MCEER RESEARCH TASK STATEMENT

<table>
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<tr>
<th>Thrust Area: 2</th>
<th>Budget:</th>
<th>Yr 9 Assigned</th>
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<tr>
<td>Task Title: Experimental data for performance of piping distribution systems: Use of solid and innovative bracing systems</td>
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<td>Yr 9 Assigned</td>
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<td>Project Number: 9.2.11</td>
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<td>Institution: University of Nevada, Reno</td>
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<td>*indicates task leader</td>
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<td>Statement of Project Goals: (Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)</td>
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<td>The main goal of the proposed research is to continue the performance of shake table experiments of hospital piping distribution systems using for the first time solid and innovative bracing systems under realistic input motions. The general layout of the system that was designed in collaboration with the Office of Statewide Health Planning and Development (OSHPD) in year 5 will be used in the proposed experiments. The previously conducted shake table experiments identified the seismic response, dynamic characteristics, damage levels, and failure modes for steel piping systems with welded and threaded joints, as well as brazed copper piping systems. The proposed research in Year 9 will establish the seismic response of steel threaded and copper piping systems with solid and innovative bracings. The systems will be initially braced using solid braces (tubes and angles) and subjected to drift-time histories that are representative of various hazard levels. These time histories will be obtained from the integration with the 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. In addition, the test results will enable the comparison of the seismic response of piping systems with cable and solid bracings. Furthermore, the use of innovative bracings (e.g. dampers) will establish the effectiveness of these devices in improving the seismic response of new and existing piping systems. The test results will also provide information to Mircea Grigoriu’s team, who are performing analytical studies and are developing the fragility information for these systems.</td>
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<td>Problem Description and Research Approach of Proposed Work for Year 9: (Detailed description of research to be conducted and methodology to be used.)</td>
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<td>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.</td>
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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 establishing the seismic performance of hospital piping sub-systems through shake table experiments. The following approach will be followed:

- Review the results of the steel piping systems with welded and threaded connections, as well as copper systems that were tested previously. Threaded connections have shown so far greater vulnerability and will be used in the new experiments.
- 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 with solid and innovative bracing systems. At this point, after recent preliminary discussions with OSHPD engineers in March 2005, it has been recommended that two systems (threaded steel pipes and brazed copper pipes), with similar geometry as the systems tested in year 6, 7 and 8 be tested. Solid bracing (tubes and angles) and innovative bracing devices (e.g. dampers) will be used instead of the cable bracing that was used in years 6, 7 and 8. By using the same geometry a direct comparison of the seismic performance of these common piping systems with different bracings (cable and solid) can be made. Furthermore, the use of innovative bracing devices will determine the effectiveness of these devices in improving the seismic response of performance in piping systems.
- Design the final shake table experimental set-ups. The experimental set-up used in years 6, 7 and 8 is shown in Figure 1. Figure 2 shows the cable bracing systems that was used in the shake table experiments for the steel pipes. A similar set-up will be used in Year 9 with different bracing systems.
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.

- Use newly developed ATC 58 experimental protocols when applicable.
- 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 to accommodate the requirements of the new experiments.

- Perform the experiments with solid 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 innovative bracing devices and compare the seismic response to solid and cable bracings.
- 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 earthquakes 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. Shake table experiments of piping sub-systems of steel pipes with threaded and welded joints showed the vulnerability of the threaded pipes under low excitation levels. Furthermore, these experiments showed the importance of the bracing systems. The proposed experiment will use solid bracings and innovative devices to improve the seismic performance.

**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, 2004, to March 31, 2005.)*

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 cable bracing system was designed by cable bracing 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 were tested in February 04 to determine their seismic behavior. Based on these
experiments, a comparison was made between welded and threaded connections of steel pipes. In addition realistic acceleration levels for braced and unbraced piping systems along with their failure modes were identified. Using the Northridge hospital test-bed structural model, realistic floor accelerations were developed for various hazard levels and will be used in May 2005 to conduct shake table experiments of brazed copper piping systems as part of the year 8 research.

**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. 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. This project has also made use of the MCEER West Coast Demonstration hospital model to develop realistic floor acceleration records.

**Possible Technical Challenges:**

1. Integrate with the MCEER West Coast Demonstration hospital model. Several drift time-histories representing various levels of seismic hazard will be used. 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 is will enable the experimental results of year 8 to be integrated with years 6 and 7. In addition the recently developed ATC 58 protocols will be used and their effects will be compared to the effects of other motions.
2. Develop simple analytical models before the experiments to identify the areas where damage is expected and develop an effective instrumentation plan.
3. Definition/identification of failure and association with performance requirements(e.g. water leakage)
4. Use of innovative bracing systems and comparison of their seismic response to the response of conventional braced systems.
| **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.) |
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<td>Information on the dynamic response of hospital piping sub-systems made out of various piping systems (steel and copper), different connections detailed (threaded and brazed) and distinct bracing systems (cable, solid, and innovative devices).</td>
<td>Experimental researchers, structural engineers, code enforcement agencies, MCEER researchers working on development of fragility curves for piping systems.</td>
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<td>Information on the effectiveness of solid and innovative bracing on the seismic response of piping systems.</td>
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<td>Damage levels and failure modes for various piping systems.</td>
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<td>Effects of newly developed floor response time histories and experimental protocols (ATC 58).</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.)*

**Milestone 1:** Finalize the design of the shake table experiments for the piping sub-systems with solid and innovative bracings. The piping subsystem includes a hot water heater tank, a heat exchanger, pumps, several valves and bracing systems. 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 threaded steel pipes and copper pipes with brazed connections. (Fall 2005).

**Milestone 2:** Integrate with the MCEER West Coast Demonstration hospital 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 (Fall 2005/Winter 2006).

**Milestone 3:** Meet with consultants and OSHPD engineers to discuss the design and analysis of the experiment and implement necessary modifications (Winter 2005/2006).
Milestone 4: Fabricate the specimen after contacting several manufacturers who could donate materials such as pipes, couplers, bracings etc. (Winter/Spring 2006)

Milestone 5: Conduct the shake table tests of the sub-system identified in milestones 1-4 (Spring 2006). Use motions from milestone 2 as well the newly developed ATC 58 protocol if applicable.

Milestone 6: Perform a fundamental analysis of the results and discuss them with other researchers of Program 2, consultants and OSHPD engineers (Spring /Summer2006).

Milestone 7: Identify suitable innovative devices that can be used in the bracing systems to improve the seismic performance of the piping system. Meet with consultants and OSHPD engineers for that purpose Conduct shake table experiments for piping systems with the innovative devices (Summer 2006).

Milestone 8: Compare the test results of all piping systems various connections and materials. Meet with OSHPD engineers/MCEER researchers to discuss test results.

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:

- Calibrate the analytical models in collaboration with researchers at Cornell.
- Develop design and analysis guidelines for new piping systems and their bracings
- Recommendation of R_p and a_p for various piping systems.
- Develop retrofit strategies for various piping systems.
- Meet with OSHPD engineers to discuss the results.

Multi-Hazard Statement:

a) (Conceptually describe in 200 words or less how some of the work you are conducting as part of your MCEER Year 9 research task can be exported/applied to other natural or man-made hazards including multi-hazard research.)

The current experimental research at the University of Nevada, Reno on the seismic response of hospital piping systems, has elements which could be applicable to determine the behavior of similar systems under other types of extreme loading. The current research helps with the evaluation of the overall response of the system to seismic loads and the identification of failure modes and weak points. This information can be used for the development and calibration of
analytical models of these complex systems. These models can be used for the prediction of the response of the systems under different types of extreme loadings such as explosions or high impact loadings. Furthermore, individual component experiments may be necessary to produce information regarding the stiffness, yielding and failure characteristics of critical components of the system. This information will be used for the development of detailed non-linear analytical models, which will be required for the study of the response of these systems under extreme loadings. However, caution should be exercised, since for several types of extreme loads high temperatures are developed which could influence significantly the behavior of the components and the overall system. Therefore, component high amplitude cyclic testing and other experiments at high temperatures may be needed for the accurate identification of the response under other types of extreme loadings. The expertise obtained from the seismic experiments, can be used for the performance of more experiments useful for other extreme loading conditions.

b) If you are seeking supplemental multi-hazard funding, describe the multi-hazard milestones that you plan to complete as part of your Year 9 research.

The following exploratory project is proposed for the piping systems of hospitals subjected to blast loadings:

1. Develop scenarios for blast loadings such as: a hospital in the immediate vicinity of an explosion or explosion on a particular floor of a hospital.

2. Perform a literature search to develop time history records for modeling such loadings.

3. Explore the capability of existing analytical models of piping systems (in particular those developed within the MCEER framework) to handle these types of loadings. Analyze simple cases if possible.

4. Identify and specify further needs for experiments and analysis to be conducted in year 10 in order to complete the solution of this case.

It is anticipated that this project, when completed in year 10, will demonstrate the procedure and use of results obtained from seismic research to investigate effects of blast loadings.