7. DAMAGE TO LIFELINE FACILITIES

7.1 Electricity

The following report is based on the field investigation and interview survey with Mr. Yung-Tien Chen, Director of System Planning Department; Dr. Chung-Lian Chang, Deputy Director of System Planning Department; Mr. Sheng-Nan Lin, Chief Engineer; and other staff of the Taiwan Power Company.

7.1.1 General Information of Power Facilities

(1) Power Facilities

* Hydraulic power plant: 4,420 MW (39 plants); 17% of the whole electric power; Mingtan Pumped Storage Power Plant (1,600 MW), Takuan No.2 Pumped Storage Power Plant (1,000 MW), Tachiachi Hydro Power Plant (1,000 MW) etc.
* Thermal power plant: 17,120 MW (27 plants); 64% of the whole electric power; coal: oil: LNG = 5:4:1
* Nuclear power plant: 5,140 MW (3 plants); 19% of the whole electric power; 1st plant (1,270 MW), 2nd plant (1,970 MW), 3rd plant (1,900 MW)

(2) Power Transmission/Transformation Facilities

There are two north-south routes covered by 345-kV extra-high voltage transmission facilities. Electricity produced by hydraulic, thermal, and nuclear power plants are distributed mainly through the Chungliao switching yard. The 3rd route under construction runs through similar locations as the existing two routes.

(3) Total Installed Capacity: 26,680MW (Japan: 191,527MW)

(4) Frequency: 60 Hz

7.1.2 Overview of The Damage

(1) As a whole, damages on power transmission towers, sub-stations and switching yards were serious, while hydraulic power plants were slightly damaged.

(2) Damages on thermal power and nuclear power plants were minimal except for mechanical damages of Taichung thermal power station(eight generator units of 550MW, coal) , while power distribution poles and cables were mainly damaged by collapse of building and other reasons.

Damage profiles of transmission/transformation and distribution facilities compared with Hanshin-Awaji Earthquake is shown in Table 7.1

Table 7.1 Damage Profiles

	Taiwan Earthquake	Great Hanshin Earthquake
Transformation facilities	Transformer ・345 kV (oil leakage, damages to bushings etc.): 6 units ・161 kV (oil leakage, damages to bushings): 2 unit Breaker ・345 kV ACB (damages to insulators): 10 units ・345 kV GIS (tilting due to ground deformation): 1 unit Disconnecting switch ・345kV(insulator breakage):1unit Transformer ・345 kV (breakage, tilting etc.): 70 nos.	Transformer ・275 kV (oil leakage, damages to bushings etc.): 8 units ・154 kV (oil leakage): 1 unit ・77 kV (damages to bushings): 2 units Breaker ・275 kV OCB (dislocation of Figure 7.18 the lapsed toting switch ・275 kV (breakage of support insulators): 20 units Lightning arrestor ・(damages to porcelain tubes): 5 units
Transmission facilities	Collapse of steel tower 345 kV: 1 no 161 kV: 9 nos. 69 kV: 3 nos. Tilting of steel tower 345 kV: 10 nos. 161 kV: 2 nos. 69 kV: 17 nos. Damages to insulators 345 kV: 2 nos. 161 kV: 1 no. 69 kV: 3 nos.	Collapse of steel tower 154 kV: 1 no. Tilting of steel tower 77 kV: 9 nos. Damages to insulators 154 kV: 15 nos.
Underground cable	No damage	Cable disconnection: 1 location Damages to pipes: 2 locations
Distribution facilities	Damages to supports: 2,108 nos. Damages to electric cables : 2,381 locations Damages to transformers : 871 units Damages to cables: 4,421 m Damages to underground devices : 103 units	Damages to supports : 11,289 nos. Damages to electric cables : 7,760 locations Damages to transformers : 5,346 units Damages to cables: 1,913 m Damages to pipes: 437 spans Damages to manholes and hand holes : 294 locations

7.1.3 Damages to Hydraulic Power Plants

(1) Facility profiles in the disaster area

Several hydraulic power plants along the Tachia river system (Taichung County) in the northern disaster area (Fig 7.1). From upstream, there are Techi branch power plant (three generator units of 234 MW plus 180m-height double curvature arch dams and

210m-deep underground powerhouse established in 1974), Chingshan branch power plant (four units of 360 MW with the biggest underground powerhouse among the Tachia river basin established in 1970 and 1973), Kukuan branch power plant (four units of 180 MW with an underground power plant established in 1961 and 1966), Tienlun branch power plant (four units of 90 MW with a 18km-long headrace established in 1952 to 1956) and Maan branch power plant (one unit of 105 MW with a 15km-long headrace established in 1996). Although surveys in the area upstream from Kukuan branch power plant could not be conducted due to traffic blockage, information from the TPC said that dams and power facilities suffered no damage, but ancillary transformation facilities were damaged.

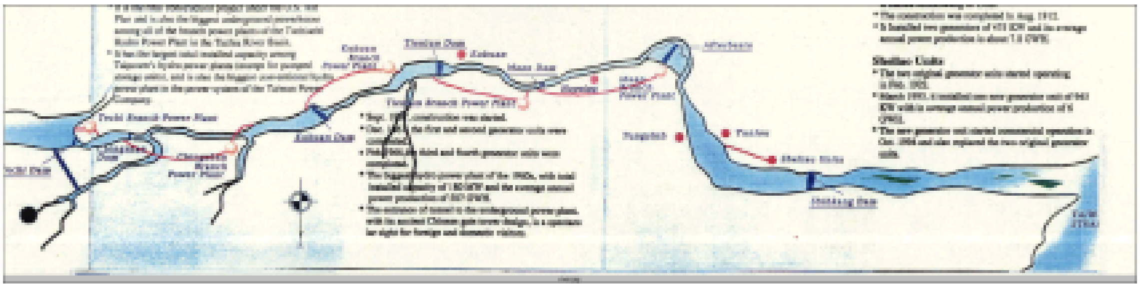


Figure 7.1 Outline of Tachia River Hydro-power Plants

In the southern disaster area, there are: Takuan No.1, a conventional hydro power station, Takuan No.2 and Mingtan, both of which are pumped storage power plant; and Ru-Yue-Tan Lake, an upper reservoir for the storage power plants located along the Juo-Suei-Shi river system (Figure 7.2). It was reported that part of power transformation facilities were slightly damaged, but dams were kept in safe conditions.

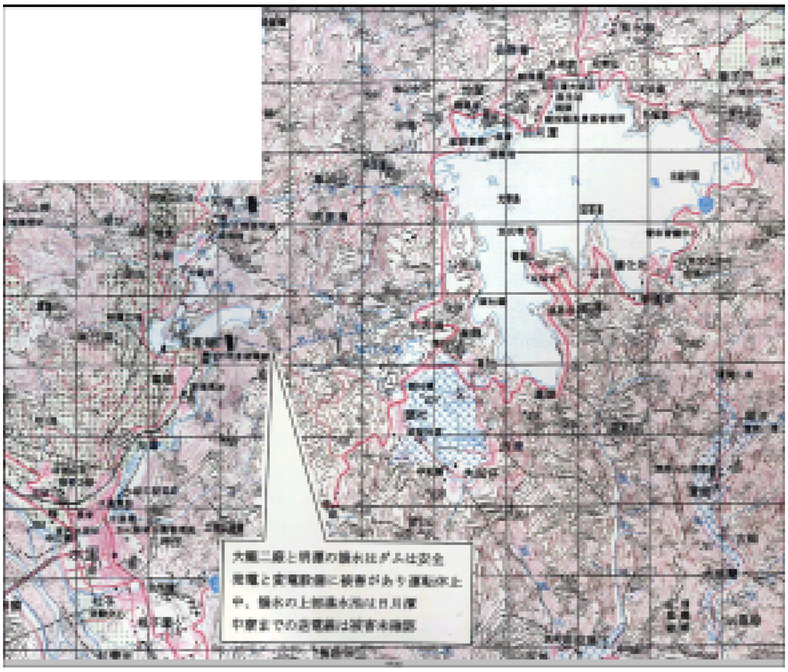


Figure 7.2 Map of Juo-Suei-Shi River Hydro-Power Plant

(2) Details of Damage

Little damage was observed in dams and damages on power facilities and ancillary transformation facilities were also minimal. Among hydraulic power plants and related facilities along the Tachia River (east of Taichung), this survey covered: from the Maan branch Power plant to the Tienlun branch power plant Dam.

Both banks of the intake weir of the Maan branch power plant (outside power plant) settled by approximately 10 cm, but presented no problem in terms of safety. However, operation has been suspended due to concrete spallings (10 cm by 30 cm) from part of the crest of the 15 km long concrete-lined headrace tunnel built in the rockmass. The steel penstock built in the rockmass suffered no damage and the indoor power facilities and outdoor fancillary transformation facilities are also in working order.

In front of the outlet, there are two 500 m square agricultural reservoirs. They have 5 m height embankment dams facing by concrete. Impoundment of these reservoirs has been halted since the partial cracking on the concrete facing could cause soil erosion from inside the embankment.

The gravity dam of the Tienlun branch power plant suffered no damage. An approximately 18 km long concrete-lined headrace tunnel built in the rockmass, four outdoor steel penstocks with diameters ranging from 1.7 m to 2.0 m, and the indoor power plant also suffered no damage. Outdoor ancillary transformation facilities are referred to in the following section, 7.1.4 Transformation facilities, since they are also used as switching stations for the north-south main power lines. Operation of this power plant was resumed from 4th October.

Hydraulic power plants along the Juo-Suei-Shi River are located within an approximately 10 km section from the epicenter of Ji-Ji to Ru-Yue-Tan. Ru-Yue-Tan is the biggest man made reservoir in Taiwan. They include two pumped storage power plant, i.e. Mingtan and Takuan No.2. Ru-Yue-Tan is used as the upper reservoir for both power plants. They also include large-scale hydraulic power plants such as the Takuan No.1. Although a lot of dams are constructed along this area, damages on them were slight. The Suei-Sheh Dam of Ru-Yue-Tan is an embankment dam with a reinforced concrete core and an upstream side gradient of 1:3. It was reported that water level of Ru-Yue-Tan was lowered, by way of precaution, because of 5 cm of surface

Figure 7.3 Mingtan Dam

settlement. TPC said that a survey conducted by an U.S. organization verified the structural safety.

Results of earthquake survey by the TPC showed that the maximum accelerations (survey points are unknown) at the Mingtan Dam and the Takuan Dam, both of which are the lower dams for pumped storage power plants, were 400 gal and 477 gal, respectively.

7.1.4 Transformation facilities

(1) Facility profiles in the disaster area

Main transformation facilities are: the Chungliao switching yard, located approximately 10 km from the epicenter; and the Tienlun substation adjacent to the Tachia Tienlun branch power plant.

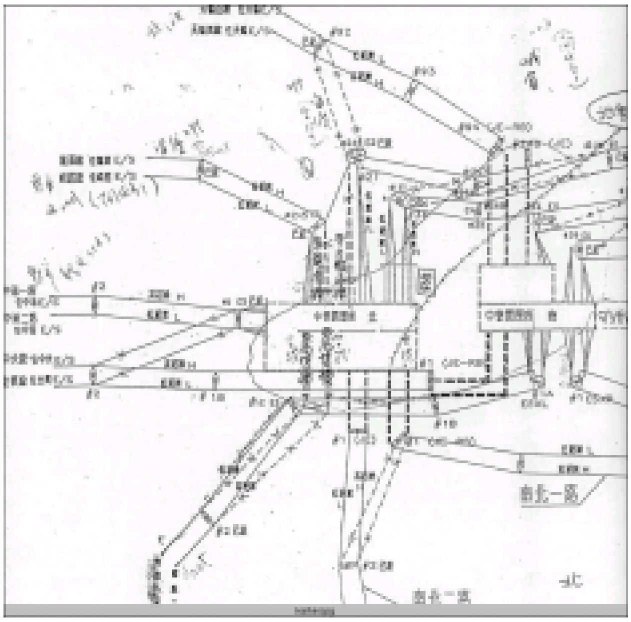
Figure 7.3 Photo of Chungliao switching yard

(2) Damage details

At the Chungliao switching yard (Figure 7.3,7.4 and 7.5), insulators and bushings for the 345-kV extra-high voltage switching facilities were damaged. The probable causes of the damages are vibration and ground movement caused by collapse of the fault which diagonally crosses the switching station. The switching station consists of the northern and the southern parts (see the plan view for reference), with the former locating approximately 20 m higher than the latter. The whole area of the switching station also has a gentle north-south gradient of approximately 5 degrees and is provided with pile foundations because of its poor soil conditions. Therefore, there is a possibility that cracks observed in the ground of the site was caused by landslide of the lower southern part (Figure 7.6).

There are reinforced concrete trench culverts (1 m wide by 1 m high) housing the underground cables for controlling switching devices. They are horizontally displaced by up to 1 m, due to which part of sections are completely closed (Figure 7.7) and shear failure (Figure 7.8) along the culvert axis occurred at other locations.

(1) Location Map (one km meshes)



(2) Plan View

Figure 7.5　Chungliao switching yard

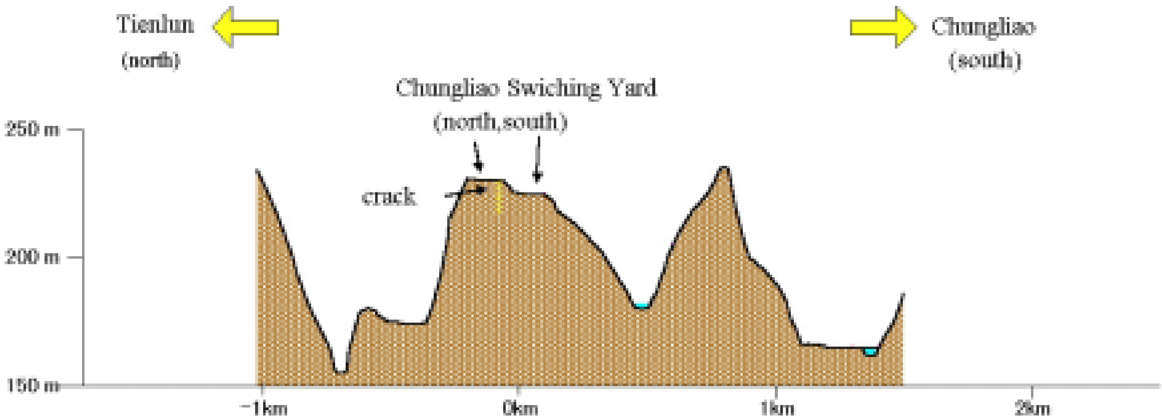


Figure 7.6 Cross-section of Chungliao switching yard

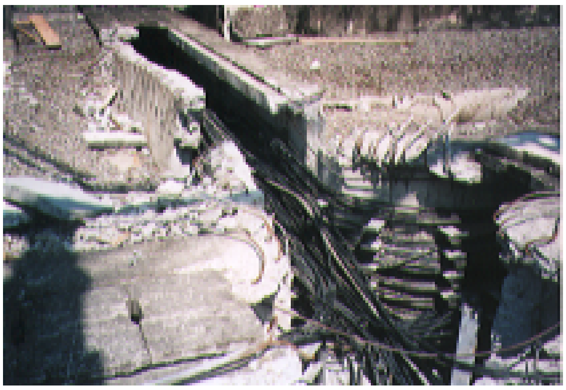


Figure 7.7　Damage of the Cable Ducts

Figure 7.8　Damage of the Culverts

Six outdoor pipes located at southern part of the switching yard escaped fracture, due to flexible joints provided at mid sections of them (Figure 7.9). However, they were slightly bent and it has not yet been confirmed whether they are in working order. The gas insulated switchgears (GIS) are products of Mitsubishi and Hitachi and started operation 12 to 13 years ago (Figure 7.10). The local engineer of Mitsubishi said that since they are obsolete, there is no engineer in Japan who is well aware of the details of their mechanism. Checking on the GIS operation system was underway and efforts had been made to partially resume their operation from 5th October. The TPC said that for the time being, bypassing electric lines without using the switching facilities would directly transmit power. The Chungliao switching yard is base of two north-south power transmission routes, so unless it is not rehabilitated, electric power cannot be transmitted from south to north; hence electric power failure in Taipei is not dissolved. Although some foundations for transmission towers were heaved, it seemed that it would not disrupt power transmission for the time being.

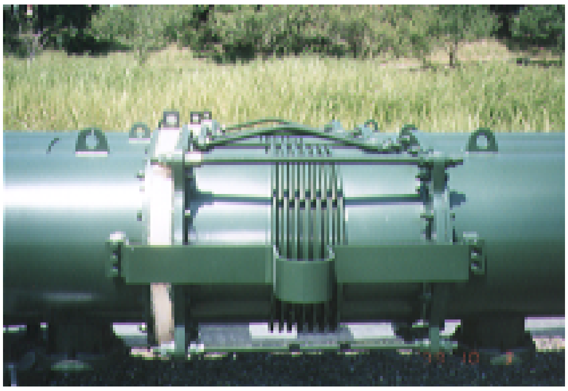


Figure 7.9 Flexible joints of Pipes

Figure 7.10 Ducts and GIS

Figure 7.11 Damage of Bushing

Figure 7.12 Damage of Foundation

Extra-high voltage transformation facilities located adjacent to the Tienlun branch hydraulic power plant were damaged, including 161 kV and 345 kV devices. The 161 kV device has been repaired (Figure 7.13), and power generation and transmission have been resumed by using it.

Although the transformer station is located adjacent to the river-side power plant, no major ground movement was observed; only minor falls with a size of approximately 10-m from the slopes within the transformation station area occurred, but devices suffered no damage (judging from the nearly vertical slope, it is considered that the site was prepared by excavation, not by embankment, and the natural ground consists of rocks). It is therefore considered that damages on the transformation devices were caused by vibrations (Figure 7.14).

The 345 kV device was out of commission due to oil leakage caused by thermal expansion (boiling) of the oil, which arose from short circuit inside the transformer. A number of insulators were also damaged and almost all air circuit breakers (ACB) were broken (Figure 7.15). The 345 kV device was covering the first north-south route, which starts from Chungliao, runs through Tienlun and leads to Long Tan. Although the 161 kV device connected to neighboring areas such as Wu-Fong and Er-Mei was slightly damaged, it has already resumed power transmission after repairing; its oil circuit breakers (OCB) suffered no damage.

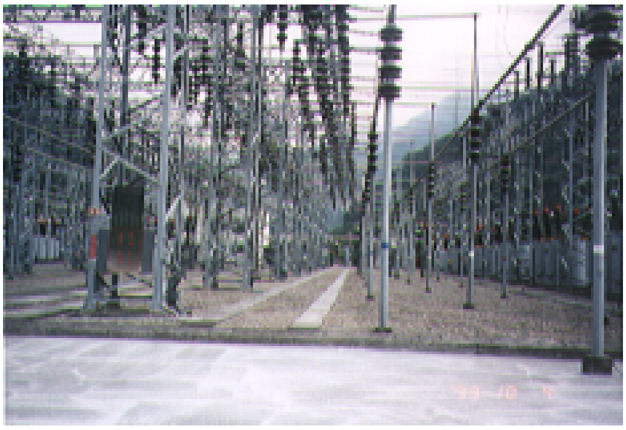


Figure 7.13 Overview of 161kv Substation

Figure 7.14 Damage of oil leakage at 345 kv Substation

Figure 7.15 Damage of ACB at 345 kv substation

7.1.5 Transmission Facilities

(1) Facility profiles in the disaster area

The 345-kV extra-high voltage transmission facility was covering the first north-south route, which starts from Chungliao, runs through Tienlun and leads to Long Tan; and the second north-south route connecting Chungliao and Er-Mei, when hit by the earthquake. The third route, which starts from Chungliao, runs through Chung-Gang and Ho-Ri, and leads to Er-Mei, is under construction (Figure 7.16).

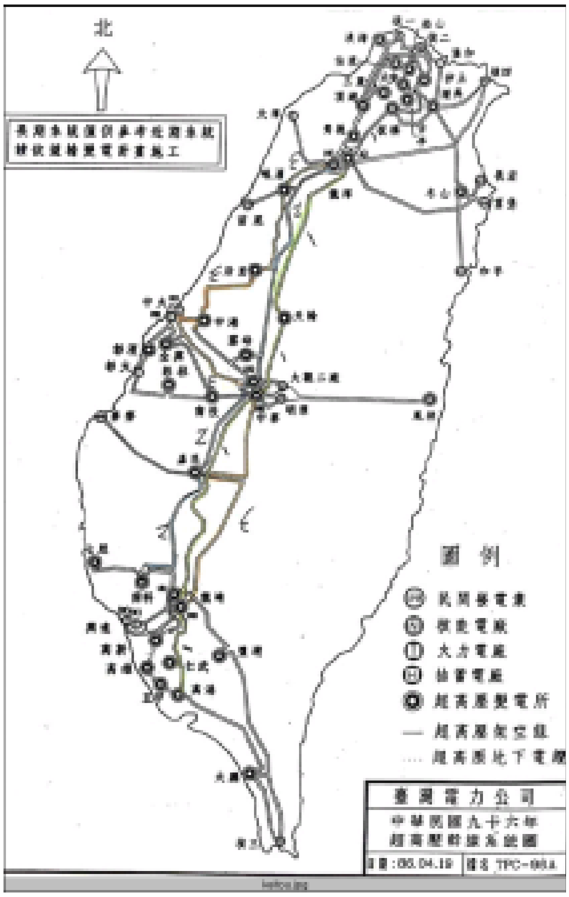


Figure 7.16 Distribution Diagram of Extra-high Voltage Trunk Line in Taiwan

(2) Damage details

The TPC's survey showed that approximately 200 transmission steel towers along the second route, running through between the Cungliao Switching Station and Er-Mei, were damaged. Survey on the first route along the mountains located east of the first route was not conducted. Main cause of the damages was tilting of transmission towers due to ground movement, which resulted in damages on insulators, and disconnection and short circuit of electric cables. At the moment, emergency repairs are mainly conducted on the tower portion; repairs on the tower foundations are not being carried out. In order to compensate collapsed or considerably tilted towers, it is scheduled to construct temporary towers comprising steel angles so that transmission lines are rehabilitated.

Tower foundations near rivers, mainly built by the well foundation (Figure 7.17) method (reinforced concrete footing, placed on a 6 m diameter well foundation with a depth ranging from 20 to 30 m, supports the four legs of the tower), were heavily damaged by ground deformation.

Figure 7.16 Well-type Tower Foundation

We also surveyed the northern area from Ru-Yue-Tan, by way of Puu-Ri, to Kuo-Shing where a transmission tower collapsed. The collapsed tower # 203 (Figure 7.18) is relatively close to the town of Kuo-Shing, about 20 minutes' by a 4WD vehicle, and located on the mountain slope. The suspended type tower collapsed at the bottom toward the valley side, perpendicular to the cable direction (Figure 7.19). The foundation level on the valley side was lower than the mountainside by approximately 10-m from the beginning (Figure 7.20). Electric cables were not disconnected and no visual damage was observed on the foundation concrete.

Figure 7.18 the collapsed tower # 203

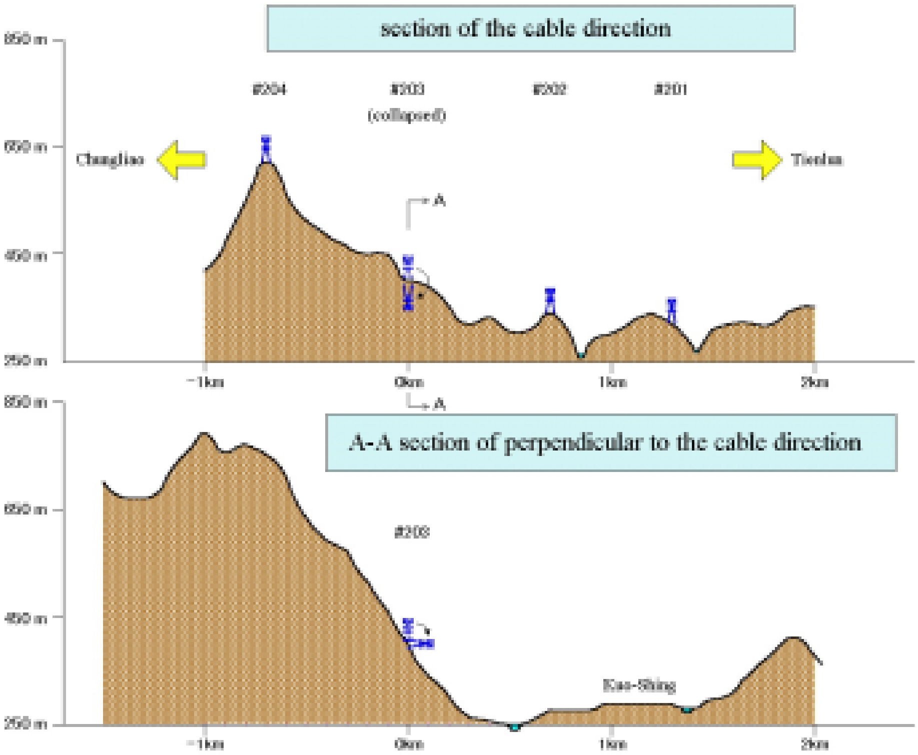


Figure 7.19 the detail location of collapsed tower # 203

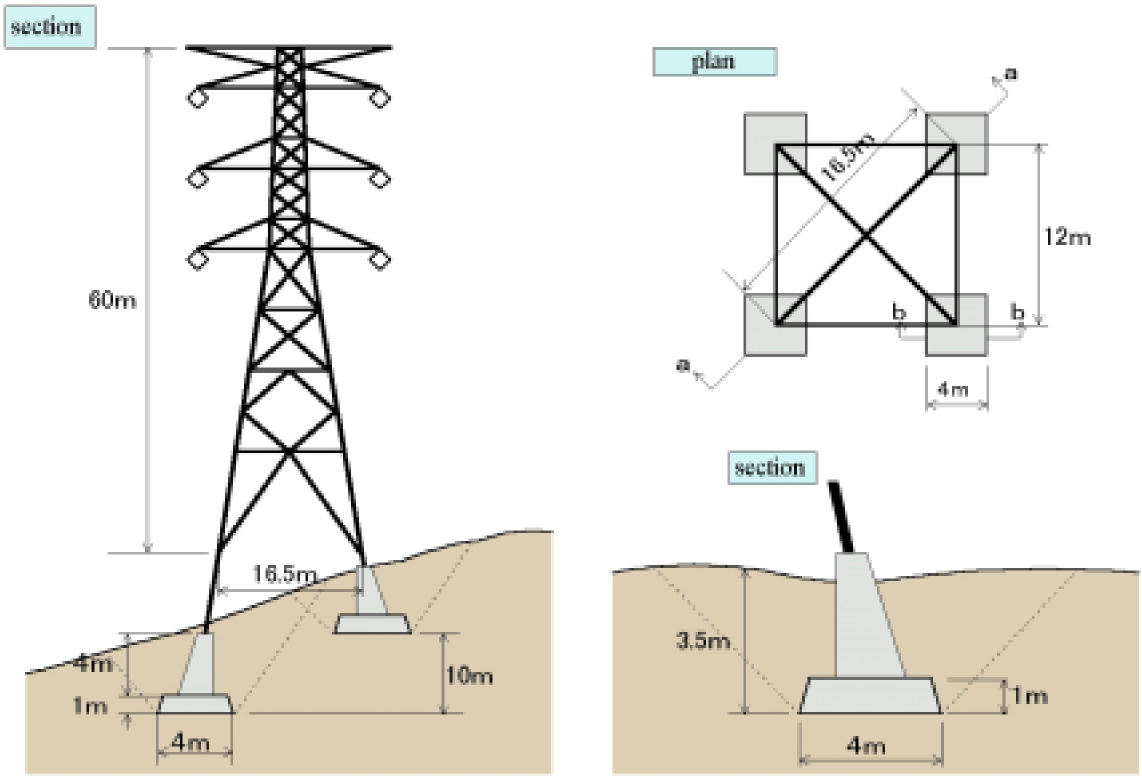


Figure 7.20 the foundation structure of collapsed tower # 203

All four tower legs were bent inward at the bottom, which indicates that the two legs on the valley side had buckled. No major fissure, other than the one which runs through the center of the four legs in the mountain-valley orientation, i.e. perpendicular to the cables, was observed around the tower. Four foundations have a pyramid-shaped profile; about 2 m from the ground surface of one foundation on the mountainside was exposed, but other three showed no serious visual damage. While ground falls at the tower location were minor, prominent falls were observed everywhere near the tower.

Probably, the main cause of the tower collapse was displacement of the foundations due to ground deformation. However, judging from the fact that the foundations suffered only minor damage, it is also necessary to further investigate the causes in connection with the vibration of upper portion of the tower. The collapsed tower was left on the site and a temporary steel tower was being constructed on the mountainside approximately 10 m from the original position. It had no foundations and was supported in such a way that wires from upper and mid portions of the tower were fixed by anchors. 24 numbers of 10 mm diameter by 2 m long anchors per one direction were used. Test power transmission was scheduled to be started at 7:00 pm on 3rd October. Regular power transmission would be partially resumed from 5th October upon completion of rehabilitation work of the Chungliao switching yard (by-pass connection).

Part of the third north-south route, which is under construction, was also damaged. Some concrete foundations before installing transmission towers on them suffered cracks and it was even reported that structures, onto which no loads acted, were damaged. Like in Japan, wind forces are the dominant factors for design of transmission steel towers in Taiwan. Such serious damages caused by this earthquake were therefore unexpected; hence subsequent in-depth studies on causes of the damages and comprehensive review including design and route selection are required.

7.1.6 Conclusion

Among the damages triggered by recent earthquakes, the damage of the Taiwan Earthquake was remarkable in terms of the influence on power supply. The power system all over the country is concentrated on Chungliao switching yard and the direct hit of the earthquake on the crucial site unfortunately made the situation worse. Firstly, therefore, the redundancy of the power system is necessary. What was found about the damages of individual structures is as follows:

- Transmission towers, which usually are designed for wind load, were severely damaged in terms of the number as well as the degree of damage.
- The damages of the mechanical instruments and conduit for control cables in switching yard were severe, thus making it difficult to restore power service for a short time.

As a result, secondly, control of damage level of the structures is necessary by clearly determining their performance and function beforehand. As for the determination of the structural performance and function, sufficient study on ground characteristics is also important. Based on the data offered by the TPC on site examination and design for Chungliao switching yard and collapsed transmission towers, the main cause of the damage has presently been investigated to acquire important lessons for the future design. In order to do that efficiently, it is important and necessary for engineers both in Japan and Taiwan to exchange each engineering techniques and collaborate with each other. Finally, the author wishes to express his deepest gratitude to the TPC and the related engineers for pleasantly cooperating in offering data on site examination and design.

7.2 Gas

7.2.1 Introduction

There are 24 gas companies in Taiwan. The government-managed Chinese Petroleum Corp. (CPC) purchases natural gas and wholesales it to the other 23 gas companies. The country's two million gas users are dispersed among large gas companies having up to 320,000 users and small ones having less than 10,000.

The damage caused by the earthquake was investigated at CPC, two gas companies in the central part of Taiwan which stopped their gas supply just after the earthquake and one company in Taipei. The performance of the gas facilities, particularly of the pipelines, of these companies is reported.

7.2.2 Chinese Petroleum Corp. (CPC)

(1) 24" – 30" (600 mm – 750 mm) pipeline

CPC constructed a 24" – 30" (600 mm – 750 mm) steel pipeline running approximately 340 km from Lin-Yuan to Hsin-Chu to transport natural gas from the Yung-An Liquefied Natural Gas Plant to the northern part of Taiwan. This pipeline was connected to the existing pipeline running from Hsin-Chu through Taipei to Chi-Lung in 1991, thus completing a pipeline that connects the southern and the northern parts of Taiwan (Figure 7.21). In the central part of Taiwan, this pipeline is buried under the fence running parallel to Expressway No.1 (Figure 7.22). After the earthquake, no ground deformation was observed in the area where the pipeline was laid, and there was no damage to the pipeline.

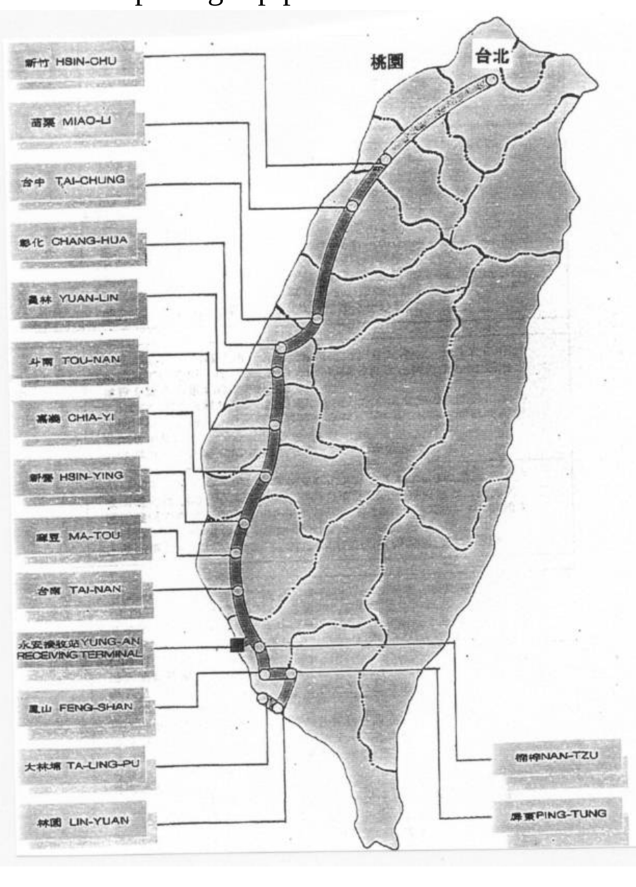


Figure 7.21 24" – 30" pipeline

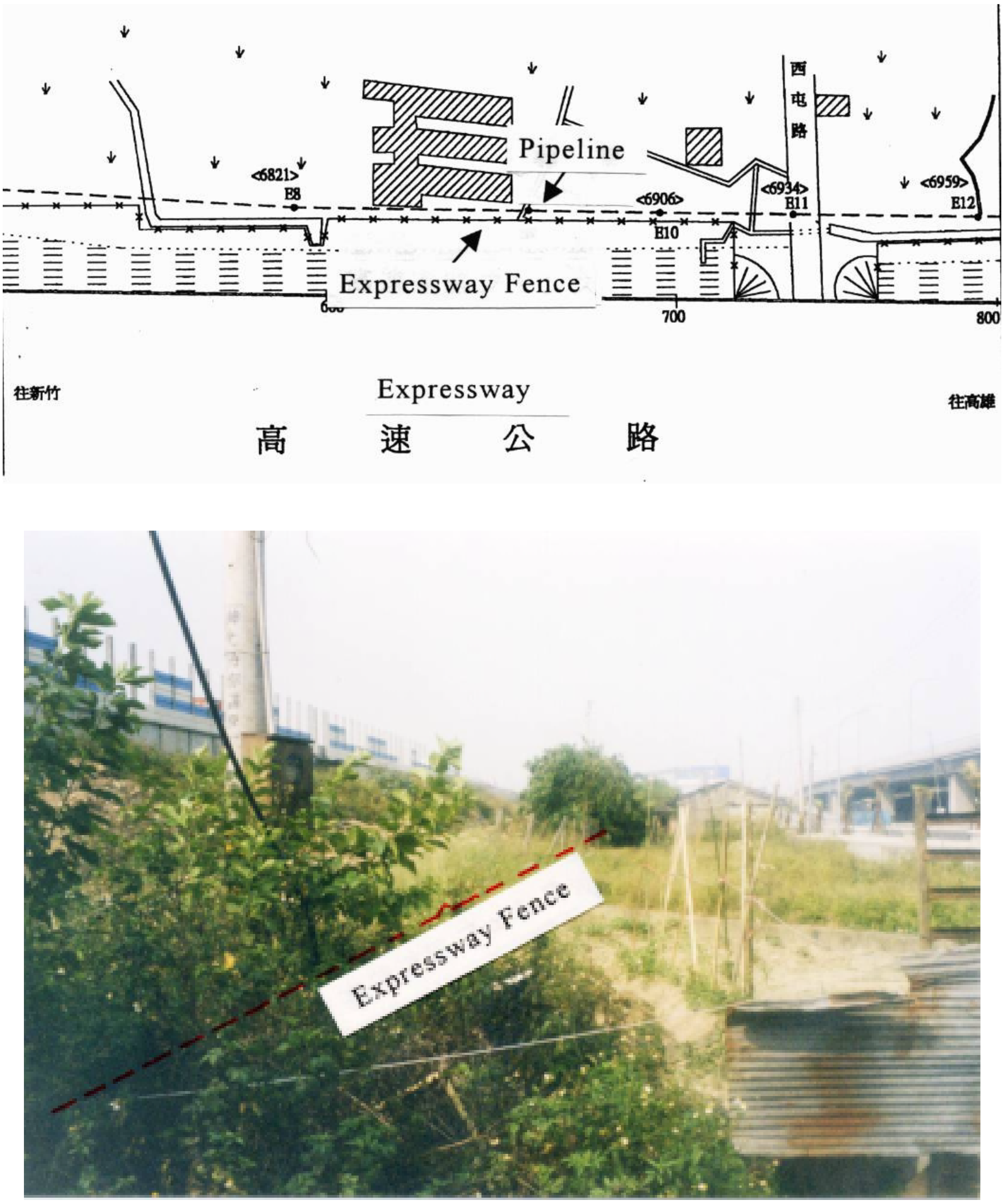


Figure 7.22 Location where 24" – 30" pipeline is buried

(2) 8" (200 mm) and 4" (100 mm) pipelines

CPC has 8" (200 mm) and 4" (100 mm) steel pipelines extending to the south of Taichung City to transport wholesale natural gas to the gas companies in the area. These pipelines were deformed by the earthquake at the Wu-Shi Bridge (Figure 7.23).

The Wu-Shi Bridge consists of two adjacent bridges. In the earthquake, the bridge girders of the east bridge fell to the ground and the piers of the west bridge inclined. The 8"and 4" pipelines attached under the bridge girders of the west bridge were bent with the inclination of the piers (Figure 7.24). The 6" steel pipeline of Shin-lin Natural Gas Co., which was laid parallel to the CPC pipelines, was also bent.

At 30 m – 40 m south of the WU-SHI Bridge, the road surface rose 1m to 2 m due to buckling by compressive force. Although the 8"and 4" pipelines laid here were not cut off, they deformed into a "Z" shape at this site, as shown in Figure 7.25.

(3) Other gas facilities

There was no damage to CPC's other gas facilities, including those at the YUNG-AN LNG Plant.

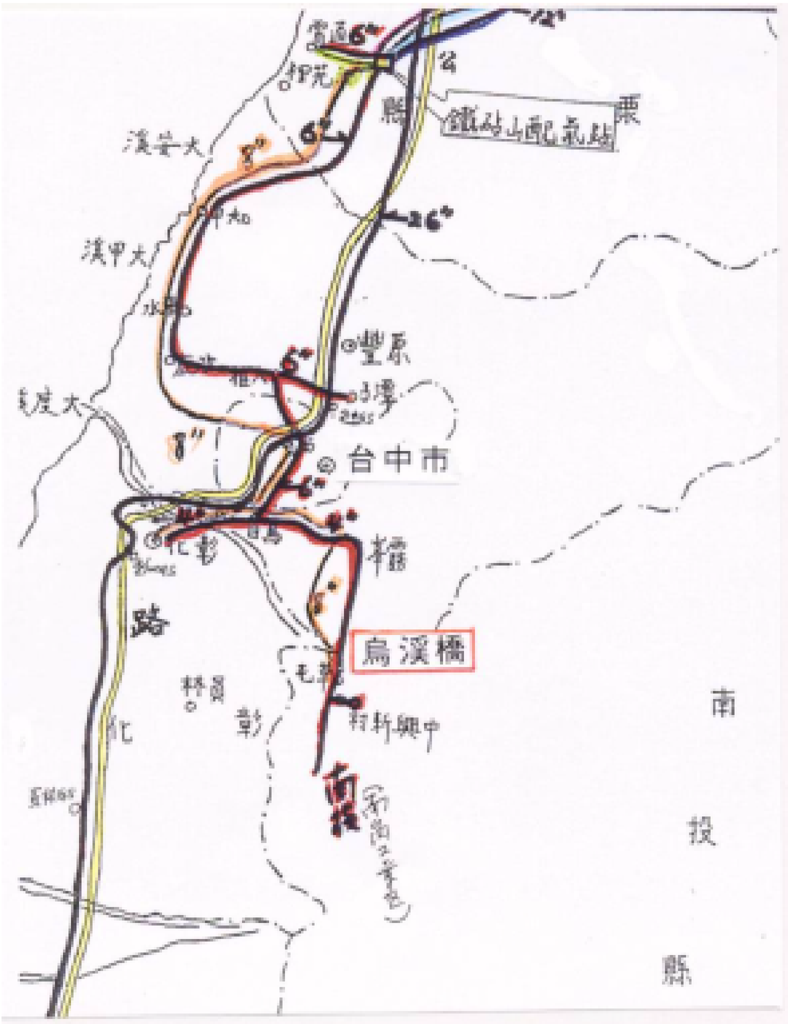


Figure 7.23 The location of the Wu-Shi Bridge

Figure 7.24 Bent pipelines at the Wu-Shi Bridge

Figure. 7.25 The rising of the road surface and the deformed 8" and 4" pipes

7.2.3 Shin-lin Natural Gas Co., Ltd.

This company has about 80,000 gas users in 10 areas south of TAICHUNG City. The company stopped its gas supply just after the earthquake, and there were no secondary disasters.

In the beginning of October, gas supply was restored to about 50% of the users.

The 10 gas supply areas have been classified into three ranks according to the damage ratio of gas facilities, as shown Table 7.2. Very extensive damage occurred near the fault and on its eastern side.

The elbows used in service pipes were heavily damaged at the point to rise up to gas meters. Gas meters were also damaged at many residences (Figure 7.26).

The company has an underground pipe gas holder in the yard of its main office in CHAO-TUEN. The holder consists of six pipes, each with a diameter of 52" (1.32 m) and a length of 72 m and 60 m. It was not damaged at all.

Table 7.2 Damage rating of 10 areas

Damage		Area
1	Very Extensive	DA-RII, TAI-PING,, WU-FONG, CHAO-TUEN, JONG SHING SHIN YSUEN, NAN-TOU, PUU-RI
2	Extensive	YUAN-LIN
3	Slight	WU-JIH, TAN-TZU

Figure 7.26 Damage to the gas meter

7.2.4 Shin-chung Natural Gas Co., Ltd.

The company, which has about 210,000 gas users in Taichung City, stopped its gas supply just after the earthquake, and there were no secondary disasters.

Houses were heavily damaged in the Dah Keng area in the northeastern part of Taichung City. Even in other areas, there are many houses too heavily damaged by the earthquake to allow an immediate gas supply. Excluding these gas users, gas supply was restored to over 90% of users in the beginning of October.

The emergency operations after the earthquake were well organized and executed (Figure 7.27) and about 360 sectors for the gas supply restoration were able to be formed quickly (Figure 7.28). As a result, the gas supply over 90% of users has been restored three weeks ahead of schedule (Figures 7.29 and 7.30).

Damage occurred mainly to service pipes and around gas meters, with approximately 1,000 units of each type repaired.

There was no damage in the 30 governor stations. There was no damage in the underground gas pipe holder which consists of 18 pipes, each with a diameter of 56" (1.42 m) and 38" (0.97m), and a length of 150 m.

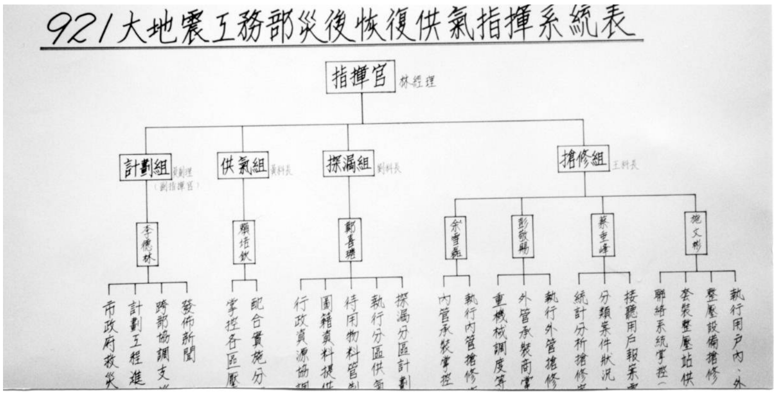


Figure 7.27 The organization of the gas supply restoration

Figure 7.28 Sectors for the gas supply restoration

Figure 7.29 The plan for and the results of the gas supply restoration

Figure 7.30 The results of the gas supply restoration

7.2.5 The Great Taipei Gas Co., Ltd.

This company has about 320,000 gas users in Taipei City. Little damage was caused by the earthquake. Three branch main pipes of 80 mm in diameter were damaged at the point where they crossed a roadside conduit, but this damage might have been exacerbated by the corrosion of the pipes themselves. Several dozens of service pipes were also damaged.

Figure 7.31 shows the SI value (Shimizu and Yamazaki, 1997) and the maximum acceleration measured in TAIPEI. The automatic shut off function of the 5,000 intelligent gas meters installed in the area did not work.

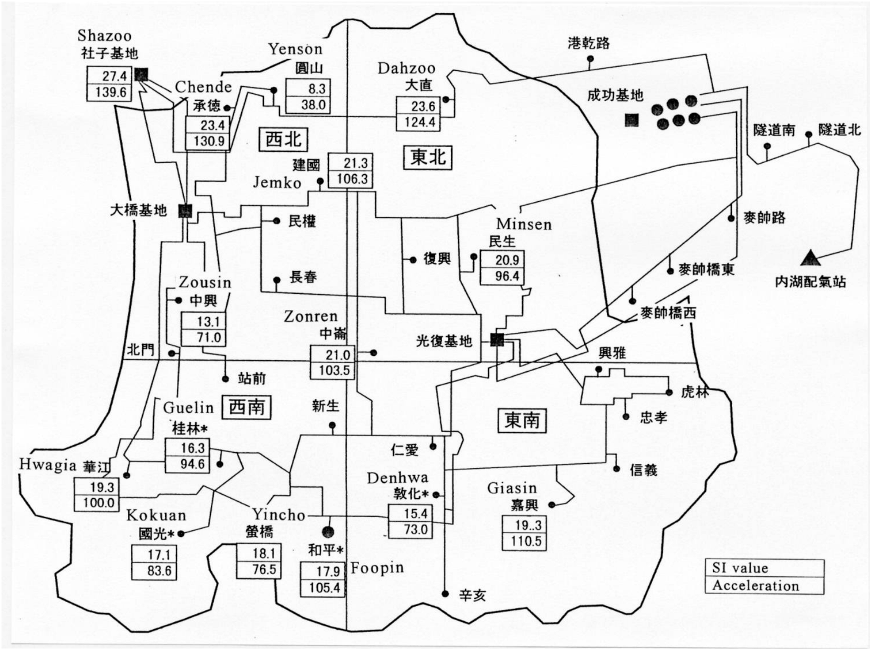


Figure 7.31 The SI value and the maximum acceleration measured in Taipei

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Shimizu, Y. and Yamazaki, F., 1997. Early earthquake warning system for city gas networks, Seismic Behavior of Ground and Geotechnical Structures, Seco e Pinto (ed.), 1997 Balkema, Rotterdam, ISBN 9054108878

7.3 Water Supply System

7.3.1 Outline of Water Works in Taiwan

There are two water supply enterprises in Taiwan; Taipei Water Department that supplies water to Taipei Shyh, and the Taiwan Water Supply Cooperation (TWSC) which covers all of Taiwan except Taipei Shyh. Since the epicenter area of the Ji-Ji Earthquake located close to Ji-Ji at Nan-tou Shyuan, damage to water supply system concentrated at the facilities of TWSC. The outline of business scale of TWSC is as follows as of the end of 1998.

a) Population served: 15,892,537
b) Rate of service pervasion: 91.3 %
c) Capacity of water supply: 8,696,000 m^3/day
d) Piping length: 48,665 km
e) Average distributed amount per day: 6,515,000 m^3/day
f) Form of management: 12 divisions

7.3.2 Area and facilities investigated

Area of investigation was central area of Taiwan where the 4th administration office manages. Service areas of the 4th administration office are Taichung Shyuan and Nan-tou Shyuan. The facilities investigated were intake facilities, water storage facilities, water conveyance facilities, purification facilities, water distribution facilities and water service installation. The situation of emergency water supply and emergency restoration work were also investigated as of 10 days after the event.

7.3.3 Damage to water supply facilities

(1) Water resource, intake and conveyance facilities

The service areas of Fon-yuan purification plant are Taichung Shyh, Tai-pingi, Da-rii and Fon-yuan and it is one of the principal purification plants. Shye-gang En (Effective storageL 2,700,000m^3) which is water resource of Fon-yuan purification plant, suffered sever structural damages. The conveyance tunnel (Section: horseshoe, Height: 4m, Width: about 3.8m) connecting to Shye-gang En was also heavily damaged. This damage is described in Chapter 6 in detail. The conveyance pipelines with 2600mm in diameter and about 900m in length suffered twelve failures between Shye-gang En and Fon-yuan purification plant. According to these damages, intake of water from Da-jia shi River and water transmission from the river to the Fon-yuan purification plant completely stopped.

(2)Purification facilities

i) No. 1 and No. 2 Fon-yuan purification plant (See Figures 7.32 and 7.33)

The capacity of the No. 1 purification plant is 400,000 m^3/day and the No. 2 purification plant 500,000 m^3/day. Their water resource is Shye-gang En. Coagulation-sedimentation and rapid sand filtration method is adopted here.

Ground under the both purification plants went up about 4m due to the fault movement after the earthquake. The major visible damages were as follows (See Figures 7.34 to 7.38).

a) Drop out of flocculator at flocculation basin
b) Drop out and collapse of inclined plates and troughs at sedimentation basin
c) Damage to liquefied chlorine injector
d) Damage to buried pipelines
e) Overturn of control facilities
f) Damage to concrete pavement in buildings
g) Fall of ceiling slab of service reservoir
h) Damage to expansion joints

The No. 1 purification plant could not work after the earthquake because of extensive damage to the purification facilities. On the other hand, the damage at the No. 2 purification plant was not so severe irrespective of neighborhood. So the No. 2 purification plant continues to work after the event.

The No. 2 purification plant takes water (400, 000 m^3/day) from Ba-bao River as an emergency because of stop of intake of water from Da-jia shi River. Insufficienly of water supply due to the shutdown of the No. 1 purification plant was covered by increase of treatment volume at Rii-yui Tan purification plant and use of water from wells in Taichung Shyh.

ii) Rii-yui Tan purification plant (See Figure 7.39)

The capacity of the Rii-yui Tan purification plant is 750, 000 m^3/day. The water resource is the Rii-yui Tan Dam (Effective storage: 122,776,000 m^3). The treatment was done by the rapid coagulation-sedimentation and sand filtration method. Although there was no severe damage to the concrete structures, many steel troughs were bent and fell down at the rapid coagulation sedimentation basin.

(3) Water Transmission and distribution facilities (pipelines)

The total piping length is 48,665km. About 79.9 % (38,902 km) of the total length is made up of polyvinyl chloride pipe, 8.8% (4,293 km) ductile cast iron pipe, 3.9% (1,883 km) cast iron pipe. The earthquake proof joint was not used for the pipelines.

The characteristics of damage to pipelines were as follows (See Figures 7.40 and 7.41).

a) Pull out and push in of pipes at joint were remarkably.
b) Damage to pipeline concentrated at the areas close to the fault.
c) Pipelines cross the fault were heavily damaged.

(4) Water service installation

Damage to water service installation was investigated at Chunglia and Jong shing shin Tsuen. Service pipe is made up of polyvinyl chloride pipe and the pipe is installed as shown in Figure 7.42. Since the service pipe passes a concrete gutter shown in Figure 7.43, it was easy for the pipe close to the gutter to break during the earthquake. It was difficult to find the water leak because the water from the breakage permeated to gravelly ground.

7.3.4 Emergency water supply and restoration

Since about 70 % of total damage to pipelines were recovered as of 10 days after the earthquake, the areas of suspension of water supply were limited. Emergency water supply by using water trucks of TWSC was continued yet. Emergency water supply and restoration work just after the earthquake were supported by the teams from other divisions that did not suffer damage.

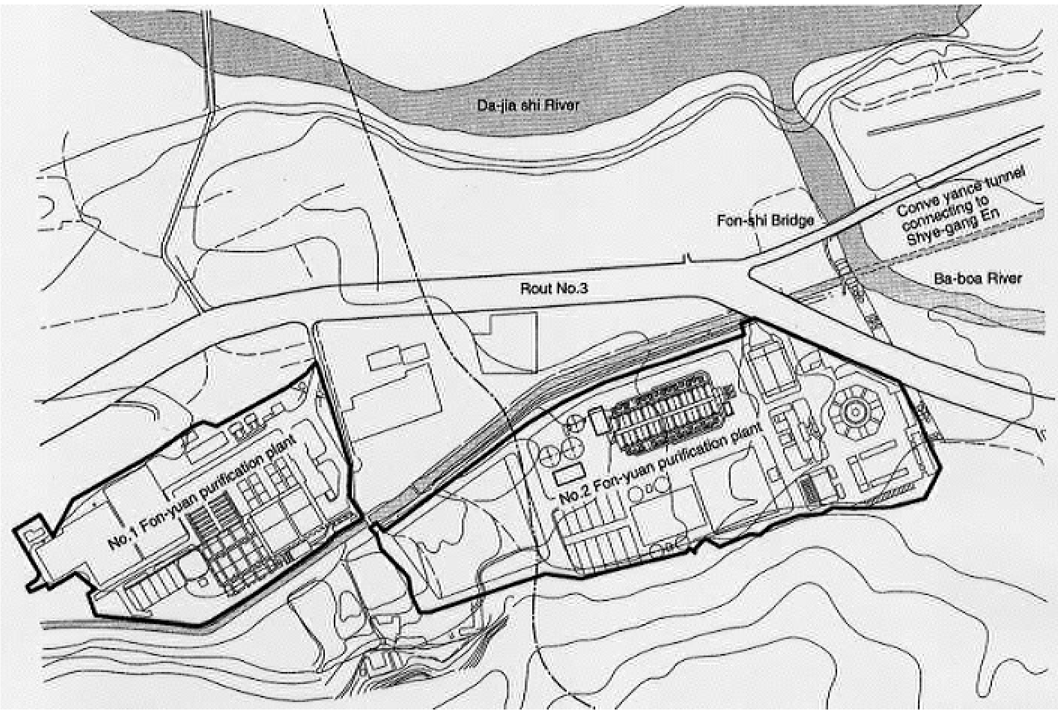

Figure 7.32 Arrangement of No. 1 and No. 2 Fon-yuan purification plant

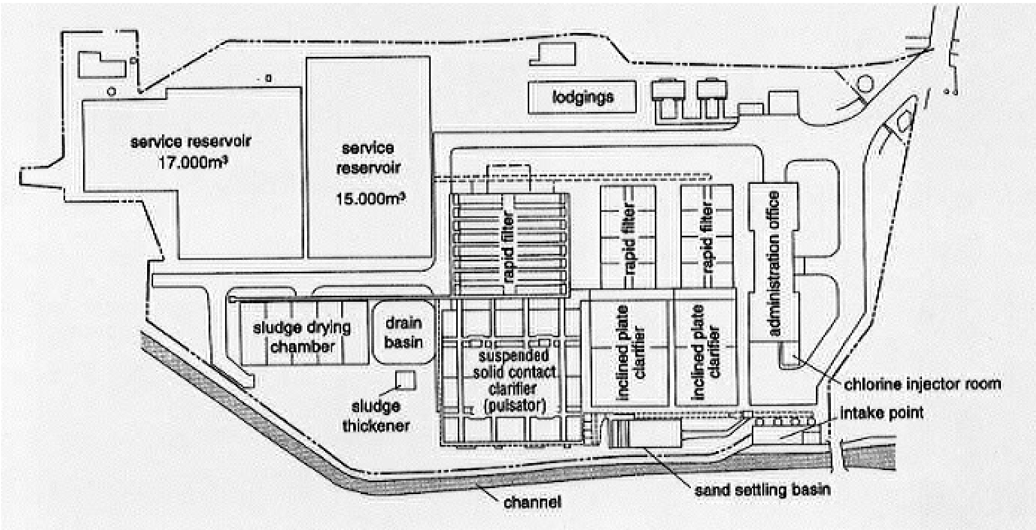

Figure 7.33 Plan of No. 1 Fon-yuan purification plant


Figure. 7.34 Damage at suspended solid contact clarifier
(No. 1 Fon-yuan purification plant)

Figure.7.35 Damage at inclined plate clarifier
(No.1 Fon-yuan purification plant)

Figure.7.36 Jump out of inclined plates(No.1 Fon-yuan purification plant)

Figure. 7.37 Fall of ceiling slab of service reservoir
(No. 1 Fon-yuan purification plant)

Figure 7.38 Overturn of control facilities(No. 1 Fon-yuan purification plant)

Figure 7.39 Damage to troughs at suspended solid contact clarifier
(Rii-yui Tan purification plant)

Figure 7.40 Damage to water convayance pipe (Diameter: 2000mm)

Figure.7.41 Push in each distribution pipe (vinyl pipe) at joints (Displacement is about 0.8m)

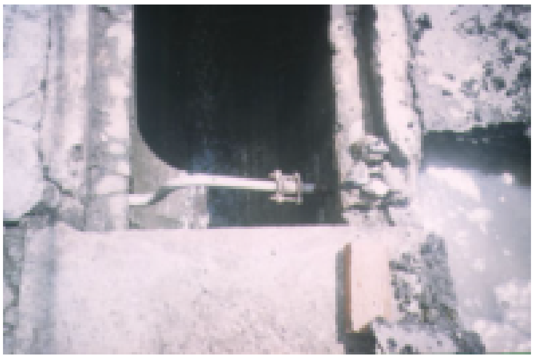

Figure.7.43 Service pipe passing concrete gutter

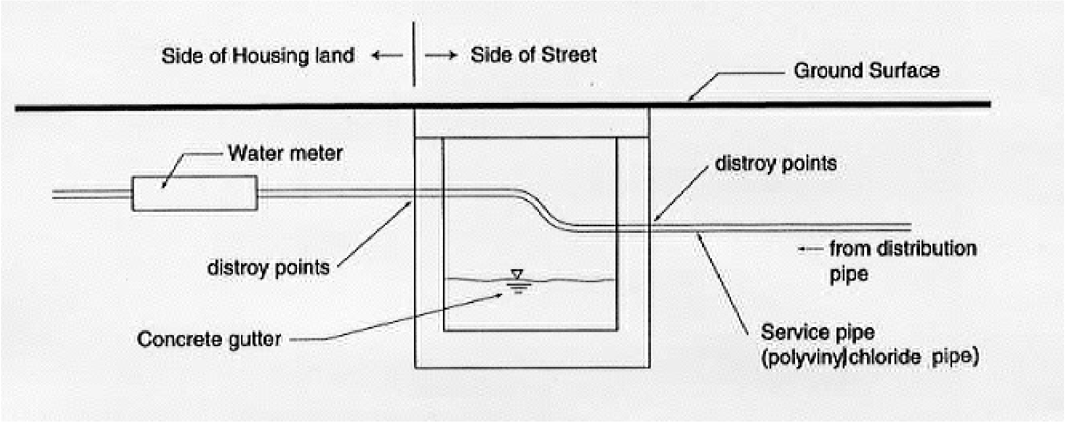

Figure 7.42 Water service installation