MCEER RESEARCH TASK STATEMENT

Thrust Area: 2  
Budget:  
Yr 9 Assigned  
Project Number: 9.2.6

Task Title: Semi-Passive Control of Buildings and Contents

Investigator/Institution: George C. Lee,* Zach Liang, Mai Tong  
University at Buffalo  
*indicates task leader

Statement of Project Goals:
The objective of this project is to develop a simple, relatively inexpensive, semi-active device to provide fail-safe mechanisms for the control of large isolation bearing displacement as well as structures with very large deformations against ground motions of unexpected magnitude (i.e. when the ground motions exceed the design values). To distinguish it from the commonly know semi-active control systems, a structure implemented with this single-action device is called a semi-passive controlled structure (a “smart structure”).

Problem Description and Research Approach of Proposed Work for Year 9:
The deformation and/or the displacement of base-isolated structures (or the bearings themselves) induced by earthquakes can exceed the design values for several reasons: (1) an earthquake with very large ground displacement (for example, strong near field earthquakes); (2) the peak excitation exceeds the design values (for example, actual peak excitation is considerably larger than that determined by design spectra); and (3) imperfection of construction, malfunction of protective devices, etc. Design of base-isolated structures using pure passive devices is not able to deal with such situations.

Many structures with redundant aseismic capacity can expect to survive unexpected large displacement. However, systems such as base isolators themselves, can suffer severe damage. In this case, using fail-safe mechanism can prevent catastrophic structural failure. At the same time, a higher level of acceleration will cause damage to the structure to a certain degree. The objective of the semi-passive device is to reduce the damage or to prevent total loss of the structure.

The semi-passive system does not use actuators. It needs no external power, and uses no integrated computer or controller. All the control actions are achieved by the pressure change inside the hydraulic chamber of the device.

The control strategy is briefly described as follows: First, this control is not continuous, but only has two levels: normal (smaller damping for regular isolation, larger damping when bearing displacement becomes large) and critical, (the device is locked). The change in levels is based on preset valve parameters. These parameters are established by using the basic principles of damping design. No extra sensors such as load cells, accelerometers, strain gages, etc. are needed. The oil pressure inside two special chambers is used as the total sensory system. When
the displacement and device forces vary, the pressure will vary accordingly. The oil pressure will also be used as control actuation to open, close, and regulate certain sets of valves with special logic.

This proposed research task up to now has been focused on seismic isolation of bridges (funded by FHWA), because the isolation system almost has zero tolerance for bearing displacement to exceed the design value. For typical building structures, inelastic deformation or other structural redundancy can provide an additional margin of safety that the fail-safe considerations will not be most critical. However, the semi-passive system can be extremely valuable for certain types of buildings and certainly for building contents.

In addition, the proposed semi-passive control system can be used to optimize the damping added to a structure. In this sense, this technology will become a stand-alone system for earthquake response modification of structures. We have just begun this line of inquiry to develop a different type of vibration reduction measure.

In figure 1, we conceptually show a control action scheme for the fail-safe mode of the seismic isolation systems. When large displacement occurs, the pressure of hydraulic fluid inside a special chamber is changed. The variation of pressure will actuate the two set of hydraulic valves that further actuate regulation valves to vary the path of the fluid. This can provide the change in damping force. More importantly, it may close the valve to make the device as a rigid member. These two kinds of forces (called device forces) will affect the dynamic behavior of the isolation system. If a bearing displacement is approaching the allowed value, a much larger damping force will be applied to prevent further deformation of the bearing. However, if the displacement continues to increase and reaches the preset value, this device will lock the bearing to prevent it from derailing.

When the superstructure begins to return to its equilibrium point, the pressure drops and the corresponding valves will be actuated to allow the device to return to its normal working condition.

In figure 2, we show a control scheme for optimal damping. When the velocity of structural response is small, large damping is used as the default preset. When velocity becomes larger than the allowed value, it will change the pressure of hydraulic fluid inside a special chamber. The variation of pressure will actuate two sets of hydraulic valves that further actuate regulation valves to vary the path of the fluid, which can provide the change in damping force, and thus modify the dynamic behavior of the structure.

When the velocity begins to reduce to the preset lower level, the pressure drops and the corresponding valves are actuated to allow the device return to its normal working condition.
The overall approach of the research task may be summarized by the following major steps:

1. Quantify the needs of regulation of large structural displacements.
2. Development of a theoretical basis for fail-safe regulations by means of semi-passive control.
| 3. Development of semi-passive actuators  
4. Experimental observations and evaluations  
5. Improvement of the devices and further studies |

**Assessment of State-of-the-Art:**
Studies on active structural control have been carried out intensively in the past decades (see, for example, Yao, 1972, Housner et al 1997; Reinhorn, 1995; Soong, 1989, 1995, 2000; Soong and Spencer, 2002; Yang, 1995). The theory and practice on semi-active control have also been developed (Examples include Kobori, 1960, 1990, 2003; Liang and Lee, 1994, 1997, 2000; Patten 1997; Spencer, 2003).

The major thrust of the above studies was focused on the reduction of structural responses. Such controls often do not have absolute targets but relative reductions in responses. Therefore, the damage level allowed under various conditions is not specified. Further, active- or semi-active control requires external power which is an undesirable feature. They also need various control algorithms based on online measurement by using sensory systems and computers. Thus, active- and semi-active control can be costly. To date, these technologies are still in the research stage. Applications in seismic protection of civil engineering structures are still many years away.

Founded by FHWA, we have started to examine the need for a fail-safe mode of the seismic isolation system for highway bridges since 2003. Special attention is given to develop a fail-safe mechanism for bridges located near a fault where large ground displacement may cause the bearing displacement to exceed the design value. The basic idea is to allow the isolation system to work normally as designed for, if the corresponding displacements are within the allowable levels. However, when the pre-set displacement limit is exceeded, a series of mechanical actions controlled by pressure change will take place to lock the bearing to prevent the collapse of the bridge span. The action will take place without external power. Therefore, we called the system semi-passive control. This technology can be fully developed and implemented in engineering practice much faster than the conventional semi-active control. In this research task, we need only to modify the system for application to buildings and building contents.

**Progress to date:**
Between April 1, 2004 and March 31, 2005, efforts have been given to theoretical formulations and the design of a prototype semi-passive control device.

**Role of Proposed Task in Support of Strategic Plan:**
A major emphasis of MCEER research is the development and application of advanced technologies for the mitigation of earthquake damages. This task addresses a new semi-passive control device to provide the fail-safe feature for structures with passive isolation devices (i.e., smart seismic isolation system). It is expected to contribute to the continued high level of MCEER reputation in advancing the state-of-the-art in structural response modification technologies.
**Task Integration:**

This task leverages the support from FHWA for bridge applications. The devices developed for building and content, protection will be part of the benchmark testing program led by A. Filiatrault and A. Whittaker.

**Possible Technical Challenges:**

The major challenge is to ensure the reaction time, which depends on the response speed of pressurized quick-release hydraulic valves. Up to now, we only have computer simulation of the device. This will be one of the major tasks of Year 9.

The second challenge is to balance the fail-safe action with permitted structural damages. A proper level must be specified under statistically pre-determined conditions.

The third challenge is to ensure the reaction with “soft-landing.” A sudden lock will create larger acceleration that may cause damage to the structures. The corresponding device must vary its damping from a relatively low-level to a high-level in a reasonable time interval.

**Anticipated Outcomes and deliverables:**

1. Principles and initial guidelines for fail-safe design of bridge isolations and for low-rise buildings and building contents based on semi-passive control
2. Design criterion of imposing the semi-passive action, balancing the action level and the allowed damage level.
3. Complete the manufacturing of a prototype semi-passive device for evaluation by using the UB experimental facilities.

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

Design and manufacturing industry involving earthquake protective devices

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

Education of one graduate student and a part-time post doctoral.

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

1. Completion of the prototype system for experimental evaluation (Fall-Winter 2005) manufacturing process already began, funded by the FHWA contract.
3. Preliminary Test (Spring 2006).
5. Further improvements and experimental studies (Summer-Fall 2006).
**Team Members:**

Andre Filiatrault and Andrew Whittaker (integrated demonstration project in Thrust Area 2)

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

1. Improve the theory and standard of fail-safe design
2. Improve semi-passive control and corresponding devices
3. Design criterion and guidelines

**Multi-Hazard Statement:**

The semi-passive device is a simple, single-action system to prevent severe damage or collapse of structures when the external loads cause unexpected large deformation of seismically isolated structure. The concept and device system can be modified to protect impact and/or vibration isolated structures against different types of forcing functions in addition to earthquake ground motions (e.g., blast loading)