2.4 Infrastructure Damage

Many infrastructures, such as bridges, port facilities and lifeline facilities, suffered minor-major damage in the disaster area. It is noted that structures on the fault rupture were severely damaged during the Chi-Chi Earthquake. The collapsed structures just on the fault rupture suggested the effect of the fault offset at the ground surface on various structures. In this section, the damages of infrastructures mainly due to the fault rupture were reported. The bridge damages on provincial, county and local routes were described in section 2.4.1. The damages of lifeline facilities, including a dam and a pipeline, were described in section 2.4.2. The damages of Port facilities due to liquefaction were reported in 2.5.

Air reconnaissance was carried out in order to understand the damage overview by helicopter on September 28. Then, we conducted the field observation for infrastructures in Taichung and Nantou counties as shown in Figure 2.4.1 on from September 29 to October 2. The aerial video record and photographs for damaged structures are contained in Appendix CD-ROM.

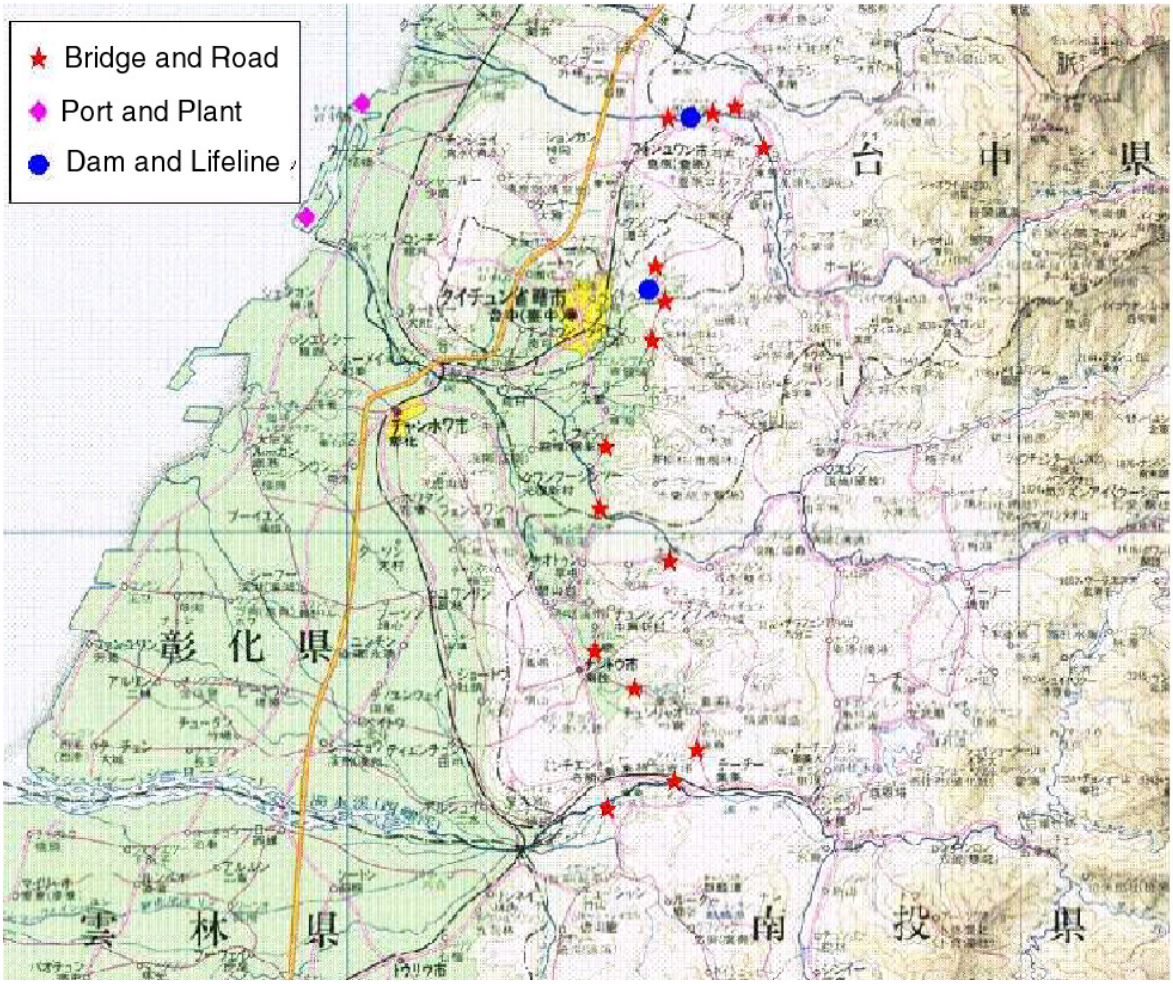

Figure 2.4.1. Survey area for infrastructures.

2.4.1 Bridge Damage

There are many hundreds of highway bridges in Taichung, Nantou, Changhua and Yunlin counties. Most of bridges escaped serious damage, while approximately 20% of them suffered minor-to-major damage (Chang, K.C. et al., 2000). Most of damaged bridges have simply-supported, reinforced or pre-stressed concrete slab-girder superstructures, and these constructed year range from 1960 to 1999. The damage to these bridges included; 1) foundation failures due to fault rupture, slope instabilities and liquefaction; 2) abutment back-wall failure; 3) shear failures in columns, pier walls and caissons; 4) displaced bearings; 5) unseated girders from bearing supports; and 6) collapse of superstructures.

Figure 2.4.2 shows the location of some severely damaged bridges in Taichung area. Most of severely damaged bridges were located close to the Chelungpu fault (Central Geological Survey, 1999) as shown in Figure 2.4.2. Provincial Route 3, which is one of main provincial routes from Taipei to Pingtung, runs close to the Chelungpu fault, and it goes across the fault at some places. Therefore, the bridges on Provincial Route 3, such as Shi-wei Bridge, Dong-feng Bridge, Wu-shi Bridge, Ming-tsu Bridge and Yang-ping Bridge, were damaged due to movement of the foundation by the fault rupture. Other bridges close to the fault, such as Chang-geng Bridge, Pi-feng Bridge and E-jian Bridge, suffered similar damages due to the secondary fault originated in the Chelungpu fault. Bridges and road embankment near Chi-chi suffered column failures and slope instabilities. These damages were due to strong ground acceleration near the epicenter.

Typical damage pattern of the three bridges, 1) Pi-feng Bridge and Chang-geng Bridge, 2) E-jian Bridge and 3) Yan-feng Bridge and Ping-lin Bridge, are described as follows.

Table 2.4.1. Severely damaged bridges (Reproduced from Chang, K.C. et al. (2000)).

Name	Route	Year	Span (m)	Length (m)	Damage description
Shi-wei	Provincial 3	1994	25	75	Collapse of girders
Chang-geng	local	1987	25	300	Collapse of girders
Pi-feng	local	1991	25	300	Collapse of girders
Dong-feng	Provincial 3	1962/1988	26	572	Gap between girders
Bei-keng	County 129	1959	5.7	5.7	Abutment failure
E-jian	County 129	1972	11	264	Collapse of girders
Wu-shi	Provincial 3	1981/1983	34.7	624	Collapse of girders Shear failure of column
Yan-feng	Provincial 14	1984	35	455	Gap between girders
Pin-ling	local	1969	25	500	Collapse of girders and colum
Mao-loh-shi	Provincial 3	1999	40-70	500	Damage to column
Ming-tsu	Provincial 3	1990	25	700	Collapse of girders
Ji-lui	local	1999	150	300	Damage to tower and cables
Yang-ping	Provincial 3	1986	13	78	Abutment failure
Tong-tou	County 149	1980	40	160	Collapse of girders

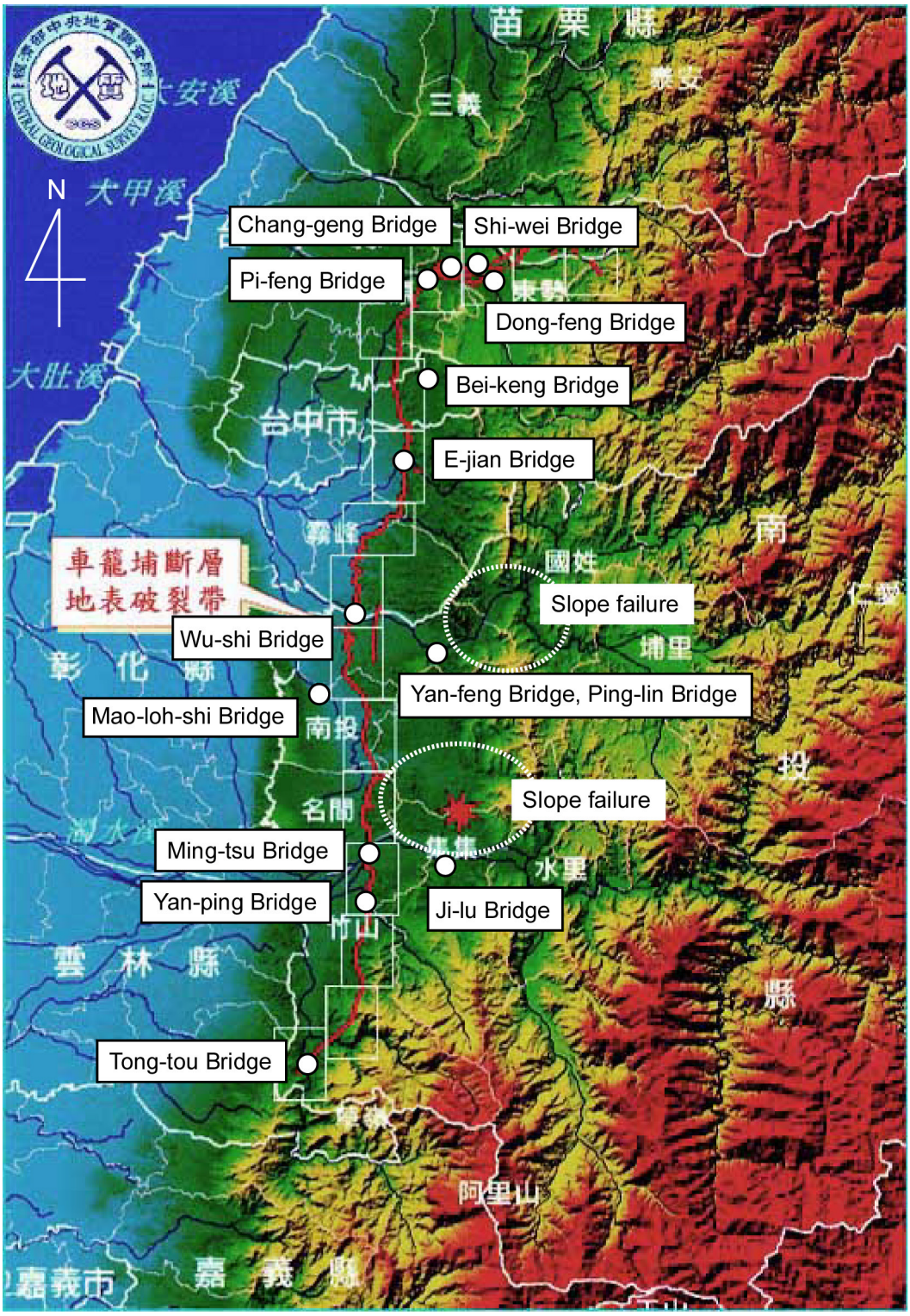

Figure 2.4.2. Severely damaged bridges and the Chelungpu fault
(Reproduced from Central Geological Survey (1999)).

Pi-feng Bridge and Chang-geng Bridge

Figure 2.4.3 shows the location of the bridges and fault rupture on ground surface in Shih-kang area (Central Geological Survey, 1999). The Pi-feng Bridge is located at the western side of Shih-kang Dam on Ta-chia River. The fault rupture runs across the abutment at the southern side of the Pi-feng Bridge. The Pi-feng Bridge was consisted of 4 simply-supported pre-stressed concrete girders as the superstructure and of single column bents on caissons as the substructure (Chang, K.C. et al., 2000). The three spans from the southern abutment fell down as shown in Photo 2.4.1. The second column bent from the southern side collapsed and lay down on the riverbed. The columns at the left side in Photo 2.4.1 are located on the lower plate of the fault, and the column at the right side is located on the upper plate. The vertical offset between the lower plate and the upper plate was about 8 meters. Photo 2.4.2 shows the waterfall at the eastern side of the bridge. The waterfall on Ta-chia River was induced by the fault rupture across the river as shown in Figure 2.4.3. The remaining columns seem to suffer no major damage as shown in Photo 2.4.1, therefore the displacement induced by the fault rupture caused this failure.

The Chang-geng Bridge is located at the eastern side of Shih-kang Dam as shown in Figure 2.4.3. Photo 2.4.3 shows the aerial view of the Chang-geng Bridge. The two spans at the southern side of the bridge fell down, although the fault did not run across the damaged section directly. The Chang-gang Bridge on Ta-chia River is located between the northern fault and the southern one. The permanent horizontal displacement for northwestern direction induced by the fault action was observed in the Shi-kang area (Central Geological Survey,

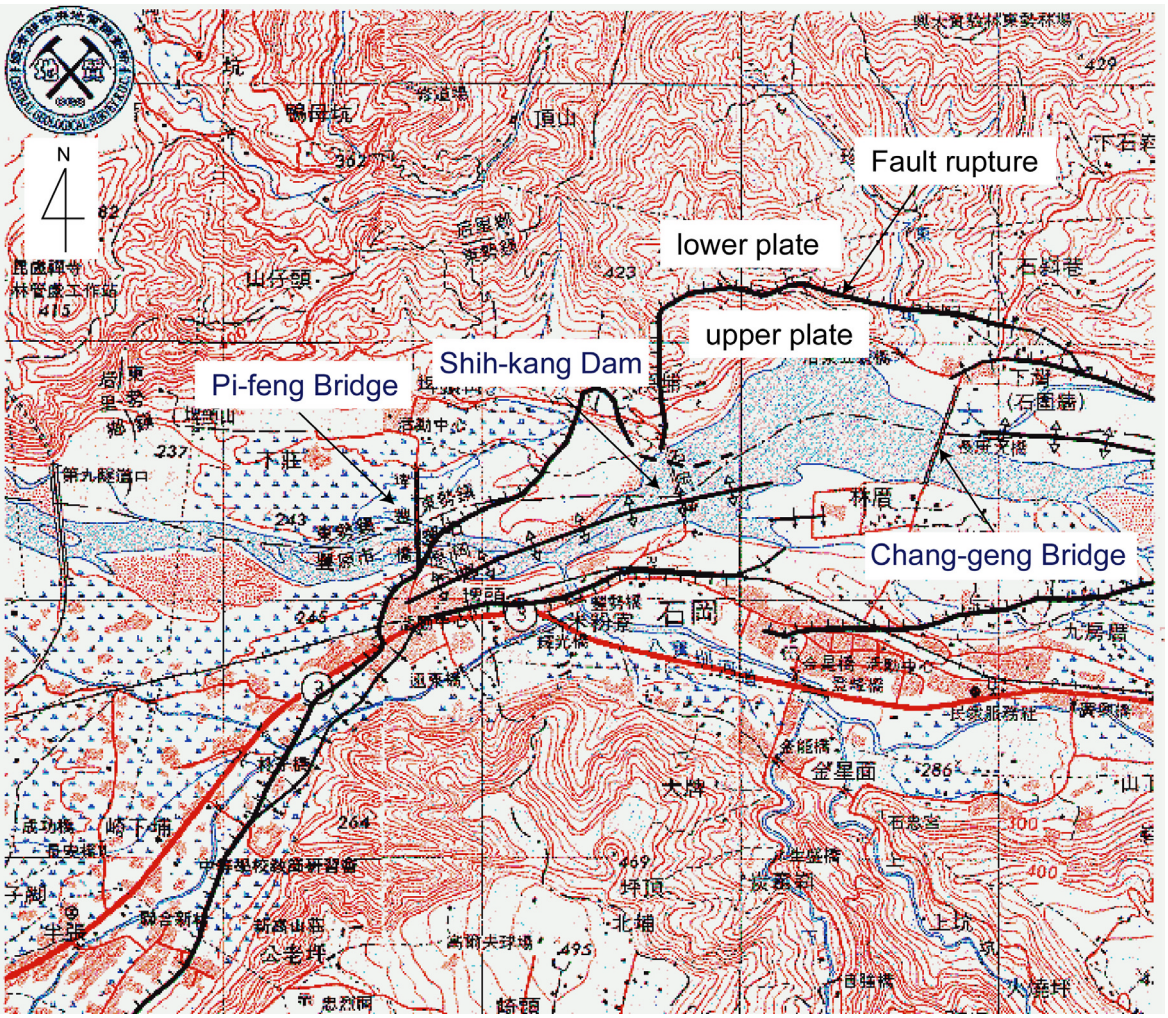

Figure 2.4.3. Location of the Pi-feng and Chang-geng Bridge with the fault rupture (Reproduced from Central Geological Survey (1999)).

Photo 2.4.1. Collapsed Pi-feng Bridge (Refer to color photo 13).

Photo 2.4.2. Waterfall induced by fault.

Photo 2.4.3. Chang-gang Bridge (Refer to color photo 14).

1999). Therefore, the sandwiched area between two faults might be compressed or extended due to the difference in the horizontal displacement of each fault rupture. The collapses of the girders were considered to due to the horizontal movement of the foundations induced by the ground displacement.

E-jian Bridge

Figure 2.4.4 shows the location of the bridge and fault rupture on ground surface in Tai-ping area (Central Geological Survey, 1999). The E-jian Bridge is located on County Route 129, and its construction was completed in 1972. The fault rupture runs across the abutment at the northern and southern side of the bridge, and runs northward. Photo 2.4.4 shows the slope failure on the foot of the northeastern mountain from the bridge. The E-jian Bridge was consisted of 24 simply-supported reinforced concrete girders as the superstructure and of concrete walls and spread foundations as the substructure (Chang, K.C. et al., 2000). The nine spans from the northern abutment fell down as shown in Photo 2.4.5 and Photo 2.4.6. The buildings at the residential area at the northern side of the bridge were severely damaged. The remaining girders at the southern side of the bridge seems to suffer no major damage as shown in Photo 2.4.5, therefore the ground movement induced by the fault rupture caused these damages. The bridge on Tou-Bien-ken River is located between the northern fault and the southern one. The permanent horizontal displacement for northwestern direction induced by the fault action was observed in the Tai-ping area (Central Geological Survey, 1999). Therefore, the sandwiched area between two faults might be compressed or extended due to the difference in the horizontal displacement of each fault rupture. This location of the bridge was similar to that of the Chang-geng Bridge in Shih-kang area. The collapses of the girders were considered to due to the horizontal movement of columns on the foundations.

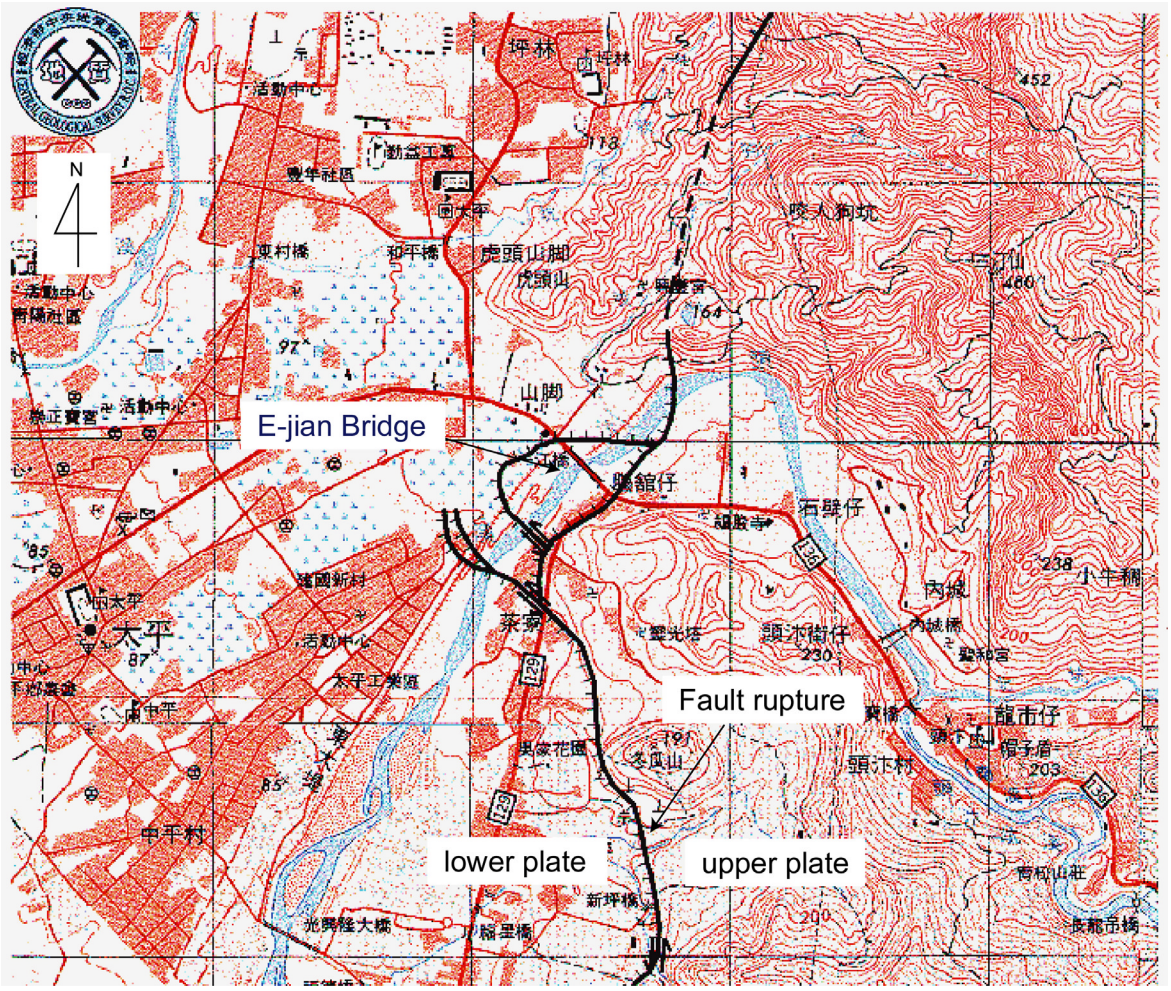

Figure 2.4.4. Location of the E-jian Bridge with the fault rupture
(Reproduced from Central Geological Survey (1999)).

Photo 2.4.4. Slope failure at northeastern mountain of the bridge.

Photo 2.4.5. Collapsed E-jian Bridge.

Yan-feng Bridge and Ping-lin Bridge

The Yan-feng Bridge and Ping-lin Bridge are located on Provincial Route 14 from Tsoutun to Puli as shown in Figure 2.4.2. These bridges are at the eastern side of about six kilometers away from the Chelungpu fault. The E-jian Bridge was consisted of 13 simply-supported reinforced concrete girders as the superstructure (Chang, K.C. et al., 2000, Japan Society of Civil Engineers, 1999). Photo 2.4.7 shows the view from western side of the bridge. The right way was closed due to restoration, and only the left way was available for passing. The temporary pavement was constructed in order to repair the lateral gap between the girder and abutment. The movement of the girders was due to the seismic motion, because the major ground failures were not appeared around the bridge.

The Ping-lin Bridge is located at the just southern side of the Yan-feng Bridge, and is not used for transportation at present. It was an old bridge constructed in 1969, and may be used before the Yang-feng Bridge was completed. The Pin-g-lin Bridge was consisted of 20 simply-supported reinforced concrete girders as the superstructure and of single columns as the substructure (Chang, K.C. et al., 2000, Japan Society of Civil Engineers, 1999). Photo 2.4.8 shows the view from western side of the bridge. Almost girders and columns were totally collapsed. The columns were broken near the bottom of the columns, and they fell down southward. These damages also were due to the strong seismic motion. Moreover, the old specification base on the 1960's seismic design code led to the severe damage.

Many slope failures beside roads were observed near the epicenter as shown in Figure 2.4.2. For example, the slope failure on County Route 139 from Chi-chi to Nantou is shown in Photo 2.4.9. The right way behind the abutment was failed, and cars passed the left way only.

Photo 2.4.6. Collapsed girders.

Photo 2.4.7. Yang-feng Bridge.

Photo 2.4.8. Collapsed Ping-lin Bridge.

Photo 2.4.9. Slope failure.

2.4.2 Lifeline Damage

Many lifeline facilities, such as electricity, gas and water supply facilities, in the disaster area were suffered minor-major damage. In this section, the damages of lifeline facilities mainly due to the fault rupture were reported. Overview of damaged lifeline facilities can be refereed to other reports (e.g. Japan Society of Civil Engineers, 1999). Typical damages due to the fault rupture in 1) Shih-kang Dam and 2) pipelines in Taichung City are described as follows.

Shih-kang Dam

The Shih-kang Dam was built across the Ta-chia River to supply steady water for irrigation etc. in Taichung area. The construction of the dam was completed in 1977. The dam lay on the sedimentary rock of Pliocene Epoch, where the upper alluvial shallow sandy and gravelly soils were excavated. The height of the dam is 25 meters, and the length is 357 meters with 18 gates. The capacity of the reservoir is 3.38 million cubic meters. An intake tunnel is located at the southern end of the dam (Japan Society of Civil Engineers, 1999). Photo 2.4.10 shows the overview of the dam before earthquake (Committee for maintenance of Shih-kang Dam, 1994).

The locations of the Shih-kang Dam and the fault rupture are shown in Figure 2.4.3. The fault from the Pi-feng Bridge ran across the northern side of the dam. Aerial overview of the dam is shown in Photo 2.4.11. The dam body was collapsed at northern side (left side in this Photo) of the dam. Photo 2.4.12 shows the damaged dam body. The vertical offset due to fault rupture was about 10 meters. The water gates on the fault were severely damaged. The left side in this Photo was located on the lower plate of the fault, and the right side on the

Photo 2.4.10. Shih-kang Dam before earthquake (Committee for maintenance of Shih-kang Dam, 1994).

Photo 2.4.11. Overview of Shih-kang Dam.

Photo 2.4.12. Damaged dam body (Refer to color photo 15).

Photo 2.4.13. Temporary intake channel.

upper plate. The vertical displacement of the lower plate is considered small, because of no clear remarks showing the varying water level at the lower side. Photo 2.4.13 shows the southern upstream side of the dam around the intake. The temporary intake channel was constructed because of the rise of the reservoir bed on the upper plate.

Pipelines in Taichung City

Restoration of pipelines was seen in cities near the fault during the field survey. Therefore, pipelines for distribution of gas, water, and sewerage were possible to suffer severe damages, if they were just on the fault rupture.

Figure 2.4.5 shows the fault rupture on the ground surface at Takeng area located on eastern side of Taichung City. The Chelungpu fault travels from south to north through Takeng area. Photo 2.4.14 shows the vertical offset of the fault rupture at the damaged area in Figure 2.4.5. The offset between the west residential area and the east road was about 3.5 meters. Although the building on the upper plate (right side in Photo 2.4.14) tilted westward, major structural damages were not observed. It is noted that the buildings beside the fault rupture suffered minor structural damage by seismic motion. Photo 2.4.15 shows the damaged sewerage pipes across the fault from east to west. The pipelines at the residential area might be connected to the main line under County Route 129 by way of the damage pipelines. Other lifelines also were cut off, because water was supplied by emergency water tanks on the residential area. The damaged pipes with a diameter of 80 centimeters were made of reinforced concrete. The damaged sections of the sewerage pipes were not clear because a part of them had already been displaced for human passing. The concrete of the pipes was collapsed by shear loading induced by the fault offset, if the section of the left underground pipe in Photo 2.4.15 was assumed the damaged

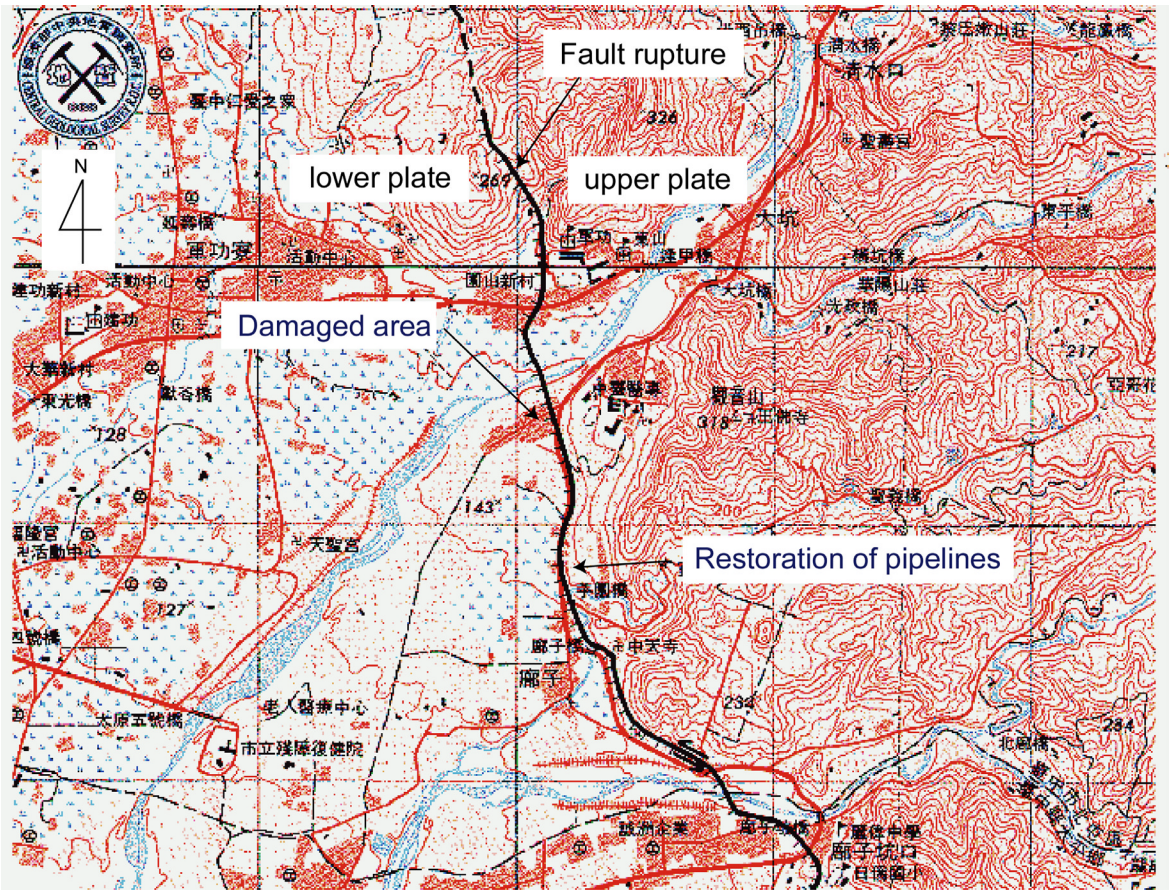

Figure 2.4.5. Location of the damaged pipelines with the fault rupture
(Reproduced from Central Geological Survey (1999)).

Photo 2.4.14. Vertical offset of the fault rupture.

Photo 2.4.15. Damaged pipelines (Refer to color photo 16).

section.

2.4.3 Summary

Many infrastructures, such as bridges and lifeline facilities, in the disaster area were suffered minor-major damage. Most of severe damages of infrastructures during the Chi-Chi Earthquake were associated with a large ground offset induced by the fault rupture and a strong seismic motion near the epicenter. The bridge damages on the fault was characterized by the collapsed girders caused by the movement of foundations. The rigid structures, such as dam, on the fault suffered severe structural and functional damages, because they could not follow a large ground displacement induced by the fault rupture. The pipelines on the fault were possible to be failed by shear loading induced by the fault offset. It is noted that these damages were observed at the local area over the fault rupture, on the other hand, structures beside the fault rupture suffered minor structural damage.

It seems difficult to design a flexible structure, which can follow a large fault offset, by a recent seismic design code. It needs further investigation to predict the location and amount of fault offset on the ground surface, and to develop a new flexible structure.

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