Case study of Taipingshan landslide triggered by Typhoon Saola

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ABSTRACT

This paper presents a case study of Taipingshan landslide triggered by Typhoon Saola. The Taipingshan villa is one of the most famous scenic spots at Taipingshan National Forest Recreation Area in northern Taiwan. Since early 1990s, the unstable appearances of the slopes had occurred frequently in the study area, such as tension cracks, ground settlements, man-made structures cracking, etc. Therefore, a series of geological investigations and in-site/laboratory tests were carried out to estimate the slope stability and predict the rainfall threshold of landslides in 2010. The results show that the critical rainfall threshold of the case study is around 1,765 mm. In 2012, however, Typhoon Saola brought tremendous rainfall to hit eastern Taiwan. The main scarp of sliding mass B located at the History Exhibition Hall in the study area. According to in-situ extensometer data, the broken moment of extensometer shows that the real accumulated rainfall which triggered this landslide is 1,694 mm. The results of coupled analysis have been demonstrated in good agreement from the field monitoring data during the typhoon event. Our preliminary results appear to be useful for assessing the rainfall threshold of landslides. The findings can also be a good reference to establish an early warning system of landslides.

Keywords: landslide, critical rainfall threshold, Typhoon Saola, Taipingshan

1 INTRODUCTION

The Taipingshan Villa is located between Datong and Nanou Townships in Yilan County. Its access road to the outside is Yilan Exclusive Highway No.1. Before 2012, the largest hazard occurred during Typhoon Haitan in July 2005. Intense rainfall struck the area that it was closed for a year before re-opening. Unfortunately, during Typhoon Saola in July 2012, over 1,800 mm of rain fell on the Taipingshan Villa within 3 days, causing parts of the side slope to slide again. Many structures were damaged, and Bongbong Train Station stopped due to railway displacement and foundation loss. The Forestry Bureau has committed large funding between 2008 and 2013 to repair, yet because of fragile and sensitive geology, during storms, soil erosion, foundation loss, and landslide often occur along Yilan Exclusive Highway No.1 and the Taipingshan Villa. Until summer 2014, as to the structure and facility damages during Typhoon Saola, they are not yet completely restored.

2 LANDSLIDE INDUCED BY TYPHOON SAOLA

Yilan County Sustainable Development Engineering Association (2009) indicates that the structures within the Taipingshan Villa have shown displacement and damage for a long time. In early June of 2010, we entered the Taipingshan Villa to investigate the damage induced by landslide (Sinotech, 2010). Comparing against the previous survey by Yilan County Sustainable Development Engineering Association, the number of cracks has increased. For example, the retaining walls beside the trail have new cracks. The Taiwan Cypress House also has concentrated tension cracks. The ground surface and retaining walls outside of Red Cypress House, China Fir House, and the restaurant also have significant subsidence and cracks. Moreover, sporadic tension cracks also occur in the western portion of the Taipingshan Villa.

In 2012, Typhoon Saola carried tremendous rainfall, which severely damaged in the Taipingshan Villa, shown as the Photo 1–3 of Fig. 1. Several parts of the railway, trail and buildings within the area were destroyed. The Taipingshan Villa was forced to close. The significant sliding mainly occurs in the western portion, including the History Exhibition Hall, Songluo Meeting House, Bongbong Train Station, and Taiwan Cypress House (Sinotech, 2012). The damage signs include: main scarp near the Taiwan Cypress House (Photo 1), cracking of retaining walls beside the Songluo Meeting House (Photo 2), subsidence and cracking of railway (Photo 3), etc.
3 CASE STUDIES

3.1 Analytical process
The analytical process is shown as Fig. 2. It included: incorporating new data into the hydrogeologic conceptual model. To improve understanding of active landslide triggering mechanisms, especially focused on the rainfall-induced landslide, modeling and analysis using two-dimensional unsaturated numerical programs, GeoStudio, was made.

3.2 Monitoring System
The monitoring system set up in the Taipingshan Villa included: one set of raingauge (IR-02), one extensometer (IE-02), two observation wells (IH-27 and IH-29), two inclinometer/observation well (IH-21 and IH-25), and one inclinometer (IH-23). The layout of monitoring system is shown in Fig. 1.

3.3 Hydrogeologic Conceptual Model
The numerical geological model was established by the 5m×5m DEM. The analysis profile is the AA’ line in Fig. 1. The hydrogeologic unit of this site can be divided into three layers: colluvium, weathered rock and bedrock. Morphometric and geotechnical analyses were carried out for the Taipingshan Villa through a series of in-situ and laboratory tests, the results of which were used as input for the modeling process.

The boundary conditions of the hydrogeologic conceptual model are shown in Fig. 3. To analyze the infiltration and seepage flow, the left side boundary (RA) was set as a constant because a crest line had
already been established. The right side boundary (SB) was set as a constant head boundary equal to the water table of the toe creek trench. The lower boundary (AB) was set as a no-flux boundary. The surface of the slope (RS) was then set as a rainfall-infiltration boundary.

3.4 Slope Stability Assessment

The reference values of parameters were obtained from the series of investigations and laboratory tests, and then further verified by the monitoring data observed from July 15, 2010 to September 26, 2010. This study first calibrated the hydraulic parameters by comparing data without measuring rainfall to the typical groundwater level for steady state seepage flow analysis. Then the fluctuating groundwater levels experienced during rainfall events (including Typhoon Fanapi, September 17-20) were used in the transient seepage analysis to identify the accuracy of parameters. Furthermore, the unsaturated soil characteristic was considered in the transient seepage analyses by Fredlund-Xing equation (Fredlund and Xing, 1994). Fig. 4 is the soil-water characteristic curve of the Taipingshan Villa. The three parameters (a, n and m) are determined as 22.5, 5.807 and 0.145. Using the above-mentioned procedure, parameters (Table 1) and groundwater level characteristic of this site were determined, and the follow-up slope stability analysis was conducted.

Fig. 3. Hydrogeologic conceptual model of the Taipingshan Villa.

Fig. 4. Soil-water characteristic curve of the Taipingshan Villa.

| Slope stability Assessment during Typhoon Fanapi. |
|---------------------------------------------------|
| Fig. 5. Slope stability Assessment during Typhoon Fanapi. |

Fig. 6. Rainfall-induced the Taipingshan villa hazard assessment.

Table 1. Hydrogeologic parameters of the Taipingshan Villa.

| Material         | Hydraulic conductivity (m/sec) | Unit weight (kN/m³) | Cohesion (kPa) | Friction angle (deg) |
|------------------|--------------------------------|---------------------|---------------|----------------------|
| Colluvium        | 9.2×10⁻⁶                      | 18.5                | 22            | 28.4                 |
| Weathered rock   | 5.1×10⁻⁶                      | 26.8                | 550           | 30.35                |
| Bedrock          | 5.0×10⁻⁷                      | 27.1                | 2050          | 26.11                |

Note: Hydraulic conductivity was obtained from permeability test and double packer test; Unit weight was obtained from soil classification tests; Cohesion and friction angle were obtained from direct shear test and triaxial test.

Fig. 5 is the results of slope stability assessment. The result shows that the potential sliding mass is located at the side slope below the borehole IH-25. The sliding surface cuts through the interface between colluvium and weathered rock. The factor of safety (F.S.) of normal condition is 1.34. Moreover, the F.S. was changed during Fanapi, the minimum F.S. is 1.28 on September 19, 2010 (Fig. 5 and Fig. 6).
3.5 Critical Rainfall Threshold Assessment

Based on above verified model, the study entered different rainfall conditions to predict the F.S. of the Taipingshan villa. In GeoStudio, user can input the unit flux in rainfall-infiltration boundary to simulate rainfall event. In this study, the rainfall condition was adopted the 72-hour duration and rank method to assess the design hyetograph (Chung et al., 2013). The rainfall data collect from Mt. Taiping (1) Rainfall Station (No.01U560) between 1991 and 2009. The result of design hyetograph of 72-hour duration in the Taipingshan villa is shown as Fig. 7.

Fig. 7. Design hyetograph of 72-hour duration.

Fig. 8 shows the relationship between F.S. and accumulated rainfall. The figure shows that when accumulated rainfall exceeding 1,245 mm, the rate of F.S. decrease accelerates. We define critical rainfall threshold as the accumulated rainfall when F.S. is equal to 1.1 (Chung et al., 2013). According to Fig. 8, the critical rainfall threshold of the Taipingshan villa is equal to 1,765 mm.

Fig. 8. Relationship between F.S. and accumulated rainfall.

3.6 Key findings of the Typhoon Saola

The observed records and key results are summarized below:

1. According to extensometer data (Fig. 9), when the accumulated rainfall reaches 398 mm, displacement begins to occur. When accumulated rainfall reaches 1,694 mm, significant displacement occurs, and the extensometer was damaged. It is inferred that the Taipingshan Villa was beginning to have a severe landslide at this time.

2. There are two sliding masses in the Taipingshan Villa. The sliding mechanism should be rainfall infiltration and upper side slope's lateral recharge causing groundwater level to rise to the interface between the weathered rock and colluvium. This reduced the sheared force of the sliding mass A and induced the slide. This caused the sliding mass B to generate retrogressive landslide, as shown in Fig. 10.

3. According to Fig. 9, the accumulated rainfall corresponding to the landslide is 1,694 mm. This is close to the prediction made by this study in 2010 where the critical rainfall threshold is 1,765 mm (Fig. 8). The difference percentage only 4% compared with the result of Fig. 8. Moreover, the position of sliding mass A is the same as the potential sliding mass predicted in 2010 (Fig. 5). This suggests this model is quite accurate.

4. This study conducted hydrogeologic conceptual model verification works via the continued observation between September 2010 and October 2012. The analysis is as shown in Fig. 6. The assessment shows that the F.S during Typhoon Saola is less 1.0.

Fig. 9. Relationship between displacement and rainfall during Typhoon Saola.

Fig. 10. Sliding mass triggered by Typhoon Saola.
4 CONCLUSION AND RECOMMENDATION

Based on the above research, the following conclusions and recommendations can be derived:

1. This paper adopts GeoStudio to perform rainfall-induced landslide potential assessment. The case study of Taipingshan landslide confirms this model can effectively assess the chronological changes in groundwater level within side slope and F.S. during rainfall. This model can target local, specific regions to conduct detailed landslide potential and change assessment.

2. The accumulated rainfall corresponding to the landslide is 1,694 mm. This is close to the prediction made by this study in 2010 where the critical rainfall threshold is 1,765mm. Moreover, the position of the sliding mass A is the same as the potential sliding mass predicted in 2010. This suggests this model is quite accurate.

3. The morphometric had been changed after Typhoon Saola, that’s the reason why analytical results of groundwater inconsistent with monitoring data. We suggest the hydrogeologic conceptual model need re-establish to do follow-up analysis.

4. The results of coupled analysis demonstrated good agreement between the predicted results and the data from field monitoring of the typhoon event. Further, it is expected the landslide initiation, enlargement, and reactivation can be more confidently predicted through using the aforementioned physics-based models.

5. Our preliminary results appear to be useful for assessing the rainfall threshold of landslides. The findings can also be a good reference to establish an early warning system of landslides.

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