Characteristics of Ground Motion on Colluviums Slope Induced by Heavy Rainfall

Caractéristiques du déplacement du sol sur la pente de colluvions induit par la pluie violente

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ABSTRACT: In this study, a slope covered with various depths of colluvium soil and set up with monitoring system has been studied. The results from hundreds of settlement and displacement observation marks were taken into account. It was found that the maximum settlement and displacement were concentrated around the buildings of Hui-tsui, Zhian and Wu-Ming, and coincided with rainfall records for the area. The direction and distribution of displacement and surface cracks supports previous findings of a sliding block. The slope stability analysis for this study was carried out with the STABL program. A drainage system with additional stability measures was proposed to prevent an unstable slope caused by the rising up of the ground water table during rainfall. Finally, a curve showing the relationship between rainfall and slope stability is established and presented.

RÉSUMÉ : Dans cette étude, une pente couverte de colluvions de différentes profondeurs et équipée d'un système de surveillance a été étudiée, ayant recours aux remarques tirées des observations sur les affaissements et les déplacements de la pente. Nous avons découvert que les plus grands affaissements et déplacements de pente, coïncidant avec les précipitations dans la région, avaient lieu autour des bâtiments Hui-tsui, Zhian et Wu-Ming. La direction et la répartition des déplacements de pente ont confirmés nos recherches précédentes sur un bloc coulissant. Cette recherche a été faite avec le programme STABL. Un système d'évacuation des eaux avec des mesures de stabilité a été proposé pour protéger une pente instable contre les eaux souterraines qui montaient lors des averses. À la fin de cette étude, une courbe a été présentée pour expliciter la relation entre les précipitations et la stabilité de pente.

KEYWORDS: colluviums slope, ground monitoring, settlement and displacement, slope stability analysis, threshold value of rainfall.

1 INTRODUCTION

Rainstorms frequently trigger colluvium landslides. For example, in November 1993, more than 800 landslides were triggered by rainstorms on Lantau Island, Hong Kong (Dai & Lee 2002). In Taiwan, colluvium slope disasters related to rainfall are very common (Jeng et al, 2007; Jeng and Lin, 2011; Pan et al, 2008). The threshold values of typhoon disasters were studied extensively by Wang and Yeh(2011) and Hu and Liao (2010). This paper focuses on the effects of heavy rainfall on the colluvium slopes in northeastern Taiwan. The results from 295 points of settlement and displacement monitoring marks and their significance to ground motion were evaluated. Finally, a threshold value curve for typhoon rainfall is proposed.

2 BASIC INFORMATION OF THE FIELD CASE

The field case discussed in this research is the campus of Huafan University in northeastern Taiwan. The University was constructed on the slope. For risk management and research on slope stability, a monitoring system was set up and data was collected for over ten years. The monitoring system includes the inclinometer, building tilt measurement, tiltmeters, crack gauges, water level observation wells, settlement and displacement monitoring marks, rebar strain gauges, concrete strain gauges and rain gauges. According to the records obtained from the rain gauges from 2003 to 2010, the average annual rainfall is about 4000mm, most of which is attributed to torrential rainfall concentrated in the period of typhoon season. The maximum monthly rainfall record is in October 2010 with 1208mm.

2.1 Geological Condition

The base stratum of the site consists of the Miocene Mushan Formation. On the ground surface is 10 to 20 meters of colluvium comprised of a bottom layer of sandstone (SS) and thin alternating layers of sandstone and shale (SS-SH). The attitude of the bedrock is strike in the east-west direction with the dip-anchor 10^{o} to 20^{o} toward south.

2.2 Ground Motion Monitoring Results

2.2.1. Settlement and Displacement Monitoring

Since 2001, hundreds of settlement and displacement monitoring marks were set up and recorded every six months. Some additional marks were gradually included over the years. Data was recorded until January 2011, and after ten years of monitoring, a total of 295 marks were collected. The accuracy of the investigation was controlled to within 1/5000 by the plane triangulatuin method with GPS (TRIMBLE 4800) for six fixed station points. Four traverse points were then laid within the survey area and double-checked for accuracy to be within 1/10000. The coordinates and elevation of each observation mark were then surveyed based on those traverse points. The displacement and settlement values were obtained by comparing the coordinates and elevation results of each survey to the initial results from the first survey. The data marks were then divided into two categories for buildings, and for roads and land.

2.2.2 Settlement and Displacement Distribution

Figure 1 shows the results of the settlement distribution. The settlement marks around buildings are shown in solid triangle and the settlement marks for roads and other land are shown in solid circles, while the heaving points are shown in hollow circles. The values of settlement or heaving are discriminated into five levels from 5 to 25mm and are represented by different size circles. As indicated in Fig. 1, the maximum annual settlement is more than 20mm, distributed around the Hui-tsui building(B1), Chih-an building(B2) and Wu-Ming building(B3). Although these values did not reach a dangerous level per the general management criteria, for some areas, the cumulated settlements reached over 10cm in the 10 years data. Moreover, when comparing the settlement distribution in Fig. 1 to the distribution of thickness of filled land, in the greater thickness of the filled land areas such as the Sport Ground(B4), the Basketball Court(B5) and Asoka Square(B6), the settlement is apparent. It is speculated that these higher settlement areas have something to do with the thicker fill. On the other hand, for the few heaving points like the upper slope of the Asoka Square, it is the result of the surface concrete pavement heaving caused by extrusion of the slope slide, not the ground surface condition.

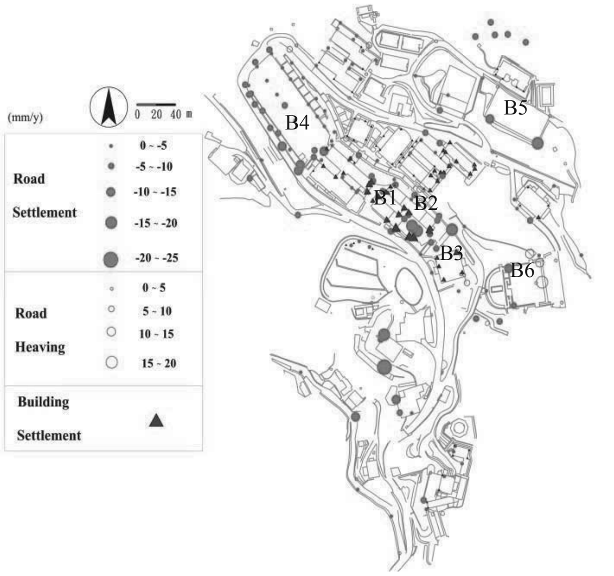

Fig. 1 The settlement distribution diagram

Figure 2 shows the displacement tracks of each observation mark on the plan map. The scale of displacement has been enlarged to 200 times to highlight its tendency. It is shown in Fig. 2 that the main displacement direction is downward to the slope in the southwest or south direction. Meanwhile, the larger displacement is distributed, same as the aforementioned settlement distribution, around the areas of Hui-tsui building, Chih-an building and Wu-ming building. However, the upper slope of the Asoka Square shows movement in the upward direction to the slope. This also can be attributed to the aforementioned heaving phenomenon caused by extrusion of the slope slide, such that an overturning condition occurred in that area. The cracks created in the crown can also confirm this situation. Additionally, the direction of movement for the Sport court is different from the upper slope Dormitory building. That is because they are departing into different sliding blocks.

2.3 Correlation WITH rainfall

According to the results of the aforementioned settlement and displacement distribution, the most critical areas are concentrated in the Hui-tsui building, Chih-an building and Wu-ming building. As expected, the most significant contributing factor is rainfall. The correlation between settlement, displacement and, rainfall for the Hui-tsui building is discussed below.

The tendency of displacement with respect to time shown in Fig. 3 is generally similar to that of settlement vs. time shown in Fig. 4. Based on the increment tendency, both can be separated into four distinct time segments: (1) May 2001 to March 2002, (2) September 2004 to June 2006, (3) June 2007 to April 2009; (4) April 2010 to January 2011.

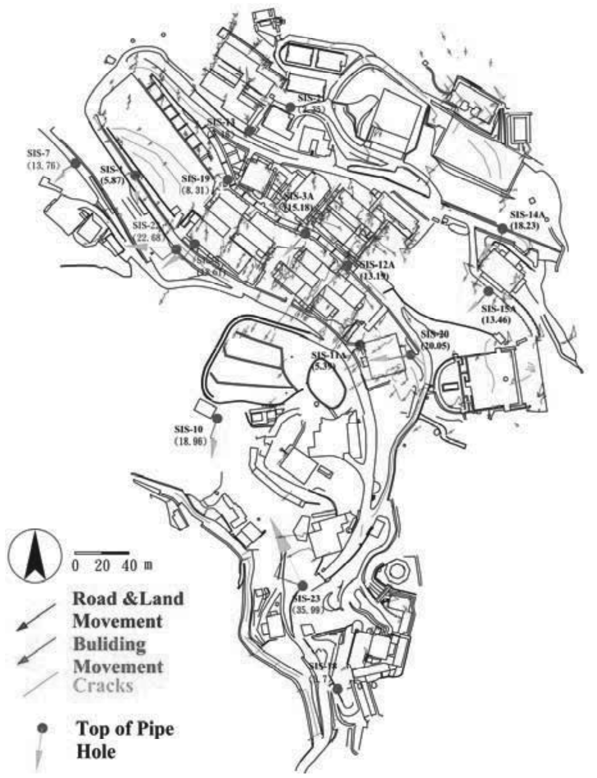

Fig. 2 displacement tracks and ground surface crakes distribution

When comparing the displacement and settlement time in Fig. 3 and Fig. 4 with the rainfall record, the displacement and settlement of the slope have a strong correlation with the rainfall record. In addition to the rainfall, another important influence factor to the displacement and settlement of the slope is the construction. For instance, within the third time segment, a new Library and Information Building were built with the excavation for the foundation at the toe of the slope. This may be the cause for the increased amount of displacement and settlement in the third time segment, despite the greater total accumulated rainfall in the second time segment (8973.5mm) versus the third (7241.5mm).

Aside from accumulated amounts, rainfall rate and duration also contribute to the threshold value that triggers displacement and settlement of the slope. Jeng and Sue (2008) illustrated that a rainfall threshold value of 800mm/month is able to trigger the displacement and settlement of the slope.

3 THE INCLINOMETER MONITORING

Many inclinometers have been installed starting the year 2000. Since then they have gradually settled in the test field, with some being damaged due to deformation. At present, 32 holes remain functional and are recording measurements. The results shows a sliding layer that deforms in depth from 14 to 15m. As seen from the core box the sliding occurs along the fracture layer.

4 COMPARISON THE RESULTS BETWEEN DISPLACEMENT MONITORING MARKS AND THE INCLINOMETER

The displacement monitoring marks are able to characterize the ground surface deformation and the inclinometer pipes can describe the ground deformation for the entire depth. To investigate the deformation of the slope, efforts were made by comparing the deformation of the top of the inclinometer pipes to the displacement monitoring marks. The comparison results shown in Fig. 2 indicated that the tendency of slope surface deformation obtained from both of these two data sets is generally consistent. The primary slope deformation is toward the southwest and south direction, similar to the slope surface direction, which means the slope soil is generally moving downward along the slope.

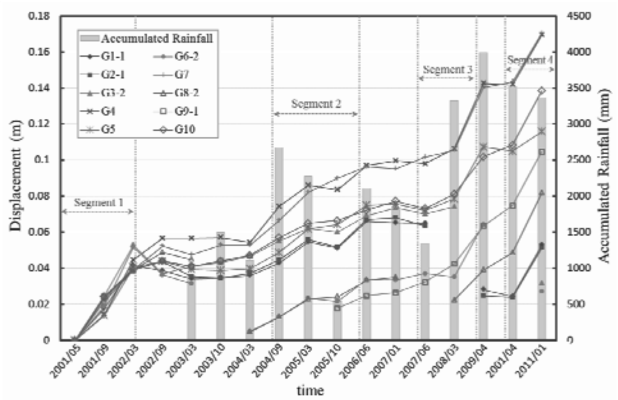

Fig. 3 Relation curves of displacement and rainfall for Hui-tsui building

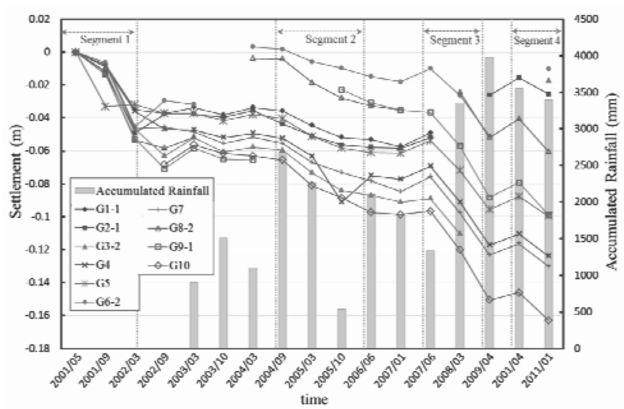

Fig. 4 Relation curves of settlement and rainfall for Hui-tsui building

5 SLOPE STABILITY ANALYSIS

After learning of the significant amount of slope deformation, there was concern for the integrity of the slope and any potentially hazardous contributing factors. To determine the slope stability, the limite equilibrium program - STABL was adopted and used for analysis. A simplified Bishop method with circular failure type was selected for the study. The input soil parameters were based on previous study (Jeng, 2003; Jeng and Li, 2009), as shown in Table 1. Areas with similar ground water variation and rainfall conditions were compared, and the crack distribution on the slope were used to assess potential failure areas.

Table 1 soils and rocks parameters

soils and rocks type	Cohesion (kPa)	Friction angle (°)	Unite weight (kN/m^3)
Colluviums	18.45	29.92	19.31
sandstone and shale alternation	41.52	32.24	25.52
Sandstone	41.85	34.60	23.86

Figure 5 shows the slope stability analysis results for normal conditions. The safety factor is 2.17, which higher than the suggested value 1.5, remains within a stable state. However for rainfall conditions, when the ground water rises 3m, the safety factor decreases to 0.86. An unstable condition can then happen. Thus, it is concluded that the slope stability is significantly influenced by the rise in ground water during rainfall events.

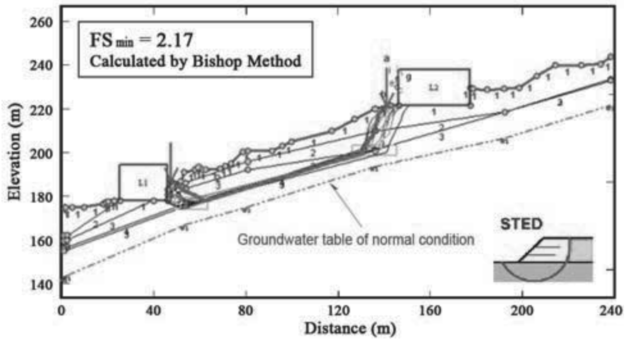

Fig. 5 Slope stability for normal condition (FS=2.17)

6 SLIDING BLOCKS DETERMINATION FROM SETTLEMENT AND DISPLACEMENT RESULTS

According to the inclinometer monitoring results provided by Jeng and Hsieh (2010), there are six sliding blocks within the slope. In that study, the sliding rate, depth and area of each block were presented. In addition to that information, this study evaluates the result of ground surface movement, including displacement direction and settlement, trend of ground water flow, and the distribution of ground surface cracks. A comprehensive evaluation was made to exam the previous sliding blocks study results. Fig.6 shows the finding which supports the presence of two sliding blocks. Among them, block No. A-1 is located in the area around Wu-Ming building, Asoca Square and the Chea-chau building; block No. A-2 is located in the area around Sport ground where there is 20m of fill. These two sliding blocks coincide with blocks R1 and L1 of the previous study (Jeng and Hsieh, 2010). Both blocks show movement in the shallow layer and are located in the active sliding areas. Numerous cracks can be found along the ground surface in these areas.

7 STABILIZE MEASURES AND THRESHOLD VALUE OF RAINFALL

According to aforementioned stability analysis results, it was learned that the rise of ground water in rainstorm conditions significantly impacts slope stability. Consequently, slope stability will be improved with the addition of drainage and drawdown systems and retaining structures. With budget and effectiveness in mind, the first step should focus on the area around the Wu-Ming building where the ground water and geological condition is least favorable. A detailed description of improvement steps includes：

1. Improvement of the ground surface drainage system for water runoff.
2. Installation of six catchpits with the horizontal drainage pipes, shown in Fig.7, to draw down the ground water level.
3. Filling of ground surface cracks to prevent seepage of water runoff into cracks.
4. Construction of bore piles and tiebacks with ground anchors behind the Wu-Ming building to strengthen the retaining structure for the toe of the slope.

Finally, for the safety management of the slope, threshold curves were established to illustrate the relationship between rainfall intensity and accumulation, and the observed slope deformation (Fig. 8). Looking ahead, these curves can be used for predicting slope stability before typhoons as it often brings significant amount of rainfal. The information correlating rainfall and slope stability improves slope management and risk assessment. To minimize the slop disaster from occurring, the proposed approaches are believed to be beneficial to the community.

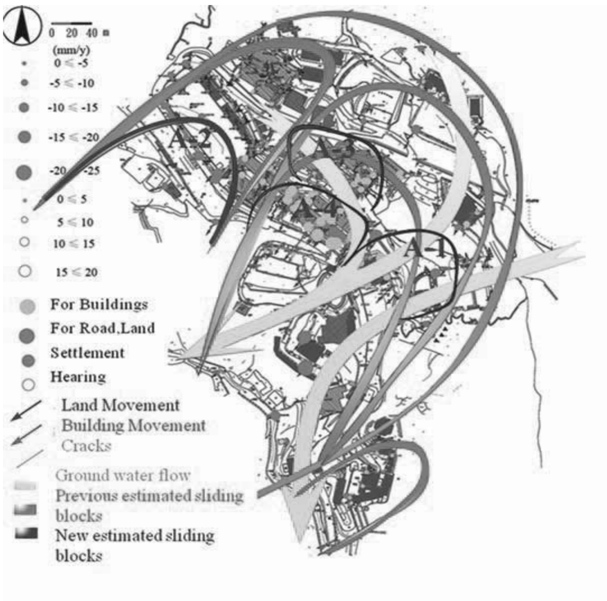

Fig. 6 Sliding blocks and movement distribution plane

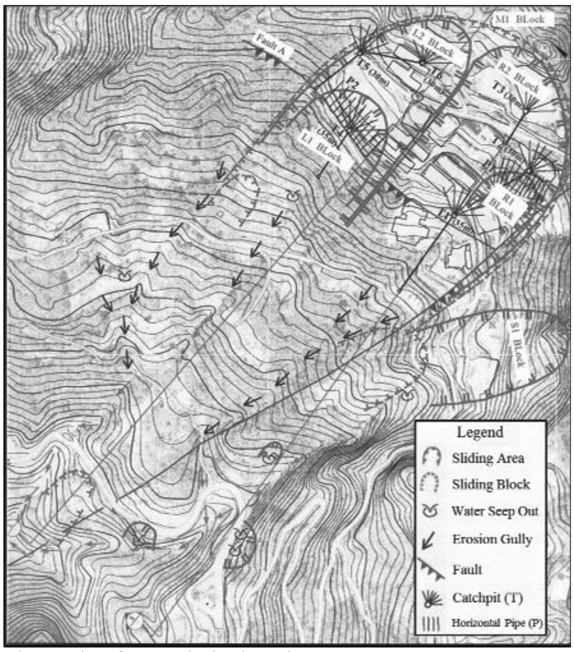

Fig. 7 Plan for catchpits location

8 CONCLUSIONS AND DISSCUSSION

This paper discusses the displacement and settlement of the slope, evaluates the sliding block theory, and analyzes slope stability. After summarizing the results, stabilization measures

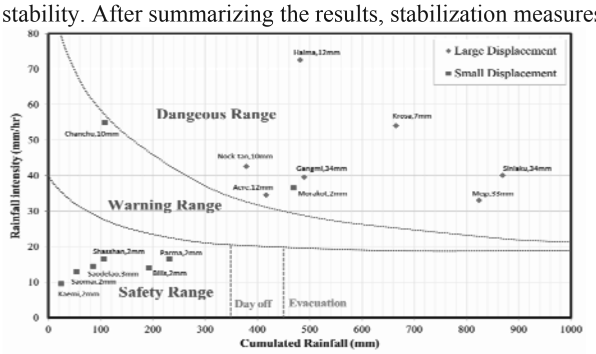

Fig. 8 Threshold value curves correlate with displacement

and rainfall threshold values were established. Based on the results, the following conclusions can be made:

1. The areas with the most significant settlement and displacement are located around the buildings of Hui-tsui, Zhian and Wu-Ming Building. Due to lack of slope stability, surface cracks appeared and several sliding surfaces have been observed.
2. The deformation of the top of the inclinometer pipes is consistent with the displacement monitoring marks. Findings indicate the primary slope deformation to be toward the southwest and south direction. In addition, rainfall was found to be the most significant factor for slope deformation and slope stability.
3. The results of the slope stability analysis show that an increase in ground water level is the most critical factor for slope stability.
4. The distribution of potential sliding blocks was examined by using slope displacement and settlement data, and the location of surface cracks. The sliding direction is strongly correlated to the direction of ground water flow. Depth or thickness of fill also contributes to slope sliding.
5. Several stabilization measures including catchpits with horizontal drainage pipes, bore piles and tieback ground anchors, and threshold value of rainfall are recommended to improve the slope stability. It was believed that the information presented is very important for slope disaster prevention.

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