**MCEER RESEARCH TASK STATEMENT**

<table>
<thead>
<tr>
<th>Thrust Area 2</th>
<th>Budget:</th>
<th>Yr 6 Assigned Project Number: 8.2.6</th>
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</table>

**Task Title:** Experimental Data for Performance of Piping Distribution Systems

**Investigator/Institution:** Emmanuel “Manos” Maragakis /University of Nevada, Reno  
Ahmad Itani/ University of Nevada, Reno

**Team Member/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.)

The main goal of the proposed research is to continue the performance of shake table tests of hospital piping distribution systems. The general layout of the system was designed in collaboration with the Office of Statewide Health Planning and Development (OSHPD) in year 5. The first shake table experiments were conducted in April 2003 (part of the research of year 6) and more experiments are scheduled for February 04 (part of the research of year 7). The objectives of the tests were to identify the capacity characteristics as well as the weak points and failure modes for welded and threaded steel pipes. The proposed systems in year 8 will include experiments of piping systems with/without bracing and other innovative devices that can be used to improve its seismic performance, in order to assess their effectiveness. Brazed copper piping systems will be considered in this phase of the research. The systems will be subjected to drift-time histories that are representative of various hazard levels. These time histories will be based on the integration with Northridge hospital test-bed structural model. The results will also be used for the identification of critical components, generation of actual acceleration levels at piping systems along with the associated failure modes. This will 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 8:** (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 systems that were tested in April 2003 and will be tested in February 04.
- Meet with consultants and OSHPD engineers in order to finalize the details and geometry of the hospital piping sub-systems that will be tested in this phase of the project, including brazed copper pipes. At this point, after recent preliminary discussions with OSHPD engineers it has been recommended that two systems, with similar geometry as the systems tested in year 6 and 7 be tested. One will consist of copper pipes with brazed connections and the other of steel pipes with threaded connections. The systems tested in year 6 and year 7, consisted of welded and threaded connections. It should be noted that the diameter of copper pipes should be smaller than the steel pipes. Copper and steels threaded pipes pipes are widespread in hospitals, and by using the same geometry a direct comparison of the performance of these common piping details can be made.
- Design the final shake table experimental set-ups. The experimental set-up used in years 6 and 7 is shown in Figures 1 and 2. A similar set-up will be used in year 8.

Figure 1
Integrate with Northridge hospital test-bed structural model so that the piping system will be subjected to drift-time histories that represent various hazard levels.

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. The rigid frame will be modified as necessary.

Perform the experiments without using any bracing. The specimens will be subjected to incrementally increasing excitation levels until significant damage, water leakage or other failures are observed.

Repeat the experiments with a bracing system. Innovative technologies such as dampers will be used in this phase.

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 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, 2003, to March 31, 2004.)

In year five, in consultation with OSHPD engineers and consultants, a piping sub-system was identified. After several iterations the experimental specimen representing the system was designed. The experimental set up, including a rigid frame from which the pipes could be suspended was designed in year 6. The bracing system was designed by brace manufacturers. The shake-table experiments of the braced and un-braced welded systems were conducted in April 03 as part of the year 6 phase of the project. Steel pipes with threaded connections will be tested in February, 04 to determine their seismic behavior. Based on these experiments, comparison can be made between the weld and threaded connections of steel pipes. In addition realistic acceleration levels for braced and unbraced piping systems along with their failure modes are identified. These preliminary results will be placed on a web site that is dedicated to the piping project so that practicing engineers and other researchers will be able to review them.

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 innovative techniques that will be tested in future experiments. 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 brazed copper piping subsystem including realistic plumbing details. Most of the fabrication will take place in on-site the UNR Large-Scale Structures Laboratory. The fabrication methods used for the fabrication of the system tested in years 6 and 7, will be used for the year 8 specimens.

2. Integrate with the Northridge hospital test-bed structural model. Several drift-time histories representing various levels of seismic hazard will be used. This is a different approach from the time history that was used in year 6 and 7. Analytical and experimental studies will be conducted to determine the hazard level of ICBO AC156 so it can be integrated in the time histories of year 8. This will enable the experimental results of year 8 to be integrated with years 6 and 7.

3. Develop simple analytical models before the experiments to identify the areas where damage is expected and develop an effective instrumentation plan.

4. Definition/identification of failure and association with performance requirements(e.g. water leakage)

5. Use of innovative bracing systems and comparison of their seismic response to the response of conventional braced systems.

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<tr>
<th><strong>Anticipated Outcomes and deliverables:</strong> <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>
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</thead>
<tbody>
<tr>
<td>Final design of a hospital piping sub-system.</td>
<td>Experimental researchers</td>
</tr>
<tr>
<td>Possible modification of the experimental protocol for the shake table test of the piping system developed in years 6 and 7.</td>
<td>Experimental researchers</td>
</tr>
<tr>
<td>Information on the dynamic response of hospital piping sub-systems made out of brazed copper as well as threaded pipes subjected to records reflecting various hazard levels.</td>
<td>MCEER researchers working on development of fragility curves – other researchers, consultants and state engineer working on hospital piping systems</td>
</tr>
<tr>
<td>Information on the effectiveness of innovative bracing on the seismic response of piping systems.</td>
<td>Researchers, consultants and state engineers</td>
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**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 experiments 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 years 6 and 7, from which the pipes will be suspended and braced simulating the actual as-built conditions. The pipes will include copper pipes with brazed connections. (Fall 2004).

**Task 2:** Integrate with Northridge hospital test-bed structural model so drift-time histories that represent various hazard levels will be used in the experimental program. Analyze the designed piping systems (specimens) and identify necessary modifications (Winter 2004/2005).

**Task 3:** Meet with consultants and OSHPD engineers to discuss the design and analysis of the experiment and implement necessary modifications (Winter 2004/2005).

**Task 4:** Fabricate the specimen after contacting several manufacturers who could donate materials such as pipes, couplers, bracings etc. (Winter/Spring 2005)

**Task 5:** Perform the shake table tests of the sub-system identified in tasks1-4 (Spring 2005).

**Task 6:** Perform a fundamental analysis of the results and discuss them with other researchers of Program 2, consultants and OSHPD engineers (Spring /Summer 2005).

**Task 7:** Identify critical components that will have to be individually tested in subsequent years (Summer 2005).

**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.

**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.
3. Design experiments focused on the use of innovative technologies.
4. 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.