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RISK ESTIMATION OF THE LI-SHAN LANDSLIDE IN TAIWAN

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Synopsis

Due to heavy rains, the sites near the highway 7A (73k+150) and the highway 8 (82k) in the Li-shan township began to subside in mid April 1990. In this study, topography, geology, and groundwater condition of this area were first reviewed. Based on this review, together with field investigations, a general hypothetic model was established to illustrate the Li-shan landslide. Then, a series of limit equilibrium back analyses were performed to understand the failure mechanism of this landslide area. In addition, the performance of the remediation treatment was reviewed with risk analysis.

Keywords
Li-shan landslide, risk estimation, failure mechanism, remediation, groundwater

1. Introduction

Located at the midway of the east-west cross-island highway (the highway 8), Li-shan is an important small town not only for transportation but also for tourism in central Taiwan (see Picture 1). In mid April 1990, due to heavy rain, the sites near the highway 7A (73k+150) and the highway 8 (82k) began to subside as their foundations are located on the sliding block of the landslide. It is generally suggested that the Li-shan landslide is predominantly caused by heavy rain together with the poor drainage condition.

In order to keep the highway functioning and secure the town for living, the government had executed the first phase emergency treatment followed by the second remediation treatment since July 1990. A dewatering system including surface ditches, drainage wells and two drainage galleries, was constructed and completed in early 2003. And the effectiveness of the remediation treatment has been strongly revealed as the Li-shan landslide survived the Chi-Chi earthquake (M_L=7.3) in 1999.

In view of the characteristics of the sliding area, it is of great interest to understand to the complicated failure mechanism, which motivates this study. In this study, topography, geology, and groundwater condition of this area were first studied with field investigations. A series of limit equilibrium back analyses were performed to understand the failure mechanism of this landslide for different phases. In addition, the performance of the remediation treatment is also discussed with risk estimation.

Picture 1. A bird eye view of the Li-shan Landslide area (looking to the southwest).

Picture 2. The rejuvenation in the Tachiachi river makes the toe steeper than the head.

2. Geology Conditions

In western Taiwan, the westward thrust front due to the compression of the Phillipine Sea Plate is obstructed by the rigid basement Peikang High (part of the Eurasian Plate) and result in a series of Quatenary thrust faults trending north-south and diping towards the east [1,2]. The 1999 Chi-Chi earthquake is considered as reactivating of one of the Chelungpu thrust fault. However, the Li-shan fault, a major ridge fault of Taiwan island also generated by the above tectonic activity, is located few kilometers west of the Li-shan landslide.

Topographically, Li-shan area is located in the valley of the Tachiachi river. Geologically, Li-shan is not far from the Li-shan fault, and it is suggested the geological conditions is more complicated than expected in this area. And it is evident that the Li-shan is located at colluvial formations originally from the Miocene Lushan slate formation. The testing results show that the Lushan slate is about 2.76 ton/m^3 of unit weight. And the mechanical properties for different weathering conditions can be summarized in Table 1.

TABLE 1. Mechanical properties of the geo-material in Li-shan area.

geomaterial type	unit weight (ton/m^3)	cohesion c(ton/m^2)	friction angle φ(°)
colluvium	2.06	0.75	30
medium to highly weathered slate	2.69	3.00	28
fresh to medium weathered slate	2.70	30.00	33
sliding plane	2.69	3.00	28

3. Failure Mechanism

Based on the field investigations together with the topographical and geological information, a general hypothetic model was established to illustrate the Li-shan landslide. This model comprises major factors as below: (1) the sliding planes is basically along the lower boundary of the regolith, about 20m below the surface, (2) there is a major old landslide at the center of the town, (3) the high erosion rate makes the slopes by the streams more dangerous than the others.

The landslide area can be divided to three regions, i.e. the west, northeast, and southeast regions (see Figure 1). Except the southeast region, most of the unstable slopes possess shallow sliding planes about 9-26 m below surface. However, there is an old landslide within the southeast region, of which boundary subdivides the southeast region to two subregions. According to the core logs and the records of drainage gallery construction, the old sliding plane is more than 40-60 m below surface. The rest of the southeast region is more or less located at a valley of a small branch of the Tachiachi river. Due to the tectonic activities, there is rejuvenation in the Tachiachi river. Thus the erosion rate of this branch is quite high, which generate higher hazard potential of this subregion (see Picture 2).

Based on the study of topography, the profiles AA', BB' and CC' (see Figure 2) were adopted and analyzed by the limit equilibrium analysis model PC-STABL [3]. The slopes are fairly stable for dry condition as the safety factor is 1.21-1.35; but they become critical with high groundwater level as the safety factor drops to 0.99-1.15. This finding might reveal there are more than one activities in this area, as the precipitation is quite high in this area, about 2340 mm annually. Therefore, it is essential to have remediation treatment in this area (see Table 2). Besides, during the Chi-Chi earthquake, the horizontal acceleration was estimated 0.15-0.20g. With this impact, this area survived except minor damages near the profile BB'. It somehow reveals the effectiveness of the remediation.

Figure 1. The topography and divisions of the Li-shan landslide area.

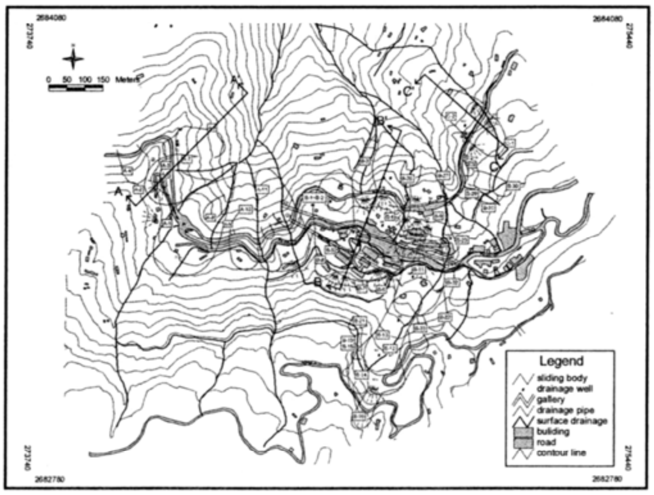

Figure 2. Illustration of the remediation treatment in the Li-shan landslide area.

TABLE 2. Safety factors for the residual slopes in Li-shan area.

profile analyzed	A-A'	B-B'	C-C'
dry(no groundwater)	1.23	1.21	1.35
wet (high GWL)	1.11	0.99	1.15
wet (with remediation)	1.23	1.18	1.22

4. Remediation

As the landslide is closely related with the rainfall and groundwater, groundwater control is essential to for slope stabilization in this area. A drainage system, composed of surface and subsurface drainage components, was designed to be a remediation treatment. For the surface drainage system, existing ditches were integrated as a system to divert the water undesirable surface flows into non-problem areas, as well as to prevent excessive water infiltration near tension cracks. In order to more efficiently control the groundwater level, a subsurface drainage system is also applied, which is consisted of three major components, i.e., horizontal drainage pipe, drainage well, and drainage gallery. There are (1) 15 horizontal drainage sites, 7-9 pipes (30-60m in length) in each site, (2) 13 drainage wells, located major in the heads of slopes, and (3) 2 drainage galleries, excavated below the sliding planes. The surface and subsurface drainage systems are illustrated in Figure 3.

From the preliminary results of groundwater level monitoring, the groundwater level has been successfully reduced about 10-20m after the drainage gallery #1 in operation. By this improvement, the stability of slopes is reasonably improved as expected with safety factors around 1.18-1.23.

5. Risk Analysis

The method coupling the probability analysis and the limit equilibrium stability analysis was adopted [4,5] to estimate the risk of the slope failure. In this approach, input parameters are considered as random variables instead of single values. The risk problem is now deduced to determine the distribution of factor of safety, which depends upon a number of random variables. To calculate a factor of safety, the Monte Carlo technique, which randomly samples the input parameters from their probability distributions, is applied. In this study, the input data are considered normally distributed for cohesion and friction angle, exponentially distributed for groundwater level. The parameters are determined according to the back analyses and lab. testing. For simplicity, generally, the input parameters are considered as completely independent variable, which is not always true in nature.

Through the Monte Carlo probability analyses with 10000 iterations, the risk for the most critical profile BB' is about 22.8 % (see Figure 3). This means that, for the combination of parameters with the assumed variations, 23 out of 100 similar slope could be expected to fail at some time during the life of the slope. However, the risk reduces to 1.0 % if we count on the contribution of remediation (see Figure 4). Therefore, the groundwater condition will still control the stability of the residual slope. It suggests that more attention should be given to the residual slopes with higher groundwater level, especially during rainy season.

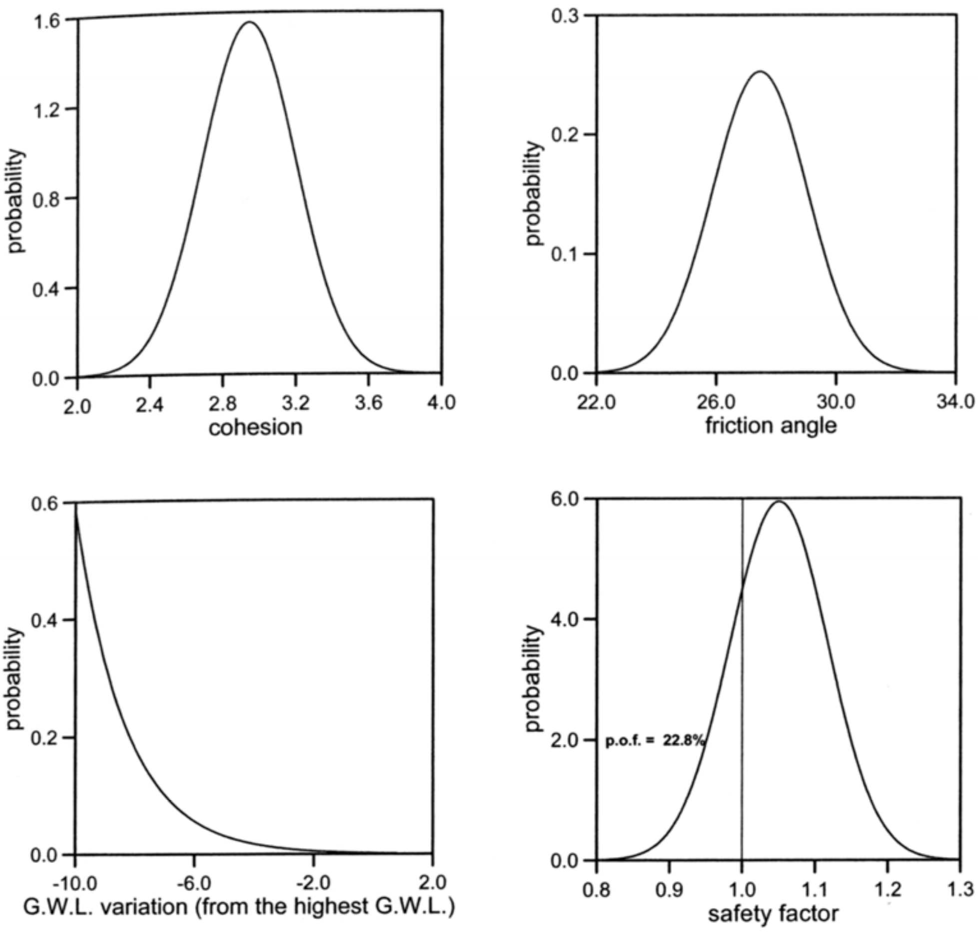

Figure 3. Risk analysis of Li-shan landslide (profile BB', before remediation).

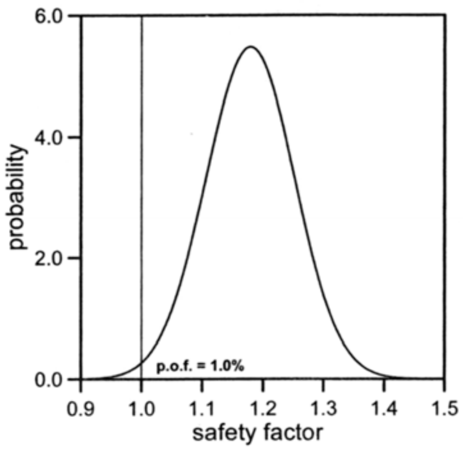

Figure 4. Risk of profile BB' after remediation (G.W.L. 20m lower).

6. Conclusion

Stability analyses were employed to study the behavior of the slope and the failure mechanism of the Li-shan landslide. The slopes are quite stable for dry condition, but become critical for fully saturated condition. The remediation treatment is essential as the precipitation in this area is quite high in this area.

The risk analysis shows that the risk of slopes is about 22.8 % with high groundwater condition. The risk reduces to 1.0 % if we count on the contribution of the remediation treatments. However, attention should be given to the potential problem caused by the high erosion rate of the nearby streams. For the risk assessment, it is essential to adopt a threshold value for the risk (an acceptable risk), in which social and economic impact must be considered.

Acknowledgements

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