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Tri-Center Field Mission 2002: Taiwan

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Summary

This paper presents some examples of civil engineering structures that were damaged or destroyed by the 1999 Chi-Chi earthquake and have been repaired or rebuilt, as well as examples of structures not affected by the earthquake but retrofitted for damage mitigation during future seismic events. It is shown that non-engineered retrofit measures are often implemented in typical residential buildings, while more rational procedures are followed for public buildings such as schools. In the case of bridges, it is shown that simply-supported spans are no longer used and have been replaced by continuous girders connected to the substructure through elastomeric bearings. All the examples have been observed and evaluated during a recent visit (Field Mission) to Taiwan made by the author and other graduate students from U.S. universities. The Field Mission was supported by the three U.S. Earthquake Engineering Research Centers (MAE, MCEER and PEER) and was coordinated by Taiwan's National Center for Research in Earthquake Engineering (NCREE).

Introduction

The central region of Taiwan was struck by a magnitude 7.6 (Richter scale) earthquake on September 21, 1999, at 1:47 a.m. local time (September 20, 5:47 p.m. Universal Time). The earthquake was caused primarily by a rupture of the Chelungpu fault and its epicenter was located close to the town of Chi-Chi, in the Nantou County. The earthquake generated a surface fault rupture of about 100 km, and the maximum offsets were among the largest ever observed: about 11 m (vertical) and 10 m (horizontal) in the northern part of the Chelungpu fault. Peak ground accelerations were of the order of 0.30–0.50 g, while peak ground velocities were between 40–80 cm/sec.

A large number of engineering structures were located in the densely populated area around the epicenter and the surface rupture. It is not surprising then that the Chi-Chi earthquake caused a vast amount of damage. Around 2400 lives were lost, about 10,000 people were injured and approximately 100,000 people were left homeless. Many kinds of structures (buildings, bridges, dams, tunnels, transmission towers, etc) were destroyed or damaged by strong shaking, large ground offsets or landslides.

Most of the damaged structures have been repaired or rebuilt, and most of the structures that collapsed have been removed and replaced by new constructions. The objective of this paper is to present some examples of engineering structures affected by the Chi-Chi earthquake that have been repaired or rebuilt. The examples were observed and selected during the recent Tri-Center Field Mission 2002 in Taiwan, where a group of eight graduate students from the three U.S. Earthquake Engineering Research Centers (MAE, MCEER and PEER) visited the Chi-Chi area. The author of this paper was a member of the group and represented MCEER. The Field Mission was coordinated by Taiwan's National Center for Research in Earthquake Engineering (NCREE), whose members provided comprehensive background information through a series of seminars and logistic support for the field trip.

Building Structures

The typical residential building in Taiwan is a 2-to-5-story reinforced concrete frame structure with masonry infill partitions and exterior walls. Since the first story is in most cases occupied by small stores, these buildings have a pedestrian corridor and open front at the side facing the street (Figure 1a). As a result, the first floor is weaker and more flexible than the upper floors, a structural deficiency that is often made worse by the stiffness eccentricity in the direction parallel to the street. These undesirable features were responsible for most of the collapses suffered by these kinds of buildings (Figure 1b). Other deficiencies (short column effect, lack of adequate transverse reinforcement, etc.) also contributed to the poor performance of this type of construction.

Photograph by Lopez Garcia

Photograph by Bruneau/MCEER

a) **b)**

Figure 1. Typical residential building in Taiwan: (a) pedestrian corridor and open front; (b) soft story damage

Most of the buildings that did not collapse but suffered some damage have been repaired (Figure 2a) and many more have been retrofitted, mainly by incorporation of new structural members (beams and columns). In most cases, these new structural members are steel elements (Figure 2b, Figure 3). Unfortunately, the majority of these retrofit measures are non-engineered and their utility in improving the seismic behavior of typical residential buildings is difficult to evaluate.

School buildings were also severely affected by the Chi-Chi earthquake and many of them collapsed (Figure 4a). An example of retrofitting measures can be seen in Figure 4b, where metallic dampers have been added to an existing steel structure. Figure 5 shows a new school building under construction, where frames are made up of composite RC-steel members.

Photograph by Lopez Garcia
a)

Photograph by Lopez Garcia
b)

Figure 2. Non-engineered retrofit of residential buildings: (a) beam-column joint retrofitted with steel plates; (b) structure strengthened by a new column

Photograph by Lopez Garcia
a)

Photograph by Lopez Garcia
b)

Figure 3. Non-engineered retrofit of residential buildings: (a) RC beam strengthened by a steel beam; (b) eccentric RC beam-column joint supported by a steel column

Photograph by Lopez Garcia
a)

Photograph by Lopez Garcia
b)

Figure 4. (a) Collapse of school building; (b) Library building retrofitted with metallic dampers

Photograph by Lopez Garcia

Photograph by Lopez Garcia

a)

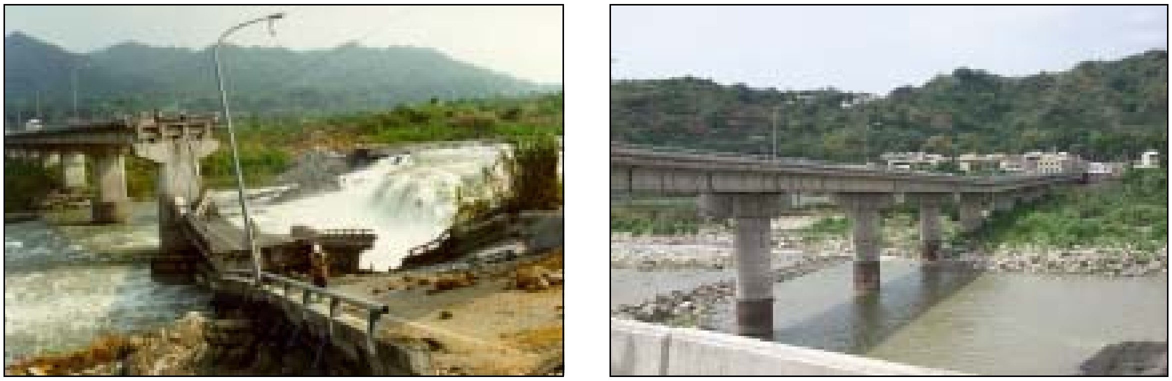
b)

Figure 5. New school building under construction: composite RC-steel frame

Bridge Structures

The Chi-Chi earthquake caused many bridge structures to collapse. Many bridges were directly affected by surface rupture and the consequent ground movement. These bridges collapsed due in large part to unseating of one or more simply supported spans (Figure 6a, Figure 7a), which was the typical structural configuration for bridges in service at the time of the earthquake. Other kinds of failures were also observed (Figure 8a). These bridges have been reconstructed, either partially (Figure 6b) or totally (Figure 7b, Figure 8b). An example of partial reconstruction is the Bei-Feng bridge (Figure 6), where some of the original columns were not demolished and were used to support the new bridge. The slope of part of the new bridge (Figure 6b) is a consequence of vertical offset. Most of the completely rebuilt bridges have composite decks supported by continuous steel girders (Figure 7b, Figure 8b), which seems to be the preferred structural configuration for new bridge structures in Taiwan. Joints between continuous segments are located at pier locations (Figure 9a) and the superstructure is supported through elastomeric bearings (Figure 9b). Restrainers against both longitudinal and transverse displacements are usually provided at pier and abutment locations (Figure 9).

Some bridges not affected by surface rupture were also damaged by strong ground shaking. An example of a repaired bridge structure is shown in Figure 10, where it is shown that a wide column damaged at the connection with the superstructure has been retrofitted by steel jacketing. The column-to-cap beam connection has also been improved by adding steel plates and post-tensioned rods.



Photograph by Shen/MCEER

a)

Photograph by Lopez Garcia

b)

Figure 6. Bei-Feng bridge: (a) collapse of end spans; (b) after reconstruction

Photograph by Buckle/MCEER

a)

Photograph by Lopez Garcia

b)

Figure 7. Shi-Wei bridge: (a) collapse of the middle span; (b) after reconstruction

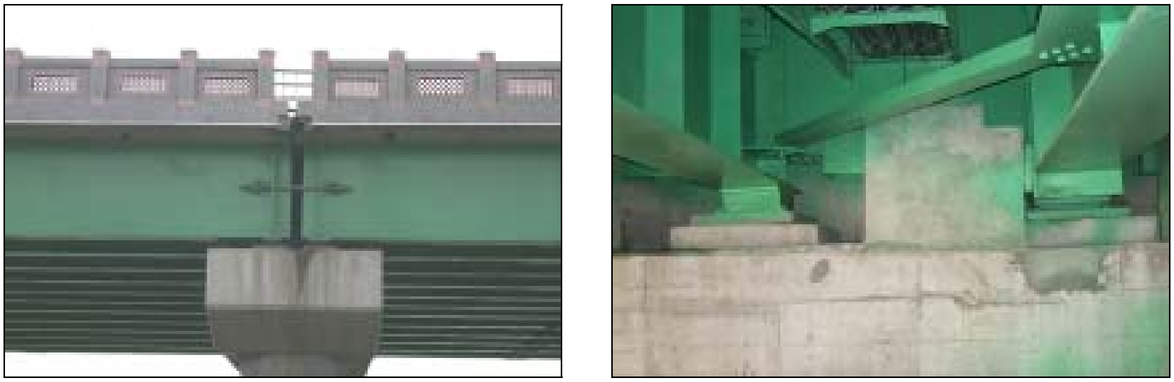
Photograph by Buckle/MCEER

a)

Photograph by Lopez Garcia

b)

Figure 8. Wu-Shi bridge: (a) diaphragm and shear key failures; (b) after reconstruction



Photograph by Lopez Garcia *Photograph by Lopez Garcia*

a) b)

Figure 9. Typical details of new bridge structures: (a) longitudinal restrainer at joint between continuous segments; (b) restrainer at abutment location

Photograph by Buckle/MCEER *Photograph by Chadwell/PEER*

a) b)

Figure 10. Mao-Lou-Shi bridge: (a) distress in eccentric connection; (b) column retrofitted with steel jackets

Concluding Remarks

The examples shown in this paper indicate that rational procedures have been followed in either repairing or rebuilding structures such as highway bridges and public buildings such as schools. Unfortunately, this does not seem to be the case of typical residential buildings, whose structural deficiencies (soft/weak story, eccentricity) make them prone to earthquake damage. The effectiveness of non-engineered retrofit measures typically implemented in this type of buildings is somewhat uncertain and should be carefully evaluated.

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