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Damage to Water Supply System and Surface Rupture Due to Fault Movement during the 1999 Ji-Ji Earthquake in Taiwan

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DAMAGE TO WATER SUPPLY SYSTEM AND SURFACE RUPTURE DUE TO FAULT MOVEMENT DURING THE 1999 JI-JI EARTHQUAKE IN TAIWAN

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ABSTRACT

On September 21, 1999, a large earthquake of magnitude 7.3 (CWB) occurred in Taiwan resulting in a death toll of over 2,000 people. It was also reported that more than 12,000 buildings and houses were damaged and about the half of those totally collapsed. Lifeline system such as electricity, water supply and gas also suffered severe damage. The present paper concerns with the damage to water supply system and surface rupture during the 1999 Ji-Ji earthquake in Taiwan. An outline of the water supply system and damage to it is presented. The relationships between the damage to water supply pipelines, pipe material, pipe diameter, etc were investigated. Survey of the surface rupture and damage evaluation of buildings was also conducted.

INTRODUCTION

An earthquake with a magnitude of 7.3 (CWB) occurred at 1:47 a.m. (local time) on 21 September 1999 in the central part of Taiwan. This earthquake was officially named as the 1999 Ji-Ji earthquake, because the epicenter located nearby the city of Ji-Ji in Nantou County. The Fire Department of Taiwan reported that the number of casualties, injuries and missing people were 2,295, 8,731 and 92, respectively. It was also reported that more than 12,000 buildings and houses were damaged and about the half of those totally collapsed. Lifeline system such as electricity, water supply and gas also suffered severe damage.

The present paper concerns with the damage to water supply system and surface rupture due to the 1999 Ji-Ji earthquake in Taiwan. An outline of the water supply system and damage to it is given. The relationships between the damage to water supply pipelines, pipe material, pipe diameter, etc. were investigated. The present paper describes the details of the damage characteristics of the water supply system and discusses the effects of surface rupture due to fault movement on the damage. Survey of the surface rupture and damage evaluation of buildings was also conducted. Results of the study revealed the characteristics of the damage close to the active fault.

OUTLINE OF WATER WORKS IN TAIWAN

There are two water supply enterprises in Taiwan; Taipei Water Department that supplies water to Taipei city, and the Taiwan Water Supply Cooperation (TWSC) which covers all of Taiwan except Taipei city. Since the epicenter area of the Ji-Ji earthquake located close to Ji-Ji at Nantou County, 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: 8,696,000m^3/day
d) Piping length: 48,665km
e) Average distributed amount per day: 6,515,000 m^3/day
f) Form of management: 12 divisions

STATISTICS OF DAMAGE TO WATER SUPPLY PIPELINE

In seismic hazardous areas in Taiwan, the total length of service pipelines is 2,868km, and that of transmission and distribution pipelines is 23,461km. The percentage of pipe length to pipe type for transmission and distribution pipelines is shown in Fig. 1. About 81% of the total length are made up of polyvinyl chloride pipe (PVCP), 10% ductile cast iron pipe (DCIP), and 4% cast iron pipe (CIP). Figure 2 indicates the percentage of that for service pipelines. About 98% of the total length is made up of PVCP, 2% galvanized iron pipe (GIP).

The total number of failures for transmission and distribution pipelines was 3,248. The damage rate, defined as the amount of failure per length of pipeline, was 0.14 /km. The total number of failures for service pipelines was

13,274 and the damage rate was 4.56 /km. The number of cases of damage and the damage rate related to pipe type are illustrated in Figs. 3 and 4 for transmission and distribution pipelines. The number of cases of damage for PVCP was the greatest, but the damage rate was the greatest for GIP. It revealed that the damage rate depends on the pipe length. Figure 5 shows the relationship for number of cases of damage, pipe diameter and type of failure. It is revealed that the majority of failures occurred in the pipelines of relatively small diameter from 80mm to 200mm. The Water Works Association of the Republic of China (Taiwan) indicated the number of cases of damage in relation to the causes as shown in Fig. 6. About a half of the total number of failures was caused by ground shaking and about 35% were by fault movement. Liquefaction was about 2%. This figure clarified that the effect of fault movement to the failure of pipeline was great in this earthquake.

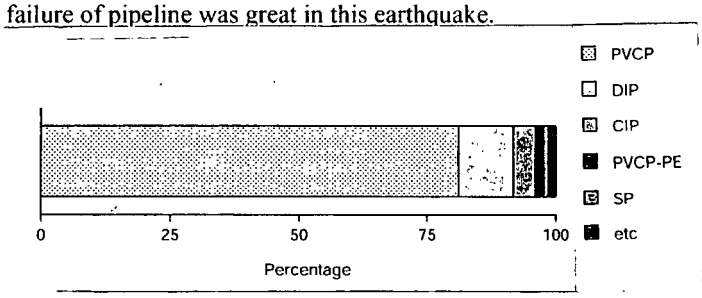


Fig. 1 Percentage of pipe length to pipe type for transmission and distribution pipelines.

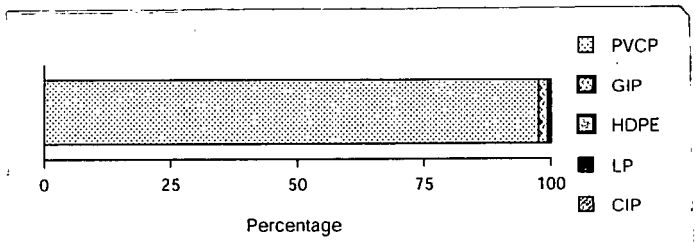


Fig. 2 Percentage of pipe length to pipe type for service pipelines.

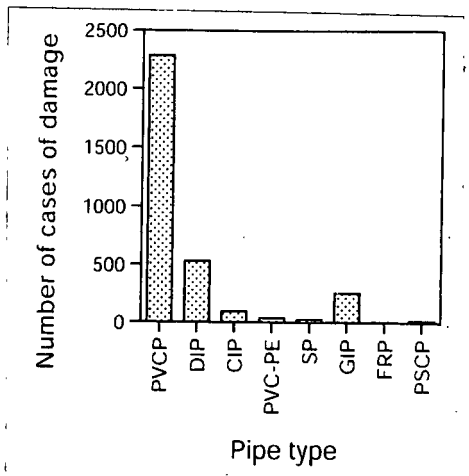


Fig. 3 Number of cases of damage related to pipe type. (transmission and distribution pipelines)

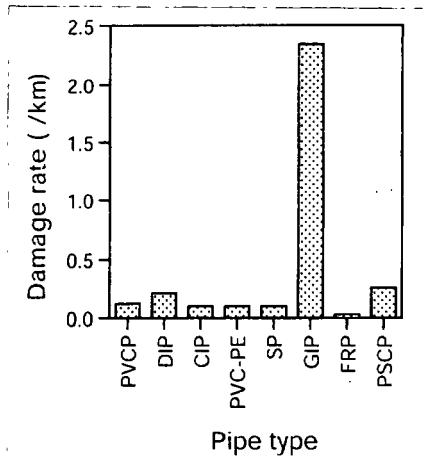


Fig. 4 Damage rate related to pipe type. (transmission and distribution pipelines)

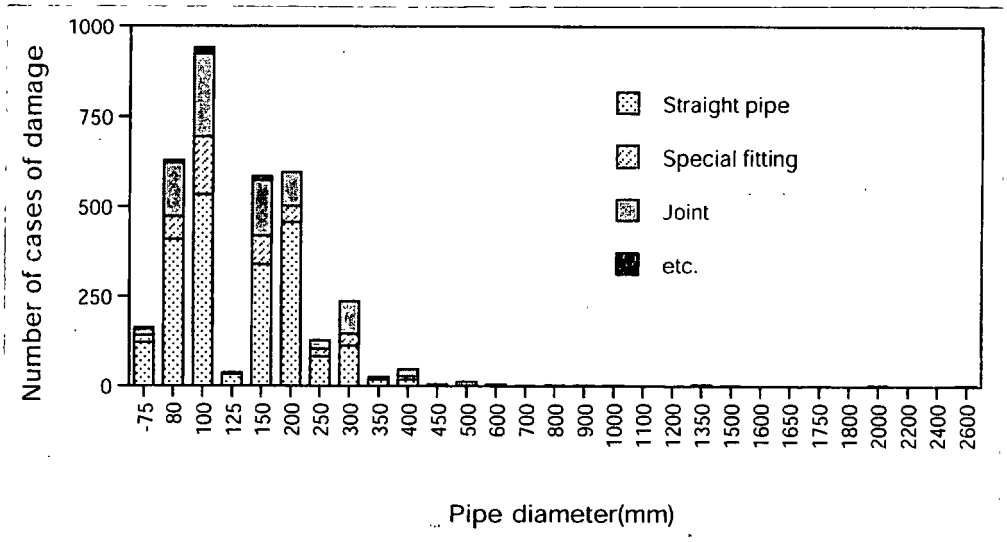


Fig. 5 Relationship for number of cases of damage, pipe diameter and type of failure.

DAMAGE TO WATER SUPPLY FACILITIES

No.1 and No.2 Fonyuan purification plants were damaged severely because ground under the both purification plants went up about 4m due to the fault movement after the earthquake. The No.1 purification plant could not work after the earthquake because of extensive damage to the purification facilities. Photo. 1 shows the damage at the inclined plate clarifier of the No.1 Fonyuan purification plant. Some inclined plates jumped out from the clarifier. The ceiling slab of service reservoir of No.1 Fonyuan purification plant fell down as shown in Photo. 2. These damages seem to show the great ground shaking.

Photo. 3 indicates the damage to water conveyance steel pipe with 2000mm of diameter which was buried cross the fault line. Photo. 4 shows push in each distribution PVC pipe at joints. The displacement was about 80cm. These damages suggest that the ground displacement induced by fault movement was remarkable at the areas close to the fault.

Photo. 1 Damage at inclines plate clarifier (No.1 Fonyuan purification plant).

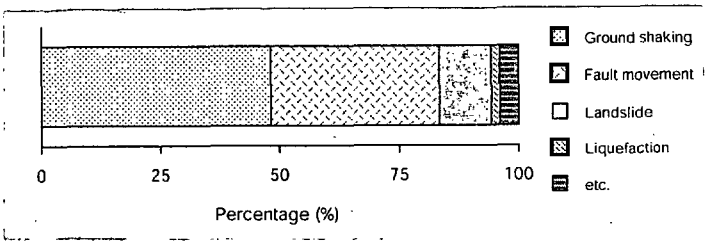


Fig. 6 Number of cases of damage in relation to causes of failure

Photo 3 Damage to water convayance pipe (Diameter:2000mm).

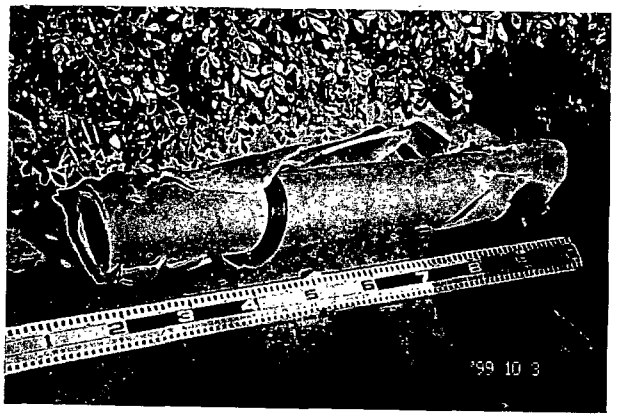


Photo. 4 Push in each distribution pipe (Vinyl pipe) at joint.

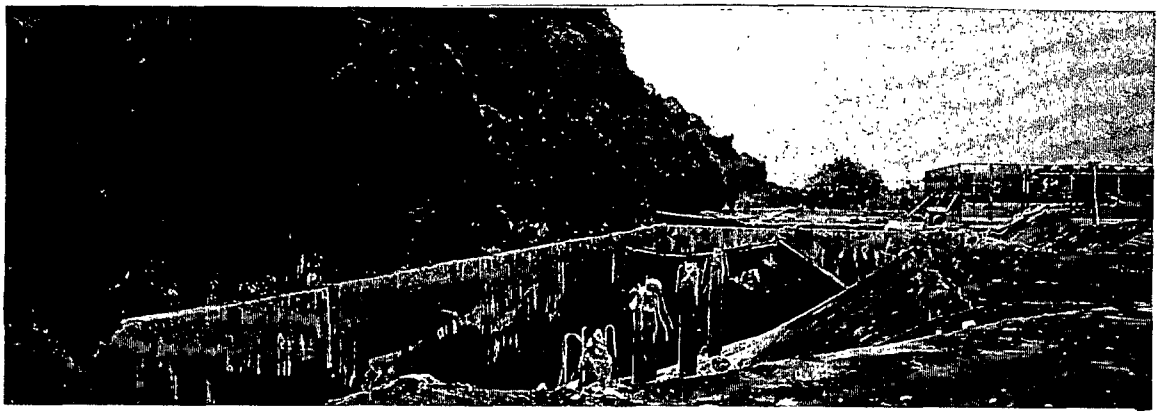


Photo. 2 Fall of ceiling slab of service reservoir clarifier (No.1 Fonyuan purification plant).

INVESTIGATION OF SURFACE RUPTURE AND DAMAGE TO BUILDINGS

To determine the degree of damage and relation between damage pattern and surface rupture, a survey was conducted during the period between January 1 to 9 of 2000. Major areas of this are, around Fonyuan, Chaotuen and Wufong where the damage to buildings was severe and the fault scarp appeared at the ground surface. Survey of fault, damage evaluation of buildings, and micro tremor measurements were conducted in the study area.

Fonyuan area

Due to hard soil in Fonyuan city area, steep deformations of 4-5m were observed as shown in Fig. 7. Further, building damage in the lower side of the heaved fault scarp was minimal, whereas the same in the upper side was found severe, with diminishing pattern as far away from the fault scarp.

In north side of the river, basically residential areas in cut and fill zones make the land-use therein, the land has heaved up more in mountainous terrain, while the same pattern with a lesser degree of deformation was seen in flat land. As far as south side of the river in concerned, since fault lies in the foot of the mountain, this has slid and tilted about 10% and slope failures up to 40 m was observed. Considering building damage, certainly it is true to say that structures on the fault line were damaged; but damage was basically limited to tilting of them thus was not that severe.

Chaotuen area

As shown in Figs. 8 and 9, there are two locations of damage, as follows:

Damage Area between Present Slope and State Route 3. This area between the present slope and State Route 3, consists of slope footage that heaved about 2 m, and though damage was limited to upper side of this upheaval, basically no damage was seen in most locations of lower side. However, there were certain locations of soft soil that lower side too moved with the upper one causing damage to buildings therein.

Damage Area of Paddy Field in the East of State Route 3. In the area of the paddy filed located east of State Route 3 due to the existence of soft soil, curvy deformations in small magnitude were observed. Further, fault branches of extended into the paddy field have caused damage in an area, rather than a linear one. Damage at distances of 50 and 90 m away from the fault was similar, with inclined buildings, while those areas sandwiched by two fault lines showed ground settlement of around 1.0m causing severely inclined buildings.

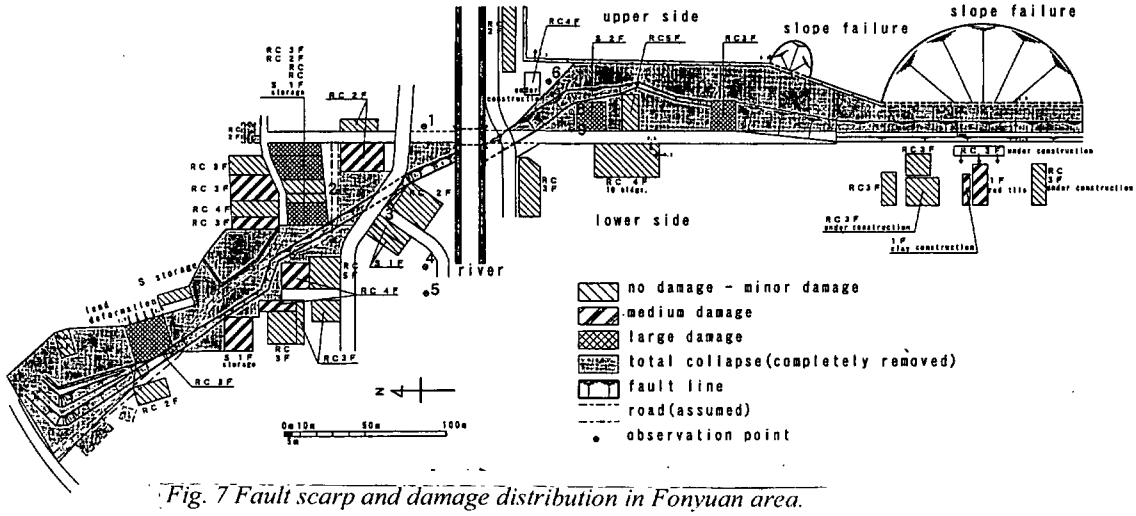


Fig. 7 Fault scarp and damage distribution in Fonyuan area.

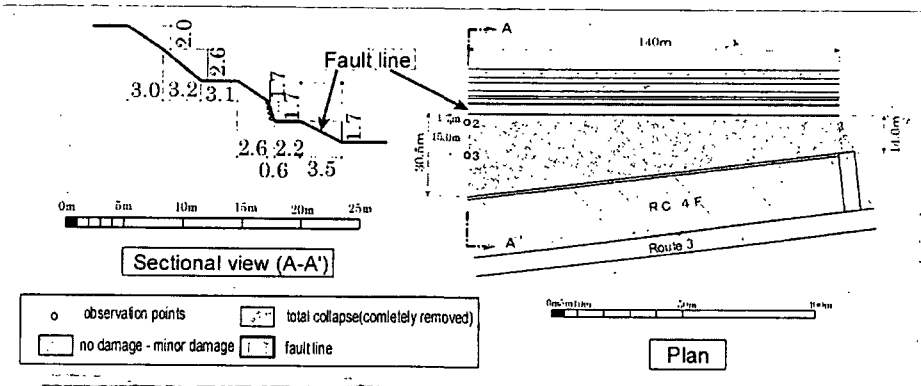


Fig. 8 Fault scarp and damage distribution close to slope in Chaotuen area.

Wufong area

In this area, Architectural Institute of Japan has already conducted a damage survey on a location near a school, as shown in Fig. 10. Continuing on this, the present conducted survey on the north part of the school. It was revealed that deformations of 2-3 m were presented at zones encompassed by two branches of faults and building damages therein were severe.

DAMAGE PATTERN TO FAULT SCARP

Having observed the damage patterns of the study area, here it is attempted to classify these damages in four categories such as *near-slope type, flat-type, hard-soil,* and *soft-soil.* Each of these is described in the preceding sections, and summarized in Table 1:

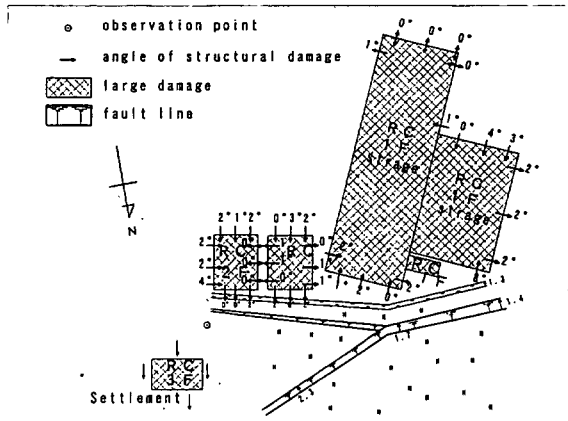


Fig. 9 Fault scarp and damage distribution at paddy field in Chaotuen area.

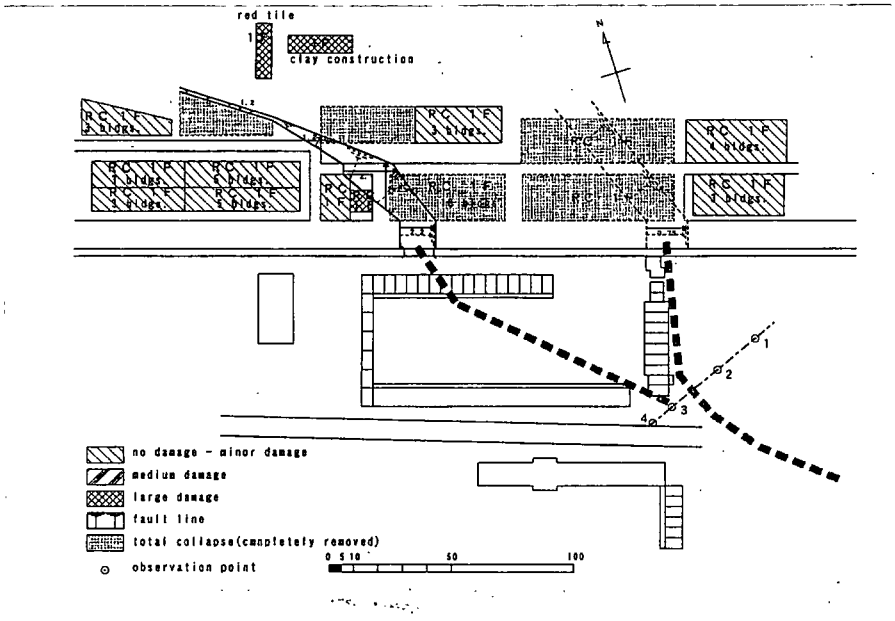


Fig. 10 Fault scarp and damage distribution in Wufong area.

Near-slop type

In the case of hard soil, fault scarp below the slope may be formed. Generally, buildings on upper-side of fault scarp indicate more damages than those do on lower side. However, when the lower side of fault scarp is a fill, there is a possibility of damages in buildings there in. Especially, in locations where are surrounded by fault and slopes in the upper-side, damages to building are severe, and depending on the location slope failure too has destructed buildings completely.

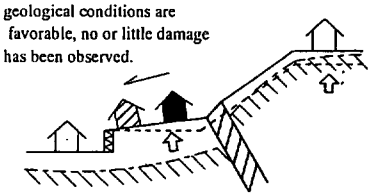
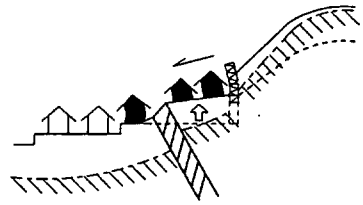
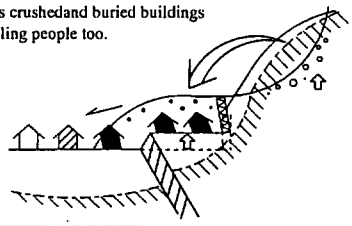
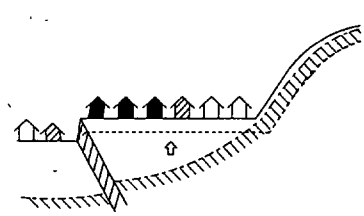
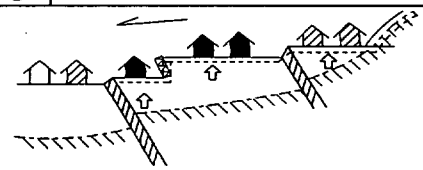
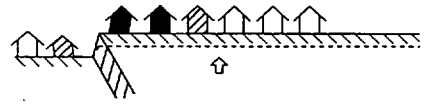
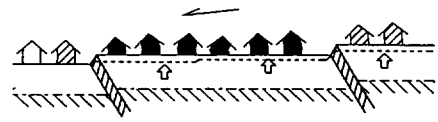
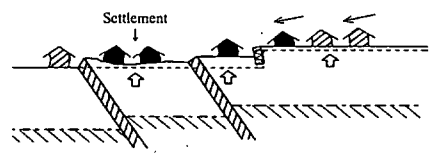
Flat type

In case of hard soil in flat terrain, the damages are relatively small. However, in the case of soft soils, damages propagate in a large area apparently due to deformations of soil profile.

CONCLUDING REMARKS

The characteristics of damage to water supply pipelines and buildings close to fault scarp were clarified in this paper. The present study revealed the details of the damage characteristics of the water supply system and discussed the effects of surface rupture due to fault movement on the damage. It was clarified that the majority of pipe failures occurred in the pipelines of relatively small diameter from 80mm to 200mm. Not only the significant great ground shaking but also fault movement caused severe damage to buried pipelines and buildings. A further in-depth study is needed concerning effect of fault ruptures on buried pipelines and buildings.

Table 1 Damage to buildings and ground conditions near fault scarp.

Type			Conditions of topography and geology		
Near-slope type	Hard soil	(a) When fault dip occurs at mountain foot	**Along State Route 3 of Chaotuen** [Deformation of land profile] Near the mountain foot, due to deformation of fault (approx.2m), upheaval of fill area of lower-side has occurred. [Building damage] Damages of large, medium scales are seen due to fill area in the lower-side(approx.14-30m in width).In areas where geological conditions are favorable, no or little damage has been observed. 	(b) When fault dip occurs near mountain foot (falling of wall)	**Foryuan Area (in the south of park)** [Deformation of land profile] Slopes of about 10% have been formed due to upheaval of fill in the area surrounded by fault lines, in the upper-side. [Building damage] Severe damage to buildings due to land deformation. 
		(c) When fault dip occurs near mountain foot (slope failure occurance)	**Fonyuan Area (in the south of park)** [Deformation of land profile] Further to land deformation of (b), slope failure occurred, with effects on lower-side(large scale ones in order of 40m in height) [Building damage] Extremely dangerous ; slope failure has crushedand buried buildings killing people too. 	(d) When fault dip ocuns at a location anay from mauntain foot	**Fonyuan Area (in the north of park)** [Deformation of land profile] Slopes formed near fault line. [Building damage] Damage in the viscinity of fault line severe, which diminishes with distance away from fault. 
	Soft soil		**East of Route 3 of Chaotuen** [Deformation of land profile] Slopes have formed due to narrowing of several fault lines and slopes.[Building damage] Severe damages were observed in buildings surrounded by fault lines and deforming land, while medium damages were seen in slopes.		
Flat type	Hard soil		**Fonyuan Area (in the north of park)** [Deformation of land profile] Deformations perpendicular to fault line is large (4-5m) [Building damage] Buildings of upper-side were severely damaged (width approx-20m).Those in lower-side had not much effect and medium damage was observed, with a narrow damage range (approx.10m).		
	Relatively soft soil		**Wufong Area (north of junior high school)** [Deformation of land profile] Fault line has branched off into few more lines and perrendicular deformations are medium (2-3m). [Building damage] Severe damages to buildings in locations surrounded by fault and land deformations were seen here.		
	Soft soil		**East of Route 3 of Chaotuen** [Deformation of land profile] Fault line has branched off into few more lines, though deformations in perpendicalar direction were small, many cracks were observed (1-2m). [Building damage] Lateral movements and settlements in land in both upper and lower sides were observed in a wide area.		

※Legend : large damage, medium damage, no damage-minor damage, Fault line, upheaval, movement of land at an angle

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