MCEER RESEARCH TASK STATEMENT

<table>
<thead>
<tr>
<th>Thrust Area:</th>
<th>Multi-Hazard</th>
<th>Budget:</th>
<th>Yr 9 Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Title:</td>
<td>Protective Jackets for Multi-hazard Mitigation Measures (ProJack-M3): Proof of Concept</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigator/Institution:</td>
<td>M. Ala Saadeghvaziri* and Bruce Bukiet / New Jersey Institute of Technology</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 goal of this research and development task is the proof of concept of an innovative water-based protective technology as multi-hazard mitigation measures for civil infrastructure (hospitals, schools, embassies, bridges, etc.). The conceptual design is based on identification of water spray as a possible mitigation system for explosion by the Naval Research Lab that is combined with jacketing, which is well established as an effective seismic retrofit measure. Additional benefits include added protection against fire and vehicular collision depending on application. Research plan during the initial year (year 9) is essentially proof of concept, which will include i) continuation and expansion of the literature search to fine tune the conceptual design, ii) small scale explosive tests, and iii) development of analytical models for future use to extrapolate explosive tests and plan additional research needs should the concept be proven viable. Successful completion of this high potential design will make it a signature project for MCEER successful transition to a multi-hazard center.

Problem Description and Research Approach of Proposed Work for Year 9: (Detailed description of research to be conducted and methodology to be used.)

Design description: An innovative water-based (or Thixotropic Fluid based) protective mitigation design has been proposed that will have multi-hazard benefits for a wide spectrum of infrastructure inventory such as hospitals, firehouses, schools, embassies, bridges, etc. It consists of water-encased membrane that can jacket or wrap around any structural shape. The measure can be used in new designs as well as in retrofitting existing structures. For example, a schematic diagram of the measure envisioned for use on unreinforced masonry (URM) walls is shown in Figure 1. URM walls are one of the most hazardous types of construction under an earthquake. A significant number of buildings in the eastern and mid-western (New Madrid) regions of the US have used this type of construction without consideration to seismic loads at the time. More importantly, many of these buildings are critical facilities and/or places of large assemblies such as hospitals, fire stations, schools, and houses of worship. Although in-plane shear failure during a seismic event is often the dominant mode of damage to URM walls it is out-of-plane failure (kick out of the wall perpendicular to its own plane) that causes loss of support for the roof and consequently building collapse; resulting in significant number of casualties during past earthquakes. The proposed measure, which uses two layers of water filled composite to sandwich the wall, will significantly enhance the out-of-plane stability of the wall. Furthermore, bursting of, and spray of water, by the water-based protective jacket during a

“There are several ways in which the use of water sprays can mitigate the effects of an explosion in a ship compartment. It may: (1) break up larger droplets into finer mist (the breakup process extracts energy from the shock and weakens it); (2) directly lead to an attenuation of the shock waves produced; (3) reduce the intensity of secondary shock and pressure wave reflections from the walls and other objects in the enclosure; (4) slow down or quench the chemical reactions taking place behind the shock waves; and (5) dilute the concentration of explosive gases in the enclosure and hence prevent a secondary gas explosion or fire.”

An important objective of the initial research effort will be to investigate extension of this observation to unconfined environments within the realm of engineering solutions.

In the proposed design spraying action is provided through the bursting/breakage of the casing/membrane. Thus, to the above factors the energy required to rupture the membrane should also be added. That is, a part of the shock energy will be used in this process and therefore less energy will be imparted to the protected structural member covered. Thus, the measure, namely ProJack-M³ (Protective Jacket for Multi-hazard Mitigation Measures) appears to be both viable and quite economical.

The use of jacketing (either steel jacketing or jacketing in the form of composite wraps) for earthquake mitigation is well established.

With regard to blast mitigation, another point that further supports the merit of the proposed protective design relates to the time of reflected pressure. The time it takes for reflected pressure waves to clear a point on a surface depend mainly on the distance to a free edge or an opening [2]. Initially the protective system is a solid boundary and will cause reflection of the shock waves. Due to bursting/breakage of the membrane (i.e., instantaneous development of a free surface) the high pressure of reflected waves immediately drops to atmospheric pressure. Furthermore, due to disintegration or bursting of the protective system there won’t be any transmission of the high reflected pressure to the protected member.

Figure 1: Application of ProJack-M³ to URM Walls

ProJack-M³
Membrane + Water
Thicknesses & connection
TBD based on Multi-hazard performance objectives.
At this stage the primary material of interest for the casing/membrane is advanced composites. There have been significant advances on applications of composites in civil engineering over the past several years both in the form of fiber structures and as rehab material in the field of earthquake engineering. Future development can possibly include pressurization of the encased water to further enhance and broaden applications of this innovative measure.

Similar to steel jacketing used in seismic retrofitting the measure can be also applied to reinforced concrete columns (Figure 2). It can also encase steel columns for blast attenuation. It should be noted that the proposed design concept has truly multi-hazard benefits since in addition to earthquake and blast load it can provide added protection against fire and act as crash cushion should the application require so. Similar approach can be used for circular or square cross sections. Indeed the concept if proven effective can be used to jacket any shape and object as long as esthetic and other requirements are addressed. Figure 3 shows application of the measure to underneath of a slab-on-girder (SOG) superstructure. It should be noted that probably for a bridge the most critical point of attack is from the underneath for couple reasons: 1) it generated reversed forces that are against design/gravity loads, and 2) the deck acts as a protective shield for attacks from the top of the bridge. For typical SOG bridges and assuming 3” jacket the increase in superstructure weight would be about 7%, much less than an inch variation in the deck thickness that is quite common in practice. However, addition of the protective system enhances superstructure stability for other hazards (seismic or wind) too. Again similar to the column application providing mutli-hazard benefits.

Figure 2: **ProJack-M3**: a) General view, b) Cross section for new columns or existing columns (with connection), and c) Cross section for application to existing columns without connection.

As shown in Figure 2c a cylinder with an almost complete ring cross section can be employed for easy installation on existing columns for locations where seismic is not a major hazard. Since
it is anticipated that the membrane even in its empty condition will be sturdy an initial symmetric pull will be exerted to slip the membrane casing over the column. It will then be filled with water. The small exposed segment can be positioned strategically toward the least critical direction or the blind spot (e.g., inner side of a building or abutment side in the case of a bridge). For application to existing columns where seismic protection is also desired the same approach can be employed along with existing seismic jacketing or the two can be combined using two half-circle with a connecting mechanism (such as snap-on or dove-tail connection).

Future development work on the proposed design could consider the use of solids (clay like) and Thixotropic fluids that liquefy when agitated upon exertion of shear forces.

![Diagram of ProJack-M3 to Bridge Superstructure](image)

**Figure 3: Application of ProJack-M3 to Bridge Superstructure**

**Research Plan:** The following are bullet list of immediate research needs in support of proposed design proof of concept that will be carried out during Year 9:

- Additional literature search on the use of water and water spray to attenuate pressure associated with shock wave.
- Small scale explosive tests. Initially this can be on a very small scale (e.g., involving less than 5-lb C4 explosives) and then extended if results are promising and analytical and literature work support the conceptual design.
- Planning a comprehensive analytical study to extrapolate the limited explosive test results, further validate and modify the design for ProJack-M3, and plan future research needs. This task will require cutting-edge analytical and numerical expertise in the use of, and application of, advanced finite element methods including knowledge of material definitions such as equation of state (EOS), and computational fluid dynamics (CFD).

The U.S. Army’s Armament Research, Development and Engineering Center (ARDEC) in Picatinny Arsenal, NJ (http://w4.pica.army.mil/PicatinnyPublic/index.asp) will provide project-critical military expertise, as well as an explosive facility for field testing. In light of Picatinny’s close collaboration with NJIT, it is expected that their contribution will be in the form of in-kind support to this project. Additional documentations in support of this will be provided upon initial approval of the task by MCEER.

Note that several specimens can be tested simultaneously as shown in Figure 4. Standoff distances will be determined based on breaching calculations using conventional weapons effect (e.g., CONWEP). However, as shown in Figure 4, to increase effectiveness of each explosive staggered standoff distances will be employed to study other parameters too.
<table>
<thead>
<tr>
<th><strong>Assessment of State-of-the-Art:</strong></th>
<th><em>Describe other relevant work being conducted within and outside of MCEER, and how this project is different.</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This is a noble and innovative design and there is no additional relevant work on this mitigation approach. It can quite possibly have great intellectual property potential for NJIT and MCEER.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Progress to date:</strong></th>
<th><em>(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.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not applicable.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Role of Proposed Task in Support of Strategic Plan:</strong></th>
<th><em>(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>By developing a truly multi-hazard protective system, this task will be a signature project as MCEER redefines its vision <em>to enhance the resilience of infrastructure against extreme events</em>. It will also support MCEER existing mission by addressing seismic hazard in its core.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Task Integration:</strong></th>
<th><em>(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Successful completion of this task not only will make substantial contribution to the new MCEER vision but it can also be integrated with both Programs 1 and 2 under existing objectives of these programs.</td>
</tr>
</tbody>
</table>

---

**Figure 4:** Explosive Test Setup to Evaluate **ProJack-M³**
Possible Technical Challenges:

None at this stage.

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

Development of a truly multi-hazard protective system.

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

General construction industry.
Federal and state government agencies, specifically US Department of State, Federal Highway Administration, and State DOTs.

Educational outcomes and deliverables, and intended audience:

- Application of advanced numerical methods.
- Understanding impact of phase changes on blast waves and its possible benefits in attenuating incident and reflected pressures.
- Classroom presentation of real world advanced structural problems and their solutions.

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

- Literature search (Fall)
- Explosive tests (Spring)
- Development of numerical models (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, Department of Civil Engineering, NJIT.
   Bruce Bukiet, Department of Math Sciences, NJIT (computational fluid dynamics, detonation waves and shock waves, front tracking, mathematical modeling and numerical analysis).
   Graduate Student, TBD (US Citizen with clearance to work at military installations).

Possible Direction of Work in Subsequent Years:

Should the design be proven to be viable, future work will include:

- Conduct analytical study to extrapolate the limited explosive test results, determine design parameters such as amount of water, and improve design.
- Work with a manufacturing partner in development of the casing
- Work on details of connection and standard drawings
- Manufacture prototype(s) for laboratory and field tests, including full scale explosive tests.
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.)

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 proposal statement is self explanatory in this regard (i.e., proof of concept of a truly multi-hazard protective measure).