Learning from Earthquakes

# Preliminary Observations on the Taiwan Earthquake of December 26, 2006

*This report is compiled from observations made by a reconnaissance team assembled by the National Center for Research on Earthquake Engineering (NCREE), and by the National Science and Technology Center for Disaster Reduction (NCDR), both of Taiwan. The following individuals served on the teams: Yuan-Tao Weng, Yung-Kai Yeh, Chu-Chieh J. Lin, Wen-Yu Jean, Tao-Ming Chang, Jun-Shang Chiou, Tsung-Chih Chiou, NCREE; and Ching-Yun Kao, Ming-Wey Huang, Siao-Syun Ke, Wen-Ray Su, Hao-Jan Hsing, Tzu-Hsiu Wu, Bing-Ru Wu, NCDR. The publication of this report is made possible by their generosity and is supported by the National Science Foundation through Learning from Earthquakes grant #CMMI-0650182. A more detailed report on the earthquake can be found on the EERI web site at* ***http://www.eeri.org/lfe/taiwan_region.html****.*

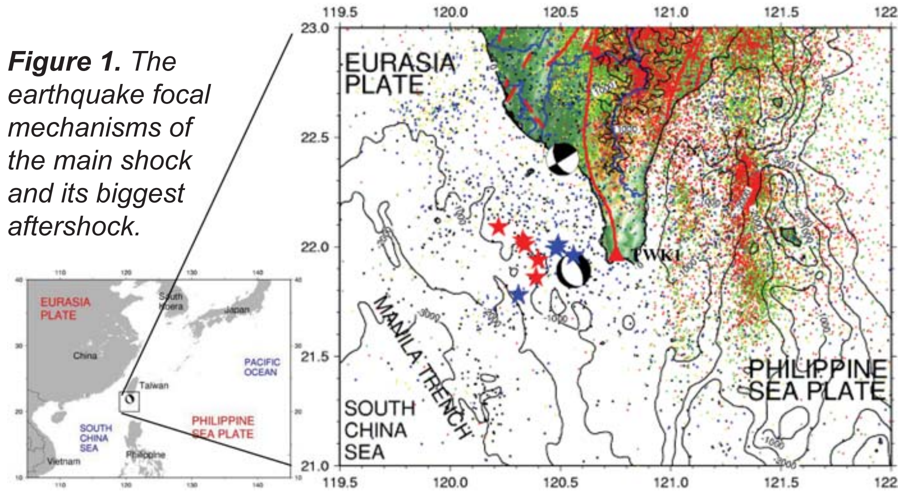



***Figure 1.*** *The earthquake focal mechanisms of the main shock and its biggest aftershock.*

## Introduction

At 8:26 p.m. local time on December 26, 2006, a $M_L$ 6.7 (MW 7.1) earthquake rocked the southern coast of Taiwan, about 22.8 km southwest of Hengchun (90 km from Kaohsiung). Eight minutes later, a large aftershock ($M_L$ 6.4 [$M_W$ 6.9]) hit the region, followed by a second aftershock ($M_L$ 5.2) at 8:40 p.m. Most buildings survived without any damage during the earthquakes, but a few street-front commercial/residential buildings, hotels, and elementary schools sustained moderate to severe damage. A four-story furniture store with a possible soft story collapsed, three apartment buildings collapsed, 134 schools were damaged, and several fire outbreaks were reported. There were two fatalities and 45 people injured. The earthquakes also damaged several undersea fiber-optic cables used to route internet and telephone services; this disrupted business in Taiwan, Hong Kong, Japan, China, South Korea, Philippines, Malaysia, Singapore, and Thailand.

## Tectonics/Strong Ground Motion

Taiwan Island is in the interaction zone of the Eurasia and Philippine Sea plates (see Figure 1). The three tectonic units of southern Taiwan are the Eurasia plate (South China Sea), Taiwan Island (Kenting peninsula) and its surrounding accretion wedges, and the Philippine Sea plate. The Philippine Sea plate is moving northwestward and is forcing the Eurasia plate to submerge eastward. The loose marine sediments have been pushed westward to form the accretion wedges and finally emerge as Taiwan Island. The Manila trench is the boundary between these two oblique colliding plates.

The main shock and its biggest aftershock represent two major focal mechanisms. The main shock was a normal faulting event brought about by the upper part of subducting Eurasia plate undergoing the tensional force caused by its overburden of thickening accretion wedges. Therefore, the strike of the rupture plane was parallel to the Manila trench. The biggest aftershock was a strike-slip faulting event caused by the accretion wedges undergoing the northwestern compression force from the Philippine Sea plate. The rest of the aftershocks can be grouped according to their focal depths: the deeper aftershocks (> 30 km) are roughly perpendicular to the Manila trench and become deeper northeastward; and the shallow aftershocks (< 25 km) are parallel to the trench. Preliminary results suggest that the main shock released the tensional strains in the subducting Eurasia plate and triggered the release of accumulated compressive strain inside the accretional wedges.

The strong ground motions were recorded by the Central Weather Bureau (CWB) TSMIP array and are shown in Figures 2 and 3 as well as Tables 1 and 2 (further information can be found on **http://www.cwb.gov.tw**). Figure 4 shows the

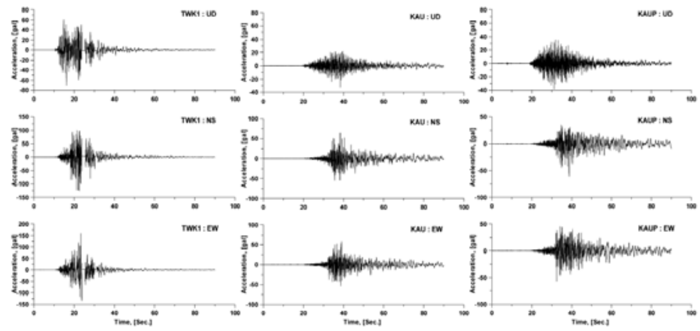


***Figure 2.*** *The ground accelerograms recorded at RTD stations TWK1, KAU and KAUP in $M_L$6.7 main shock.*

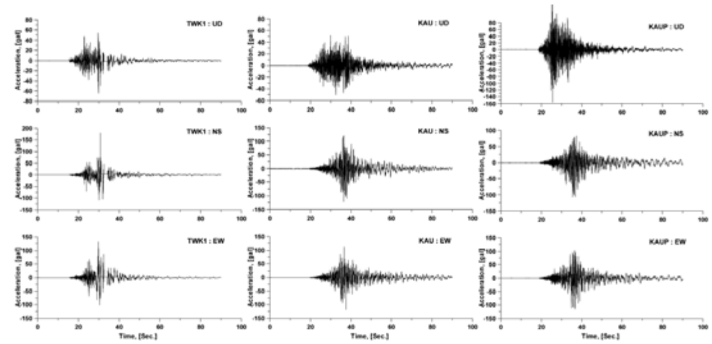


***Figure 3.*** *The ground accelerograms recorded at RTD stations TWK1, KAU and KAUP in $M_L$6.4 main shock.*

***Table 1.*** *PGA records of main shock ($M_L$6.7)*

| Station ID | Epicentral Dist.(km) | PGA (cm/sec$^2$) | Sa(T=0.3) (cm/sec$^2$) | Sa(T=1.0) (cm/sec$^2$) |
|---|---|---|---|---|
| TWK1 | 26.206 | 159.6 | 316.1 | 244.8 |
| KAU | 78.805 | 64.5 | 171.4 | 60.3 |
| KAUP | 77.794 | 61.3 | 154.9 | 67.6 |
| SSD | 94.727 | 73.5 | 117.2 | 24.3 |
| SPT | 86.962 | 64.9 | 176.8 | 91.5 |
| WCH | 242.819 | 60.7 | 104.3 | 12.9 |
| SCK | 147.193 | 61.5 | 129.0 | 26.0 |
| SGL | 92.458 | 53.3 | 135.4 | 95.8 |
| SCL | 146.878 | 47.9 | 104.4 | 24.3 |
| SCZ | 53.831 | 48.9 | 88.1 | 28.6 |
| TAW | 61.989 | 47.4 | 132.3 | 67.9 |
| CHN3 | 132.453 | 46.9 | 102.1 | 26.2 |
| TAI2 | 126.441 | 40.0 | 80.9 | 20.1 |
| TCUP | 261.677 | 32.7 | 90.8 | 30.6 |
| PNG | 211.931 | 35.9 | 46.6 | 7.2 |
| TWK1 | 26.206 | 159.6 | 316.1 | 244.8 |
| KAU | 78.805 | 64.5 | 171.4 | 60.3 |

***Table 2.*** *PGA records of aftershock ($M_L$6.4)*

| Station ID | Epicentral Dist.(km) | PGA (cm/sec$^2$) | Sa(T=0.3) (cm/sec$^2$) | Sa(T=1.0) (cm/sec$^2$) |
|---|---|---|---|---|
| TWK1 | 59.526 | 179.6 | 277.8 | 272.9 |
| KAU | 27.289 | 123.5 | 375.4 | 134.5 |
| KAUP | 26.683 | 156.4 | 347.1 | 167.2 |
| SCK | 92.914 | 118.3 | 270.9 | 109.1 |
| SPT | 29.588 | 90.7 | 275.1 | 144.3 |
| SGL | 35.085 | 81.5 | 204.0 | 157.9 |
| CHN3 | 75.323 | 74.9 | 187.9 | 44.6 |
| SSD | 39.180 | 74.6 | 173.4 | 35.8 |
| SCL | 90.951 | 70.6 | 163.9 | 62.5 |
| TAI2 | 71.410 | 64.1 | 134.8 | 48.8 |
| SCZ | 11.620 | 56.8 | 151.5 | 54.2 |
| TAW | 39.867 | 57.2 | 147.1 | 66.9 |
| WCH | 185.662 | 57.4 | | |
| LAY | 114.711 | 59.2 | | |

response spectra of three RTD stations that experienced the largest ground acceleration (159.88 gal at Kenting) in the main shock. The design spectrum of the current Taiwan building code (TBC ’05) for Hengchun, the most damaged site, is also shown for comparison. The spectral acceleration is a little higher than that of the design earthquake for the TWK1 station, which is located at Hengchun and near the damaged area. Figure 5 shows a similar comparison for the largest aftershock (156.42 gal at Kaohsiung Harbor).

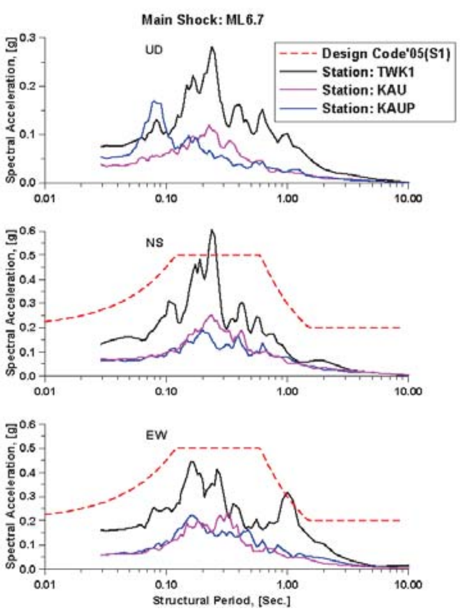



***Figure 4.*** *The comparisons of response spectra (5% damping) at selected RTD stations in main shock ($M_L$6.7).*

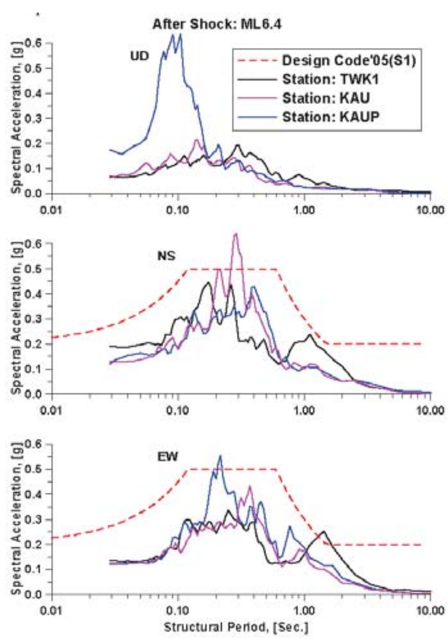



***Figure 5.*** *The comparisons of response spectra (5% damping) at selected RTD stations in largest aftershock ($M_L$6.7).*

## Geotechnical Effects

Serious geotechnical hazards were not found, but there were some cracks in ground surfaces and some displacement of school buildings. The asphalt pavement in front of the third nuclear power plant was damaged, and along an alley in front of the nuclear power plant, a series of parallel 1-5 cm wide cracks 5-10 m apart (in the direction of NW to SE) were observed on the road. At Hengchun Elementary School, some cracks were observed on ground surface, and ground settlement and horizontal displacement were observed, as shown in Figure 6. However, no sand boils or sign of

***Figure 6.*** *Ground settlements and lateral displacement observed in the Hengchun Elementary School.*

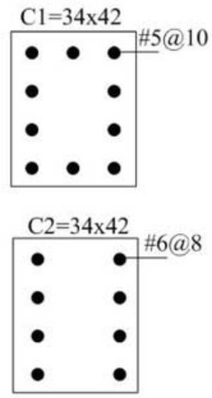
soil liquefaction was observed nearby.

## Structures

**Commercial/Residential Buildings:** The four-story collapsed furniture store with residential upper floors was constructed in the early 1980s. The brick walls were first erected and then reinforced concrete columns, beam, and slab were constructed using the brick wall as part of the formwork (reinforced masonry building). The total width and length of this building is 7 m x 23 m, respectively. The first floor of this building was for commercial use, and the rest of the floors were residential. Large openings for doors and windows were located at the street sides of the building. The frames above the ground floor were infilled with a brick masonry perimeter and partition walls. Thus, the bottom floor was comparatively weak due to the open front and open space. Figure 7 shows the schematic plan views of the building. There were a total of 15 columns. Along the long axis, the number of spans ranged from four to six; along the short axis there were one to two spans. There was obviously not enough redundancy. Most of the brick walls were located on the right side along the long axis, which made the planar lateral stiffness asymmetric. Figure 8 shows the collapsed building after the main aftershock.

A few other street-front residential buildings were also damaged. Brick walls and beams were seriously stressed, and the interior ground was cracked.

**School Buildings:** Damage to school buildings was significant in Pingtung County. Most school buildings in Taiwan at the primary and secondary levels usually lack engineering, and they are constructed and expanded in a patchy way. It is easy to see that the structural systems of school buildings have intrinsic defects. Classrooms are generally located side by side in a row. The plan of each classroom is about 10 m in width along the corridor and 8 m in



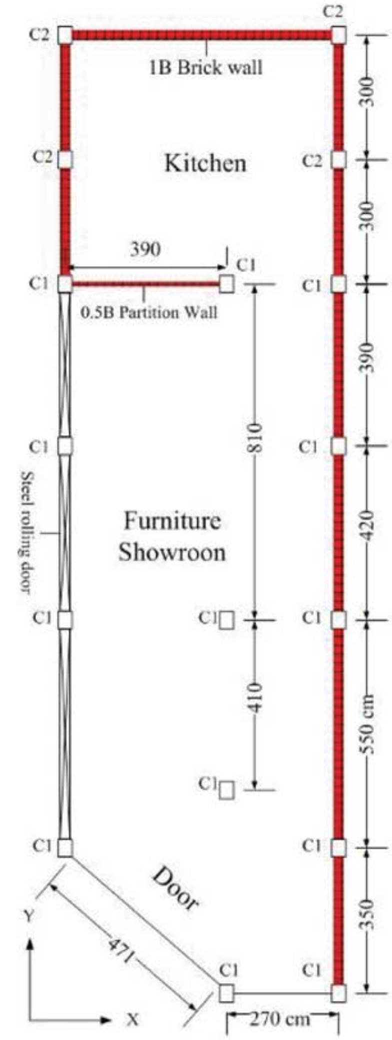




***Figure 7.*** *Floor plan of the 4-story furniture store.*

***Figure 8.*** *Side view of the collapsed furniture store.*


***Figure 9.*** *The damaged column along the corridor.*

depth perpendicular to the corridor. The corridor may or may not be cantilevered. The stiffness in the direction perpendicular to the corridor is much higher than that along the corridor. In order to utilize the natural light and ventilation, windows and doors fully occupy both sides of the corridor. At the upper portion of the columns, they are constrained by the window frame made of aluminum or wood. The lower portions of the columns are constrained by the windowsill made of brick walls. Since the windowsill is rigid compared with the window frame, the effective length of the column is shortened. The shorter the column, the larger the shear force. Therefore, the columns tend to fail in the shear mode rather than in the flexural mode. Figure 9 shows the column failure in shear mode, while Figure 10 shows a typical short column.

***Figure 10.*** *Shear cracks due to the short column effect.*

**Historical Sites**: The old city wall and gate tower of Hengchun were damaged. Several eaves of the gate tower collapsed, and a 30 m-long crack was found on the top of the wall. Around 15 battlements collapsed, as shown in Figure 11.

## Lifelines

In general, lifelines sustained relatively little damage, with the exception of at least eight undersea fiber-optic cables connecting north and southeast Asia to one another and to North America. These were substantially damaged in the earthquakes, which caused interruption of international telephone and internet services for millions of customers. Companies managed to restore about 70% of services in a week by rerouting traffic through satellites and undamaged cables; however, Chunghwa Telecom Co., Taiwan's biggest phone company, estimated revenue loss from the cable damage at about $3 million. The cost of repairing the cable was estimated at $1.53 million, and it was originally anticipated that the cables would be fixed in three weeks; however, bad weather and heavy seas, as well as problems with a repair ship, delayed full repairs until the end of January and no doubt increased the repair cost.

Steel transmission towers were mostly unaffected. Bridges experienced almost no damage. Two gas leakages were reported in Hengchun. Power shortages were reported right after the earthquakes, but electricity was restored at 23:00 that night. About 3,000 houses were affected. Twelve elevator traps were reported in Kaohsiung. The #2 reactor of the third nuclear power plant and Dalin gasoline refinery were shut down manually and are back to normal operation now. Do-mestic telecommunications—both line and mobile—were overloaded right after the earthquakes due to demand, but all systems were back to normal in 30 minutes.

## Acknowledgments

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***Figure 11.*** *Collapsed battlements of the old city wall.*