Case History

Geotechnical structure damages during the 2009 Typhoon Morakot

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1. INTRODUCTION

This news reports the geotechnical disasters in Taiwan in August, 2009, that were caused by the extremely heavy rainfalls associated with Typhoon Morakot. Figure 1 shows the path and date of the travel of the typhoon. It is seen herein that the typhoon remained in the Taiwan's neighborhood from August 7th to 10th. This situation resulted in an extremely heavy accumulation of rainfall. As observed by radar in Fig. 2, the wind brought a lot of cloud and water from the Taiwan Strait towards mountains in the southern part of Taiwan Island. Fig. 3 presents rainfall data during the typhoon period. From August 7th to 10th, the total rainfall in the southern part of Taiwan exceeded 1,500 mm. Furthermore, the 24-hour rainfall on August 8th was more than 700 mm in the same area. A typical rainfall data in the mountain region is the one in Fig. 4, in which the accumulated rainfall reached as much as 2,700 mm in four days.

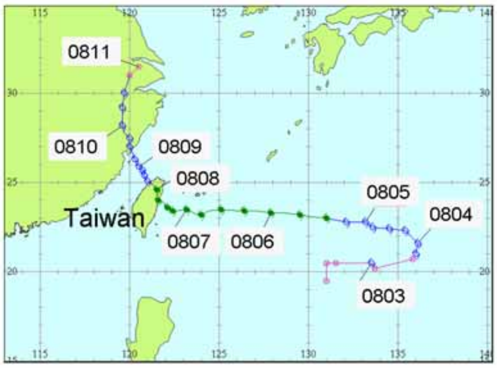

Figure 1. Path of Typhoon Morakot

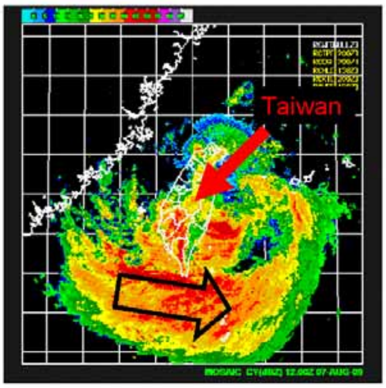

Figure 2. Vortex of typhoon cloud (radar observation)

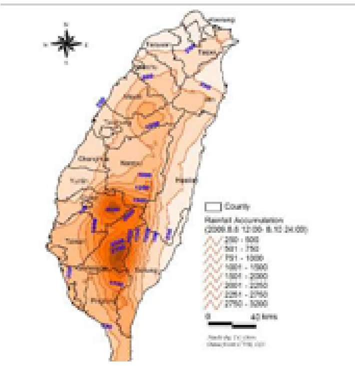
Figure 3. Data of precipitation during typhoon time(Tien-Chien Chen)

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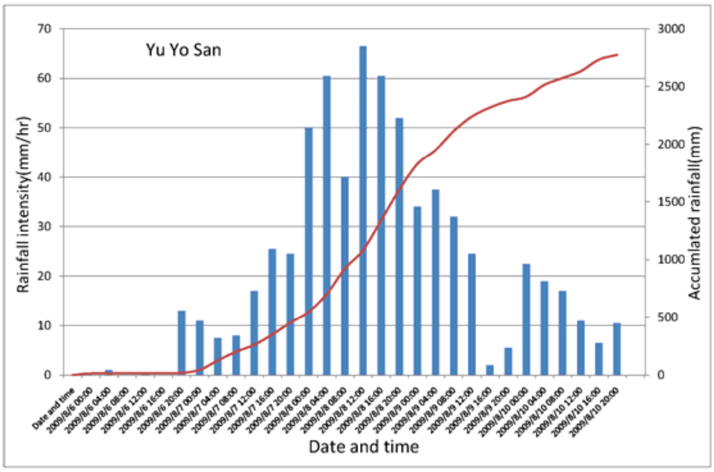

Figure 4. Rainfall data at Yu Yo San station

2. GENERAL IDEA ABOUT GEOTECHNICAL DAMAGES

The heavy rainfall in the southern part of Taiwan caused severe geotechnical damages at many places. Damage investigations revealed that they are classified into three categories;
(1) Failure of slopes : cut slope failures along roads and huge landslides,
(2) Failure of embankments such as river levees and road embankments, and
(3) Failure of bridge structures caused by scouring in foundations, collision of debris flows, and erosion of abutments.
Most of them were concentrated in the mountainous region (Fig. 5). More details of the damages are introduced in the following chapters.

3. CHEN-YU-LAN RIVER REGION

Typhoon Morakot caused a heavy rainfall in a very short time. Therefore, the river water level rose suddenly and made emergency action very difficult. Fig. 6 shows a significantly eroded river channel that endangered dwellings of people. Steep mountain slopes and valleys with deposits of weathered materials produced debris flows (Fig. 7).

Cut slopes along roads were destroyed at many places. Fig. 8 demonstrates an example in which a gravelly deposit, which was probably produced by an ancient debris flow, failed and a road structure was affected. A new road is being reconstructed in the steep slope. Noteworthy is that many retaining structures were destroyed as well. In Fig. 9, the damaged wall did not have a stable foundation and was easily affected by scouring in the base, leading to its total collapse. In Fig. 10, a ground anchor that had supported a retaining wall was pulled out.

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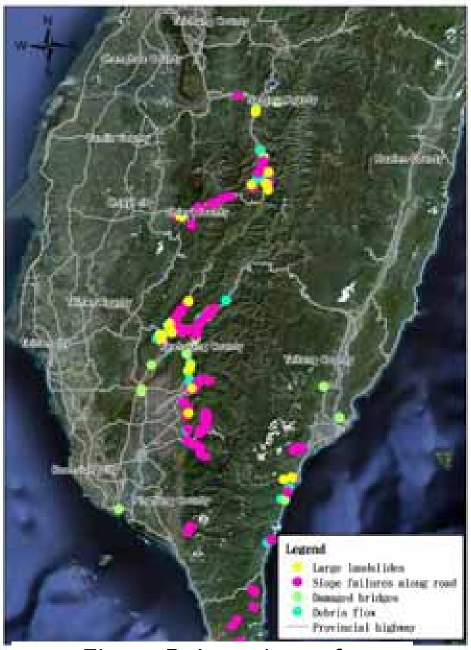

Figure 5. Locations of geotechnical damage

Figure 6. Erosion along river channel

Figure 7. Source valley of debris flow

Figure 8. Failure of natural slope along road

Figure 9. Collapse of retaining wall without stable foundation

Figure 10. Destroyed shape of ground anchor.

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Consequently, the observed geotechnical damages in the Chen-Yu-Lan river region can be summarized as what follows. First, there are many valleys that are prone to debris flow. The rapid rise of water level resulted in significant erosion along river channels. These two situations resulted in flow of huge amount of debris in the downstream areas. Second, retaining walls along mountain roads were damaged substantially. Accordingly, reconstruction of new roads is a difficult task, including construction of stable retaining structures, anti-scouring structures, and even re-routing.

4. ALI MOUNTAIN AREA

Ali Mountain is located near the central part of the Taiwan Island. Because of the steep mountain slopes and rainy climate together with its young geology, this area is substantially vulnerable to slope disasters. After the 1999 ChiChi earthquake, the loosened slopes have been producing debris in many valleys and this seems to be one of the reasons for many occurrence of debris flow in the present rainfall.

Figure 11 demonstrates an areal view of a slope failure and flow of debris. As indicated in Fig. 12, not only the surface deposits but also base rock failed. Fig. 13 shows a damaged situation of a road along a valley. It appears that the stability of this slope was affected to some extent by the erosion at its toe during the flooding. Reconstruction of road in this section poses a question about stability of this road during a future heavy rain storm.

Figure 11. Aerial view of large slope failure

Figure 12. Deep-seated failure of slope

Figure 13. Mountain road destroyed by slope failure

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It is noteworthy that the present natural disaster was so powerful as to affect massive structures that had been considered stable under an extreme natural actions. Fig. 14 shows a rock-shed tunnel which was situated in an unstable slope. Apparently, a big amount of soils and debris came down from this slope. Fig. 15 indicates a distortion of this tunnel. It seems that this problem was induced not by the earth pressure of the flowing soil mass but the instability and deformation in the foundation of this tunnel (Fig. 16).

The lessons learnt from the damage in the Ali Mountain area are as what follows. First, the slopes in this area have been unstable and are subjected to large-scale failures. The combined effects of the present rainfall and a past earthquake shaking need to be studied further. Second, the effects of slope instability affected even such heavy structures as a rock-shed tunnel. Third, although reconstruction efforts are desperately going on, there is a fear about the stability of those slopes during future heavy rainfalls.

Figure 14. Rock shed tunnel subjected to slope failure

Figure 15. Distortion of rock-shed tunnel

Figure 16. Subsidence in foundation of rock-shed tunnel

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5. CHI-SAN RIVER AREA

Along the Chi-San River, erosion and scouring were significant. Fig. 17 shows erosion in the toe of a cliff that affected road in the higher elevation. The power of erosion and scouring was substantial during the present event. Fig. 18 indicates a bridge that was washed away due to foundation scouring. Further, Fig. 19 indicates erosion of abutment and embankment approaching a bridge. Erosion at the toe of road embankment occurred at many places (Fig. 20).

Figure 17. Toe erosion in river channel

Figure 18. Destroyed bridge because of scouring

Figure 19. Bridge abutment and embankment destroyed by erosion

Figure 20. Erosion at toe of road embankment

6. GIGANTIC SLOPE FAILURE IN SHAO-LIN VILLAGE

One of the most tragedic events during the present typhoon was the total devastation of the Shao-Lin Village. In Fig. 21, minor streams behind the village had been considered vulnerable to possible occurrence of debris flow. During the present typhoon, a huge slope failure of 1.9×10^7 m^3 in volume occurred (Fig. 22) and formed a landslide dam in the river channel on the upstream side of the village (Fig. 23). This dam breached shortly and totally destroyed the village (Fig. 24). The number of victims reached 474.

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Figure 21. Areal view of Shao Lin Village before rainfall


Figure 22. Gigantic slope failure behind Shao Lin Village

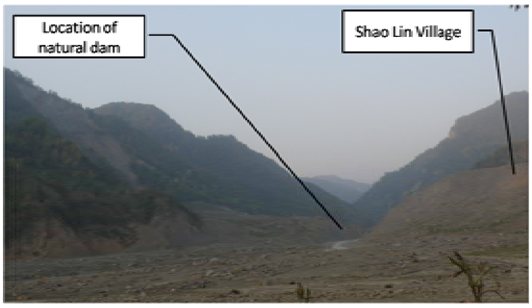

Figure 23. Location of natural dam

Figure 24. Areal view of Shao Lin Village after the disaster

7. LAO NON RIVER AREA

Many slope problems occurred in this area as well (Fig. 25). Fig. 26 indicates erosion along a river channel and consequent failure of a retaining wall. It is important to note that erosion occurred at special points alone in a curved narrow river channel (Fig. 27) probably because the direction of rapid water flow was winding and hit limited places. The same situation may occur in a bridge as well. For example, the bridge in Fig. 28 was damaged only in its part where the power of the flooding was most significant during the typhoon.

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Figure 25. Big slope failure

Figure 26. Erosion at bottom of retaining structure

Figure 27. Erosion along curved river channel.

Figure 28. Destroyed bridge

8. TAITUNG AREA

This area is situated in a coastal plane in the south-eastern part of Taiwan. Rivers brought a huge amount of debris together with water and caused damages. Fig. 29 reveals erosion of a river wall and collapse of a building as its consequence. Note that the upper photograph in this figure was taken after the water-front wall had been eroded. Thus, the scale of the flooding was greater than the design level, and the backfill soil was easily eroded.

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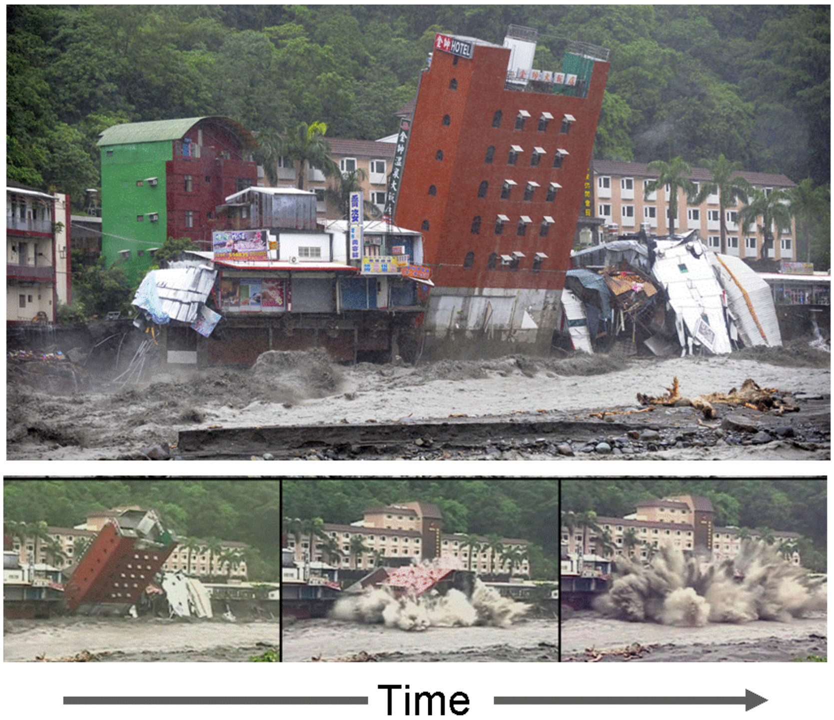

Figure 29. Erosion-induced failure of river wall and collapse of building

Figure 30. Air photograph of Taimali River channel before flooding

Figure 31. Damages in bridges and river levees

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Figure 30 shows an air photograph of the previous topography in the mouth area of Taimali River. Although the ancient river flowed on the left (north) side, human activities shifted it towards the right bank. When the flooding occurred in 2009, the river flow destroyed the levees and came back to its original channel on the left side (Fig. 31). Consequently, both railway and road bridges were destroyed on that side. See Figs. 32 and 33 for those bridges during flooding and reconstruction.

Figure 32. Bridges during flooding

Figure 33. Reconstruction of railway bridge

9. ADDITIONAL REMARKS

The geotechnical damages caused by the Typhoon Morakot clearly indicate the problem of such an extreme natural event for which the design consideration is insufficient. The heavy rainfall triggered many slope failures in the mountain area, resulting in high water level in the downstream area (Fig. 34) and debris flow. Consequently, erosion and scouring destroyed river walls and bridges. The extent of scouring during a single flooding was unexpectedly substantial (Fig. 35) and needs more elaborate design consideration in future. Moreover, the effect of drifting woods on failure process of bridges deserves attention. As shown in Fig. 36, a huge number of trees fell down from mountain slopes into rivers, and hit bridges in the downstream areas.

It is frequently claimed from the viewpoint of global climatic change that the possibility of extreme weather condition is going to increase from now on. It is supposed that the probability of heavy rainfall may increase in the coming decades. If those ideas are meaningful to any extent, it is important to learn from the Typhoon Morakot events about the consequence and induced hazards of an extraordinary magnitude of rainfall. Erosion and scouring seem to deserve further attention.

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Figure 34. Extremely high level of river water

Figure 35. Scouring in bridge foundation

Figure 36. Accumulation of drifting wood on bridge deck

10. ACKNOWLEDGMENT

The authors express their sincere gratitude to Taiwan Geotechnical Society who conducted very energetic reconnaissance activities after the disaster. It is hoped that the lessons from this tragedy will be useful for the safety of people in future.