Human and Institutional Perspectives of the 921 Chi-Chi, Taiwan Earthquake

by George C. Lee and Chin-Hsiung Loh

Research Objectives

MCEER and the National Center for Research on Earthquake Engineering (NCREE) have had a cooperative agreement to carry out fundamental earthquake engineering research in areas of mutual interest since 1992. Shortly after the devastating Chi-Chi earthquake of September 21, 1999, the Directors of the two Centers planned a joint MCEER-NCREE workshop to identify important short-term strategies and actions for post-earthquake restoration and identify research needs. In April 2000, a second workshop was held between NCREE, MCEER, the Pacific Earthquake Engineering Research (PEER) Center at the University of California, Berkeley, and the Office of National Science and Technology Hazard Mitigation of the Taiwan government, to develop a highly focused Center-to-Center research program. The program will incorporate the vast amount of reconnaissance information gathered in Taiwan and apply it to specific problem-focused research already underway at the four Centers. This plan, together with observations of the authors with respect to the societal and government responses, is offered herein.

On Tuesday, September 21, 1999, a devastating earthquake struck the central region of Taiwan. This earthquake became known as the 921 earthquake or the "Ji-Ji" or "Chi-Chi" earthquake. The magnitude of the 921 earthquake was M_S = 7.6 (Richter scale) or M_L = 7.3 (the system used in Taiwan). There were ten aftershocks greater than magnitude 6. Of these, an M_L = 6.8 occurred about 30 hours and 120 hours after the main shock, respectively. An M_L = 5.3 aftershock was recorded as late as 260 hours later causing collapses of already damaged structures. As of October 8, the death toll was more than 2,350. Over 8,700 people were injured, and dozens remained missing. Approximately 10,000 buildings/homes collapsed and over 7,000 more were damaged.

For the past eight years, MCEER and the National Center for Research on Earthquake Engineering (NCREE) have had a research collaboration agreement to carry out fundamental earthquake engineering research in areas

Sponsors

National Science Foundation, Earthquake Engineering Research Centers Program
New York State
University at Buffalo, State University of New York
Federal Emergency Management Agency

Research Team

***George C. Lee**, Director, Multidisciplinary Center for Earthquake Engineering Research, University of Buffalo, State University of New York*
***Chin-Hsiung Loh**, Director, National Center for Research on Earthquake Engineering, National Taiwan University*
***Jack Moehle**, Director, Pacific Earthquake Engineering Center, University of California, Berkeley*
***Chin-Lien Yen**, Director, Office of National Science and Technology Hazard Mitigation*

Links to Current Research

Program 1: Seismic Evaluation and Retrofit of Lifeline Systems
Program 2: Seismic Retrofit of Hospitals
Program 3: Emergency Response and Recovery

of mutual interest. A number of joint studies in the general area of seismic response control are in progress and last year, two additional research projects were added (remote sensing applications, and protective systems for bridges).

Photograph by M. Bruneau

■ Figure 1. Surface faulting caused major damage to the Shih-kang Dam

Under the umbrella of continuing cooperative research, the authors discussed the best way to join forces following the 921 earthquake. They decided to hold an MCEER-NCREE workshop, which took place on October 3-5, 1999 in Taiwan. The purpose of the workshop was to identify important short-term strategies/actions for post-earthquake restoration and research needs, including specific cooperative projects for investigators from both centers to work as teams based on the 921 experience. Many reports have since been published by NCREE on a variety of technical areas (in Chinese) and MCEER has a reconnaissance report in press at this time (Lee and Loh, 2000), which focuses on both technical and societal issues.

This growing body of knowledge and its vast potential prompted MCEER to examine whether or not our research results, which are carried out in concert with achieving our vision of creating earthquake resilient communities, could help in Taiwan; and if so, how it could best be accomplished. To explore this possibility in greater detail, a second workshop was organized in April 2000 in Taiwan and included two more centers, the Pacific Earthquake Engineering Research (PEER) Center at the University of California, Berkeley, and the Office of National Science and Technology Hazard Mitigation of the Taiwan government. The Directors from each of the four Centers held discussions to further define and clarify how to bring their collective strengths together to make this vision a reality. The result was the establishment of a three-year Center-to-Center research program. The specific research projects to

Post-earthquake information is valuable for the enhancement and validation of existing models, methods and practices. It is anticipated that the results of this research effort will be used by earthquake hazard mitigation experts for this purpose, and will ultimately strengthen our existing knowledge base in a wide variety of areas. On the Taiwan side, one focus will be to validate HAZ-Taiwan, to develop more accurate loss estimation methodologies. For both the U.S. and Taiwan, new knowledge gained will be applicable to code improvements and implementation in both countries.

be carried out under this program are described later in this paper.

The first part of this paper summarizes the observations and reflections of the authors shortly after the earthquake with respect to the societal and government responses of the 921 earthquake. The authors are of the opinion that this earthquake not only destroyed a segment of Taiwan's physical landscape, but also made a significant impact on the society and government. Taiwan, like the U.S., is lucky because it hasn't experienced a major destructive earthquake with large death tolls in recent memory. This 921 earthquake presents a reminder and an opportunity for the people and government in Taiwan to begin a serious effort to establish more resilient communities against future earthquakes. The second part of the paper describes the new Center-to-Center research program.

Initial Observations and Reflections

The Public

Earthquake ground motions are felt by people living throughout Taiwan. Thus, the term "earthquake" is a familiar one. However, an earthquake of the magnitude of 921 has not happened in recent history. To many people, an earthquake amounted to the swaying of buildings and the development of cracks on a wall. Occasionally, the roof of some houses collapsed. The building code in Taiwan provides for reasonable design guidelines (the most recent update to the guidelines was made in 1997). Based on historical data and measurements made by strong motion instrumentation programs, the Taichung/Nantou area is classified as a region of moderate intensity with a design peak horizontal acceleration of 0.23 g. The 921 earthquake generated a horizontal force of more than four times this maximum design criterion. It is thus easy to see why so many buildings and bridges collapsed. Psychologically, the public in the area was accustomed to earthquakes, but not one of such destructive magnitude, occurring in built-up areas.

The public showed tremendous spirit as they worked together to save lives and help each other with the basic needs to survive in the days following the earthquake. After a day or two, many began to complain that the government was too slow in its rescue and relief efforts. As a few more days passed and people were forced to accept the loss of a loved one whose body had not yet been located, these complaints of ineptitude and inefficiency were understandably intensified. Nonetheless, it seemed that the government was actually quite swift and effectual in its response

Web Sites

Multidisciplinary Center for Earthquake Engineering Research
http://mceer.buffalo.edu/research/taiwaneq9_99/default.html

National Center for Research on Earthquake Engineering
http://www.ncree.gov.tw

Pacific Earthquake Engineering Research Center
http://peer.berkeley.edu/index.html

Photograph by M. Bruneau

Figure 2. Damage to buildings and bridges was widespread throughout the epicentral area

"An effective institutional structure for earthquake hazard mitigation is needed to develop well-prepared communities."

to the event, given its magnitude. At the same time, many people praised the efforts of military personnel and international emergency response teams, even though such help was limited in its effectiveness by the scarcity of critical information such as local area maps, building blueprints, and other such data. The disaster management effort at the regional and local level was clearly unprepared for this disaster.

In speaking with a variety of individuals, one can see that this earthquake has had an enormous impact on the way the public views the importance of building safety and location of both workplace and residences. In the short three-day visit, questions regarding these issues were the most frequently raised by the general public. Now is the time in Taiwan to emphasize public education about earthquake hazards and mitigation measures. A well-educated public will affect improvements in policy regarding mitigation and preparedness for earthquake and other natural hazards. In the past, real estate properties for many are the means to become rich. The landslides, the disappearance of the lake (reservoir), and the interrupted skylines in the city caused by the 921 earthquake had elevated the awareness of the public to treasure the small island shared by 22 million people. One may expect that environmental conservation and protection will be emphasized. Activities such as illegal pumping of fresh ground water for growing seafood (sinking land surface level) will be condemned by the public.

Photograph by M. Bruneau

■ Figure 3. Newly constructed buildings suffered severe damage

The Government

On the national level, the government seems to have responded well. It was certainly not possible to satisfy all those affected by the earthquake. However, many of the complaints stemmed from lack of preparedness rather than lack of emergency action. Within hours of the initial main impact, the national government announced policies for relief, short-term restoration and an organized interagency structure for efficient execution of rescue efforts. By September 28th (one week later), there were 17 major policies implemented, including hotlines, information and health centers, temporary housing, disaster relief funds and materials, and others.

However, a lack of earthquake disaster preparedness at both the national and local levels was evident. To varying degrees, this state of affairs exists everywhere in the world with respect to unexpected natural disasters. Because the occurrence of devastating earthquakes is probabilistic in nature, the consequences of such events are often not taken seriously by either the government or its constituents. In recent decades, the professional communities and government in Taiwan have made significant progress to mitigate earthquake hazards by, for example, funding the Strong Motion Instrumentation Programs at the Central Weather Bureau of the Ministry of Transportation and Communication, and funding earthquake and earthquake engineering research projects by the National Science Council, including the establishment of NCREE. The Ministry of the Interior and the various structural engineering professional organizations have also been active in updating building codes, and the Ministry of Education has been investing in human resources development and earthquake engineering facilities at the universities. Additionally, a National Science and Technology Program for hazard mitigation was established several years ago to coordinate the development of national hazard mitigation strategies.

All these efforts have been carried out by many talented researchers and administrators. They now beg the question, "What difference did these programs make in the communities where the earthquake struck?" Other than building code improvements for recently-built structures, very little can be said about how the investment of tax money improved the preparedness and resiliency of the communities. It seems that a systems approach involving multiple agencies and professionals at all levels from national to local must be designed and implemented. An effective institutional structure for earthquake hazard mitigation is needed to develop well-prepared communities. It is important, however, to distinguish between a comprehensive block diagram of relevant components (which is easy to draw) and a properly functioning hierarchy of agencies (which makes decisions at each level in a manner consistent with the overall system objectives).

Lessons Learned and Recommendations for Possible Actions

An earthquake resilient community should have three elements at its core:

- Properly developed codes for the physical infrastructure and high quality professional practice in planning, design, construction and maintenance.
- An informed and participating public.
- An institutional infrastructure system prepared for mitigation and response.

All three of these points require long-term sustained commitment from both the government and its citizens.

The 921 earthquake offers a chance to learn from "real world experience." Many issues related to earthquake engineering, from both the research and practical sides, have been addressed in other reports co-authored by investigators from both NCREE and MCEER. Several reconnaissance teams have also issued technical observation reports (for examples, the NSF-supported reconnaissance team, the EERI reconnaissance team, and others). In this section, the authors

"Within hours of the initial main impact, the national government announced policies for relief, short-term restoration and an organized interagency structure for efficient execution of rescue efforts."

"A well-educated public will affect improvements in policy regarding mitigation and preparedness for earthquake and other natural hazards."

reflect on their observations of the damage from the 921 earthquake and its effect on the local people, their community and government infrastructure, and the level of public knowledge on issues of earthquake hazard preparedness. Other reconnaissance reports have paid special attention to earthquake engineering research opportunities and the importance of long-term professional practice dealing with the physical world. The following observations are made from the total perspective involving human, institutional, and physical infrastructure system. They are offered for the public and the government in Taiwan as they face the restoration challenge after the 921 earthquake.

1. If the epicenter of the 921 earthquake had been located just 50 miles either north or south of the Taichung/Nantou area, the devastation to Taiwan's economy and the quality of life would have been much worse. To the north, the high-tech industrial park in Hsin-Chu and the political and economic center Taipei would have been struck; to the south, the center of heavy industry and manufacturing KaoHsiung could have been destroyed or seriously damaged. Eventually, these areas will be hit with a major earthquake. The opportunity exists today to carry out careful loss estimation and risk assessment studies for these areas. Ground motion information, geotechnical and structural design information all exist in sufficient quantities to conduct credible analyses of possible earthquake scenarios. These results could have a significant impact on the general public, elected officials and other decision-makers and stakeholders in Taiwan. Many individuals and organizations have gained financially from the booming real estate market of the past several decades – these groups will surely be supportive of such studies while the 921 earthquake is fresh in the population's collective memory. This type of study would allow for some quantification of the vulnerability of critical regions in Taiwan and could serve as the focus for a sustained effort in public education.

   Many individuals directly impacted by the earthquake require psychological help, for which the government has implemented a program. Often, survivors of critical events (drunk driving car crash, recovery from a terminal disease, and other traumatic events) become the best crusaders. These individuals may be provided with adequate understanding of the issues involving earthquake preparedness so that they can contribute to the public education task.

2. There is an immediate need for reliable methods to evaluate the extent of damage to a structure so that proper decisions can be made with regard to its retrofit/repair/replacement. More than 7,000 damaged buildings remain standing in and around the epicenter and they all need critical assessment of the damage sustained. This is a significant opportunity to begin accumulating the knowledge about "building damage" by developing an "expert system" or standardized system of measures

for non-destructive building evaluation. Of high priority is the evaluation of essential infrastructure buildings such as command centers, hospitals, manufacturing complexes and critical lifeline systems such as water, electrical power networks and bridges. An additional research effort to explore advanced technologies for deployment and implementation of emergency response, communication and rescue is also appropriate at this point, based on the lessons learned. There are many other long-term research opportunities in earthquake engineering that will not be addressed in this article.

3. The current emergency management and restoration organizational structure should be replaced gradually by a long-term institutional infrastructure which involves agencies at all government levels concerning all types of hazards. But beyond a simple box diagram of the hierarchy, such a system requires thoughtful implementation. One very important element is the appointment of the proper individuals at key positions in the various agencies (an Emergency Response Corps - the ERC). In an emergency situation, these individuals of the ERC are the connecting nodes of the system of agencies. They must be well versed in and loyal to the overall strategic and tactical aims of the system because they may be called upon to make decisions on short notice without the ability to consult either their superiors or their subordinates. These individuals would need to meet regularly, say twice a year, to review the emergency operating plan that should exist, and to update their coordinated efforts in mitigation and emergency preparedness. An institutional infrastructure for multiple hazard mitigation and response may be organized differently consistent with a country's own system and culture. The system in the United States (Congressional hearings and actions, the NEHRP agencies, the lead agency FEMA and its regional office, etc., and how they function) can be used as a starting point for development.

In general, a functioning institutional infrastructure system is much more difficult to establish than to reconstruct the physical infrastructure system. The latter may be targeted for completion in three or five years if resources are available. Emergency response and short-term actions require a top-down approach. But for long-term re-establishment, the top-down approach must be coupled with the bottom-up efforts of the participation of a well-educated public. In the opinion of the authors, the central government responded swiftly and in an organized manner with reasonable policies to help the affected people. However, preparedness at the local and regional levels was very inadequate, due to the lack of emergency awareness and relief plans. A

"A functioning institutional infrastructure system is much more difficult to establish than to reconstruct the physical infrastructure system."

Photograph by T.T. Soong

■ Figure 4. Reliable methods to evaluate the extent of damage are needed workable system to empower local government and a strategic system that ties together local and national government agencies during times of crisis is needed to avoid potential bottlenecks that could impede the implementation of Taiwan's five-year reconstruction plan. Addressing these issues is one of the major challenges ahead for post-921 revitalization.

4. One of the most pressing issues in short-term restoration is that of construction quality. This has always been an ill-defined factor that makes the evaluation of existing damaged facilities more difficult. It also becomes a factor of importance in the time immediately following an earthquake, as reconstruction begins. Other issues such as public education, research, institutional effectiveness and building code improvements are longer-term efforts. However, working with the real estate and construction industry can and should begin immediately with the restoration efforts. A workshop might be organized to review the current practice in building inspections (see item 2 above) and construction monitoring. Additional guidelines or recommendations would be issued as necessary. Building inspection and construction quality assurance should be examined from the overall perspective of planning, design, construction, decision-making processes (in the case of public works) and cost.

5. The short-term and long-term research needs identified by the 921 earthquake indicate that most of the research programs of MCEER and NCREE, particularly those involving current and potential joint MCEER-NCREE research efforts in: (a) loss estimation and risk assessment, (b) developing evaluation and retrofit strategies for critical facilities (water and electric power networks, medical facilities and bridges) and (c) application of advanced technologies in structural response mitigation and emergency responses, can benefit from the real world experience of the 921 earthquake. At the same time, these efforts can make a contribution to the state-of-the-art of earthquake engineering practice both in Taiwan and U.S. We look forward to a success story resulting from this center-to-center cooperation enhanced by the 921 earthquake.

Photograph by M. Bruneau

Figure 5. Failure of non-ductile details was frequently observed

Opportunities for Collaborative Research Projects

As noted in the introductory section, MCEER and NCREE have had a long-term cooperative agreement since 1992. Over the past several years, many workshops and discussions have been carried out to identify joint research and information exchange between the two Centers. At the time of the 921 earthquake, some of these research activities were already underway.

A special workshop was held shortly after the 921 earthquake during the first week of October 1999 in Taipei, organized by the directors of the two Centers. In view of the observations made following the devastating earthquake, workshop participants reexamined current research efforts, and priority was given to those issues that may answer questions related to Taiwan's short-term restoration efforts. These projects include:

1. Seismic retrofit (retrofit strategy) of transformer-bushing systems: system evaluation and analysis, develop retrofit options.
2. Seismic response, system identification, non-destructive evaluation and response modification technologies for hospitals, manufacturing facilities, and other facilities; bridges; and lifeline systems (electric power).
3. GIS-integrated technologies (including optical and RADAR-based remote sensing) for damage assessment from a system viewpoint.
4. 3-D time domain characterization of ground acceleration at a point and experimental validation of Tong-Lee kinematic formulation.

More recently, a Center-to-Center cooperative research program was initiated, including MCEER, NCREE and two additional Centers, the Pacific Earthquake Engineering Research Center (PEER) at the University of California at Berkeley in the U.S., and the Office of National Science and Technology Hazard Mitigation in Taiwan. The proposed three-year effort aims to take advantage of areas of overlapping interest and strengths of the four Centers, and to capitalize on the extensive results collected by the research team in Taiwan's reconnaissance efforts. Two major areas of emphasis were identified:

- The analysis of new information to enhance model validation, and to develop a better understanding that will lead to a new, more accurate knowledge base.
- Code improvements and implementation specific to Taiwan developed by earthquake hazard mitigation professionals.

These types of efforts are already underway and funded through the research programs of the four Centers. The proposed focus of the Center-to-Center research program is as follows:

1. Ground motion attenuation, site effects, spatial variation and validation.

Photograph by M. Bruneau

■ Figure 6. Damage to the Veteran's Hospital in Puli reduced its capacity to about 50% at a time when demand was highest.

2. Development of retrofit strategies for buildings shown to be vulnerable by the Chi-Chi earthquake. This includes two parts: development of specific retrofit ideas for 1-3 story and 8-12 story buildings; and development of evaluation and retrofit strategies for hospitals and selected manufacturing facilities including contents. This effort is an extension of existing projects on structural control technologies.
3. Development of evaluation and retrofit strategies for electric power (extension of existing project) water systems; and system analysis of electric power and water systems (extension of existing project).
4. HAZUS and HAZ-Taiwan Program (with Chi-Chi earthquake data, develop new system-related loss estimation methods for HAZ-Taiwan).
5. Social and economic issues.

References

Lee, G.C. and Loh, C-H., editors, 2000, *The Chi-Chi Taiwan Earthquake of September 21, 1999: Reconnaissance Report*, MCEER-00-0003, in press.