MCEER RESEARCH TASK STATEMENT

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<th>Thrust Area: Multi-Hazard</th>
<th>Budget:</th>
<th>Yr 9 Assigned</th>
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<td>Project Number: 9.4.1</td>
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**Task Title:** Hamiltonian Methods for Dynamic Analysis of Deteriorating Structures in Multi-Hazard Environments

**Investigator/Institution:** G.F. Dargush, A.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.)

The objective of this research task is to advance the development of a computational platform suitable for the analysis of structures subjected to severe multi-hazard environments. While a number of approaches are available for analyzing structural systems under dynamic conditions, none are able to handle the complexities associated with deteriorating response to severe transient loadings; in particular complexities associated to progressive collapse or sudden changes of geometry and complex stability issues. The proposed approach, based upon a Hamiltonian formulation developed at UB (Sivaselvan, 2002; Sivaselvan and Reinhorn, 2004), has the potential to address these problems in a more systematic way. Consequently, this research is intended to provide MCEER with a unique most advanced computational capability that would be helpful for seeking multi-hazard funding beyond Year 10.

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

During the proposed Year 9 effort, we will develop the basic computational framework for large deformation analysis of steel frame structures with deteriorating characteristics. We will employ an Open Source framework similar to that utilized in the PEER OpenSees platform in order to facilitate future expansion and potential collaborations. Additionally, this framework will be developed to readily interface with the evolutionary design methodologies currently under development within MCEER. While those approaches are valid in principle for multi-hazard design, more robust analysis techniques are required to perform transient nonlinear dynamic analysis of the structural system with increasing amounts of damage. This is particularly important when structures may approach a collapse condition, as a result of an extreme event, such as a severe blast loading. The Hamiltonian methodology includes both forces and velocities as primary variables and simultaneously balances momentum and energy by solving an optimization problem associated with the variational statement during each time step. This enables more robust tracking of the structural system as it progresses through deteriorating stages toward possible collapse.
Assessment of State-of-the-Art:  *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

In attempting to analyze deteriorating structures, one is faced with a range of complicated physical processes. For example, analysis of a steel moment frame, undergoing progressive collapse as a result of an extreme event, may involve the following: (i) cyclic elastoplastic and viscoplastic response; (ii) fracture, damage and fatigue; (iii) geometric nonlinearity, P-\(\Delta\) effects and buckling; (iv) contact and frictional interface behavior; (vi) dynamic response and impact; (vi) fragmentation and projectile motion. Consequently, one is faced with modeling time-dependent non-linear multi-scale phenomena that exhibit strong tendencies toward localization and also sensitivity to initial conditions.

Although gaps still remain in our ability to handle these issues, significant efforts have been made. Early work such as that by Gross and McGuire (1983) and Karamchandani and Cornell (1992) used “event-to-event” algorithms, where the structural model must be reformulated whenever an “event” occurs. The sequence of events following the explicit removal of a member is traced. When an element is lost, the forces carried by that member are redistributed to the rest of the structure and the stiffness matrix is condensed to reflect the lost member. Modern finite element programs such as ABAQUS (2000) and Larsa 2000 (Karakaplan et al., 2004) have phased analysis features that permit performing such analyses. However the “loss” of an element is in reality not a well defined event. Moreover, such approaches are unsuitable for dynamic analysis where loading is not monotonic. Blandford (1997) has discussed the progressive collapse analysis of space trusses considering material and geometric nonlinearity following the loss of one or more critical members with static load redistribution, but the dynamical aspects are not treated. Furthermore, a number of researchers have developed elements to model deteriorating characteristics (de Souza, 2000; Elwood, 2003; Kaewkulchai and Williamson, 2004). These elements work in the context of the conventional displacement-based incremental iterative framework (e.g., Crisfield, 1991). On the other hand, specific issues relating to dynamics and time-stepping that are critical to collapse simulation are not addressed.

Another approach for collapse analysis involves using the Discrete Element Method or its variations. A discrete element system consists of a number of distinct solid bodies interacting with each other in a defined space, with the interactions defined by constitutive equations. The origin of the method is in rigid body dynamics and in the dynamics of granular media (e.g., Cundall and Strack, 1979). Hakuno and Meguro (1993) proposed a related method for dynamic collapse analysis of frame structures by considering an assemblage of elements and “pore springs”. The constitutive laws of the pore springs are based on fracture mechanics. Sun et al. (2003) and Bicanic et al. (2003) used this approach recently to simulate the collapse of bridge structures. However, we believe that the Hamiltonian-based approach, with its solid fundamental base, is far better suited for the dynamic analysis of deteriorating structures.
**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.)*

This is a new multi-hazard research task proposed for Year 9. However, the original development of this concept was done at UB under the direction of Reinhorn (Sivaselvan, 2002; Sivaselvan and Reinhorn, 2004). A somewhat related force-based large increment method has been developed for nonlinear static analysis by Dargush with collaborators at UB. More generally, both PIs have extensive experience developing computational methods.

**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 long-term vision of MCEER involves the extension of current strengths into the areas of multi-hazard mitigation. The proposed work is intended to create a unique capability that will enable MCEER to better position itself for funding beyond Year 10. However, the proposed work is also directly applicable within earthquake engineering in order to understand, predict and ultimately prevent progressive collapse of structural systems.

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

As indicated above, the Hamiltonian methods developed here will be formulated to directly interface with the evolutionary framework for multi-hazard design and retrofit. Furthermore, the open source format will enable other models developed within MCEER to be readily incorporated in the overall platform. For example, a number of new structural concepts and protective technologies are currently under development within Thrust Area 2 and one may envision that other innovative systems will be developed to address multi-hazard conditions. The proposed Hamiltonian formulation and numerical implementation will permit inclusion of the mathematical models resulting from these developments.

**Possible Technical Challenges:**

We are attempting to solve very difficult structural problems. The most challenging aspects are associated with the modeling of deterioration. While many different approaches have been proposed for these problems (e.g., damage mechanics, cohesive elements, discrete elements), none have adequately resolved the issue of localization. Consequently, numerical results are as a rule mesh-dependent. Although we cannot be certain that the Hamiltonian framework is the ultimate answer, it does provide a very sound theoretical underpinning and a conceptually different point of view that seems to be ideally suited for modeling the dynamic response of deteriorating structures.
| **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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<tr>
<td>Formulation and implementation of an initial Hamiltonian-based open source code for nonlinear dynamic analysis of frame structures with deteriorating elements</td>
<td>IAB members and other practicing engineers interested in multi-hazard structural analysis and design</td>
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<td>Several computational examples to demonstrate the capabilities of the approach</td>
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<td>Ultimately, code and documentation will be available through the MCEER User Network</td>
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<td>Conference and journal papers documenting progress</td>
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### Educational outcomes and deliverables, and intended audience:

Initially, one Ph.D. student will be involved in this proposed research project.

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

- Develop framework for the Hamiltonian computational platform by end of Fall 2005.
- Complete Hamiltonian formulation and implementation plan for the first phase of development involving inelastic steel framing members (beam-columns) with damage by end of Spring 2006.
- Complete initial computational examples by end of Summer 2006.

### 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.)

G.F. Dargush (PI), A.M. Reinhorn (PI), TBD (PhD student). The team will benefit from the participation of Dr Sivaselvan a junior faculty at University of Colorado. He will be consulted and perhaps he will join the effort.
Possible Direction of Work in Subsequent Years:

The development of a significant computational platform for multi-hazard structural analysis is a long-term activity. The idea of this proposal is to initiate the work on deteriorating structures and to bring the capabilities of the platform to a level that will attract additional funding from outside MCEER. The combination of this analysis package with the MCEER evolutionary design methodologies could be quite attractive. The work will be presented to other agencies to explore possibilities of outside funding, DoD, DHS, NSF, etc. Contacts will be made to check possibility of support of commercial software houses (Larsa Inc., CSI, etc) to develop user interfaces for possible use from start.

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 proposed work is intended specifically for multi-hazard applications.

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.