2.3 Building Damage

2.3.1 Overview

Over 17,000 buildings were collapsed or severely damaged in the Chi-Chi earthquake as shown Table 2.3.1. About 90% of them were concentrated in Taichung City, Taichung County and Nantou County. It is noticed that the number of collapsed buildings exceeds the number of severely damaged buildings. The field survey by an EDM team was carried out for the cities mainly along the Chelungpu Fault: such as Taichung City, Taichung County (Tungshih, Shihkang, Fenyuan, Tali, Wufeng), Nantou County (Nantou, Chungliao, Chi-Chi), Changhua County (Yunlin), as shown in Figure 2.3.1. Although the survey did not cover all the areas of each city, we had an impression that the municipalities such as Tungshih, Wufeng, Jungliau, Puli, and Chi-Chi were most severely damaged. Among others, the building damage in Jungliau looked catastrophic. Building damages were observed locally in Taichung, Fenyuan and Tali etc. Especially the collapses of comparatively new mid-height (about 10-story or so) RC residential buildings were seen in several places. Although some buildings around the collapsed buildings suffered from some extent of damage like cracks to the walls, many of the neighboring buildings had almost no damage.

In the areas where the surface faulting was seen, such as Shihkang, Fenyuan, Takeng in Taichung City, Wufeng etc., many inclined or collapsed buildings due to the fault displacement were seen. However, buildings located only a few meters from the fault line were mostly seen to be of little damage. In Taiwan, to avoid strong sunshine and rainfall, public paths called "Qi Lou", where the first floors of buildings are set back and the overhanging upper floors are partially supported by outside columns, are quite common. . The RC buildings suffered from damage mostly have this "Qi Lou". Because the pillars in the building's front were collapsed, the buildings were inclined or tripled by loosing the supports.

Damages to the first story were also observed for new mid-rise and high-rise residential buildings. But mid-story collapses, often seen in the 1995 Kobe earthquake, were hardly seen in this earthquake. Damages were also observed for old wood-frame buildings and structures with earthen walls.

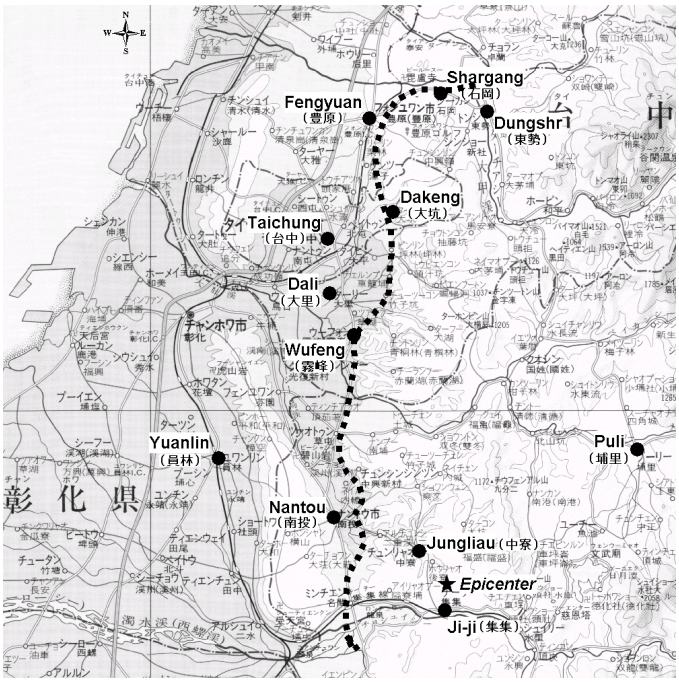

Figure 2.3.1. Areas of the field survey.

Table 2.3.1. Damage statistics of buildings.

County/City	Collapsed	Severely Damaged	Total
Taipei City	3	20	23
Taipei County	1	2	3
Taoyuan County	9	2	11
Ilan County	5	0	5
Hsinchu City	5	0	5
Hsinchu County	2	1	3
Miaoli County	136	221	357
Taichung City	496	616	1,112
Taichung County	2,785	3,018	5,803
Nantou County	4,431	3,509	7,940
Changhua County	30	2	32
Yunlin County	256	250	506
Chiayi City	1	0	1
Chiayi County	40	33	73
Tainan County	0	1	1
	8,200	7,675	15,875

Data Source: Taiwan Fire Department Statistics Data

2.3.2 Damage to High-rise Buildings

Damages of high-rise buildings were seen in Taichung City, Fengyuan, Tali, Yuenlin, Tungshih and Puli. In many cases, however, mid-rise or low-rise buildings around damaged high-rise buildings sustained almost no damage.

Photo 2.3.1 shows a high-rise apartment building in Taichung City, whose first and second stories were crushed. Due to the uneven collapse of right and left parts of the building, the central part of the building sustained a displacement of one-story height. Damages to mid-height or low-rise buildings were not seen around this building.

Photo 2.3.2 shows the damage of a high-rise apartment building located near the north side of the building in Photo 2.3.1. Many cracks developed on the wall.

Photo 2.3.3 shows high-rise apartment buildings in Tali, located in the south of Taichung City. The building in Photo 2.3.3 (a) was inclined due to the collapse of the first story. The building in Photo 2.3.3 (b) is a collapsed high-rise apartment building, which is located in several hundreds meters away from the building in Photo (a). Among four similar buildings, only one of them collapsed. The same thing (one collapsed out of four similar buildings) also happened in the opposite side of the street. The mid-rise and low-rise buildings around these collapsed high-rise performed well against the strong shaking and no major damage was observed.

(a) Damage situation from the 2nd floor to the top floor

(b) Collapse part of first and second stories (Refer to color photo 5)

(c) Surrounding area. The collapsed building is in the right side back.

Photo 2.3.1. High-rise apartment building in Taichung.

(a) Overall view

(b) Cracks on the wall

Photo 2.3.2. A damaged RC building in Taichung City.

(a) Inclined apartment building
(Refer to color photo 6)

(b) Collapse of high-rise apartment building.
One building out of four similar buildings was collapsed.

Photo 2.3.3. Collapse of RC buildings in Tali.

2.3.3 Damage to Low-rise Buildings

Setting back the 1st story of a building from the street and supporting the building with pillars in the front, the sidewalk of the street with roof becomes possible. This sort of buildings are quite common in Taiwan. RC buildings that suffered from damage due to the earthquake were mostly of this kind of structure. Because the front pillars of the buildings were destroyed, the building were inclined or collapsed.

Photo 2.3.4 shows the 2-4 storied RC buildings in (a) Fengyuan, (b) Tungshih, (c) Nantou City, (d) Chungliao. As seen in the photos, the first stories of these buildings were completely crushed. This type of damage was seen in the most of the affected areas.

Photo 2.3.5 shows the damage of a 3-storied RC building in Puli. A flexure failure was developed at the top of the pillars in the first story.

Photo 2.3.6 shows damage of low-rise non-engineered buildings. In the hard-hit areas, collapses of wooden and earthen buildings/walls were seen as well as damage to engineered buildings.

(a) Fengyuan
(Refer to color photo 7)

(b) Tungshih

(c) Nantou City

(d) Chungliao
(Refer to color photo 8)

Photo 2.3.4 Collapse of 2-4-story RC buildings.

(a) Overall view

(b) Damaged pillar top of the first story

Photo 2.3.5 Damaged 3-story RC building in Puli.

(a) Damage of Chi-Chi Station
(Refer to color photo 11)

(b) Collapse of a building with earthen wall in Chi-Chi

(c) Collapse of an earthen brick building in Tungshih

Photo 2.3.6. Damages of low-rise non-engineered buildings.

2.3.4 Building Damage near the Fault

In the areas along the Chelungpu Fault, building damages were concentrated just on the surface faulting. On the contrary, many buildings only a few meters away from the surface rupture were intact.

Photo 2.3.7 (a) shows an inclined building in Fengyuan. The surface faulting runs just beneath the building, and hence, the building was inclined due to the displacement. A similar looking building located in scores of meters away from the rupture was intact as seen in Photo 2.3.7 (b).

Photo 2.3.8 shows buildings in Funyuen along the fault rupture. Although the buildings in Photo (a) standing on the fault sustained apparent damage, no clear damage can be seen the buildings in Photo (b), which are in about ten meters from the fault.

Photo 2.3.9 shows damage to RC buildings in Wufeng a school building in Photo (a) was collapsed due to the fault displacement of 1m, passing underneath the building. The building in Photo (b) sustained severe damage in the middle part because the fault rupture ran across the building.

(a) Inclined building just on the fault rupture
(Refer to color photo 9)

(b) An intact building with the similar structure as (a) located near the fault

Photo 2.3.7. Damaged and undamaged 4-story RC buildings in Fengyuan.

(a) Building on the fault (b) Building not on the fault

Photo 2.3.8. Damaged and undamaged buildings in Fengyuan.

(a) School building
(Refer to color photo 10)

(b) A 5 story RC building

Photo 2.3.9 Collapsed buildings in Wufeng due to the surface faulting.

2.3.5 Damage in Chi-Chi

The epicenter of the September 20, 1999 earthquake is located in Chi-Chi, a small agricultural village in the mountain. Unlike the areas long the fault line, building damages due to strong shaking were observed in Chi-Chi. The damage statistics due to the local government show that the number of collapsed buildings is 1,261, severely damaged buildings 755, and the number of affected people whose houses were collapsed or damaged reached 7,422. Two kinds of building surveys were conducted in the area, one for quick safety inspection and another for compensation by the local government.

The field survey by an EDM team was carried out in the central part of Chi-Chi, near the railway station. A GIS map shown in Fig. 2.3.2 was developed using the data collected during the field survey and the video pictures and photographs taken the survey team. Building damages along the main streets are plotted on the map. The damage in Chi-Chi was much more extensive than other municipalities near the fault line. The buildings in Chi-Chi were mostly one or two-storied wooden houses and most of them were collapsed or severely damaged due to the earthquake. Some engineered buildings also sustained severe damage, e.g. collapse of soft first story. In the slabs and walls of some collapsed buildings, gallon-size oil cans and polyvinyl chloride pipes were observed, which might be partially responsible for the collapse.

The building of the station (Photo 2.3.6 (a)) was made by wood-frame with roof-tile, a typical Japanese style construction, since it was built during the Japan regime. The station seems to be a landmark of the town. When we visited ten days after the earthquake, restoration of the damaged roof started by the residents.

Roads were closed at two locations due to the collapsed buildings. Collapsed brick walls/fences were seen at many places and they made the roads narrower. Since Chi-Chi is located in countryside, no traffic jam was seen due to the road closures.

When the survey team visited the site 10 days after the earthquake, various recovery activities were going on: removal of debris, information services by the local government, application of the document for compensation of collapsed/damaged buildings, funeral services, distribution of meals/foods etc.

There were five major public open spaces in the central district: tourist parking lots, elementary schools, and a park. These open spaces were used as refugee centers and tents were set up for residents who lost their houses. Various services by the local government were conducted in a tent established in front of the government office. Similar service tents were also seen in the plaza in front of the railway station and refugee centers.

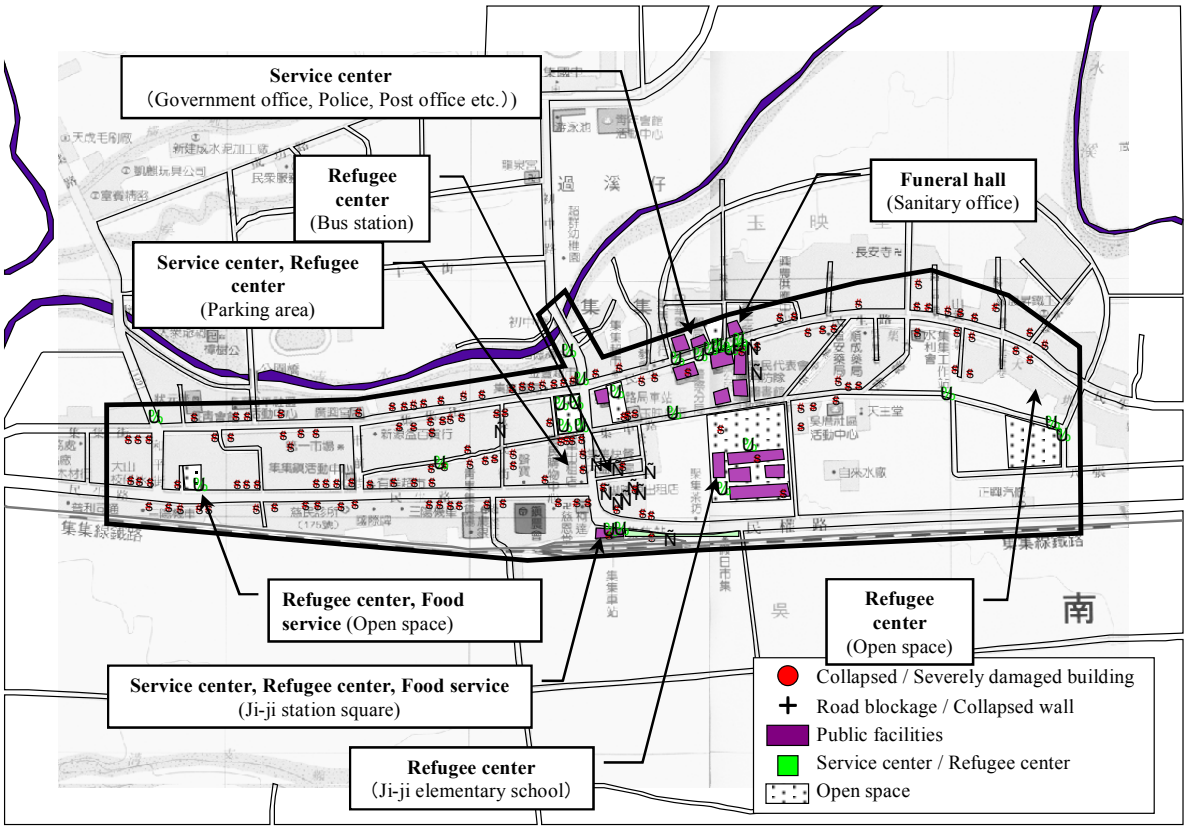

Figure 2.3.2. Damage data map of Chi-Chi based on the field survey.