Investigation of Creeping Slope Movements of a Suspected Colluvium Deposit

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ABSTRACT: This paper describes a case study with an initial failure incident of a pile supported retaining wall of a development whereby the investigation reveals the presence of colluvial deposits at the hill along a river valley floor. The approach of the investigation starting from desktop study, site reconnaissance, borehole exploration, laboratory and field testing, field instrumentation is presented to show the importance and proper investigative procedures of these interlinks of evidence. Clear evidence from visual observation on the presence of matrix of round cobbles, pebbles and unsorted angular gravels confirms high possibility of colluvium from deposition of earlier river alluvium with continuous cutting by a river system. One of the important aspects of the observed slope creeping movement relates to the perched hydrogeological regime of the region, which was likely be evidenced as a triggering factor of the on-going creep movement of the inherent marginally unstable colluvial deposits. The inclinometer profiles also show the extent of unstable colluvial mass over the identified slip surface.

KEYWORDS: Creeping movements, Colluvium, Hydrogeological regime, Inclinometers

1. INTRODUCTION

This paper describes a case study on a moving slope with an initial failure incident of a pile supported retaining wall of a development. Slope movement and cracks on retaining wall were found after an incident of heavy rain in July 2010. The retaining wall cracked and translated towards the development site on December 2010. Intensive remedial works such as additional retaining wall and removal of unstable slope behind the retaining wall have been carried out. Creeping was observed on the reprofiled distressed slope 2 months after completion of remedial works. As a result, an independent investigation was requested by the contractor to investigate the observed continuous slope creeping.

2. DESKTOP STUDY

2.1 Topography

The development was on a hilly site fronting a river valley at the south as shown in Figure 1. The highest ground within the site boundary with elevation of about RL 431m located at the northern site boundary while the lowest ground with elevation of about RL 384m located at the southern site boundary. The elevation difference across of the project site is about 47m.

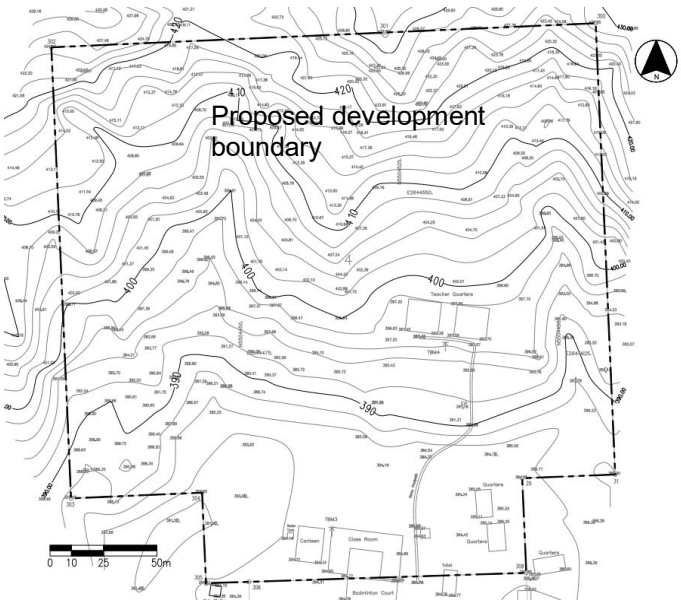

Figure 1 Topography survey layout plan

2.2 Hydrology and Site Natural Drainage

The rainfall data relevant to the development area was obtained from Department of Irrigation and Drainage and was reproduced in a daily rainfall format as shown in Figure 2. The highest rainfall data recorded is 43mm in August 2010.

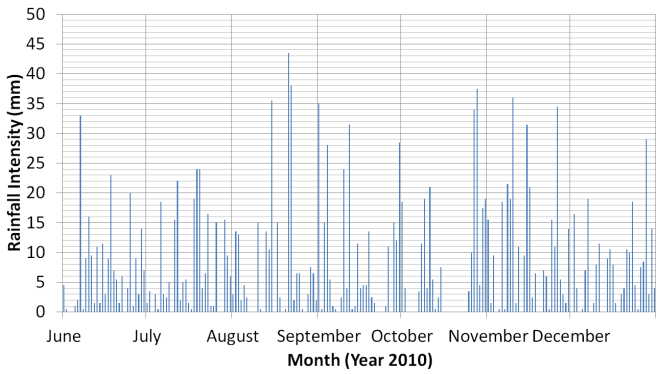

Figure 2 Daily rainfall data from June to December 2010

Three streams running southward are found located within the compound of the development site before the commencement of the project. These streams then join the main river at southern side of the development as shown in Figure 3.

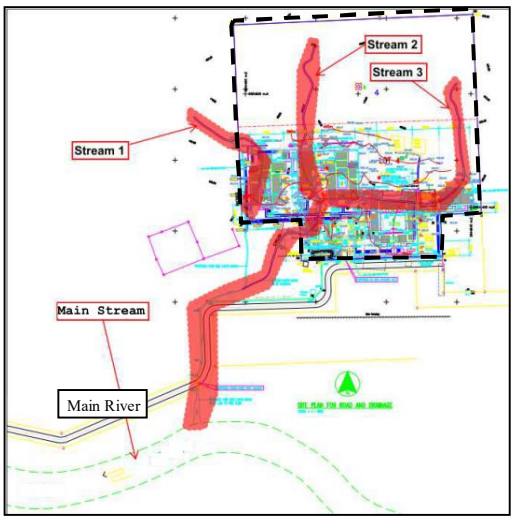

Figure 3: Location of stream and river

2.3 Site Conditions

The development is situated at foot hill of a mountain range which is sloping southward into a river valley. The site has been cut and fill to form building platforms as the site was developed at the downhill edge of mountain range.

3. SITE RECONNAISSANCE

3.1 Site Inspections

Site inspection was carried out on March 2014 to collect more evidences related to the investigation work and to identify the probable causes of the slope distress based on the site conditions at the time of inspections.

3.2 Site Observations

Observations during the site visit were summarised below:-

1. Global slope movement towards south (towards the river) was observed as evidenced from the tension cracks on slope with crack width of about 150mm as shown in Figure 4.

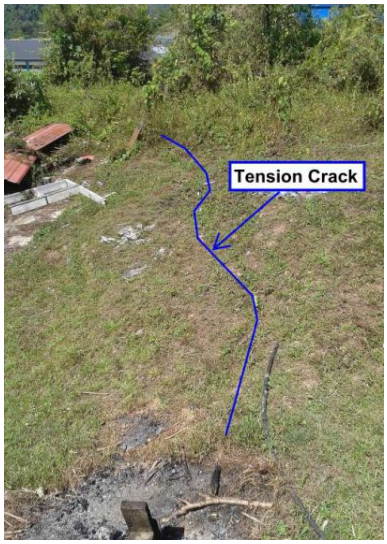

Figure 4 Observed tension crack on slope

2. Some existing trees on the adjacent slopes were observed with bottom stems tilted at early stage of the growth whereas the upper stems grew vertically. This implies that some slope creeping movements may have occurred some time ago during the earlier stage of the tree growth, thereafter the slope movement may have been stabilised and allowed the trees to develop vertical growth. Condition of the tilted trees was as shown in Figure 5.

Figure 5 Existing tree condition

3. Water springing out / ponding on the distressed slope was observed at eastern side of the distressed slope as shown in Figure 6.

Figure 6 Existing water ponding and wet patches on site

4. Heaved reinforced concrete slab of the existing building in front of the retaining wall was observed. The ground floor slab has heaved up of about 150mm, which is likely due to the creeping slope movement extending beyond the wall toe as shown in Figure 7.

Figure 7 Heaving ground slab near distressed wall and creeping slope movement beyond the wall.

5. There is no outcrop of parent bedrock observed within the site. Some boulders mixed with small cobbles were observed as shown in Figure 8. The mixtures of the unsorted round and angular shape rocks or cobbles implied the possibility of alluvial deposits. This is not uncommon at the foot hill of mountain range and valley flood with thickly deposition of transported material at higher elevation by river flow before further hydraulic cutting of river to deeper invert level. The rock fragments with angular shape suggest possibility of colluvial deposits which intermix with the alluvial deposits mentioned earlier.

Figure 8 Observed boulders mixed with small rounded cobbles.

6. The site is located at reduced level of about RL384m. Northward direction of the site is uphill slopes while Southward direction of site is generally a flat ground toward river with plenty of round boulders (Figure 9). It is believed that the southern relatively flat area is deposited with the river deposits carried down from far up stream of the river where various sizes of round boulders and pebbles along the river course were observed.

Figure 9 Existing river condition

7. It was informed by the contractor that the distressed retaining wall was founded on wooden piles with installed pile length from 1 to 3 lengths (1 length = 6m approximately). In addition, it is also worth to note that the piles were installed with large deviations and many round shaped rocks or cobbles were encountered during the piling work. In addition, the rise of river water can be high during the raining season.

4. SUBSURFACE INVESTIGATION

4.1 Boreholes Exploration

There were two (2) stages of subsurface investigation (SI) carried out at this development. Preliminary SI was carried out in 2008 for design planning of the proposed development. Whilst second additional SI with slope movement monitoring were planned and implemented in May 2014 for obtaining crucial subsurface information to facilitate investigation of the failure mechanism.

Figure 10 shows the layout for the additional SI which consists of four (4) additional boreholes, four (4) inclinometers and four (4) groundwater standpipes with cross-sections for illustration of subsoil profiles. The interpreted subsoil profiles are illustrated in Figures 11 to 13.

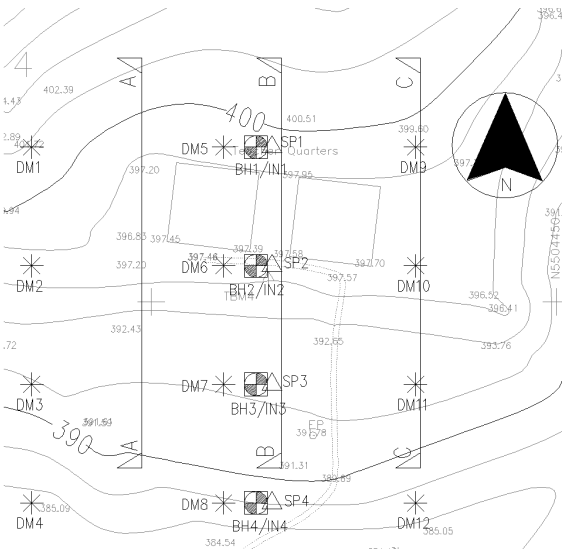

Figure 10 Subsurface Investigation Layout Plan

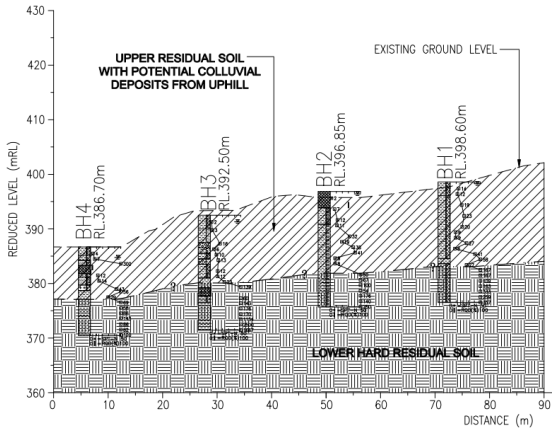

Figure 11 Interpreted Subsoil Profile (Section A-A)

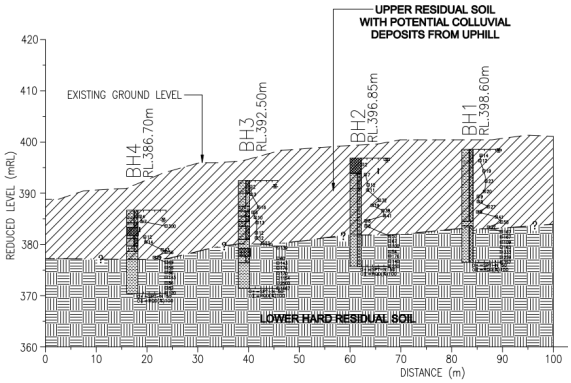

Figure 12 Interpreted Subsoil Profile (Section B-B)

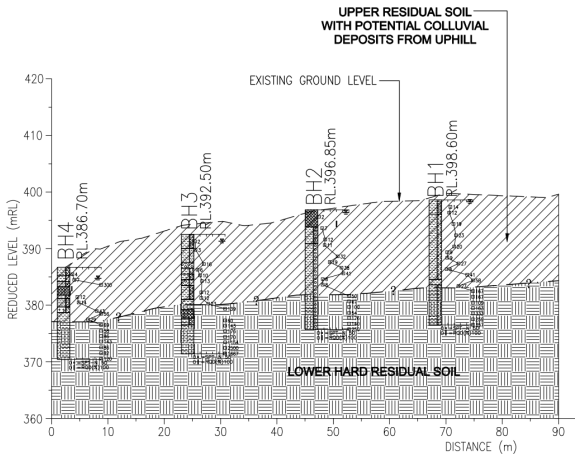

Figure 13 Interpreted Subsoil Profile (Section C-C)

Generally, the subsoil stratum of the site consists of a layer of 9m to 15m thick clayey colluvial / alluvial deposits with some boulders, gravels and small stones overlying the hard residual soil.

4.2 Groundwater Monitoring

Groundwater level of the slope was monitoring from four standpipes in the second stage SI works. The groundwater levels recorded from standpipes namely SP1, SP2, SP3 and SP4 ranged from 1.5m to 2.5m below ground level excepted for SP3, where the groundwater level was consistently at 0.3m above ground level as shown in Figure 14. This phenomenon is consistent with observed perched water at area of the wet patches and water ponding spot near to SP3.

4.3 Inclinometer Monitoring Work

Figures 15 to 18 present the inclinometer monitoring results from the inclinometers, namely IN1, IN2 IN3 and IN4 from mid July

2014 until end September 2014. There were some discrepancies of the inclinometer installation by the SI contractor, where the principal and secondary groove directions could have been misaligned due to forced rotation in inserting the inclinometer tubes. However, the significant slope creeping movements still permit the direction of the slip surface of the unstable slope mass. The maximum lateral displacement for slope movements were about 21mm to 28mm with average displacement rate of 2.4mm per week during the monitoring period.

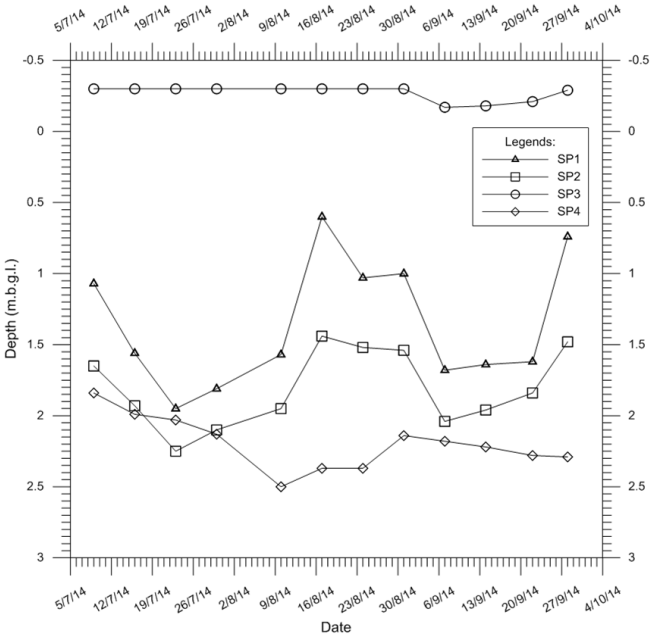

Figure 14 Groundwater Monitoring

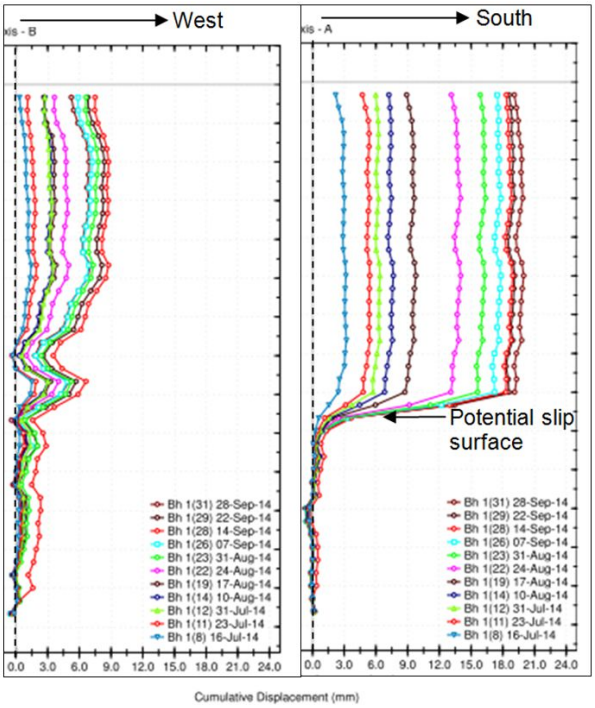

Figure 15 Inclinometer (IN1) Monitoring Results

5. RETAINING WALL AND SLOPE STABILITY ASSESSMENT

5.1 Retaining Wall Assessment

Assessment of the distressed retaining wall using external wall stability with Rankine earth pressure theory was carried out based on three groundwater conditions, namely full water level (Condition A), water level at one-third of wall retained height (Condition B) and no water (Condition C) for sensitivity check. The global slope stability was based on limits equilibrium analysis (LEA) with critical slip circles. Summary for retaining wall stability assessment is tabulated in Table 1.

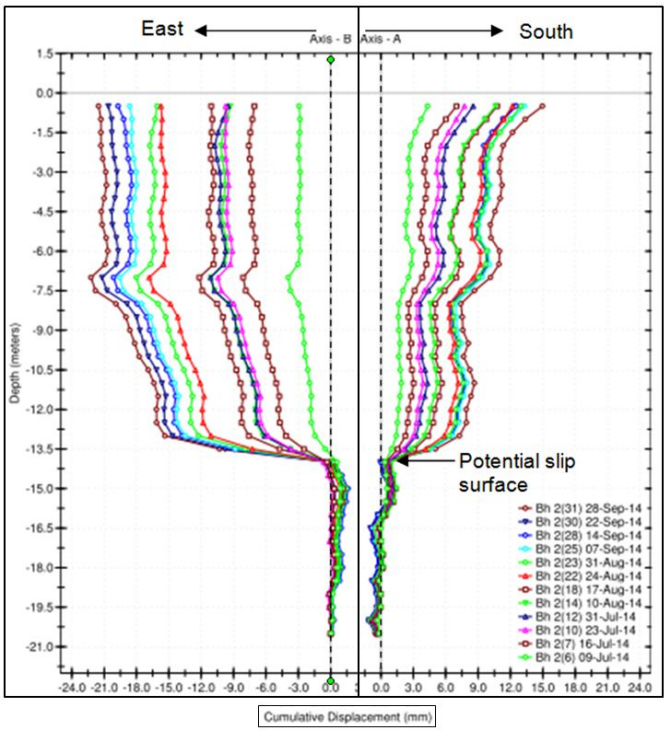

Figure 16 Inclinometer (IN2) Monitoring Results

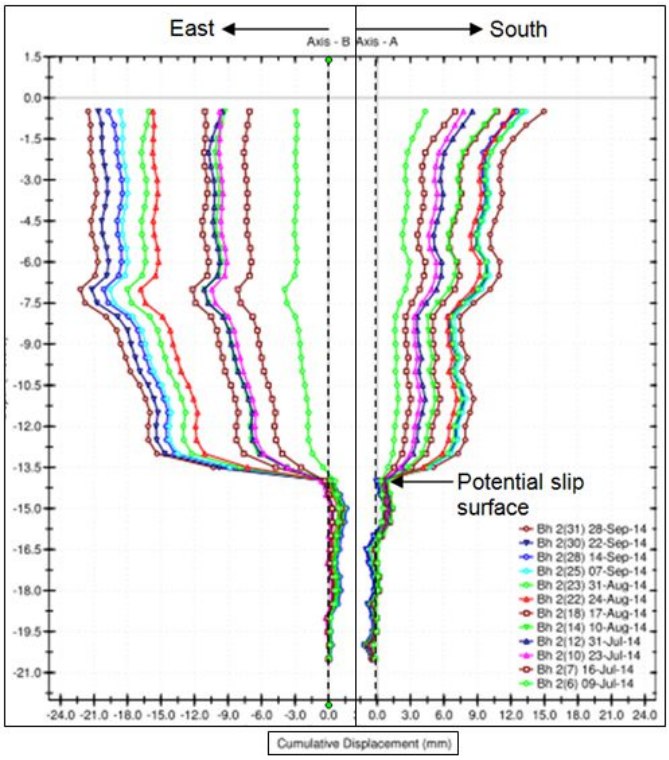

Figure 17 Inclinometer (IN3) Monitoring Results

From the independent assessment, the factor of safety (FOS) for sliding check is insufficient for all conditions (FOS<1). It shall be noted that FOS for sliding check of the retaining wall is all less than 1 as the lateral resistance of retaining wall against sliding failure is solely relied on the lateral pile resistance. It is believed that the construction of retaining wall will have some wall base contact with

the ground, thus providing balance of the short fall in resistance to maintain the marginal lateral stability. However, with a slight increase in lateral disturbing force, the wall becomes unstable. At condition with full water, global stability and overturning check are marginal with FOS 1.08 and 1.1 respectively. With all three modes of failure on marginal factor of safety, the wall distresses were reasonably expected.

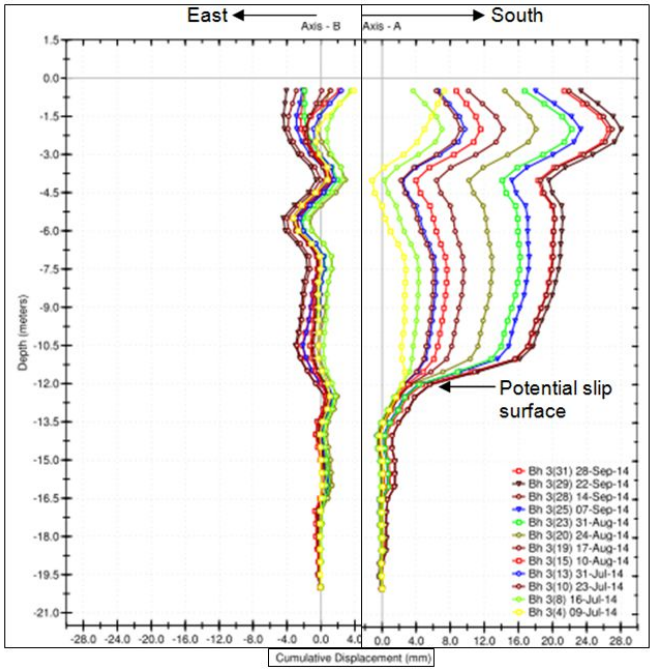

Figure 18 Inclinometer (IN4) Monitoring Results

Table 1 Summary of Global Stability and External Stabilities of Distressed Retaining Wall

Conditions	FOS* for Global Stability	Overturning Check (FOS*)	Sliding Check (FOS)	Bearing Check (FOS)
Condition A	1.08	1.1	0.36	2.59
Condition B	1.36	1.7	0.45	3.07
Condition C	1.40	1.9	0.48	3.20

*FOS denoted as Factor of Safety.

5.2 Slope Stability Analysis

The stability of the slope was assessed using limit equilibrium analysis (LEA) software with potential failure mechanisms of slice methods which is commonly used by Civil Engineer for slope stability design. LEA using Slope/W software (2012) was used to check for the slope stability with consideration of critical slip surface.

Table 2 shows the summary of LEA checks where it is observed that the FOS of the LEA checks for all three cross sections with the interpreted groundwater profile range from 0.95 to 1.12.

Table 2 Summary of FOS for LEA on Global Slope Stability

Cross Section	Factor of Safety (FOS)
A – A	0.95
B - B	1.10
C - C	1.12

6. INVESTIGATION OUTCOME

6.1 Probable Cause of Failure

Based on the topography information, the site is located near to thick river valley floor within the hilly terrain ground from RL384m to RL431m.

Few streams or creeks are observed from upper hill flowing southward to the river. From the ground surface observation, some boulders, round-shaped stone, angular shaped rocks and varying sized cobbles can be found in the creeping slope mass. During the additional subsurface investigation, some boulders were encountered during borehole drilling and small cobbles were encountered during soil sampling in the boreholes.

Figure 19 shows the multiple cobbles stuck in the casing of undisturbed sampling tube during Subsurface Investigation (SI).

Figure 19 Cobbles Encountered During SI

The slope creeping movement has been further confirmed by monitoring results with average slope movement of 2.4mm per week toward southern direction principally over the monitoring period of 3 months and the slope movement will likely continue after monitoring period. Therefore, the slope can be considered as active creeping soil slope.

The slope material can be classified as colluvial deposit of an original alluvial deposits by the early stage of river development after studying the site topography condition, verification by site inspection and slope movement monitoring.

The term “colluvium” is frequently applied broadly to include mass wasting deposits in a variety of topographic and climatic settings. Blikra and Nemec (1998) described colluvium as any “clastic slope waste material, typically coarse grained and immature, deposited in the lower part and foot zone of a mountain slope or other topographic escarpment, and brought there chiefly by sediment gravity processes”. Therefore, colluvium can be described as non-homogenous mixture of soil cobbles and boulders that are formed by agents of gravitational forces and mostly along or towards the base of long slopes of moderate to steep grades.

Therefore, it is expected that the affected building and retaining wall are founded on colluvial deposits with active creep movement and potential perched groundwater regime as triggering factor to the intermittent creep movements. The constructed retaining wall was found cracked and finally moved towards building direction until contacting with the columns of building. The existing floor slab was observed heaving at area in front of retaining wall. This condition is mainly caused by the active soil creeping of retained slope and the instability of colluvial slope intermittently triggered by high perched groundwater level.

While examining the daily rainfall before the reported wall distress, it is not convinced that there was any single extreme rainfall event concluding the possibility of rainfall as a triggering factor of the wall distressing. As such, the rainfall incident before the wall distress, at best, can be taken as contributing factor for gradual deterioration of slope stability to a marginal stability condition with indication of slope creeping movement until a point where a slight disturbance of groundwater fluctuation from unremarkable rainfall event is sufficient to trigger the wall cracking in brittle manner.

The independent retaining wall stability assessment confirms the marginal FOS for overturning, insufficient sliding stability and critical in overall stability of the retained slope when groundwater rises near to full water level condition. From the groundwater monitoring results, full water level was recorded at upper slope behind retaining wall. Therefore, high water level can then be logically expected and thus triggering the instability of retaining wall and finally moving toward building direction.

Based on the slope stability analysis results (after demolition of retaining wall) with the interpreted soil strength, groundwater regime and re-profiled slope surface, the computed factor of safety (FOS) ranges from 1.0 to 1.1 which is marginally high risk of instability and also indicates the high possibility of soil creeping potential. Therefore, the slope is considered as unsafe slope for this development with high risk to life loss and economy damage.

Liew & Gue (2001) had presented a case study of massive creep movement of a post-glacial deposits with high groundwater level at the foothill of Mountain Kinabalu, Kundasang area of Sabah state, East Malaysia. The conditions of the creeping post-glacial deposits is similar to the colluvial deposits in this case study. Similarly, the high groundwater regime provides the additional driving force to the creep movement in addition to the gravitational force.

In both case, very distinct slip surface is detected to depict the relatively upper rigid slope mass movements over the slip surface. There is no significant lateral creep straining over the upper unstable slope mass. Nevertheless, the slide movements in these marginally stable transported collapsed debris behave likes creeping rather than sudden intermittent large movement in brittle manner.

Similarly, high perched water regime seems to be the common feature in this type of collapsed and transported deposits from the mountainous terrain.

Hence, it is suggested to allow instrumentation scheme to monitor the potential of slope creeping movement during the investigation stage for hillside development when the slope materials are identified with the nature of collapsed types of deposits. Given a practical monitoring period of two to three months, creep movements shall be detectable for the decision on the site suitability assessment if the risk of continuous creep movement exists.

7. REMEDIAL MEASURES

Based on the geotechnical investigation findings, the insufficient safety factor of slope stability and creep movement is a result of high perched groundwater table triggering the meta-stable colluvial deposits. Therefore, the slope is identified unsafe for development within affected area under high groundwater condition. Based on the investigation, slope with high water table is the primary triggering factor of the instability with ongoing active creeping slope movements. Dewatering scheme (lowering down the groundwater table) was then proposed as a mean to enhance the slope stability. To achieve long term stability condition, minimum FOS of 1.4 is required.

Preliminary conceptual remedial proposal consists of a series of 4m diameter deep wells with series of horizontal radial subsoil drains install into the unstable slope mass. The groundwater will then be collected by these horizontal radial subsoil drains surrounding the deep well and finally discharged out by either pumping or gravitational flow to the surface drainage at the downhill slope.

Typical details of the dewatering well are as shown in Figure 20.

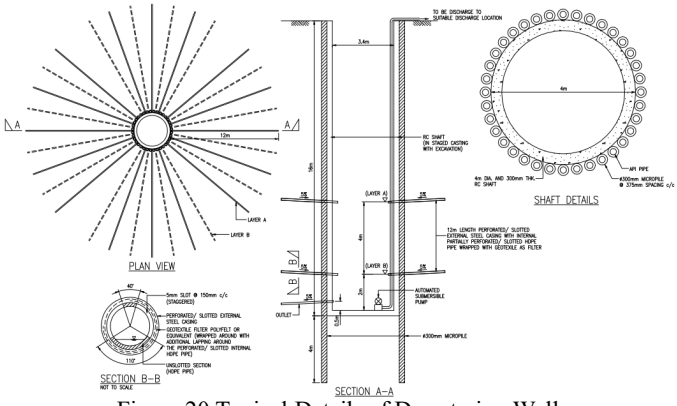

Figure 20 Typical Details of Dewatering Well

8. CONCLUSIONS AND RECOMMENDATIONS

After reviewing the provided information, site conditions and the stability assessment of retaining wall and slope, the followings are the conclusions and recommendations:

1.) The overburden subsoil of the distressed slope is evidenced with distinct slip surface identified by inclinometer for the colluvial deposit with active soil creeping movement.

2.) The cause of retaining wall failure is primarily caused by the insufficient wall sliding resistance provided by the vertical wall foundation piles and overall instability triggered by high water level in the creeping colluvial deposits. The likelihood of subsequent building construction activities in front of the constructed retaining wall contributing to the distressing of the retaining wall and slope creeping would be remote.

3.) The slope instability is likely triggered by high groundwater level at development site. Hence, dewatering scheme with 4m diameter deep wells with radial subsoil drains was proposed to lower down the groundwater table to achieve long term stability.

4.) Colluvial deposits being a collapsed and transported debris from previous landslides seem to be destabilised with high perched groundwater regime and maintain its meta-stable condition with respect to groundwater condition. Controlling the rise of groundwater table will be an effective means for improved stability.

5.) Despite the sliding movements is primarily of a rigid unstable slope mass over the distinct slip surface, the meta-stable condition of such colluvial deposits behave in a creeping movement rather than sudden sliding movement. Hence, the use of inclinometer with sufficient monitoring duration shall yield evidence of creep movement if it exist. Thus, decision can be made on the site suitability assessment during the investigation stage.

9. REFERENCES

Blikra, L.H. & Nemec W. (1998). “Postglacial colluvium in western Norway: Depositional processes, facies and paleoclimatic record”. Sedimentology, 45, pp909-959

Liew, S.S. & Gue,S.S. (2001). “Massive Creep Movements of Post-Glacial Deposits in Kundasang Areas.” GSM-IZM Forum: Engineering Geology and Geotechnics of Slopes, Kuala Lumpur.

Slope/W Manual (2012). Calgary, Alberta: GEO-SLOPE International Ltd.