events and to devise effective organizational mitigations.

Currently conducting research with Craig Taylor, Ph.D. on quantitative decision-assisting models for the natural hazard mitigation investment decision, in connection with a forthcoming publication of the American Civil Engineering Society.

**COLLABORATORS**

**GRADUATE AND POSTDOCTORAL ADVISORS**
All Graduate and Postdoctoral Advisors are deceased.

**THESIS ADVISOR AND POSTGRADUATE-SCHOLAR SPONSOR**
Advisor to more than 20 masters level students in organizational science and management, none of whom are engaged in work in the field of structures, earth science, seismology, or natural hazards.
AMJAD J. AREF
Department of Civil, Structural and Envir. Engineering
State University of New York at Buffalo
235 Ketter Hall
Buffalo, NY 14260
Phone: 716-645-2114 x 2423
Fax: 716-645-3733
e-mail: aaref@eng.buffalo.edu

EDUCATION
Ph.D. Civil Engineering, University of Illinois at Urbana-Champaign, January 1997.
Dissertation: A Novel Fiber Reinforced Composite Bridge Structural System.
M.S. Civil Engineering, New Jersey Institute of Technology, Newark, New Jersey, 1991.
B.S. Civil Engineering, Birzeit University, West Bank, 1987.

APPOINTMENTS
Assistant Professor of Civil Engineering August 1997-present

RESEARCH INTERESTS
Application of fiber reinforced composite materials in bridge construction.
Optimization of FRP structural systems.
Behavior of fiber reinforced composite joints.
Earthquake Engineering
Computational Mechanics

PUBLICATIONS
Archival Journals


**GRADUATE RESEARCH ASSISTANTS**

- Mr. Wooyoung Jung (Ph.D. Student);
- Yihong He (Ph.D. Student, graduated May 2002);
- Yasuo Kitane (Ph.D. Student);
- Methee Chiewanichakorn (Ph.D. student)
- Wasim Barham (Ph.D. student)
SARAH BILLINGTON
Assistant Professor of Structural Engineering
Cornell University
220 Hollister Hall
Ithaca, NY  14853
Ph. 607-255-3294
Fax 607-255-9004
sb88@cornell.edu

PROFESSIONAL PREPARATION
1992-97 The University of Texas at Austin, M.S.E. 1994, Ph.D. 1997, Structural Engineering
1990-91 The Swiss Federal Institute of Technology, Fulbright Fellowship, Civil Engineering, Zurich
1986-90 Princeton University, B.S.E., High Honors 1990, Civil Engineering, Certificate in Architecture Studies

PROFESSIONAL APPOINTMENTS
Feb.-Dec. 1998 Visiting Professor with the Computational Mechanics group of Prof. René de Borst, Faculty of Civil Engineering, Delft University of Technology, The Netherlands
July 1997 - December 2002   Assistant Professor of Structural Engineering, Cornell University, Ithaca, NY
April-July 1992 Structural Engineer, Greiner Engineering, Inc., Timonium, Maryland
Sept.-Oct. 1991 Construction Management Intern, Elektrowatt Engineers, Laufenburg, Switzerland

SELECTED PUBLICATIONS


SYNERGISTIC ACTIVITIES
Organizing committee member for Cornell University Research In Engineering (CURIE) Program - a week long summer program for high school girls introducing them to engineering
Member of Provost's Task Force on Environmental Sustainability, advising the Provost on promising research thrust areas for Cornell University
Faculty advisor for Cornell student chapter of the Earthquake Engineering Research Institute, currently developing an exhibit on earthquake engineering for the local Science Center
Implementation of modified constitutive models for improved prediction of cyclic performance of structural concrete columns (for use with the finite element software, DIANA)
Contributing author to the ACI Committee 341 document on Performance-based Seismic Design of Concrete Bridge Columns. Organizing chapter on Seismic Behavior of Concrete Bridge Columns.

RECENT RESEARCH COLLABORATORS
Prof. John Breen, Civil Engineering, The University of Texas at Austin
Prof. René de Borst, Computational Mechanics, The Technical University of Delft
Prof. Tony Ingraffea, Civil Engineering, Cornell University

GRADUATE ADVISORS
Prof. John Breen, Civil Engineering, The University of Texas at Austin
Prof. Michael Kreger, The University of Texas at Austin
Prof. D. Andrew Vernooy, The University of Texas at Austin

GRADUATE STUDENTS, THESIS CHAIR
Mr. Tong-Seok Han, Ph.D. candidate, Cornell University, Aug. 1999 - April 2001
Mr. Keith Kesner, Ph.D. candidate, Cornell University, Aug. 1999- Jan. 2003
Mr. J. Matthew Rouse, Ph.D. candidate, Cornell University, Jan. 2000-
Mr. Kyle Douglas, Ph.D. candidate, Stanford University, Oct. 2002 -
Ms. Jaekyung Yoon, M.S. candidate, Cornell University, June 2000-May 2002
Mr. Ruben Ortiz, M.S. candidate, Cornell University, Jan. 2002 -
PROFESSIONAL AFFILIATIONS
American Society of Civil Engineers (ASCE)
American Concrete Institute (ACI)
Earthquake Engineering Research Institute (EERI)
International Association of Bridge and Structural Engineers (IABSE)
International Federation of Concrete (fib)
Precast/Prestressed Concrete Institute (PCI)

PROFESSIONAL SERVICE
Member, ACI-ASCE Joint Committee 423, Prestressed Concrete
Member, ACI Committee 341, Lateral Response of Concrete Bridges
Member, JCI Task Force for Highly Ductile Fiber-reinforced Cement-based Composites
Associate member, ACI-ASCE Joint Committee 447, Finite Element Analysis of Reinforced Concrete
Reviewer for the ASCE Journal of Structural Engineering, ACI Structural Journal, PCI Journal
Scientific Advisory Committee for 5th EURO-Conference on Computational Modeling of Concrete
Local Organizing Committee for 5th FRAMCOS Conference on Fracture Mechanics for Concrete Structures

HONORS & AWARDS
Fiona Ip Li ’78 and Donald Li ’75 Excellence in Teaching Award, College of Engineering, Cornell University, June 2002
ACI Structural Engineering Award (for best paper), 2002
ARC Career Award from the Civil Engineering Research Foundation (CERF), 2000
NSF Early Career Award, 2000
University of Texas Graduate Research Fellowship, 1994-1997
National Science Foundation Graduate Research Fellowship, 1993-1996
W.R.Grace Fellowship from the American Concrete Institute, 1993
Endowed Presidential Graduate Scholarship, University of Texas 1992
Fulbright Fellowship, 1990-91 (Zurich, Switzerland)
New Jersey Chapter Award from the American Concrete Institute, 1990

INVITED PRESENTATIONS

TEACHING EXPERIENCE
Cornell University: Advanced Structural Concrete (grad.), Structural Concrete Systems (grad), Structural Analysis (undergrad.), Physical and Computational Simulation of Materials (undergrad.)
MICHEL BRUNEAU  
Multidisciplinary Center for Earthquake Engineering Research  
State University of New York at Buffalo  
105 Red Jacket Quad  
Buffalo, NY  14261-0025  
Phone: (716) 645-3391 x 104  
Fax: (716-645-3399  
email: bruneau@acsu.buffalo.edu

PRESENT POSITION  
Professor, Department of Civil, Structural and Environmental Engineering  
Deputy Director, Multidisciplinary Center for Earthquake Engineering Research  
State University of New York (SUNY) at Buffalo

EDUCATION  
B. Sc. Civil Engineering, Université Laval, Québec (1983)  
M.S. Structural Engineering, University of California, Berkeley, USA (1984)  
Ph.D. Structural Engineering, University of California, Berkeley, USA (1987) with specialization in Earthquake Resistant Design.

SCIENTIFIC CONTRIBUTIONS  
Author or co-author of 44 referred journal papers, 58 papers in conference proceedings, and 33 research and engineering reports. Author or co-author of one textbook, 3 textbook chapters, and 2 EERI slide-sets. 10 invited conference presentations and keynote lectures, and over 30 invited presentations.

PROFESSIONAL EXPERIENCE  
1998 - Corresponding Member, Building Seismic Safety Commission, NEHRP Recommended Provisions Update Committee, Technical Subcommittee 6 on Steel Structures.  
1998 - Research Team Member, NCHRP 12-49 Comprehensive Specification for the Seismic Design of Bridges.  
1994 - Member Seismic Committee of Canadian Highway Bridge Design Code.  
1994 - 1998 Director, Ottawa Carleton Earthquake Engineering Research Centre.  
1993 - Member, American Society of Civil Engineers (ASCE) Steel Bridge Committee.  
1994 - Member, Canadian Association for Earthquake Engineering Standing Committee on Seismic Design.  
1992 – 1995 Associate Member, American Concrete Institute ACI-ASCE Committee 442 (Response of Concrete Buildings to Lateral Forces), Sub-committee on Masonry.  
Since 1985 Member, American Society of Civil Engineering.  
Since 1984 Member, Earthquake Engineering Research Institute.
Since 1994  Member, Canadian Association for Earthquake Engineering.
Since 1981  Member, Canadian Society of Civil Engineering.

Reconnaissance Visit to Earthquake Stricken Area:

On-site observation and study of structural damage for:
Hyogoken Nanbu (Kobe, Japan) earthquake of January 17, 1995, Richter Magnitude 7.2.
Loma Prieta (San Francisco/Oakland/Santa Cruz/Watsonville) earthquake of October 17, 1989, Richter Magnitude 7.1.
Mexico City, Mexico, earthquake of September 19, 1985, Richter Magnitude 8.1.

HONORS AND AWARDS
1996  Pratley Award for best paper in bridge engineering in the Canadian Journal of Civil Engineering.
1996  First recipient of University of Ottawa Young Researcher Award, awarded to best young researcher at the University of Ottawa.
1996  George S. Glinski Award for Excellence in Research, awarded to best researcher of the University of Ottawa Faculty of Engineering.
1994  Gzowski Medal, for best paper in the Canadian Journal of Civil Engineering.

SELECTED PUBLICATIONS
STEPHANIE E. CHANG
Research Assistant Professor
Department of Geography
University of Washington
Box 353550
Seattle, Washington 98195-3550
Phone: (206) 616-9018
Fax: (206) 543-3313
e-mail: sec@u.washington.edu

PROFESSIONAL PREPARATION
Princeton University Civil Engineering & Operations Research B.S.E., 1989
Cornell University Regional Science M.S., 1993
Cornell University Regional Science Ph.D., 1994

APPOINTMENTS
1997- present Research assistant professor, Dept. of Geography, Univ. of Washington
1994- 2001 Project/Lead eng. economist, ABS Consulting (formerly EQE International)

PUBLICATIONS

Most closely related publications

Other significant publications

SYNERGISTIC ACTIVITIES
1. Participated in the testing, refinement, and validation of HAZUS (FEMA's nationally applicable earthquake loss estimation software tool for local government disaster decision-support and other uses), specifically its economic loss modules.
2. Participating in King County/Pierce County Project Impact, an effort to evaluate potential earthquake impacts and convey this information to local businesses.
6. Member of EERI's Learning From Earthquakes committee.
7. Has supported student research assistants who are members of underrepresented groups (women, minorities) and is herself a member of under-represented groups.

COLLABORATORS & OTHER AFFILIATIONS
Collaborators
Ballantyne, D., ABS Consulting
Beyers, W.B., University of Washington
Eguchi, R.T., ImageCat, Inc.
Goltz, J.D., Caltech
Gordon, P., University of Southern California
Moore, J.E., Univ. of Southern California
Nojima, N., Gifu University
Okuyama, Y., West Virginia University
Seligson, H.A., ABS Consulting
Shinozuka, M., University of California, Irvine
Tierney, K.J., University of Delaware
Zerbe, R., University of Washington

Graduate and Postdoctoral Advisors
Graduate advisors: Barclay G. Jones (deceased), Erik Thorbecke, Thomas D. O'Rourke
TSEN-CHUNG CHENG
Lloyd F. Hunt Professor & Director, Electric Power
System Program, University of Southern California
634 PHE
Department of Electrical Engineering
University of Southern California
Los Angeles, CA 90089-0271
Phone: (213) 740-4712
Fax (213) 740-8677
e-mail  cuason@mizar.usc.edu

EDUCATION
Massachusetts Institute of Technology, B.S., 1969
Massachusetts Institute of Technology, E.E. and M.S., 1970
Massachusetts Institute of Technology, Sc.D., 1974

FIELD OF INTEREST
Power devices & systems; Neural network based analysis of power system and reliability; Power
system contingency planning during earthquakes.

PROFESSIONAL EXPERIENCE
1984 - present Lloyd F. Hunt Professor & Director, Electric Power Program, USC
1984 - 1984 Professor & Director, Electric Power Program, USC
1980 - 1984 Associate Professor & Director, Electric Power Program, USC
1974 - 1980 Assistant Professor, USC
1977 - 1977 Engineering Specialist, LADWP
1976 - 1976 Engineering Specialist, LADWP
1975 - 1975 Electric Power Research Institute, Palo Alto, CA

PROFESSIONAL ACTIVITIES
Fellow IEEE, Fellow IEEE PES, Fellow IEEE EIS
Member IEEE ICWG, Member IEEE NIWG, Member IEEE PEEC
Member IEEE LIS Member IEEE EISEC, Member IEEE OSEC
Member IEEE DC CSS
Secretary IEEE PEERS
Chair IEEE Working Group on CC HVDCSS
Member National Committee,
Conference Internationale Des Grounds Reseaux
Electriciens a Haute Tension

HONORS AND AWARDS
1988  Prize Paper Award, IEEE Power engineering Society (one of top two
papers out of 3000)
1987  Power System Relaying Committee Award for Prize Winning Paper
Listed in marquis "Who's Who in the West," "Who's Who in California"
and "Who's Who in America"
1981 IEEE Working Group Award

1981 Recipient of "Faculty Service Award," School of Engineering, USC

1976 Recipient of "Outstanding Electrical Engineering Faculty Member" USC

Engineering Member Honor Societies: Sigma Xi, Tau Beta Pi & Eta Kappa Nu

AREA OF CONSULTATION

Qualified to testify as expert witness in all areas involving product liability, personal injuries, fires of electric origin, electrical appliance failures and fires, electrical accidents, accident investigation and reconstruction, National Electric Code, National Electric Safety Code, General Order 95 (California), etc. Directing a high voltage laboratory with all the modern techniques for electrical measurements and analysis, simulation and accident reconstruction.

RELEVANT PUBLICATIONS


OTHER SIGNIFICANT PUBLICATIONS


COLLABORATORS

A.S. Farag, Electrical & Electronics Engineering Dept., College of Engineering, University Tenaga Nasional, Malaysia
M.Q. Feng, Dept. of Civil and Environmental Engineering, University of California, Irvine
Don Penn,  Drpenn Inc., 1477 Bradbury Rd., San Marino, CA  91108
Masannobu Shinozuka, Dept. of Civil and Environmental Engineering, University of California, Irvine
Ala Saadeghvaziri, Dept. of Civil Engineering, New Jersey Institute of Technology

GRADUATE STUDENTS/POSTDOCTORAL ADVISORS
Xianhe Jin, (post doctor)  Dept. of Electrical Engineering, USC

THESIS ADVISOR AND POSTGRADUATE-SCHOLAR SPONSOR
Xianhe Jin, Dept. of Electrical Engineering, USC

Total of 200 graduate students advised; 15 postdoctoral scholars sponsored
MICHAEL C. CONSTANTINOU  
Department of Civil, Structural and Environmental Engineering  
University at Buffalo  
State University of New York  
132 Ketter Hall  
Buffalo, NY 14260  
Tel: (716) 645-2114 Ext 2404 or 2446  
Fax: (716) 645-3733  
E-mail: constan1@eng.buffalo.edu

CURRENT AFFILIATION  
Professor and Chairman, Department of Civil, Structural and Environmental Engineering  
Co-Director, Structural Engineering and Earthquake Simulation Laboratory  
University at Buffalo, State University of New York

EDUCATION  
Diploma in Civil Engineering (5 year course), University of Patras, Greece, 1980  
M.S., Rensselaer Polytechnic Institute, Troy, N.Y., 1981  
Ph.D. in Civil Engineering, Rensselaer Polytechnic Institute, Troy, N.Y., 1984

ACADEMIC POSITIONS  
Assistant Professor, Dept. of Civil Engineering, Drexel University, Philadelphia, PA, 1984 to 1987.  
Assistant Professor, Department of Civil Engineering, University at Buffalo, State University of New York, 1987 to 1989.  
Associate Professor, Department of Civil Engineering, University at Buffalo, State University of New York, 1989 to 1994.  
Director of Graduate Studies, Department of Civil Engineering, University at Buffalo, State University of New York, 1990 to 1992.  
Professor, Department of Civil, Structural and Environmental Engineering, University at Buffalo, State University of New York, 1994 to present.  
Co-Director, Structural Engineering and Earthquake Simulation Laboratory, University at Buffalo, State University of New York, 1997 to present.  
Chair, Department of Civil, Structural and Environmental Engineering, University at Buffalo, State University of New York, 1999 to present.

PROFESSIONAL POSITIONS AND CONSULTING  
Consultant on analysis and design of structures with emphasis on seismic design, 1984-today.
Consulted on the following projects: Mesologgi Hospital, Greece; Corinth Canal Bridges, Greece; LNG Tanks, Greece; U.S. Court of Appeals Building, San Francisco; San Bernardino County Medical Center Replacement Project; Queensboro Bridge, NY; ISP Chemicals Tanks, Kentucky; University Bridge, Seattle; San Francisco Airport International Terminal; Corinth Canal Railway Bridge, Greece; Rion-Antirion Cable-Stayed Bridges; Caltrans SRMD Test Facility; JFK Roadways, NY; Beijing Railway Station, China; Hearst Mining Building, Berkeley; Rion-Antirion Approach Viaduct, Greece; Santa Clara Police Facility, CA; Yerba Buena Tower, San Francisco; 196th Street Bridge, Seattle; Woodrow-Wilson Bridge, Washington, D.C.; Ataturk International Airport Terminal, Turkey; Pasadena City Hall, CA; Ingram Micro Building, Santa Ana, CA; AboveNet Building, San Francisco, CA, Univ. Avenue Building, Palo Alto, CA; Bolu Viaduct, Turkey; Shemya Radar Facility, Alaska; CYTA Building, Cyprus; SouthBay Tower, San Jose, CA; Ashley Phosphate and US 52 Bridges, Charleston, SC; Museum of the Acropolis, Greece; Centre Administratif Pictet-Acacias, Switzerland;

Willamette River Bridge, Portland, Oregon; Sakhalin 2 Gas Platforms, Russia, Willamette River Bridge, Oregon; Sakhalin 1 Gas Platforms, Russia; New de Young Museum, San Francisco.

Consultant on analysis and design of industrial systems, identification of machine vibration problems and design of motion control systems for machines and equipment, 1984- today. Examples of projects: nonlinear, large displacement analysis of shelving systems; identification of vibration problems of paper processing machines; design of tuned mass dampers for machines; investigation of methods for enhancing damping in order to reduce vibration in machines; design of bridge expansion joints; testing of vibration isolation systems; design of seismic isolation system for telecommunication equipment, testing of bearings, testing of energy dissipation devices; design of vibration/seismic isolation system for 5,000 ton transfer press.

**PROFESSIONAL ACTIVITIES**

*Instructor of Professional Courses*
Drexel University

*Reviewer of Technical Papers*
American Society of Civil Engineers, Journal of Structural Engineering
American Society of Civil Engineers, Journal of Bridge Engineering
American Society of Civil Engineers, Journal of Engineering Mechanics
American Society of Civil Engineers, Journal of Geotechnical Engineering
Earthquake Engineering and Structural Dynamics
Probabilistic Engineering Mechanics
American Society of Mechanical Engineers, Journal of Applied Mechanics
Engineering Structures
Earthquake Spectra
International Journal of Solids and Structures
Mechanics of Structures and Machines
Structural Engineering and Mechanics
Advances in Structural Engineering
Reviewer of Research Proposals
National Science Foundation
Ministry of Research and Technology, Greece.
Ministry of Public Works, Greece.
U.S. Geological Survey

BOOKS AND BOOK CHAPTERS:


PUBLICATIONS
Selected Refereed Journals


GRADUATE STUDENTS
Supervisor of 26 Graduate and Doctoral Students
ANDREA S. DARGUSH  
Assistant Director for Education and Research Administration  
Multidisciplinary Center for Earthquake Engineering Research (MCEER)  
State University of New York at Buffalo  
107 Red Jacket Quadrangle  
Buffalo, New York 14261-0025  
Tel:  (716) 645-3391 Ext. 106  
Fax:  (716) 645-3399  
e-mail: dargush@acsu.buffalo.edu

PROFESSIONAL PREPARATION  
State University of New York at Buffalo  
BA Geography (1974), BA Geology (1975)  
University of Michigan, SUNY Buffalo  
Graduate Studies Geography, Geology

PROFESSIONAL APPOINTMENTS  
1993 - present Assistant Director for Education and Research Administration, MCEER  
1987-1993 Executive Assistant to the Director, MCEER  
1981-1986 Special Projects Geologist, Berea Oil and Gas Corp., Buffalo, NY  
1980-1981 Cartographer, Calocerinos & Spina, Buffalo, NY  
1978-1980 Cartographer, Coastal Corp., Detroit, Michigan  
1975-1977 GIS Technician, Calspan Corp., Buffalo, NY

PROFESSIONAL ACTIVITIES  
2002 Designate, American Geological Institute, EarthScope Education And Outreach Committee  
2000 Present Alternate, Interim National Committee for the Advanced National Seismic System  
2000 Member, National Science Teachers of America  
1999 Present Member, EERI Publications Committee  
1999-present Present Member, Project Impact Steering Committee, City of Buffalo  
1997 Consultant, New York Geographic Alliance  
1998-present New York City Area Consortium for Earthquake Loss Mitigation - Executive Committee  
1994-present Consultant, SUNY Environmental Studies Project  
1993-present Member, EERI Technology Transfer Committee  
1994-present Member, Earthquake Engineering Research Institute  
1985-present Member, Buffalo Association of Professional Geologists  
1999-present Member, American Geological Institute  
2001-present Member, National Science Teachers of America  
1991-present Member, Association of Women Geoscientists  
1988-present Member, Eastern Section - Seismological Society of America  
1988-present Member, Seismological Society of America  
1983-present Member, American Association of Petroleum Geologists
RELEVANT PUBLICATIONS
GARY F. DARGUSH
Professor
Department of Civil, Structural and Environmental Engineering
State University of New York at Buffalo
230 Ketter Hall
Buffalo, NY 14260
Tel. 716-645-2114 x 2405
Fax: 716-645-3733
Email: gdargush@eng.buffalo.edu

EDUCATION
Ph.D. State University of New York at Buffalo (1987)
M.S. State University of New York at Buffalo (1977)

PROFESSIONAL EXPERIENCE
State University of New York at Buffalo
Department of Civil, Structural and Environmental Engineering
- Professor (2002-Present)
- Associate Professor (1998-2002)
- Assistant Professor (1996-1998)
- Research Associate Professor (1990-1996)
- Research Assistant Professor (1987-1990)
- Research Assistant (1986-1987)
General Motors Corporation
Harrison Radiator Division, Lockport, New York
- Senior Engineer (1982-1986), Finite Element Analysis Group Leader
- Project Engineer (1980-1982), Industrial Heat Exchanger Group
Ford Motor Company
Structural Analysis Department, Dearborn, Michigan
- Research Engineer C (1977-1978)

PROFESSIONAL AFFILIATIONS
Faculty Advisor - SUNY/Buffalo Student Chapter (1996-1998)
American Society of Civil Engineers - Member
- Buffalo Section - Vice President (2001-2002), Secretary (2000-2001)
Faculty Advisor - SUNY/Buffalo Student Chapter (1996-1998)
American Society of Mechanical Engineers - Member
United States Association for Computational Mechanics – Member
SELECTED GRANTS
Evolutionary Aseismic Design and Retrofit; PI; Multidisciplinary Center for Earthquake Engineering Research, National Science Foundation and New York State, 2001-2003, $161,000.
Thermomechanical Modeling of Engineering Surfaces in Sliding Contact; co-PI with A. Soom (PI); National Science Foundation, 2000-2002, $150,000.
The Application of a Finite Element-Based Large Increment Method for Nonlinear Structural Problems; co-PI with A. Aref (PI); National Science Foundation, 2000-2003, $180,000.
Fragility of Passively-damped Structural Systems; PI; Multidisciplinary Center for Earthquake Engineering Research, National Science Foundation, 1998-2000, $176,000.
Active Aerodynamic Control of Civil Structural Systems; PI; National Science Foundation, 1997-2002, $209,000.

RESEARCH INTERESTS
Dr. Dargush conducts research in computational mechanics, earthquake engineering and structural control. He has developed finite element and boundary element methods, along with the corresponding software, for structural analysis and design. He has expertise in constitutive modeling of hysteretic and viscoelastic materials, in nonlinear analysis, and in fracture mechanics. He has also worked toward the development of a mechanics-based approach to problems of structural control. This latter effort led to the publication of the first book on passive energy dissipation systems, co-authored with Prof. T.T. Soong. In addition to this book, Dr. Dargush has published over forty papers in archival journals, a half dozen book chapters and numerous conference papers.

FIVE PUBLICATIONS RELATED TO EARTHQUAKE ENGINEERING
FIVE ADDITIONAL PUBLICATIONS

RECENT COLLABORATORS
Soom, A., Mechanical and Aerospace Engineering, SUNY/Buffalo
Aref, A., Civil, Structural and Environmental Engineering, SUNY/Buffalo

PRESENT POST-DOCTORAL AND PH.D. ADVISEES
Hadjesfandiari, A.; Grigoriev, M.; Lin, L.; Sant, R.; Cho, H.; Yu, Q.; Wang, Y.; Wang, C-H.
RICARDO DOBRY
Professor, Department of Civil Engineering
Rensselaer Polytechnic Institute
Troy, NY 12180-3590
Phone: 518-276-6934
Fax: 518-276-4833
e-mail: dobryr@rpi.edu

EDUCATION
Massachusetts Institute Of Technology, Sc.D., Civil Engineering, 1971
National University Of Mexico, Unam, M.S., (Soil Mechanics), 1964
University Of Chile, Structural Engineering, 1963

PROFESSIONAL EXPERIENCE
1981-Present  Professor, Civil Engineering, Rensselaer Polytechnic Institute, Troy, NY.
1988-Present  Director, Geotechnical Centrifuge Research Center, Rensselaer Polytechnic
             Institute, Troy, NY.
1984-1985  Visiting Professor, Civil Engineering, University of Texas at Austin, TX.
1977-1981  Associate Professor, Civil Engineering, Rensselaer Polytechnic Institute, Troy,
           NY.

HONORS/GUEST LECTURES/STATE-OF-THE-ART PRESENTATIONS
1985  J. James R. Croes Medal, American Society of Civil Engineers.
      Geotechnical Engineering of Soft Soils, Mexico City.
1991  Guest Lecture on “Soil Properties and Earthquake Response,” 10th European Conf. of
      Soil Mechanics and Foundation Engineering, Florence, Italy.
1991  Guest Lecture on “The Properties of Soils and Their Behavior During Earthquakes,” 9th
      Pan-American Conf. of Soil Mechanics and Foundation Engineering, Viña del Mar,
      Chile.
1992  Invited Special Lecture on “Centrifuge Modeling of Soil Liquefaction During
      Earthquakes,” 10th World Conf. on Earthquake Engineering, Madrid, Spain.
      Seismic Conditions,” 3rd Intl. Conf. On Recent Advances in Geotechnical Earthquake
      Engineering and Soil Dynamics, University of Missouri, St. Louis, MO.
1995  Keynote Lecture on “Centrifuge Modeling of Liquefaction Effects During Earthquakes,”
      1st Intl. Conf. on Earthquake Geotechnical Engineering, Tokyo, Japan.
1996  State-of-the-Art report on “Soil Dynamics,” 11th World Conf. on Earthquake
      Engineering, Acapulco, Mexico.
1998  Emerging Art report on “Liquefaction,” ASCE Specialty Conf. on Geotechnical
      Earthquake Engineering and Soil Dynamics, Seattle, Washington.

II.C-37
RELEVANT PUBLICATIONS

OTHER SIGNIFICANT PUBLICATIONS

OTHER COLLABORATORS IN LAST FOUR YEARS
K. Arulanandan I.M. Idriss G.R. Martin M.F. Riemer R.V. Whitman
J.P. Bardet K. Jacob T.-T. Ng R.F. Scott T.L. Youd
M. Baziar H.-Y. Ko T.D. O’Rourke R.B. Seed X. Zeng
I. Buckle B.L. Kutter E. Parra M. Shinozuka A.-W. Elgamal
P. Lam J. Prevost K.H. Stokoe II

THESIS ADVISEES/ POST DOCTORAL SCHOLARS

GRADUATE ADVISORS
MIT: Robert V. Whitman, José Roesset
EDUCATION
University of California, Los Angeles, CA, M.S., Systems and Earthquake Engineering (1975); B.S. Engineering, (1975)

PROFESSIONAL EXPERIENCE
2000-present President & CEO, ImageCat, Inc., Long Beach, California
1991 - 2000 Vice President, EQE International Inc., Irvine, California
1986-1991 Associate, Dames & Moore, Los Angeles, California
1984-1986 Senior Associate, Engineering Mechanics Associates
1983-1984 Principal Engineer, Agbabian Associates, El Segundo, CA
1975-1983 Department Manager, J.H. Wiggins Company, Redondo Beach, California

PROFESSIONAL ACTIVITIES
American Society of Civil Engineers
   Past Chairman of TCLEE Executive Committee (1990-1991)
   Past Chairman of TCLEE Committee on Seismic Risk
   1997 ASCE/TCLEE C. Martin Duke Lifeline Earthquake Engineering Award
   Member of Editorial Board, Natural Hazards Review
Earthquake Engineering Research Institute
   Past Member of Editorial Board, Earthquake Spectra
   Member of Seismic Risk Committee
   Member of Technology Transfer Committee (1992-Present)
   Member of Research Committee (2002-present)
U.S. Geological Survey
   Scientific Earthquake Studies Advisory Committee (2002-2004)
American Society for Testing and Materials
   Chair of Subcommittee on Seismic Fragility Formulations for Water Transmission Systems (2002 – present)
Multidisciplinary Center for Earthquake Engineering Research (1991 -Present)
   Member of Research Committee
   Member of Implementation Committee
   Member of FHWA/MCEER Research Committee
Chairman, FEMA/NIST Steering Committee to Develop a Plan for Assembling and Adopting Seismic Design Standards for Lifelines (1991-1992)
National Academy of Engineering, National Research Council
Member of Committee on Assessing the Costs of Natural Disasters
Member, City of Los Angeles, Mayor's Blue Ribbon Panel on Seismic Hazard
Reduction (1994-Present)
Member, Special California Seismic Safety Commission Panel that prepared a
report on the January 17, 1994 Northridge Earthquake in response to
Executive Order W-78-94

FIVE PUBLICATIONS MOST RELATED TO MCEER RESEARCH
1. Huyck, C.K., Mansouri, B., Eguchi, R.T., Houshmand, B., Castner, L.L. and M. Shinozuka,
   “Earthquake Damage Detection Algorithms using Optical and ERS-SAR Satellite Data –
   Application to the August 17, 1999 Marmara, Turkey Earthquake, Proceedings of the 7th
   U.S. National Conference on Earthquake Engineering, Boston, Massachusetts, July 21-25,
   2002.
   Application for Remotely Sensed Data: Construction of Building Inventories Using Synthetic
   Aperture Radar Technology,” Research Progress and Accomplishments, 1997-1999,
   published by the Multidisciplinary Center for Earthquake Engineering Research, Buffalo,
   New York.
   Workshop on Mitigation of Earthquake Disaster by Advanced Technologies, MEDAT-1, Los
   Angeles, California, March 2-3, 2000.
   Bortugno, “Real-Time Loss Estimation as an Emergency Response Decision Support
   System: The Early Post-Earthquake Damage Assessment Tool (EPEDAT),” Earthquake
5. Eguchi, R.T., Goltz, J.D., Taylor, C.E., Chang, S.E., Flores, P.J., Johnson, L.A., Seligson,

OTHER SIGNIFICANT PUBLICATIONS
1. EQE International and the Geographic Information Services of the State of California, "The
   Northridge Earthquake of January 17, 1994: Preliminary Report of Data Collection and
2. Eguchi, R.T., Goltz, J.D., Seligson, H.A., Heaton, T.H., "Real-Time Earthquake Hazard
   Assessment in California: The Early Post-Earthquake Damage Assessment Tool and the
   Earthquake Disaster Prevention for Lifeline Systems, NIST Special Publication 840, US
4. Eguchi, R. T., "Lifeline Damage and Resulting Impacts, Chapter 3, Socioeconomic Impact,

SYNERGISTIC ACTIVITIES
(1) Transfer of research findings on Lifeline Earthquake Engineering into Practice – Awarded ASCE’s 1997 C. Martin Duke Lifeline Earthquake Engineering Award; (2) Teaching and training on Lifeline Earthquake Engineering – Developed Earthquake Hazard Mitigation Course on Lifelines for the Federal Emergency Management Agency (FEMA) – taught over 50 courses throughout the U.S.; (3) Conducted innovative research on the use of remote sensing technologies for natural disaster assessment – currently participates as task coordinator on this topic as part of MCEER Research Committee; (4) Created a real-time loss estimation tool for the California Governor’s Office of Emergency Services – a tool that is still being used by the State and the City of Los Angeles.

COLLABORATORS
M. Shinozuka, F. Yamazaki, K.J. Tierney, B. Houshmand, H.A. Seligson, S.E. Chang and M. Matsuoka
MARIA Q. FENG
Department of Civil and Environmental Engineering
E4139, Engineering Gateway
University of California, Irvine, CA 92697-2175
Tel. 949-824-2162
Fax 949-824-2117
e-mail mfeng@uci.edu

EDUCATION
Ph.D. Degree (6/92), Department of Mechanical Engineering, Institute of Industrial Science,
University of Tokyo, Japan
MS Degree (3/87), Department of Mechanical Engineering and Intelligent Systems, University
of Electro-Communications, Tokyo, Japan
BS Degree (7/82), Department of Mechanical Engineering, Southeast University, Nanjing, China

ACADEMIC APPOINTMENTS
12/00-Present Leader of the Environment and Civil Infrastructure Layer
California Inst. of Telecommunications and Information Technologies
6/97-Present Associate Professor
Department of Civil and Environmental Engineering
University of California, Irvine
6/92-5/97 Assistant Professor
Department of Civil and Environmental Engineering
University of California, Irvine
4/90-6/92 Research Associate
Department of Civil Engineering and Operations Research, Princeton University

AWARDS AND HONORS (partial list)
CAREER Award by National Science Foundation (1995)
The Alfred Noble Prize jointly awarded by American Society of Mechanical Engineers, Institute
of Electrical and Electronics Engineers, American Society of Civil Engineers, American
Institute of Mining, Metallurgical, and Petroleum Engineers, and Western Society of
Engineers. (1995)
The Collingwood Prize by American Society of Civil Engineers (1995)
Charles Pankow Finalist Award for Innovation by Civil Engineering Research Foundation,
American Society of Civil Engineers (1997)
The Walter L. Huber Civil Engineering Research Prize by American Society of Civil Engineers
(1999)
Outstanding Research Award by Department of Civil and Environmental Engineering,
University of California, Irvine (2000)
Outstanding Alumi Award by University of Electro-Communications (2001)

PROFESSIONAL SERVICE AND ACTIVITIES (partial list)
Secretary and member of Technical Committee on Performance-Based Design and Evaluation,
American Society of Civil Engineers (2000-present).
Member of Technical Committee on Health Monitoring and Structural Identification of Constructed Facilities, American Society of Civil Engineers (1998-present).
Member of HITEC National Evaluation Panel for Seismic Isolation and Energy Dissipation Devices sponsored by Federal Highway Administration (FHWA) (1994-present).

SELECTED RECENT PUBLICATIONS RELATED TO THE PROPOSED SUBJECT

SELECTED RECENT PUBLICATIONS RELATED TO THE PROPOSED SUBJECT
MIRCEA GRIGORIU  
Professor  
School of Civil and Environmental Engineering  
Cornell University  
367 Hollister Hall  
Ithaca, NY 14853  
Tel. 607-255-3334  
Fax 607-255-4828  
e-mail: mdg12@cornell.edu

PROFESSIONAL PREPARATION  
Dipl. Ing. in Civil Engineering, Bucharest Institute of Civil Engineering, 1967.  
Dipl. Math, University of Bucharest, 1972.  
Ph.D. in Civil Engineering, Massachusetts Institute of Technology, 1976.

APPOINTMENTS  
- Professor, School of Civil and Environmental Engineering, Cornell University, July 1980 - Present (Associate Professor July 1980 - December 1986)  
- Visiting Professor, University of Innsbruck, August 1993 - January 1994  
- Visiting Professor, Princeton University, and Technical University of Munich, January 1987 - August 1987  
- Visiting Associate Professor, Department of Civil Engineering, University of Waterloo, July 1981 - August 1981 and October 1979 - June 1980  
- Research Assistant Professor, Department of Civil Engineering, University of Waterloo, May 1979 - September 1979  
- Research Associate, Department of Civil Engineering, McGill University, July 1977 - May 1978  
- Associate Professor, Department of Civil Engineering, Simon Bolivar University, February 1976 - February 1977  
- Assistant, Bucharest Institute of Civil Engineering, February 1967 - October 1973

PUBLICATIONS  
5 publications most closely related to the proposed project:  
A list of up to 5 other significant publications:


SYNERGISTIC ACTIVITIES


Professor Grigoriu is a member of the American Academy of Mechanics, American Society of Civil Engineers (Fellow), Committee on Probabilistic Methods (Chair, 1993-1994), Committee on Lifeline Earthquake Engineering, Committee on Fatigue and Fracture Reliability, Committee on Bridge Safety. Professor Grigoriu is on the editorial board of the Probabilistic Engineering Mechanics and Structural Safety journals, and he will be the next editor of the Journal of Engineering Mechanics starting on October 1, 2002.

Professor Grigoriu and his research group developed a library of computer codes for Monte Carlo simulation. Some of these codes are included in his most recent book on Applied Non-Gaussian Processes Prentice Hall, 1995. Additional software for generating material microstructures have been developed for his new book on Stochastic Problems in Applied Mathematics, Science, and Engineering.

Professor Grigoriu’s research and education reports have been recognized by the 1993 IASSAR Research Prize for contributions to modeling non-Gaussian processes and the 1998 SAE Distinguished Probabilistic Methods Education Award. He also has a remarkable record of professional activities. For example, Professor Grigoriu will be the Editor of the Journal of Engineering Mechanics starting on October 1, 2002.

COLLABORATORS & OTHER AFFILIATIONS

Collaborators during the last four years: L Bergman (University of Illinois, Urbana), G.G. Bucher (University of Innsbruck, Austria), P. Dawson (Cornell University), O. Ditlevsen (Technical University of Denmark), R. Ghanem (Johns Hopkins University), D. M. Ghiocel (STI Technologies, New York), V. Gusella (University of Perugia, Italy), A.M. Hasofer (La Trobe University, Australia), A. Ingraffea (Cornell University), A. Kareem (University of Notre Dama), S. Mukherjee (Cornell University), R. Rackwitz (Technical University of Munich Germany), A. Reinhorn (State University of New York at Buffalo), I. Rychlik (University of
Lund Sweden), M. Shinozuka (Princeton University), E. Simiu (NIST, Maryland), T.T. Soong (State University of New York at Buffalo), T. Stathopoulos (Concordia University Canada).

**Thesis Advisor and Postgraduate-Scholar Sponsor (last five years):** Sanjay Arwade (Johns Hopkins University), Stavroula Balopoulou (Athens Greece), Aldulrahman El Kalidi (GE Corporate Research Development and Cornell University), Chris Roth (Advanced Structural Mechanics and Design, Pretoria South Africa), Peyman Givi (State University of New York at Buffalo), Shigeru Kushiyama (Hokkai Gakuen University, Japan), Ehab Mostafa (Cornell University), Christopher Roth (Cornell University), Ivan Markov (University of Syracuse New York), Massimiliano Gioffre (University of Perugia, Italy), Federico Waisman (EQE California), Han Zunan (Department of Mechanical Engineering, Tsinghua University China).
BIJAN HOUSHMAND
Adjunct Associate Professor
Department of Electrical and Computer Engineering
University of California at Los Angeles
1781 Oakdale Street
Pasadena, CA 91106
Phone: (626) 449-3543
E-mail: bijan@ucla.edu

EDUCATION
University of Illinois at Urbana-Champaign (1986)

PROFESSIONAL ACTIVITIES
Institute of Electronic and Electrical Engineers (IEEE).
Union of Radio Science Institute (URSI).
Member of URSI Commission B.
Tau Beta Pi (Engineering Honor Society)

PUBLICATIONS
Selected Recent Publications
Comparison of IFSAR and LIDAR data,” IEEE Geophy. and remote Sensing, vol. 38, no. 4,

2. P. Gamba, and B. Houshmand, “Detection and Extraction of Buildings from Interferometric

3. P. Gamba, and B. Houshmand, “An Efficient Neural Classification Chain of SAR and

4. G. Hepner, B. Houshmand, I. Kulikov, N. Bryant, "Investigation of the Integration of
AVIRIS and IFSAR for Urban Analysis," Journal of Photogrammetric Engineering and
remote Sensing, August, 1998.

Analysis of Microwave Circuits Involving Highly Nonlinear Phenomena and EMC Effects,”

and Design Using Multimode Parallel FDTD Diakoptics,” IEEE Trans. on Microwave

7. N. Kaneda, B. Houshmand, and T. Itoh, "FDTD Analysis of Dielectric Resonators with
Curved Surfaces," IEEE Trans. on Microwave Theory and Tech., vol. 45, No. 9, pp. 1645-
1648, September 1997.


BOOK CONTRIBUTIONS


GEORGE C. LEE
Director
Multidisciplinary Center for Earthquake Engineering Research, and
Samuel P. Capen Professor of Engineering
University at Buffalo, State University of New York
109 Red Jacket Quadrangle
Buffalo, NY 14261-0052
Tel: Phone: (716) 645-3391 x 111
Fax: (716) 645-3399
e-mail: gclee@mceermail.buffalo.edu

EDUCATION
National Taiwan University, B.S., Civil Engineering (1955)
Lehigh University, M.S., Civil Engineering (1958)
Lehigh University, Ph.D., Civil Engineering (1960)

PROFESSIONAL EXPERIENCE
1996-present Director, Multidisciplinary/National Center for Earthquake Engineering Research
1992-1998 Director, National Center for Earthquake Engineering Research
1995-present Senior University Advisor for Technology, State University of New York at Buffalo
1989-1990 Acting Director, National Center for Earthquake Engineering Research
1/1978-1995 Dean, School of Engineering & Applied Sciences, State University of New York at Buffalo
1984-1990 Associate Director, Calspan-UB Research Center, Buffalo, New York
1984-1985 Acting Director, Health-Care Instrument and Device Institute, New York State Center of Advanced Technology, State University of New York at Buffalo
1977-1978 Head, Engineering Mechanics Section, National Science Foundation
1974-1977 Professor and Chairman, Department of Civil Engineering, State University of New York at Buffalo
1970-1971 Acting Chairman, Department of Civil Engineering
1973-1974 Department of Civil Engineering, State University of New York at Buffalo
1969-1977 Senior Research Fellow, National Institute of Health, Department of Physiology, Harvard School of Public Health, Boston, Massachusetts
1961-present Department of Civil Engineering, State University of New York at Buffalo, Samuel P. Capen Professor (1995-present), Professor (1967-1995), Associate Professor (1963-1967), Assistant Professor (1961-1963)
1960-1961 Postdoctoral Fellow, Lehigh University
1956-1960 Research Fellow, Research Assistant, Research Associate, Lehigh University
FIVE PUBLICATIONS MOST RELATED TO PROPOSED PROJECT


OTHER PUBLICATIONS


SERVICE TO THE SCIENTIFIC AND ENGINEERING COMMUNITY

Professional Memberships
Member, American Society of Civil Engineers (current)
Member, Structural Stability Research Council (current)
Member, Earthquake Engineering Research Institute (current)
Member, Committee on Hazard Mitigation Engrg., National Research Council (past)
Member, Committee on Earthquake Engineering, National Research Council (past)
HONORS AND AWARDS

2000 ASCE Newmark Medal
1995 University at Buffalo President's Medal in recognition of extraordinary service
1985 Man-of-the-Year Award, Niagara Frontier Technical Societies Council
1983 Engineering Educator's Award, Erie-Niagara Chapter of the NYS Professional Engineers Society
1980 Engineering Achievement Award, Chinese Institute of Engineers
1977 Superior Accomplishment Award, National Science Foundation
1974 Adams Memorial Award, American Welding Society

GRADUATE STUDENTS/POSTDOCTORAL SCHOLARS

Professor Lee has advised over 100 graduate students including 34 Ph.D. students and 16 post-doctoral fellows. Their own initiatives to decline the opportunity to review this proposal are expected. (Names in the last five years include: C. Shen, Z. Shen, Ti Chiang, Jim Zhu, W. S. Pong, S. H. Kim, R. H. Yang, M. C. Kim, W. K. Chen, M. Elkordy, E. T. Lee, G. C. Yao, X. S. Ma, C. F. Yang, H. Liu, M. Tong, Z. Liang, C. S. Tsai, W. Huang, S. Ruan, J. Shen, R. Tao, W.-C. Liu, W. Liu and Y. Kitane.)
EMMANUEL "MANOS" MARAGAKIS
Professor and Chairman, Civil Engineering
University of Nevada, Reno
Mail Station 258
Reno, NV 89557
Tel: 775-784-6937
Fax: 775-784-4466

EDUCATION
B.S. Civil Engineering, National Technical University of Athens, June 1980 (5-year program)

WORK EXPERIENCE
1994-Present: Professor and Chair, Department of Civil Engineering, University of Nevada, Reno
1989-1994: Associate Professor, Department of Civil Engineering, University of Nevada, Reno
1984-1989: Assistant Professor, Department of Civil Engineering, University of Nevada, Reno

SOCIETY MEMBERSHIPS
Associate Member of ASCE, Member of ASCE - Reno Chapter, Member of EERI, Member of AREA, Member of National Technical Chamber of Greece, Registered Professional Engineer in Greece.

COMMITTEE MEMBERSHIP
Member of the ASCE Technical Committee of the Engineering Mechanics Division on the Dynamics of Structures (until 1994),
Member of the ASCE Technical Committee on the Methods of Analysis (until 1995),
Chair of TRB Task Force A2C52 on Seismic Design of Bridges (until 1999),
Founding Chair of TRB Technical Committee on the Seismic Response of Bridges,
Member of AREA Committee 9, Seismic Design of Railway Bridges,
Reviewer for ASCE, TRB, NSF, SSA, EERI and several other journals.

MAJOR RESEARCH INTERESTS

COURSES TAUGHT AT THE UNIVERSITY OF NEVADA
MAJOR PUBLICATIONS

Dr. Maragakis has a total of over 130 publications.


LIST OF COLLABORATORS


Graduate Advisor: Dr. Paul Jennings;

Graduate Students: Q. Chen (Ph.D.), Saber Abdel-Ghaffar (Ph.D.), Spiros Vrontinos (Ph.D.), P. He (M.S.), J. Jones (M.S.), W. Abouelmaaty (M.S.), U. Sandiresagaram (M.S.), S. Ismail (M.S.), B. Nath (M.S.), G. Thornton (M.S.), M. Rondall (M.S.), A. Vlassis (M.S.), P. He (M.S.), R. Meis (Ph.D.), F. Sanchez (Ph.D.), K. Selvanitharan (M.S.).
THOMAS O'ROURKE
Thomas R. Briggs Professor of Engineering
Cornell University
School of Civil and Environmental Engineering
273 Hollister Hall
Ithaca, NY 14853-3501
Phone: (607) 255-6470
Fax: (607) 255-9004
email: tdo1@cornell.edu

EDUCATION

Ph.D. University of Illinois at Urbana/Champaign (1975)
M.S.C.E. University of Illinois at Urbana/Champaign (1973)
B.S.C.E. Cornell University (1970)

PROFESSIONAL EXPERIENCE

Professor O'Rourke has been a member of the teaching and research staffs at Cornell University and the University of Illinois at Urbana-Champaign. His teaching and professional practice have covered many aspects of geotechnical engineering including foundations, earth retaining structures, slope stability, soil/structure interaction, underground construction, laboratory testing, and elements of earthquake engineering. He has authored or co-authored over 280 publications on geotechnical, underground, and earthquake engineering.

He was elected a member of the National Academy of Engineering in 1993. He was awarded the C.A. Hogentogler Award from ASTM in 1976 for his work on the field monitoring of large construction projects. In 1983 and 1988, Prof. O'Rourke received the Collingwood and Huber Research Prize, respectively, from ASCE for his studies of soil and rock mechanics applied to underground works and excavation technologies. In 1995 he received the C. Martin Duke Award from ASCE for his contributions to lifeline earthquake engineering, and in 1997 he received the Stephen D. Bechtel Pipeline Engineering Award from ASCE for his contributions to the profession of pipeline engineering. In 2002 he received the Trevithick Prize from the British Institution of Civil Engineers and was designated as an NSF Distinguished Lecturer. He received the 1996 EERI Outstanding Paper Award. In 1998, he was elected to the EERI Board of Directors and serves as President from 2003-2005. In 1998, Prof. O'Rourke received Cornell University’s College of Engineering Daniel Lazar ’29 Excellence in Teaching Award. In 2000 he was elected a Fellow of the American Association for the Advancement of Science and received the Distinguished Alumnus Award in Civil and Environmental Engineering from the University of Illinois. He testified before the US House of Representatives Science Committee on engineering implications of the 1999 Turkey and Taiwan earthquakes. He has served on numerous earthquake reconnaissance missions, and holds a US patent for innovative pipeline design.

Professor O'Rourke has developed engineering solutions for problems concerning foundation performance, ground movement effects on structures, earth retaining structures, pipelines,
earthquake engineering, tunneling, and infrastructure rehabilitation, both on a research and consulting basis. He has served as chair or member of the consulting boards of several large underground construction projects, as well as the peer reviews for projects associated with highway, rapid transit, water supply, and energy distribution systems. He has assisted in the development and application of advanced polymer and composite materials for the in-situ rehabilitation of water supply and gas distribution pipelines. He has developed techniques for evaluating ground movement patterns and stability for a variety of excavation, tunneling, micro-tunneling, and mining conditions. He has developed analytical methods and siting strategies to mitigate pipeline damage during earthquakes, analyze and design high pressure pipelines, and has established full-scale testing facilities for transmission and distribution pipelines. He has developed geographical information systems and network analysis procedures for water supply systems in areas vulnerable to earthquakes and other natural disasters.

PROFESSIONAL ACTIVITIES

He is a member of the ASCE, ASME, ASTM, AAAS, ISSMEE, EERI, and IAEG. He is a member of the NSF Engineering Directorate Advisory Committee, and serves on the Executive Committees of the Multidisciplinary Center for Earthquake Engineering Research and the Institute for Civil Infrastructure Systems. He was chair of the U.S. National Committee on Tunneling Technology and a member of the NRC Geotechnical Board and Board on Energy and Environmental Systems. He is a past chair of the UTRC Executive Committee and both the ASCE TCLEE Executive Committee and Technical Committee on Gas and Liquid Fuel Lifelines. He is a past chair of the ASCE Earth Retaining Structures Committee, as well as past president of the ASCE Ithaca Section, and was a member of the intermunicipal water commission in his home town.

RELEVANT PUBLICATIONS


COLLABORATORS

Persons who have worked on projects, articles, books, etc. within the last 48 months: Netravali, H.E. Strt, C.O’Donnell, S. Toprak, J. Pease, M. Palmer Professor E.J. Cording, University of Illinois

GRADUATE STUDENTS/POSTDOCTORAL SCHOLARS

APOSTOLOS S. PAPAGEORGIOU
Professor
Department of Civil, Structural and Environmental Engineering,
State University of New York at Buffalo
222 Ketter Hall
Buffalo, NY., 14260-4300
Phone: (716) 645-2114 x 2416
Fax: (716) 645-3733
e-mail: papaga@eng.buffalo.edu

EDUCATION
B.Sc. Civil Engineering (Structural Engineering) M.I.T. (1976)
M.Sc. Civil Engineering (Structural Engineering) M.I.T. (1978)

ACADEMIC/PROFESSIONAL HISTORY
1999 - present Professor, Department of Civil, Structural, and Environmental Engineering,
University at Buffalo, January
3/90– 12/98 Associate Professor, (with tenure), Department of Civil Engineering, R.P.I.
9/83-3/90 Assistant Professor, Department of Civil Engineering, R.P.I.
10/81-8/83 Military Service: Greek Army Corps of Engineers
9/76-2/81 Research Assistant, Department of Civil Engineering, M.I.T.

HONORS AND AWARDS
The Richard Lee Russel Award of 1976, of the Department of Civil Engineering, M.I.T., “in recognition of distinguished academic achievements”.

GOVERNMENT COMMITTEES AND SERVICE
Reviewer of the research conducted by the Lawrence Livermore National Laboratory (LLNL) and the Electric Power Research Institute (EPRI) on the Seismic Hazard Characterization of the Eastern United States. Review requested by the Panel of Seismic Hazard Analysis of the Committee on Seismology, National Research Council, National Academy of Sciences.
Member, for three consecutive years, of a review panel for research awards granted by U.S. Geological Survey for the National Earthquake Hazards Reduction Program (NEHRP).
Member of the Seismic Effects Committee of the Structures Division of the American Society of Civil Engineers (ASCE).
Member of the Dynamics Committee of the Engineering Mechanics Division of the American Society of Civil Engineers (ASCE).

RELEVANT PUBLICATIONS


OTHER SIGNIFICANT PUBLICATIONS


PROFESSIONAL PREPARATION
DPA, University of Southern California, Los Angeles, CA (1969)
MPA, University of Southern California, Los Angeles, CA (1969)
MBA, University of Southern California, Los Angeles, CA (1963)
BSME, University of Pittsburgh, Pittsburgh, PA (1956)

APPPOINTMENTS
1998 – present Professor, School of Policy Planning and Development, University of Southern California
1986-1998 Professor of Systems Management, University of Southern California
1973-1986 Associate Professor of Public Administration, University of Southern California, (Adjunct 1973-1982)
1970-1974 Associate Professor of Public Administration, California State University, Fullerton, California

PUBLICATIONS
5 publications most closely related to the projects:

Five Other Significant Publications

SYNERGISTIC ACTIVITIES

2000 - 2001 Chair, EERI/Public Agency Risk Managers Association Joint Project on Earthquake Risk management for Local Government
1998 - 2002 Member, Steering Committee, City of Los Angeles FEMA/OES Hazard Mitigation Grant on Seismic Grading and Retrofitting Evaluation Project
1993-1995 Member, Seismic Risk Subcommittee of the Blue Ribbon Panel on Seismic Hazard Reduction, City of Los Angeles, California.
1993-1996 Member, Seismic Rehabilitation Advisory Panel, Building Seismic Safety Council (BSSC), Washington, D.C.
1985-1991 Member, Committee on Natural Disasters, National Research Council, National Academy of Sciences, (Chair, 1988-89).

COLLABORATORS AND OTHER AFFILIATIONS
Daniel Alesch, University of Wisconsin, Green Bay
Ronald Eguchi, Imagecat, Inc
John Falcocio, Brooklyn Polytechnic University
Peter Gordon, University of Southern California
Richard John, University of Southern California
Craig Taylor, Natural Hazard Management, Inc
Elliot Mittler, Consultant
James Moore, University of Southern California
Joanne Nigg, University of Delaware
Tom O'Rourke, Cornell University
Richard Schuler, Cornell University
Masonuba Shinozuka, University of Southern California
Roy Sparrow, New York University
Kathleen Tierney, University of Delaware
Howard Kunreuther, University of Pennsylvania
Detlof von Winterfeldt, University of Southern California
Rae Zimmerman, New York University
Graduate And Postdoctoral Advisors: Kim Nelson, Retired; Neeley Gardner, Deceased; Lyle Knowles, Pepperdine University.

Thesis Advisor: Vilas Mujumdar, Regulation Services, Division of the State Architect, Sacramento, California.
RUPA PURASINGHE  
Professor, Department of Civil Engineering  
5151 State University Drive  
California State University at Los Angeles  
Los Angeles, CA 90032  
Tel: 323-343-4459  
Fax: 323-343-6316  
email: rpurasi@calstatela.edu

PROFESSIONAL PREPARATION  
University of Peradeniya, Civil Engineering, B.S. October 78  
Portland State University, Oregon, Structural Engineering, M.S. Dec 81  
Case Western Reserve University, Ohio, Structural Engineering, Ph.D., Jan 85  
Registered Professional Engineer (California and Ohio)

APPOINTMENTS  
Professor 1992 - present; Associate Professor 1988-1992  
Department of Civil Engineering, California State University at Los Angeles,  
CA 90032

Research Associate (Summers 1996, 1997) in Dynamic Analysis of Structures  
Department of Civil Engineering, University of California, Irvine

Research Associate, (Summers 1992, 1993) in Pointing and Accuracy Analysis of Solar  
Concentrator Support Structures, Phillips Laboratory, U.S. Air Force, Edwards, CA

Assistant Professor 1994 - 1998  
Department of Civil engineering, North Dakota State University, Fargo, ND 58103

PUBLICATIONS  
Mostly related to proposed project
Frames with Viscous Dampers- Simplified Method of Analysis," Invited Keynote  
Presentation at 12 th Symposium on Earthquake Engineering, Roorkee, India, December  
2002.
3. Purasinghe, R., Feng, M., Moragumi, S., Shinozuka, M., Mercado, E., Olmedo W.  
"Development of Pneumatic Muscle Actuator System," Presented paper, New Frontiers in  
(Note: Mercado, E, Olmedo, W. are underrepresented minority undergraduate students at  
CSLA.)
Control of Building Frames," Presented paper, Structures under Shock and Impact (SUSI)  
International Conference, Thessaloniki, Greece, June 1998. (Note: S. Cho, Graduate Student  
at CSLA.)
5. Purasinghe, R., Alam, J., and Apanay F., "Parametric Based Solid modeling and Stress Analysis," Proceedings of the 7th International Conference on Computing in Civil and Building Engineering, Seoul, Korea, August 97. (Note: Apanay F., Graduate student at CSLA.)

Other significant publications

SYNERGISTIC ACTIVITIES
1. Civil Engineering Professor of the Year Award, Engineering, Computer Science, and Technology Student Council, CSLA, February 2003.
2. Award of Appreciation by Structural Engineers Association of Southern California, in recognition of distinguished service as a Faculty Advisor, Structural Engineering Association of CSLA, 96.
4. Distributed Online Line Learning in an Engineering Design Project Course," $ 5,000.00 , CSLA Innovative Instruction Award, 99/00.
5. Plaque in appreciation for outstanding service to Minority Engineering Science Achievement (MESA) Program, MESA/CALTRANS/CSULA Summer Intern Program, for high school minority students 93.

Collaborators & Other Affiliations:
Collaborators:
1) Alam, J. Youngstown State University 2) Feng, M. Univ. of California at Irvine
3) Kim, J.M., University of California at Irvine 4) Lee, G., University at Buffalo
5) Moragumi, S., Univ. of California at Irvine 6) Shinozuka, M., Univ. of California

Graduate and Post Doctoral Advisors:
Mullen M. (Ph.D. Advisor) Case Western Reserve University
Mueller, W. (M.S. Advisor), Portland State University

Post Graduate Scholar Sponsor for
Apanay F., Akelan S., Wei S., Liping, S., Valencia, B, Cardelon, M., Worku, D. (Post graduate scholar sponsor for about 10 graduate students in last 5 years)
ANDREI M. REINHORN
Clifford Furnas Eminent Professor of Structural Engineering
Department of Civil, Structural and Environmental Engineering
State University of New York at Buffalo
231 Ketter Hall
Buffalo, NY 14260-4300
Phone: (716) 645-2114 x 2419
Fax: (716) 645-3733
email: reinhorn@buffalo.edu

EDUCATION
1968 Technion - Israel Institute of Technology. Haifa, Israel, B.S. Civil Engineering,
1978 Technion - Israel Institute of Technology. Haifa, Israel, D.Sc. Civil Engineering
Registered Professional Engineer: NY, P.E. No. 59572 (1982); Israel, P.E. No. 07402 (1968)

APPOINTMENTS/POSITIONS
Visiting Professor, (Lady Davis Fellowship) Technion Israel Inst. of Tech., Israel, Fall 1999 and Spring 1991
Lecturer, (equivalent of Assistant Professor) Technion Israel Institute of Technology. 1978-79
Project Manager (to Captain), Corps of Engineers-Israel Defense Forces, Haifa, Israel 1968-72
Member of Technical Update Subcommittee 2, Development of NEHRP Provisions for Seismic Regulations, 1996-2000
Associate Editor, ASCE- Journal of Structural Engineering
Editorial Board, EERI - Earthquake Spectra

Consulting/(Reinhorn Consulting Engineers) - Recent Involvements:
1993-present John A. Martin & Associates, CA
1993-1995 Base Isolation Consultants, San Francisco, CA
1990-1994 Fleming Corp., San Francisco/Los Angeles, CA
1987-1994 Westinghouse Electric Company/ABB, Bloomington, IN

PATENTS
Press Brake Deflection Compensation Structure,
Diagnostic techniques for momentarily operating machinery’s
AWARDS AND HONORS
Engineer of the Year Award - NYSPE (2002)
AGC/Build San Diego Award for NCEER project of seismic protection of Naval Station Bldg. (1998)
Outstanding Achievement Award - LA Tall Building Engineering Society (1996)
Outstanding Paper Award - The Structural Design of Tall Buildings (Journal) (1996)
Historical Achievement Award “Active Control Implementation” NYSPE/Buffalo Historical Soc. - (1995)
Best Paper Award - 3rd World Congress on Joints, Sealings and Bearings (1992)
Educator of the Year Award - NYSPE (1991)
Lady Davis Fellowship/Theresa Palay Manson Lectureship/Technion IIT (1991)
Listed in “Who is Who in the World,” & “Who is Who in America”

MEMBERSHIP IN SCIENTIFIC & PROFESSIONAL SOCIETIES
Earthquake Engineering Research Institute, EERI, 1986-present
   Member, Committee on Experimental Research
American Society of Civil Engineers, ASCE 1981-present
   Fellow since 1995Past President, Buffalo Section 1993-1994
   Former Director, Board of Directors, Buffalo Section 1986-96
Member, National Committee of Seismic Effects / Structural Engineering Institute 200-2005
Chair / Founder, National Structural Control Subcommittee 1992-1994
Concrete Inst., ACI 1982-present
Past member of ACI committee 449 seismic loading
Structural Engineers Association of New York (SEAoNY) 1998-present

SUPERVISION
18 Post Doctoral Fellows and Visiting Scholars, 15 (25) Ph.D. and 32 MS completed; 4 Ph.D and
1 MS. in progress; 42 Ph.D. Committees/Outside Reader

PRESENTATIONS
68 Invited Lectures; 114 Conference Lectures with Proceedings; 24 Seminars and Conference
Lectures w/o Proceedings; 22 Chaired Sessions in Conferences and Workshops

PUBLICATIONS
89 Reviewed papers in Journals; 34 Reviewed papers in Edited Books; 1 Section in Codes and
Standards; 4 Computer software platforms with international distribution; 114 Papers in
Conference Proceedings; 48 NCEER/MCEER Reports; 32 Miscellaneous Technical Reports

RELEVANT PUBLICATIONS
R/C Structures with Viscoelastic Braces,” Earthquake Spectra, 9(3),, 419-446.
Concrete Buildings Designed for Gravity Loads: Performance of Structural Model,”


OTHER SIGNIFICANT PUBLICATIONS


5. IDAR2D - Vers. 1.0 - 5.0 “Inelastic Damage Analysis of Reinforced Concrete Frame - Shear Wall Structures,”- Computer Platform - NCEER & NISEE/EERC - U/C Berkeley, University of California at Berkeley, June 1988 (w/S.K. Kunnath) - Last release: IDARC2D-Ver. 5.0 (1999); IDARC- BRIDGE or IDARC 3D in progress (released Ver 1.0 1999).
http://civil.eng.buffalo.edu/idarc2d50/.


RECENT RESEARCH ASSOCIATES (past 48 months)

PH.D ADVISERS:  J. Gluck, A. Rutenberg (Israel)

ADVISEES:  S. Kunnath, S. Nagarajaiah, M. Riley, J. Bracci, V. Simeonov, R. Lobo, C. Li, etc.
ADAM ROSE
Professor
Department of Geography
The Pennsylvania State University
315 Walker Building
University Park, PA 16802-6813
Phone: 814-863-0179
Fax: 814-863-7433
email: azrl@psu.edu

EDUCATION:  Ph.D. (Economics), Cornell University (1974)
M.A. (Economics), Cornell University (1972)
B.A. (Economics), University of Utah (1970)

PROFESSIONAL EXPERIENCE
1988-02- Professor, Department of Energy, Environmental, and Mineral Economics, The Pennsylvania State University (Department Head, 1988-02)
1984-88 Professor, Department of Mineral Resource Economics, West Virginia University (Department Chairman, 1986-88)
1986 Visiting Associate, Environmental Quality Laboratory, California Institute of Technology
1981-84 Associate Professor, Department of Mineral Resource Economics, West Virginia University (Department Chairman, 1981-83)
1981-88 Faculty Associate, Regional Research Institute, West Virginia University
1979 Visiting Scholar, Natural Hazards Research Applications Information Center, University of Colorado, Boulder
1975-81 Assistant Professor Department of Economics, University of California, Riverside
1974-75 Senior Council Economist, New York State Council of Economic Advisors

PUBLICATIONS RELATED TO THE PROPOSED PROJECT

SIGNIFICANT OTHER PUBLICATIONS

SYNERGISTIC ACTIVITIES
• NSF/Earthquake Engineering Research Institute, Panel on Research Opportunities for Earthquake Engineering, 2001-
• Acting Associate Editor, Natural Hazards Review, 2001-
• Cofounder and Advisory Board Member, Natural Hazards Center, The Pennsylvania State University, 1998-
• Developer and Principal Instructor, Economics of Natural Hazards Course, Department of Energy, Environmental, and Mineral Economics, The Pennsylvania State University, 1998-
• Co-chair and Scientific Advisory Committee Member, NSF US/Japan Joint Seminar on Civil Infrastructure Research, 1997.
• Steering Committee Member, EERI/FEMA Conference on Analyzing Economic Impacts and Recovery from Urban Earthquakes: Issues for Policymakers, 1996.

RECENT COLLABORATORS
David Abler, Juan Benavides, David Brookshire, Irwin Bulte, Yiqing Cao, Stephen Casler, Stephanie Chang, Hal Cochrane, Tim Considine, Jae Edmonds, Ronald Eguchi, Ann Fisher, Henk Folmer, Landis Gabel, Shelby Gerking, Kenneth Hanson, Snorre Kverndokk, Rajnish Kamat, Dongsoon Lim, Shi-Mo Lin, Gbadebo Oladosu, Steven Rayner, Masanobu Shinozuka, James Shortle, Brandt Stevens, Kathleen Tierney, Marshall Wise, Brent Yarnal

PI's Ph.D. Mentor: Walter Isard

Students Supervised With Completed Degrees (past 5 years):
Samuel Addy, Juan Benavides, Yiqing Cao, Nathan Collamer, Gauri Guha, Rajnish Kamat, Shu-Yi Liao, Dongsoon Lim, Gbadebo Oladosu, Chunsheng Shang, Philip Szczesniak
M. ALA SAADEGHVAZIRI
Professor
New Jersey Institute of Technology
Department of Civil and Environmental Engineering
Room 260K
Newark, NJ  07102
Tel.  973-596-5813
Fax:  973-596-5790
Email:  ala@njit.edu
www.ec.njit.edu

PROFESSIONAL PREPARATION
University of Illinois @ Urbana-Champaign, Civil Engineering,  B.S. 1982 (high honors)
University of Illinois @ Urbana-Champaign, Civil Engineering,  M.S. 1983
University of Illinois @ Urbana-Champaign, Civil Engineering, Ph.D. 1988

APPOINTMENTS
2001-Present Full Professor, NJIT
1993-2001 Associate Professor, NJIT
1988-1993    Assistant Professor, NJIT

PUBLICATIONS
1. Saadeghvaziri, M. Ala, and S. Ersoy, "Analytical Evaluation of the Effects of Transformer-
Bushng Interaction on Their Seismic Response," Proceedings, 7th National Conf. on
Experimental Evaluation of Friction Pendulum System for Seismic Isolation of
Transformers," Earthquake Spectra, Journal of Earthquake Engineering Research Institute,
Research Institute, Vol 17 (4), November 2001.
3. Saadeghvaziri, M. Ala, and S. Ersoy, "Evaluation of Seismic Response of Transformers and
Effectiveness of FPS Bearings for Base-Isolation," Proc., 2001 Structures Congress, ASCE,
5. Saadeghvaziri, M. Ala, Alireza Yazdani-Motlagh, and Saeid Rashidi, "Effects of Soil-
Structure Interaction on Longitudinal Seismic Response of MSSS Bridges," Soil Dynamics
7. Saadeghvaziri, M. Ala, and S. Rashidi, "Seismic Retrofit and Design Issues for Bridges in
Inelastic Fiber Element for Cyclic Analysis of CFT Columns," Journal of Engineering
Load" Structural Journal, American Concrete Institute, Vol. 96, No. 6, Nov-Dec., 1999.

SYNERGISTIC ACTIVITIES
1. Reviewer to professional societies (ASCE, ACI, EERI) and funding agencies (NSF, USGS).
2. Member of professional societies (ASCE, EERI, ACI) and active in technical committees and in organizing national sessions and regional seminars.
3. A leader in curriculum improvements and adoption of modern technologies.
4. Active in multidisciplinary research such as application of engineering mechanics and computational methods in design of dental implants.
5. Innovative use of renewable materials to improve performance and environmentally responsive.

COLLABORATORS & OTHER AFFILIATIONS
1 - Mau, S.T., NJIT (Collaborator)
2 - Foutch, D., Univ. of Illinois (Graduate Advisor)
3 - Rashidi, S., Stevens Inst. of Tech. (Thesis advisor)
4 - Shams, M., (Thesis Advisor)
MASANOBU SHINOZUKA  
UCI Distinguished Professor and Chair  
University of California, Irvine  
Civil and Environmental Engineering  
E/4150 Engineering Gateway  
Irvine, CA  92697  
Tel.  949-824-9379  
Fax:  949-824-9446  
Email:  shino@uci.edu

PROFESSIONAL PREPARATION  
Kyoto University, B.S. in Civil Engineering, 1953  
Kyoto University, M.S. in Civil Engineering, 1955  
Columbia University, Ph.D. in Civil Engineering, 1960

APPOINTMENTS  
2001-present UCI Distinguished Professor and Chair, Department of Civil and Environmental Engineering, University of California, Irvine  
1995-2002 Fred Champion Professor of Civil Engineering, University of Southern California  
1988-1995 Sollenberger Professor of Civil Engineering, Princeton University  
1990-1992 Director, National Center for Earthquake Engineering Research at SUNY/Buffalo, (on leave from Princeton University)  
1990-1992 Visiting Capen Professor of Civil Engineering, SUNY/Buffalo  
1977-1988 Renwick Professor of Civil Engineering, Columbia University  
1969-1977 Professor of Civil Engineering, Columbia University  
1965-1969 Associate Professor of Civil Engineering, Columbia University  
1961-1965 Assistant Professor of Civil Engineering, Columbia University

PUBLICATIONS MOST RELATED TO PROPOSED PROJECT  
OTHER SIGNIFICANT PUBLICATIONS
1. Ho-kyung Kim, Masanobu Shinozuka and Sug-Pil Chang, “Nonlinear Buffeting Response of a Cable-Stayed Bridge”, Journal of Engineering Mechanics, ASCE, Accepted for publication, 2002

SYNERGISTIC ACTIVITIES
1. Long history of working with engineers at LADWP (Los Angeles Department of Water & Power) and MLGW (Memphis Light, Gas and Water) to estimate the seismic performance of their systems and recommend to the management for optimal retrofit.
2. In teaching, an innovative team project concept was devised and implemented that requires development of computer codes deploying Monte Carlo Simulation Methods to evaluate the performance of lifeline systems for which no analytical solutions and often only open-ended answers exist.
3. Development of useraided computer algorithms that create 3D digital images for seismically damaged structures from stereoscopic digital photos and videos.
4. Participated in joint research projects with a university officially designated as underprivileged taking the lead.
5. Served more than four decades as chairs and members of ASCE committees in Structural and Engineering Mechanics Division, and also served and serving as Executive Vice President and President of International Association of Structural Safety and Reliability.

COLLABORATORS

GRADUATE AND POSTDOCTORAL ADVISORS: Graduate Advisor: The Late Professor A.M. Freudenthal
ADVISEES: (Only active researchers not listed in C above) J.N. Yang, C.-B. Yun
THESIS ADVISOR AND POSTGRADUATE-SCHOLAR SPONSOR: The Late Professor A.M. Freudenthal
BILLIE F. SPENCER, JR.
Nathan M. Newmark Professor of Civil Engineering
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
205 North Matthews Ave
Urbana, Illinois 61801
Phone: (217) 333-8630
Fax: 443-646-0675
Email: bfs@uiuc.edu

PROFESSIONAL PREPARATION
University of Illinois at Urbana–Champaign, Theoretical and Applied Mechanics, Ph.D., 1985.
University of Illinois at Urbana–Champaign, Theoretical and Applied Mechanics, M.S., 1983.
University of Missouri–Rolla, Mechanical Engineering, B.S., 1981.

APPOINTMENTS
Newmark Prof. of Civil Engrg., University of Illinois, Urbana, Illinois, 2002–present.
Prof. of Civil Engrg., University of Notre Dame, Notre Dame, Indiana, 1995–2000.
Visiting Prof., Harbin Institute of Technology, Harbin, China, 2001.
Visiting Prof., South China Construction University, Guangzhou, China, 2000.
Schmidt Distinguished Visiting Prof., Florida Atlantic University, Boca Raton, Florida, 1999.

MAJOR AREAS OF TEACHING AND RESEARCH INTEREST
Smart structures for natural hazard mitigation
Structural health monitoring and damage detection
Fatigue and fracture reliability
Computational probabilistic methods
Deterministic and stochastic structural dynamics
Structural reliability

SELECTED MEMBERSHIPS AND SERVICES
American Society of Civil Engineers – Member
Member, International Association for Structural Control
Member, Committee on Probabilistic Methods, ASCE Engineering Mechanics Division, 1988–present.
Member, Committee on Structural Control, ASCE Structural Division, 1991–present.
Chair, 1994–present.
Member, Committee on Dynamics, ASCE Engineering Mechanics Division, 1992–present.
Member, Committee on Fatigue and Fracture Reliability, ASCE Structures Div., 1987–1992,

PUBLICATIONS AND AWARDS
2 books, 230 publications in refereed journals and technical conferences, 4 technical videos.
IASSAR Junior Research Prize, Alcoa Foundation Faculty Development Award, Co-recipient of
the ASCE Norman Medal, Cited by the Science Coalition in Great Advances in Scientific
Discovery, JSPS Short-Term Invitation Fellowship, and J.O. Smith Award as the Outstanding
Young Teacher in Engineering Mechanics.

Five Publications Relevant to Proposal
1. S.J. Dyke, B.F. Spencer, Jr., P. Quast, M. K. Sain, D. C. Kaspari, Jr. and T.T. Soong,
   “Acceleration Feedback Control of MDOF Structures,” Journal of Engineering Mechanics,
2. B.F. Spencer, Jr. S.J. Dyke, M.K. Sain and J.D. Carlson, “Phenomenological Model for
   Part I: Active Mass Driver System. Part II: Active Tendon System,” Earthquake Engineering
   JSME International Journal: Special Issue on Frontiers of Motion and Vibration Control,
5. G. Yang, B.F. Spencer, Jr., J.C. Carlson and M.K. Sain, “Large-Scale MR Fluid Dampers:

Five Other Significant Research Publications
1. B.F. Spencer, Jr., On the Reliability of Nonlinear Hysteretic Structures Subjected to
   Broadband Random Excitation, Lecture Notes in Engineering (series editors: C.A. Brebbia
2. S.J. Dyke, B.F. Spencer, Jr., P. Quast and M.K. Sain, “The Role of Control-Structure
   for Aseismic Protection,” Journal of Engineering Mechanics, Vol. 120, No. 1, pp. 135–159,
   1994.

SYNERGISTIC ACTIVITIES
Based on his research activities, B.F. Spencer, Jr. has developed new courses in Experimental
Structural Dynamics and Stochastic Concepts in Engineering, as well as short courses in Health Monitoring and Structural Control. He initiated the Shakes and Quakes middle school outreach program, developed the NSF sponsored Natural Hazard Mitigation in Japan program, developed the Java-based virtual laboratories for earthquake engineering education, organized the Linbeck Distinguished Lecture Series in Earthquake Engineering, and has been a keynote/plenary lecturer at numerous conferences and workshops.

RECENT GRADUATE STUDENTS
H. Deoskar, M.S. September 1996  G. Yang, Ph.D. December 2001
W. Yi, M.S. February 1998  R. Christenson, Ph.D. December 2001
N. Duran, Ph.D. in progress
Y. Gao, Ph.D. in progress
M. Ruiz, Ph.D. in progress
Total Number of Graduate Students: 22

RECENT RESEARCH ASSOCIATES
Ph.D. Advisor: L.A. Bergman
KATHLEEN J. TIERNEY
Professor, Department of Sociology
Director, Disaster Research Center
University of Delaware
77 East Main Street
Newark, DE  19711
Phone: (302) 831-6618
Fax: (302) 831-2091
email: tierney@udel.edu

EDUCATION:
B.A. Sociology, Youngstown State University (OH), 1972
M.A. Sociology, Ohio State University, 1974
Ph.D. Sociology, Ohio State University, 1979

APPOINTMENTS
1989-present  Associate to Full Professor, Department of Sociology, and Director, Disaster
   Research Center, University of Delaware
1988-1989 Assistant Professor, Program in Social Ecology, University of California, Irvine
1985-1987 Assistant Research Sociologist, University of California, Los Angeles
1984-1989 Research Associate, University of Southern California
1983-1984 Special Consultant, California Seismic Safety Commission
1979-1982 National Institute of Mental Health Postdoctoral Research Fellowship, Department of
   Sociology, University of California, Los Angeles
1979-1983 Adjunct Assistant Professor/Visiting Lecturer, Department of Sociology, University
   of California, Los Angeles

PUBLICATIONS
1. Tierney, K. J. and G. R. Webb. Forthcoming. "Business Vulnerability to Earthquakes and
   Seismic Resilience of Communities." Earthquake Spectra.
   Resilience: Lessons from the Emergency Response Following the September 11, 2001
   Attack on the World Trade Center." Proceedings of the Third Workshop for "Comparative
   Study on Urban Earthquake Disaster Management," Kobe, Japan.
   Earthquake Loss-Reduction: Contextualizing the Role of Engineering Research." Natural
   and Zietlinger.

SYNERGISTIC ACTIVITIES
Member, NIBS panel to develop a methodology for measuring the costs and benefits of mitigation measures for natural hazards (2001).
Member, USGS committee to develop a plan for coordinating NEHRP post-earthquake investigations (2001).
Member, editorial board, Earthquake Spectra (1995-2001), Natural Hazards Review (2000-).
Member, EERI "Learning from Earthquakes" Committee (1995-).
Director, Disaster Research Center. DRC, which was founded in 1963 and moved to the University of Delaware in 1985, maintains the world's largest data archive and library devoted to the social-scientific study of disasters and hazards.

COLLABORATORS AND OTHER AFFILIATES
Linda Bourque, School of Public Health, UCLA
Stephanie Chang, University of Washington
Ronald Eguchi, ImagecatInc.
Paul Flores, EQE
Michael Lindell, Hazard Reduction and Recovery Center, Texas A&M
John Harrald, Center for Crisis and Disaster Management, George Washington University
Dennis S. Miletì, Dept. of Sociology and Natural Hazards Center, University of Colorado
Joanne Nigg, Disaster Research Center, University of Delaware
Ronald Perry, School of Public Affairs, Arizona State University
Hope Seligson, EQE

Graduate Advisor:
E. L. Quarantelli, Professor Emeritus, University of Delaware

Postdoctoral Advisor:
Oscar Grusky, UCLA

Thesis Advisor and Post-Graduate Scholar Sponsor - Ph. D. dissertations directed:
James Dahlhamer
Lisa Reshaur
Catherine Simile

Postdoctoral scholars:
James Dahlhamer
James Kendra
Jasmin Riad
Gary Webb

Graduate Students:
Michael Antonio
Keith Appleby
Michael Broderick
Marcia Cavanaugh
Rory Connell
Kathleen Curry
Heather Dillaway
Melvin D'Souza
Michael Kiley-Zufelt
Kristy Kompanik
Nicole Mott
Matthew Lee
Angela Tweedy
Tricia Wachtendorf
Nicole Vadino
DETLOF VON WINTERFELDT
Professor of Public Policy and Management and
Associate Dean or Faculty Affairs and Research
School of Policy, Planning and Development
University of Southern California
214 RGL, Los Angeles, CA 90012
Tel: (213) 740 4012
e-mail: detlof@aol.com

PROFESSIONAL PREPARATION
University of Michigan, Ann Arbor - Mathematical Psychology, Ph.D., 1976
University of Hamburg, Germany – Psychology, MS, 1972
University of Hamburg, Germany – Psychology, BS, 1970

RECENT APPOINTMENTS
Associate Dean for Research and Faculty Affairs, School of Policy, Planning, and Development,
USC (2000-);
Professor of Public Policy and Management, SPPD, USC (1998-);
Director, Institute of Civic Enterprise, SPPD, USC (1998-);
Professor of Systems Management, Department of Systems Management, USC (1987-1997); Associate Professor, Department of Systems Science, ISSM, USC (1982-1987);
Research Associate, Social Science Research Institute, USC (1978-1986);
Research Scholar, International Institute for Applied Systems Analysis, Laxenburg, Austria

PUBLICATIONS
Publications Most Closely Related to the Project
Other Significant Publications


SYNERGISTICS ACTIVITIES

Scientific Panels: Committee on Alternatives for Controlling the Release of Solid Materials from Nuclear Regulatory Commission-Licensed Facilities, National Research Council (2001-2002);
Panel on the EPA/NSF Program for Environmental Statistics, National Science Foundation and Environmental Protection Agency, 2001;
Committee for the Impact of Low-Level Radioactive Waste Management Policy on Biomedical Research in the United States, National Research Council (2000-2001);
Panel on Protecting the Health of U.S. Deployed Forces. Board on Army Science and Technology, National Research Council (1999-2000);

AWARDS

Frank P. Ramsey Medal for Distinguished Contributions to the Field of Decision Analysis, Decision Analysis Society of INFORMS;
Distinguished Service Award (2000);
Finalist, Franz Edelman Award for Achievement in Operations Research and the Management Sciences (2000);
Fellow, Society for Risk Analysis (1994).

PROFESSIONAL SERVICE

Chairman, Decision Analysis Society (1998-2000);
Editorial Board, Risk Decision and Policy (1998-);
Area Editor, Social Science and Decision Making, Risk Analysis, (1997-2000);
Editorial Board, Risk Analysis (1988-);
Associate Editor, Management Science (1989-1994);
COLLABORATIONS

Collaborators: Richard John (USC), Ralph L Keeney (USC), William Petak (USC), James Moore (USC), Rae Zimmerman (NYU), Robin Gregory (UBC), Robin Dillon (George Mason U), Thomas Eppel (UCI), Duncan Luce (UCI)

Ph.D. Students: Richard John (USC), Thomas Eppel (UCI), James Smith (USC)

Thesis Advisors: Ward Edwards (USC, retired), Clyde Coombs (deceased), David Krantz (Bell Labs), Edward Patchella (U of Michigan)
ANDREW WHITTAKER  
Associate Professor  
Dept. of Civil, Structural and Environmental Engineering  
State University of New York at Buffalo  
230 Ketter Hall  
Buffalo, NY  14260-4300  
Phone:  716-645-2114 x 2418  
Fax:  716-645-3733  
Email:  awhittak@eng.buffalo.edu

PROFESSIONAL PREPARATION  
B.E., Civil Engineering, University of Melbourne, Victoria, Australia, 1977  
M.S., Civil Engineering, University of California at Berkeley, 1985  
Ph.D., Civil Engineering, University of California at Berkeley, 1988  
Civil Engineer, California, No. C045013, 1989  
Structural Engineer, California, No. S03618, 1992

APPOINTMENTS  
Associate Professor, University at Buffalo, State University of New York, 2000-present  
Associate Director, Pacific Earthquake Engineering Research Center, University of California, Berkeley, 1997-2000  
Associate Director, Earthquake Engineering Research Center, University of California, Berkeley, 1992-1997  
Associate, Forell/Elsesser Engineers, San Francisco, California, 1989-1992  
Research Engineer, University of California at Berkeley, 1988-1989  
Senior Engineer, Connell Wagner, Melbourne, Australia, 1978-1984

FIVE PUBLICATIONS RELATED TO THE PROPOSED PROJECT  
FIVE OTHER SIGNIFICANT PUBLICATIONS


SYNERGISTIC ACTIVITIES

Co-PI of the NSF- and NYS-funded UB-NEES project

Board Member and Research Committee Chair, Consortium of Universities for Research in Earthquake Engineering (CUREE), 2001-present; Vice President, 2003

Member (1992-present) and Co-Chair (2001-present), BSSC, PUC Technical Subcommittee 12

Member, New Technologies and Analysis Teams, ATC 33: Seismic Rehabilitation of Buildings, 1992-1997

Team Leader, Structural Performance Products, ATC-58 Project: Performance Based Earthquake Engineering

Member, Seismic Task Committee, ASCE-7, 2000-present

COLLABORATORS

*Listed below are research collaborators (faculty and sponsors) for the past 4 years. Professional colleagues on committees and students are not included in the list.*

Vitelmo Bertero (UCB), Michel Bruneau (UB), Ian Buckle (UNR), Christis Chrysostomou (HTU), Peter Don Clyde (UCB), Michael Constantinou (UB), Marc Eberhard (UW), Gregory Fenves (UCB), Eric Fujisaki (PGE), Amir Gilani (Caltrans), Gary Hart (Hart-Weidlinger), Masahiko Higashino (Takenaka), Henry Ho (PGE), W.-H. Huang (UCB), Charles Kircher (CKA), Peter Lee (SOM), Taejin Kim (UCB), Stephen Mahin (UCB), Nicos Makris (UCB), Jack Moehle (UCB), Dorie Mellon (Caltrans), Tony Morgan (Forell/Elsesser), Khalid Mosalam (UCB), Claudia Ostertag (UCB), Thomas Post (Caltrans), Oscar Ramirez (UB), Andrei Reinhorn (UB), Chris Rojahn (ATC), Frieder Seible (UCSD), Halil Sezen (UCB), Bozidar Stojadinovic (UCB), Shakhzod Takhirov (UCB), Andrew Thompson (Arup), K.-C. Tsai (NTU), Panos Tsopekas (CU), Patxi Uriz (UCB), C.-M. Uang (UCSD), Emmanuel Velivasakis (LZA), John Wallace (UCLA)

**Graduate Advisor:** Professor Vitelmo Bertero, University of California, Berkeley

II.C-94
Thesis Advisement or Co-Advisement, Past Five Years
M.S./M.E.: Michael Astrella (UB), Hiram Badillo (UB), Edgard Escobar (UB), Janet Lane (UB), Troy Morgan (Forell/Elsesser), Gilberto Mosqueda (UCB), Andrew Thompson (Arup), Despoina Tsamandoura (UB).
Ph.D.: Fei Deng (UB), Taejin Kim (UCB), Claudia Marin (UB), Gordon Warn (UB)
Post-Doctoral: Juan Chavez (UCB), Amir Gilani (Caltrans), Shakhzod Takhirov (UCB); Michio Yamaguchi (TIT, Japan)