Ninth Canadian Conference on
Earthquake Engineering
Ottawa, Ontario, Canada
26-29 June 2007

A FRAMEWORK FOR INTERDISCIPLINARY RESEARCH TO MINIMIZE SESIMIC RISK TO SOCIETY

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ABSTRACT

Research in seismic discipline has far too long concentrated in engineering disciplines without integrating with the associated disciplines such as social sciences, economics, emergency management, and public policy. Input from each of these disciplines is critical in *research design* to minimize seismic risk to society. The framework of *cause* and *effect* has not served well as the dynamic in the society changes constantly. This is one of the main reasons that in spite of significant advances in understanding seismic effects on structures and improved construction quality, losses to society continue to increase. It is argued in this paper that a *systems level* approach needs to be developed integrating various disciplines and creating a continuous feedback loop providing input on the behavior of the system. This *systems level* approach provides a cost effective and efficient holistic solution to minimize seismic risk to society as it takes into account the impact of sub-systems on the overall system considering their interdependent characteristics.

Introduction

Seismic risk to society had been dominated by two primary considerations: uncertainty in the occurrence of a major seismic event; and life safety as a consequence of the event. The code provisions and other regulatory mechanisms emphasize and are based on the life safety aspect of the seismic risk. For critical facilities, an added provision related to their functionality during and after a major seismic event is also emphasized. Although the progress made to date in predicting a major seismic event within a specific time period for a region is very slow due to insurmountable difficulties in this field, considerable progress through research has been made in understanding the behavior of structural systems subjected to major seismic events. Loss of life in the last two significant seismic events in California: Loma Prieta, 1989 and Northridge, 1994 has been low as compared to a similar magnitude seismic event in Kobe, Japan in 1995. While less than 70 persons died in each of the California events, the loss of life toll in Japan was over 5000. The toll in subsequent similar magnitude seismic events in India, Iran, and Pakistan have been significantly higher but are not compared here because of vast differences in construction quality in those countries as compared to US and Japan.

Two important findings from the seismic events in California, Taiwan, and Japan are worth noting: 1) damage to non-structural systems in buildings in California was significantly higher than the damage to structural systems thus causing serious disruptions to business operations resulting in considerable

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economic losses, and 2) global economic interconnectedness caused economic and societal disruptions and losses beyond the borders of individual countries. This second aspect was particularly noted in the Chi-Chi earthquake in Taiwan in 1999 where US companies manufacture electronic components for worldwide use, and in the Kobe earthquake in Japan where 15% of the Japanese export are shipped through Osaka port which had to be closed following the earthquake, impacting availability of goods from Japan, worldwide. These types and magnitudes of impacts to society are beyond the assumptions of code provisions, based on life safety considerations alone that were developed primarily to prevent major damage to structures or to prevent the collapse of structures. In general, global interconnectedness leads to increased interdependence.

The total seismic risk comprises of technical, economic, and societal components as shown in Fig.1. To reduce the risk requires consideration of all three components which act interdependently

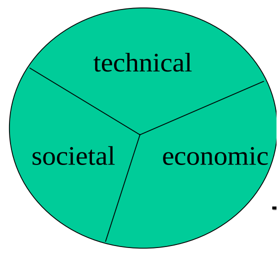

Figure 1. Total Seismic Risk.

In 2004, the Subcommittee on Disaster Reduction stated in a report to the US President " Protecting American communities from disasters….depends on policy makers adopting an *integrated approach* to disaster risk reduction, drawing on existing knowledge….combined with new information on risks…".

Systems Approach

A new framework to conduct integrated interdisciplinary research in minimizing seismic hazard risk is needed. Such a framework should be based on the multidisciplinary nature of seismic hazard risk to society and needs to incorporate input from various divergent disciplines making a subsystem, into a larger system connecting these subsystems. Thus, the larger system incorporates multiple disciplines which interact and influence the outcome of the behavior of the *system* as a whole. However, a '*system* needs to be defined first. *A system can be defined as group of independent but interrelated elements or subsystems forming a unified whole, that interact coherently and synergistically to achieve a beneficial purpose.* As a system often requires contribution from diverse disciplines, interdisciplinary research is required, which is inherently complex. Interaction among system components is neither well understood nor well defined.

System Types and Characteristics

For a system to be robust, each component of the system needs to be robust by itself. Weakest link in the system determines the overall robustness of the system, particularly when the components are connected in *series*. The type of connection between components is very important. Linkages between components must be flexible to allow modified behavior based on the input from subsystems through feedback loops. These feedback loops play an important role in making the system behavior *adaptable*. There are two basic types of systems: *static; and dynamic. Static* systems are non-adaptive as they rarely have feedback loops. *Dynamic* systems on the other hand are adaptive and generally have feedback loops. Components of a system can be connected in series, parallel, hybrid (combining series and parallel), or in a random way. These connections can be linear or non-linear and can be flexible, semi-rigid or rigid. Possibly, a third type of system can be classified; a *hybrid* system. This type of system combines the characteristics of both static and dynamic systems.

Static Systems

Many civil physical infrastructure systems are static with components connected in series with linear rigid type connectors. Example of such a system is shown in Fig. 2. Both the building system and the bridge system are composed of components which rely on the linear rigid connections of its subsystems in series. e. g. in the bridge system, if the substructure fails or is badly damaged, the superstructure resting on it will not be supported. Consequently, any structural or non-structural systems supported on the superstructure will not be usable when the superstructure fails. This is a classic example of a system connected in series linearly.

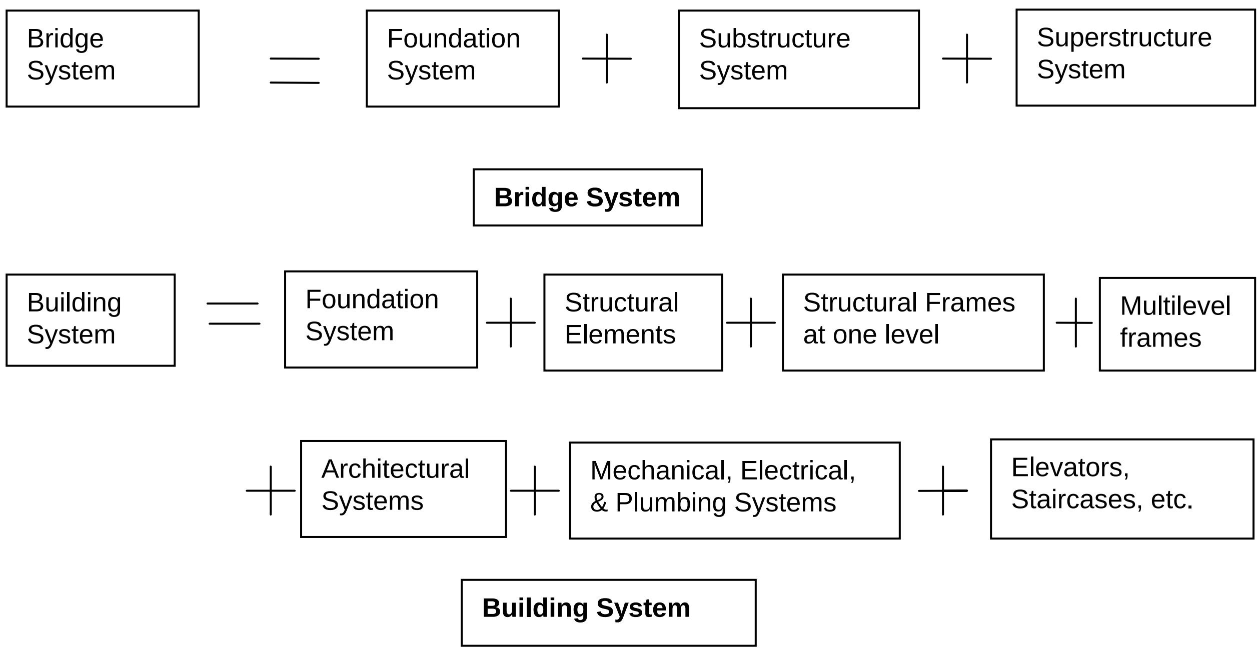

Figure 2. System Components connected in Series.

Surface transportation networks, although part of the physical infrastructure system network may have their components connected in parallel depending upon the available linkages. Bridges usually lead to a series type connection thus rendering the system unusable when the bridge cannot be used, unless multiple bridges are available for a crossing. However, if we consider bridge structures as isolated examples in the surface transportation networks, it can be assumed that most of these networks have components in parallel, i.e. alternates routes are available to keep the network still functional, although at a lesser capacity, after a major seismic event has damaged parts of it. An example of such a system is shown in Fig. 3.

Although both systems are static by design, the highway network system connected components in parallel allows the system to remain functional even if a link in the system may be broken. In this case, robustness of the system results from having multiple links (redundancy in structural terms), although individual links may not be robust by themselves.

Figure 3. Highway Network System – Components connected in Parallel.

Utilities such as water supply networks, electrical networks and gas distribution lines may have hybrid connections, i.e. some major parts are connected in series but the network may also be connected in parallel with other similar networks providing vital service in case of disruption in the service due to a major earthquake event. Utility networks are critically interdependent (see Fig. 4) e.g. water supply networks rely on pump stations which need uninterrupted electrical service. If the electrical network is disrupted, water supply is impacted although there may not be damage to its pipelines. In general these systems are also static but provide robustness due to hybrid connections.

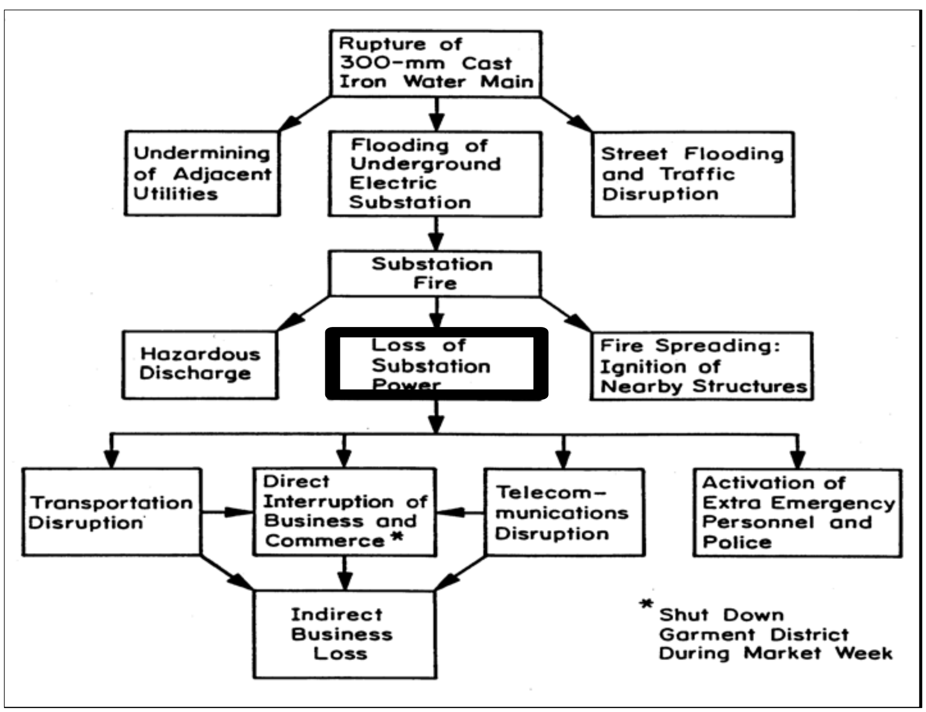

Figure 4. Interdependence of various utilities.

Dynamic Systems

Most societal network systems are dynamic by nature as they adapt and respond to changing conditions. The linkages between various components comprising these systems are flexible and non-linear. The connections also tend to be random and present difficulties in determining their connection paths. This very aspect presents the difficulty in combining societal systems with engineering systems to determine the overall impact of a major seismic event on society. Recent advances in quantifying societal impacts as consequences of major seismic events have led to development of their inclusion in the research design at the fundamental level. However, such inclusions are extremely limited in earthquake engineering research field. This paper essentially argues that inclusion of all subsystems is necessary to reliably estimate the impact of a major seismic event and thus design of appropriate steps for seismic hazard impact minimization.

Linkages

Linkages can be rigid or flexible and linear or non-linear. Some of these are shown in Fig. 5.

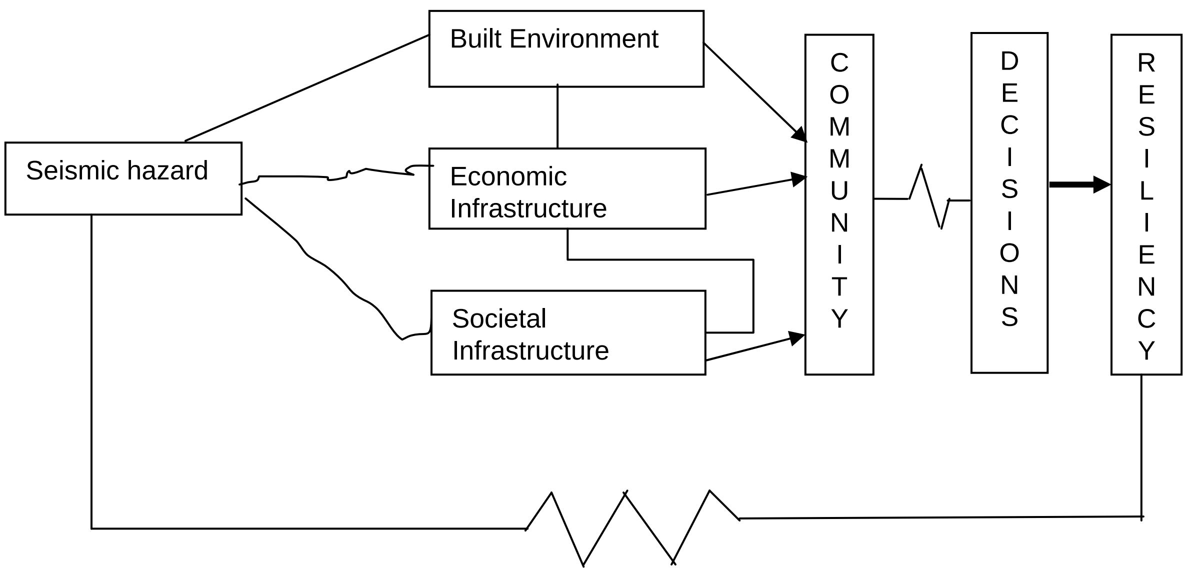

Figure 5. Various linkages of subsystem components.

Consider a seismic hazard that is capable of a major disruption to a community. Its impact on various subsystems can be judged by the type of linkage it has with a particular subsystem. The impact on the built environment results in damages and possibly loss of life depending on the severity of damage and the type of damaged structure. This type of link is usually linear and rigid as it does not allow any different modified behavior of the structure due seismic impact. The link to economic infrastructure is non-linear and also somewhat flexible. The non-linearity results from varying degrees of economic damage depending on the type of economic activity where the seismic impact has been greatest. e. g. if the seismic event is located close to a major financial center such as Tokyo, the disruption would result in financial and economic market disruptions with repercussions throughout the world. On the other hand, if the seismic event is close to location such as Los Angeles, the repercussions to financial markets worldwide would be limited and the economic damage would be regional rather than national or international. The link is also flexible because the economic infrastructure is global and can respond to disruptions with support through alternate links providing some resiliency. Examples of this type of resiliency can be found in response to terrorist attacks in Mumbai (2005), London (2003), and Tokyo

(2004). Although these are not seismic activities, the impact on society is similar. In all these cases, financial markets were open within 48 hours and economic repercussions were limited in degree and extent. Societal links are also non-linear and flexible.

Finally, the link between the community and the impact due to seismic hazard is shown by a flexible link (spring) which has the characteristics to absorb shocks. Depending on the degree of resiliency in a community, the damage and disruption to a community can be modified for a similar event. It is extremely important to understand the type of linkages with various subsystems within a system to understand the overall behavior of a larger system. The concentration in seismic research has been dominated by making subsystems robust without due consideration to larger seismic hazard minimization system.

Integrated Interdisciplinary Research

Although a lack of integration leads to independent systems that are sub-optimal as they do not consider input from other relevant dependent systems, barriers to conduct integrated research are listed below:

1. Basic academic training is discipline specific
2. Easier to focus on research in a specific discipline
3. Academic reward system is discipline –research based
4. Research methodologies are different for different disciplines
5. Lack of common vocabulary across disciplines

Various attempts have been made to integrate different disciplines at different levels. A recent initiative called Network for Earthquake Engineering Simulation (NEES), in integrating various engineering disciplines with information technology, computational sciences and experimental techniques was undertaken by National Science Foundation. It connects sixteen geographically distributed sites in the US, with capacities in different fields through a cyber-infrastructure network to conduct experimental and computational research in real time. An example of this type of integrated research is shown in Fig. 6.

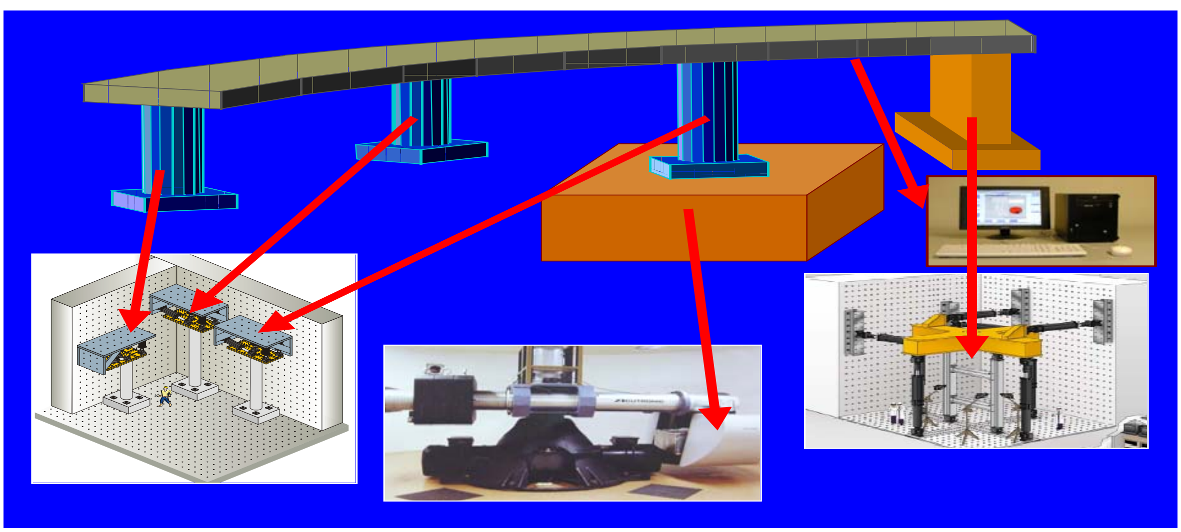

Figure 6. Bridge Behavior Simulation.

In this example, the bridge piers are tested at one facility, the abutment at a different facility, the foundation system at a centrifuge facility and the bridge deck is being modeled on analytical basis. The entire bridge behavior is being studied in real time through feeding input/output to each other from different sites. This is an example of integrating only the bridge components and does not go into any other systems. From a systems view point this is a structural subsystem.

Extending the system beyond structural engineering subsystem to incorporate social and economic sciences, and decision sciences requires multidisciplinary approach. Such an approach is demonstrated in Fig. 7. The framework shows integration of seismic hazard and performance of structures activities with engineering, earth sciences and social sciences disciplines.

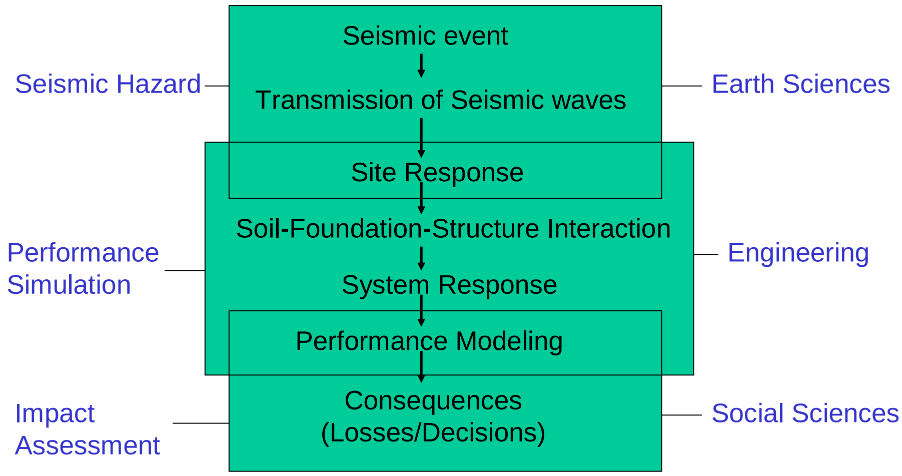

Figure 7. Framework for integrating activities with disciplines.

Although the framework shown in Fig. 7 connects the activities with disciplines, it does not fully explain the interconnection of various disciplines and how the input from one system is taken into account in modifying research agenda based on that input. The complete seismic hazard reduction system with various components is shown in Fig.8. It should be noted that the interconnection is not linear.

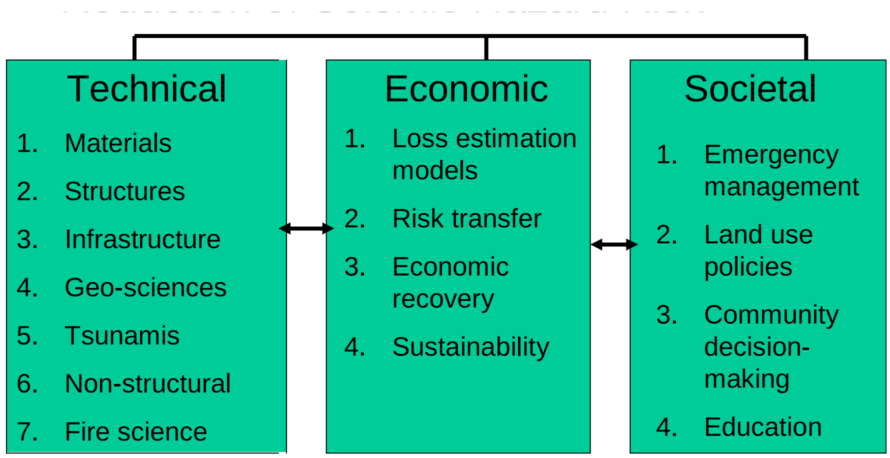

Figure 8. Seismic Hazard Reduction System Framework.

To conduct integrated research, certain minimum conditions are necessary. One of the primary conditions is to develop necessary algorithms to combine the qualitative and descriptive aspects of social sciences discipline with the quantitative methodologies of engineering discipline. Integrated interdisciplinary research environment can be conducive only when the challenges enumerated below are satisfactorily addressed.

Challenges

1. Language differences between earthquake engineers, social scientists, public policy officials and economists need to be overcome to agree on shared definitions.
2. Different disciplines make assumptions which may not be common to a problem. These need to be shared by all so that assumptions are clearly understood.
3. Researchers must develop respect for each other's disciplines.
4. Agreement on research methodologies and intended outcomes.
5. Culture of collaborative research is not prevalent in engineering research. Such a culture is extremely necessary in seismic risk reduction research that is inherently multidisciplinary.
6. Creating meaningful incentives for collaborative research is important.
7. Research resources need to be shared.
8. Seismic risk reduction requires distributed decision-making approach. Recognition of this approach by all is necessary.
9. Adoption of and subscription to multi-criteria-decision-making methodologies.
10. Developing common audiences to engineering and social science and problem framing for the intended audience.
11. A passion for solving larger, complex, and cross-disciplinary problems.

Conclusions

New integrated risk assessment models for operability of *critical infrastructure system components* leading to improved vulnerability analyses of system interdependencies are required. As an integral part of seismic risk reduction to society, integrated models of mitigation, preparedness, and evacuation planning needs to be developed. There is also a lack of communication between integrated databases and disaster management community. This gap needs to be bridged.

From a public policy perspective, when an earthquake occurs, decisions have to be made by various officials located remotely from each other. This process of decision-making is not well understood. Distributed decision-making models specifically addressing seismic hazard risk need to be developed. More incentives in insurance, mortgages, tax policy, building codes and zoning regulations (civil infrastructure) need to be provided. It is also important to speed transfer of research to practice via reliable and useful tools.

Most importantly, a culture of collaborative integrated and interdisciplinary research in the academic institutions needs to be developed and rewarded. Integrated research involving engineering, social sciences such as, political science, decision science & public policy disciplines is essential to make impact on reducing Natural Hazard Risk.

Acknowledgments

Author wishes to acknowledge Pacific Earthquake Engineering Center (PEER), Mid-America Earthquake Center (MAE), and Multidisciplinary Center for Earthquake Engineering Research (MCEER) for providing photos and figures used in this paper. All three Centers are funded by National Science Foundation.