Advanced Technology in Natural Hazard Mitigation: A New Landscape for International Cooperation

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ABSTRACT

This paper reviews recent research in the field of natural disaster mitigation, and illustrates the transition of such research over time as some enabling technologies have emerged. A new framework for natural hazard mitigation, in response to the new technology development is described, which includes: the autoadaptive media, integrated hardware and software systems for data sensoring, measurement, transmission, and processing, and their applications such as structural health monitoring. These technological opportunities and challenges create a new landscape where major advances in enhanced safety and performance of buildings and civil infrastructures can be achieved with greater efficiency than in the past.

INTRODUCTION

Natural hazard reduction research is a cluster of integrated activities, consisting of engineering and social and economic research for such hazards as earthquakes, windstorms, floods, landslide, etc. The recent focus has been on pursuit of frontier research that responds to new technologies and that leads to rapid new knowledge discoveries. The needs resulting from natural disasters and improvement of technology and expertise worldwide have made the advances in natural hazard mitigation into a landscape for international cooperation in engineering.

CURRENT RESEARCH HIGHLIGHTS

Structural Control Technology

A major accomplishment achieved in the last decade was development of control technologies to reduce the dynamic response of structures. A major 5-year research initiative in structural control was carried out in the US under the support of National Science Foundation (NSF) in mid-90s, which included a significant component in cooperative research with Japan. Over this time, a US Panel on Structural Control, chaired by Professor George Housner of California Institute of Technology, was established to provide technical coordination among the researchers and crucial bilateral liaison for this program of multitude projects. Much progress has been made in terms of the fundamental concepts and theories, software and hardware systems and their integration, and issues of practical engineering implementation of active, passive, and hybrid systems for control of dynamic responses and safety protection of structures against natural hazard forces. As part of this development, control systems employing smart damping devices (SDDs) probably combine the best features of both passive and active control systems to offer substantial potential for near-term acceptance of control technology in civil engineering and natural hazard mitigation. SDDs offer the adaptability of active control devices without requiring the associated large power sources. In fact, many SDDs can operate on battery power, which is critical during severe natural hazards when external power sources may fail.

Presently accepted definitions consider a SDD as one, which cannot inject mechanical energy into the controlled structural system, but has properties, which can be controlled to optimally reduce the responses of the system. One can view SDDs as controllable passive systems. SDDs, in contrast to active control devices, are stable since they cannot inject energy into the structural system. Preliminary studies indicate that control strategies employing SDDs perform significantly better than passive systems and have the potential to achieve nearly the same performance of fully active control systems. Examples of semi-active control devices include variable-orifice fluid dampers, controllable friction devices, controllable tuned liquid dampers, controllable-fluid dampers and controllable impact dampers.

Cooperative Program in Wind Engineering

A major effort in the Cooperative Program in Wind Engineering (CPWE) between Colorado State University and Texas Tech University has been undertaken since 1989. The program, which has involved a large cross-disciplinary research team of engineers, atmospheric scientists, meteorologists, economists, and many graduate and undergraduate students, focused on developing and integrating fundamental understandings of wind loads, wind hazards, and wind effects on buildings. The research has resulted in:

- Updating of wind load standard ASCE 7-95, national wind loads design standard for buildings and other constructed facilities, which is a trillion-dollar a year industry.
- Improved understanding of wind damage economics and its public policy implications and social consequences. This portion of research was been co-funded by FEMA for the last three years and has led to the graduation of two doctoral candidates, one at each institution.
- Advances in wind tunnel technology through integration of wind effects testing in the field (at TTU) and in wind tunnel (at CSU). Ultimately more reliable and economics consistent design of wind resistant buildings will be achieved.

Tsunami Research

Tsunami is an infrequent but often a catastrophic hazard associated with under ocean seismic events. Fundamental research in tsunami generation in subduction zones, long wave and short wave propagation, their shoreline inundation and its interaction with and impacts on coastal structures have been continued under intensive study over the last ten years. Investigations for recovery of tsunami data, such as field reconnaissance by a combined team of engineers and earth scientists following the 1998 Papua New Geinea tsunami, have been carried out whenever there are perishable scientific and damaging data to be collected. The body of new knowledge coming out of these studies is expected to lead to better tsunami risk mapping, improved capability of tsunami modeling, and more accurate techniques and instrumentation for tsunami warning.

NEW TECHNOLOGIES

Research in the use of smart materials in structures, both in civil, aerospace and automotive engineering applications, has seen contributions globally. Contributors include USA, Japan, European countries, Australia, and others. Researches in smart structures include health monitoring, smart manufacturing, active-controlled/adaptive structure, and actuator materials development.

Smart material and devices currently include shape memory alloys, controllable fluids (magneto-rheological and electro-rheological fluids), and electro-strictive (piezoelectric) and magneto-strictive elements. Key market drivers for smart technology include: initial cost, life-cycle costs, performance and reliability of the sensor, the environmental effects of the technology, and how these technologies affect our quality of life. New sensors to detect cracks, measure stress and strain, predict corrosion, and measure temperature are being studied. Some of these sensors have been developed, but their use is currently limited to the laboratory environment. Smart materials or devices can be integrated with damage detection systems to achieve target performance and intelligent functionality.

New sensors should be wireless, portable, self contained, capable of differentiating among different types of data, robust, durable, and maintenance free. MEMS technology is being used in sensors to reduce their sizes. Although these sensors are microscopic, some of them containing over a million transistors are no more than 10 square millimeters in size. Such miniaturization allows these sensors to process and store the data and transmit them wirelessly to a remote location. But to make them truly wireless and portable, small long-life reliable power sources are required. Nano motors, currently being developed, may one day generate the necessary power to run these portable wireless sensors.

New technologies that are mature enough to find some applications in civil engineering including GPS, cellular technology, nano-technology, LADAR, LIDAR, and RADAR can be used to enhance structural health monitoring, and their use should be encouraged. GPS has been used to monitor slip and creep movement of faults, and to measure displacement in long-period structures and bridges. Detection of delamination and bond using electric resistance change, electro-mechanical impedance, and interactive piezoelectric sensor/actuator devices -- surface attached and/or embedded -- are promising techniques. The basic principle behind impedance-based technique is to utilize high frequency structural excitation through the surface-bonded piezoelectric sensor/actuator to detect changes in structural point impedance due to the presence of damage. As the cost of smart materials decreases, they can be used in large quantity. The damaged sensors can then be ignored. Such ubiquitous inexpensive sensors are useful in concrete construction because the mixing, pouring, and curing environments are harsh enough that many sensors may not survive.

Ground penetrating radar uses electromagnetic waves to identify underlying features in solid structures can be used to study bridge decks to identify damage due to corrosion, delamination, and degradation of concrete. Magnetostrictive tagged composite to measure the stress in the material. Taking advantage of the magnetic properties of steel at different stress levels, assessed the stress level in the prestressed steel can be assessed. This technique can also used to monitor corrosion damage.

Shape-memory alloys (SMA) have been targeted as seismic energy absorbing devices to suppress damage due to dynamic forces. They are now finding application in deflection control, reinforcement bars in concrete members, isolation systems, control of room temperature, and unlocking doors during emergency. Albeit some of these applications are still in the experimental stages. Magneto-rheological materials have also been limited to small-scale applications to date. Current research using full-size structures shows promising results. However, material characterization under different conditions needs to be studied before this material can be used in real applications with confidence. Some current researches such as the theoretical study of the heat transfer behavior of MR materials is already underway.

Microsensors are basically silicon, piezoelectric wafer or polymer devices that convert a mechanical signal into electronic one using microelectronics technology. Signals are amplified, conditioned and fed to application specific integrated circuit chips. They can be mounted outside the material as well as embedded inside the material. Sensors must be reliable, accurate, self-diagnostic, inexpensive, and lightweight. Different sensors are used to measure the following: Lamb waves are useful for sensing impact damage, cracks, delamination, bond, and corrosion. Love waves are useful for detection of ice formation, and works well with AE for crack detection. Bulk waves are useful for propagating longitudinal and shear waves into a structure. Rayleigh waves are useful for sensing deflection, strain, temperature, humidity, pressure, acceleration and high sensitive gyroscope. In addition to the traditional use of sensors to measure vibrations, many indirect measurement techniques can be used to measure such difficult quantities as corrosion damage in concrete. These methods include the measurement of pH levels, Cl ions and moisture levels in concrete.

One of the biggest challenges for engineers in the 21st century is to develop intelligent systems, which possess capability in sensing, processing, actuating, repairing, or any such combinations. Since 1990 a number of specialized workshops and initiatives have been developed with this vision in mind. At the present time, intelligent or smart material systems are considered as those engineered systems which are autonomous, which can maximize performance, possess adaptive functionality, and which could minimize life-cycle cost. Following these initial efforts, a planning activity aimed at developing a joint US-Japan cooperative research in Autoadaptive Media (AAM) has been carried out. This study culminated with a report on future research needs based on recommendations deliberated during two consecutive joint workshops held on 17-19 May 1998 in Sonoma, California and 8-9 January 1999 at Purdue University.

INTERNATIONAL COOPERATIVE RESEARCH

International cooperative research has been a major component of the natural disaster mitigation research program in the US. Under the US-Japan Cooperative Research Program on Utilization of large-scale Earthquake Testing Facilities, five phases of experimental research, each on a major building type, have been carried out jointly by US universities and the Building Research Institute of Japan. These five phases are: (1) Reinforced Concrete Buildings, (2) Steel Buildings, (3) Masonry Buildings, (4) Precast and Prestressed Buildings, and currently research in (5) Composite and Hybrid Structures.

Following major earthquake disasters in 1994 (Northridge, USA) and 1995 (Kobe, Japan), researchers in both countries discovered many surprises and damaging phenomena, which were not previously known. Following an intensive planning effort by top researchers in the field from both countries, NSF and the Japanese Ministry of Education, Sports, and Cultures (Monbusho) jointly announced a 5-yr cooperative research program, under the framework of US-Japan Common Agenda, in 1998. Due to the complexity of the program due to its size, diversity, nature and needs for research integration and coordination, a Joint Technical Coordination Committee (JTCC) was established to provide overall program coordination and guidance for direction. During the first three years of this joint research, approximately 30 projects covering all five announced thrust research areas: (1) Performance-based Design and Engineering, (2) Integrated Social Science Research, (3) Advanced Steel Structures, (4) Geotechnical Engineering Systems, and (5) Advanced Technologies have been supported. It is anticipated that future efforts will continue to emphasize new technologies such as smart materials and structures, IT for global disaster information system, wireless technologies and internet-based data systems, networking technologies for innovative experiments and model simulations, chips as micro sensors with embedded data/signal processing capability for real-time structural condition monitoring, diagnosis, damage detection and identification, and post-event emergence response such as urban traffic control and search and rescue.

The US-China earthquake protocol was one of the original state-to-state S&T agreements established shortly after the resumption of bilateral diplomatic relation between USA and China. NSF has been responsible for since 1981, in counterpart with the Ministry of Construction (MOC) of China, the development and implementation of Annex III of the protocol, covering mutually beneficial and challenging research activities in earthquake engineering and hazard mitigation. These included cooperative investigations in strong-motion array and data analysis, structural control techniques including a large-scale demonstration project using active mass driver to control wind vibrations caused on Nanking TV Tower (3,000 Meters plus in height), comparative hazard risk and mitigation strategy study of urban cities, and others. These projects, which have been coordinated though an annual protocol joint staff meeting, and have greatly expanded earthquake hazard data base and produced new knowledge in safe and cost-effective engineering design methods, Construction practices, and other countermeasures for seismic and wind safety of structures.

Following the devastating M7.6 earthquake in Chi Chi that occurred on September 21, 1999. Intensive efforts have been made to capitalize the rich field damage and instrument data recorded to further understand the causes of damaging effects of near-field earthquakes and to develop improved policies and measures — technical as well as socioeconomic — to minimize future casualty and loss. The US National Science Foundation has initiated a research solicitation calling for proposals for study of the 921 Taiwan and the August 17 (M7.4, along North Anatolian Fault) and November12, 1999 Turkey earthquakes.

To focus on short and mid-term research that could make a difference in mitigating future earthquakes in Taiwan, the National Science Council (NSC) of Taiwan held an International Workshop on 921 Earthquake in Taichung — the central provincial capital city near the earthquake damaged area — on December 14-17, 1999. More than 200 participants, including many government officials, practicing professionals and international experts attended the symposium. The discussions focused on the following areas: (1) Geoscience and Geotechnical Engineering, (2) Structural Engineering, (3) Emergency Response, Disaster Recovery, and Reconstruction, and (4) International Cooperation. Specific, high-priority researches and government programs and actions were recommended. The workshop proceedings will soon be published by the Office of National Science and Technology Program for Natural Hazard Mitigation, NSC.

The workshop recommended that a center-to-center research program be initiated to implement an integrated program of diverse investigations. This particular form of center research, which has been proven successful in a number of cases involving US-Japan cooperative studies, has advantages in overcoming the lack of a critical mass of the diverse manpower required, maintaining the research direction over the course of the joint research, and facilitate coordination among investigators. Critical to these ends, a Joint Technical Coordination Committee (JTCC) is to be established (Figure 3). Possible players in such center-to-center programs are the current three earthquake engineering research centers in the US, i.e., PEER, MCEER and MAE centers, and Taiwan's National Center for Earthquake Engineering Research (NCREE) and the National Science and Technology Program for Earthquake Hazard Mitigation.

CONCLUDING REMARKS

Technology has progressed in a rapid rate beyond our widest imagination. With technology and unlimited future challenges, the world and how people live and conduct their business evolve. With this trend how people conduct research and mitigate natural hazards have also been transformed. This paper attempts to present a quick view on the transformation in natural disaster mitigation research and glimpses into the future over this transition time. Technology is not a substitute or replacement for conventional engineering research and its traditional approaches. Technology, due to its added effectiveness to improvement of infrastructure safety and performance, has provided an extra dimension to such research. Opportunities created by modern and emerging technologies are abundant, and their frontiers are without limits. It is important for researchers, practitioners, and other natural hazard professionals across the world to stay close and react to the new technological developments, to explore their potential of applications, and to integrate them fully into the decision making and implementing strategies for natural hazard mitigation.