

8. LANDSLIDE, SLOPE FAILURE AND LIQUEFACTION

8.1 Landslide and slope failure

8.1.1 Overview

Many large scale landslide and slope failure were occurred around the western piedmont district along the central mountain range within the focal distance about 60km. It has been reported that the area in which the inclination of slope was over 20 degree had 53% to the gross area of Taiwan. The slope of the mountain in the country has high possibility for landslide and slope failure. and that the area where had high possibility to occur landslide was over 1000ha. The record about the landslide in Taiwan have been reported[Ishihara,1985]

Huge landslides at Chao-Ling and Mt.Jio-Fun-Ell-Shan is firstly described at the section of 8.1.2 and 8.1.3. Secondly, huge slope failures at Gwu-Guan and Mt. Huyen shan is described at the section of 8.1.4 and 8.1.5. The locations of these four areas are shown in Figure.8.1.



Figure.8.1 The location of points for the Landslide and Slope failure

8.1.2 Landslide at Chao-Ling

Huge landslides occurred at Chao-Ling where was located along Ching-Shoei river around the border between Yui-Lin Shyuan and Chia-Yii Shyuan. Hence Ching-Shoei river is the branch of Juo-Suei-Shi river. The landslide as shown in Photo.8.1 generated around both sides of the mountains along the river and swallowed the village by the soil and gravel. The gross volume of the flow and the total length of the slide estimated to be more than 3 million m³ and 4 km, respectively. Furthermore, a river which has 80m width was filled with the soil and gravel, and a new lake was created.



Photo.8.1 Landslide at Chao-Ling

(Provided from the investigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)

8.1.3 Landslide at Mt. Jio-Fun-Ell-Shan

Huge landslides occurred at Mt. Jio-Fun-Ell-Shan where located about 3.0km west from Nan-Kan in Nan-Tou prefecture. The landslides were generated at the two mountains which were close to each other. Photo.8.2 shows the landslide occurred at one of the mountains. Due to the landslide, two villages were swallowed. Furthermore, the flow dammed up the river, and a new lake was created. The gross volume of the flow estimated to be more than 0.5 million m³.



Photo.8.2 LandSlide at Jio-Fun-Ell-Shan Mountain

(Provided from the investigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)

8.1.4 Slope failure at Gwu-Guan

A road(Jon-Buh-Heng-Guann-Gong-Luh) crossing the central part of Taiwan Central was interrupted at Gue-Guan due to a lot of large scale slope failures, one of example of which is shown in Photo.8.3. The road was constructed on the slope in the mountain range at upstream of Dai-An River and had an important role to connect between the eastern and the western parts of Taiwan. Many slope failures have also occurred during the aftershocks.



Photo.8.3 Slope failure at Gwu-Guan

(Provided from the investigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)

8.1.5 Slope failure at Mt. Hoyen-Shan

Mt. Hoyen-shan became bald as shown in Photo.8.4. due to the surface slope slidings. The mountain is located about 12 km east from Wu-Fong in Taichung County. The height of the mountains is 526 m and the slope is very steep. It had been all covered with trees up to the top before the earthquake. Cobblestones were observed around the top. The large scale slope failures resulted from the steep slopes and the unstable soil with cobblestones.



Photo.8.4 Whole view of Hoyen-Shan which became a bald mountaion

(Provided from the invesigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)



Photo.8.5 Close view of Hoyen-Shan which became a bald mountaion

(Provided from the invesigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)

8.2.1 Overview

Among these sites, Taichung port was seriously damaged, and the damages has been described at chapter.6. Then, the damages caused by liquefaction are described here except Taichung Port.



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8.2.2 Nan-Tou City

Damage due to liquefaction was observed at several places along the branch of Da-Jia river. The locations of the liquefied areas are shown in Figure.8.3. Among them, Both sides of the dike along Mao-Luoh river subsided to about 1m as shown in Photo.8. 6 and 8.7. The subsidence occurred to be about 5.0km long between Juin-Gong bridge and Nan-Gang. At Lyu-Mei Bridge, the dike of the river moved toward the river center due to liquefaction and the abutment of the bridge. Photo.8.8 shows the settlement of the approach road on the abutment. The total movement of the dike which was measured as the amount of crack width parallel to the river was reported as about 80cm. The similar damage was observed at Juin-Gong bridge which is close to Lyu-Mei bridge.

At Juin-Gong Lii about 200m north-west from the above-mentioned bridge, It was reported that many houses and side walks of a road were settled as shown in Photo.8.9 and a lot of sand boils were observed in a banana plant as shown in Photo.8.10. Sand boils were also found at a banana plant, south of Jenn-Shin bridge in Ping Ling lii.

A building was inclined as shown in Photo.8.11. It is clear that the inclination of the building was caused by soil liquefaction, since evidences of the liquefaction such as sand boils and ground fissures were observed around the buildings.

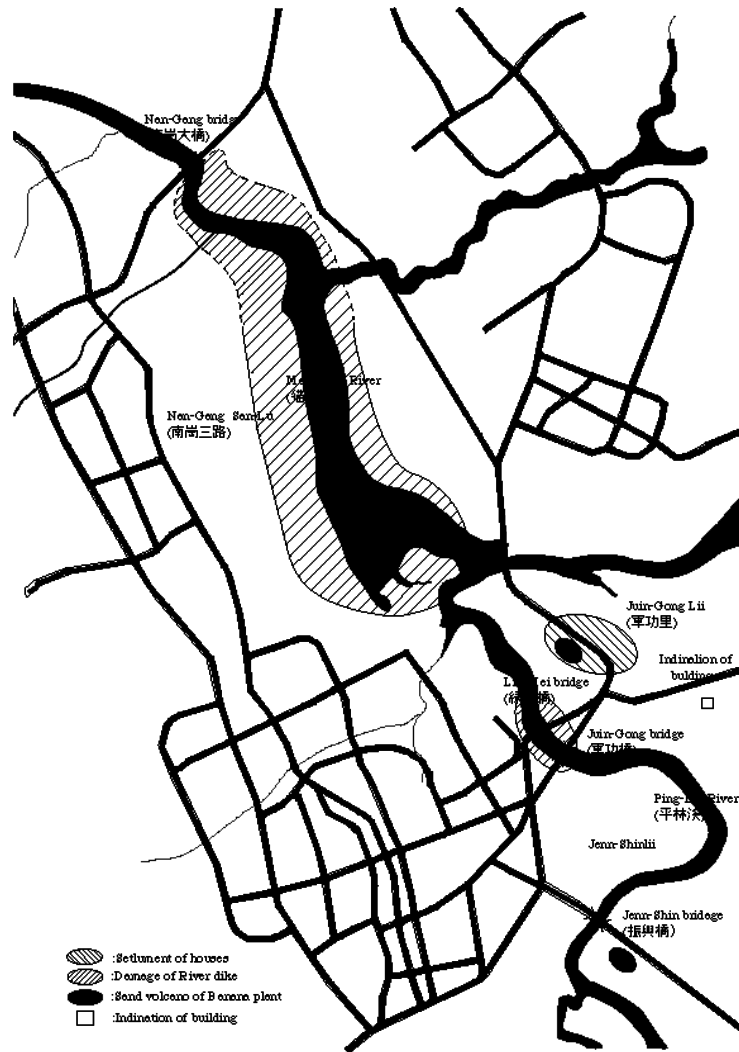


Figure.8.3 The location of the damaged area in Nan-Tau city



Photo.8.6 Settlement of River Dike



Photo.8.7 Crack along the facing of River Dike

(Provided from the investigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)



Photo.8.8 Failure of Abutment at Lyu-Mei Bridge(Provided from the investigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)



Photo.8.9 Settlement of Houses and Side walk



Photo.8.10 Sand Volcano in Banana Plant



Photo.8.11 Inclination of Building
(Provided from the investigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)

8.2.3 Chungliao Switching Yard

Chungliao switching yard of Taiwan Electric Power Company as shown in Photo.8.12 locates in the north from the epicenter. The switching yard was constructed on the top of a hill by cutting of the soil. Some fissures were observed around the filled area in the yard as shown in Photo.8.13. These fissures were supposed to be caused by the liquefaction, because a lot of sand volcanos were observed as shown in Photo.8.14. The erupted soils around sand volcano contains an amount of fine contents.

Ground around the foundation of a transmission tower subsided about 20 to 30 cm and sand boils were observed as shown in Photo8.15.



Photo. 8.12 General view



Photo. 8.13 Fissure generated by liquefaction



Photo. 8.14 Erupted soils on the lower site



Photo. 8.15 Settlement of foundation of the transmission tower

8.2.4 liquefaction along Da-Jia river

Ground fissures due to liquefaction as shown in Photos.8.16 and 17 were observed on the river front of the downstream of Da-Jia river around Chang-Hua city.



Photo.8.16 Fissure on the river front



Photo.8.17 Boiled sand around fissure

8.2.5 Lu-Gang and Yuan-lin

Sand boils due to liquefaction at Lu Gang which was under construction was observed as shown in Photo.8.18. However, the dynamic compaction method had been used in a part of the reclaimed land to improve the soil against liquefaction. Any sand boil was not observed in the improved area..



Photo.8.18 Sand Volcano in Lu-Gang

(Provided from the investigation team for The 1999 Ji-Ji Earthquake by The Japanese Geotechnical Society)

Sand boils and damage due to liquefaction were also reported at Yuanlin. Table 8.1. shows the list of liquefied sites reported by an official of Yuanlin Town.

Table 8.1. List of liquefaction sites reported by the Chief of Yuanlin Town

No.	Investigation sites	Description
1	崙雅里員水路一段 404巷2號	Soil eruption vegetable field, sank 60 cm, inclined by 3 degrees.
2	崙雅里員水路一段 446巷31弄13,15,17號	Soil eruption with gray fine sands, subsidences by 5 to 10 cm in the front side of a building and by 20 to 30 cm in the back side.
3	崙雅里員水路一段 446巷17-1號	Subsidence by 10 to 20 cm.
4	崙雅里員水路一段 348巷1,2,4號	Subsidence by 30 cm surrounding a building, soil eruption with gray fine sands in the rear side of the building.
5	大饒里員集路二段492巷	4 points of soil eruption on the center of street with gray fine sands, surrounding houses subsided by 20 cm.
6	大饒里員集路二段492巷37號	One point of soil eruption on the center of street with gray fine sands, surrounding houses tilted by 3 degrees.
7	大饒里員集路二段488號	House tilted by 3 degrees and soil eruption with gray fine sands in the vicinity of 492 road.
8	大饒里員集路二段493巷13弄1號	Damage to beams and columns of a house.
9	惠來里惠明街101號	Subsidence on the left side of a house with 3 degree tilting.
10	惠來里惠明街75巷國富鎮	(1) 5 points of soil eruption on the underground floor of a building. one of the 5 points showed 3 meters in height of eruption. (2) 2 points of soil eruption on the western passage with gray fine sands. (3) Considerable volume of erupted soil in the eastern drainage
11	民生里南興街59 ~ 71號&永春街79 ~ 95號	Erupted soils fill a drainage channel. There are fissures on roads. Houses tilted.
12	萬年里萬年巷52之3號	Erupted soils fill a drainage channel. There are fissures on roads. Houses tilted.
13	振興里員水路一段276號	Erupted soils fill a drainage channel. There are fissures on roads. Houses tilted.

8.2.6 Grain Size Distribution of Liquefied Soil

Figure 8.4 shows grain size distribution curves of the erupted soils. The ranges of high possibility of liquefaction, which is recommended by *the Technical Standard on Port Facilities and Its Explanation*(1989) is also shown in this figure. The grain size of the sand sampled at Nantou City and Taichung Port are in the range of "High Possibility of Liquefaction". The soil sampled Chungliao Switching Yard is classified to be silt because fine contents are more than 50%. The soil sampled soil at Taichung Ports is also classified to be silt.

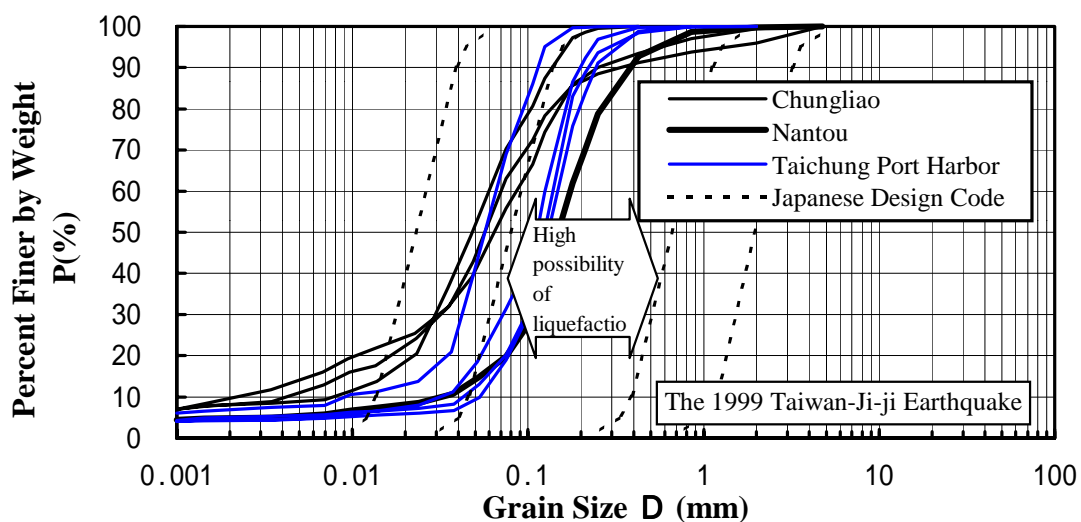


Figure 8.4 Grain Size Distribution of Liquefied

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- Kuribayashi, E. and Tatsuoka, F. (1975): Brief review of liquefaction during earthquake in Japan, *SOILS AND FOUNDATIONS*, Vol.15, No.4, 81-92.
- Japan Port and Harbor Association (1989): *Technical Standard on Port Facilities and Its Explanation* (in Japanese).