Proceeding *20th SEAGC - 3rd AGSSEA Conference in conjunction with 22nd Annual Indonesian National Conference on Geotechnical Engineering.* Jakarta - INDONESIA, 6 -7 November 2018. ISBN No. 978-602-17221-6-9

Case Study of a Partially Collapsed RS Wall at a Building Site

EG Balakrishnan[1], Allan Y. L. Chwee[2] and A. Mohd Redzuan[3]

[1] Managing Director, GCU Consultants Sdn Bhd, Malaysia

[2] Assistant Engineering Manager, GCU Consultants Sdn Bhd, Malaysia

[3] Director, GCU Consultants Sdn Bhd, Malaysia

E-mail: bala@gcu.com.my

ABSTRACT: It has been a common practice in Malaysia to adopt reinforced soil walls as one of the common wall types particularly at housing earthworks platforming. This paper will discuss one case study of the failed reinforced soil walls used in the housing project. The paper will discuss on the background on the construction of the site development works leading to the construction of the RS wall on a deep fill ground. The paper will highlight on the wall failure and the postulations on the likely reasons for the failure. The subsoil and groundwater details from extensive ground investigation together with the short term and long term remedial solutions to strengthened the fill slopes and wall will be discussed. The paper will also present all the instrument monitoring results validating the remedial works performance. Lessons learned from these experiences will be highlighted and discussed in detail.

Keywords: Failed reinforced soil wall, remedial works with soil nail, case study.

1. INTRODUCTION

The project site where the wall collapsed is located about 15km from Kuala Lumpur City within a refutable suburb housing project. Existing bungalow houses are located on the south side of the site with a road dividing the collapsed wall and the houses. The north side is predominantly undeveloped and comprise of flat ground after the slopes reserved for future development of Muslim cemetery and school. The forest reserve is located on the eastern side. A stream is located at the toe of the slope flowing from the forest reserve to the west.

Based on the topographic map obtained from the relevant authority of Malaysia, the site was located at the eastern boundary of an estate on a north trending valley along the eastern slope of a ridge. The map also indicates a stream together several ephemeral streams originally passed through the site. Three streams or rivulets coming from the north and east directions converged into a bigger stream north of the site. As the three streams shown in the map initiated just outside or within the development site, this may not contribute to any underground seepage. The stream from the north side originating within forest serve may contribute to the underground seepage as this stream was not diverted during the site development stage in year 2000 to 2001.

During the site development (earthworks), the western and south-eastern parts of the site were being cut whilst the north part being filled with the cut materials which comprise of earth and rock fragments. Between 2001 and 2004, the southeastern hill was further cut and the north valley was filled to form the building platform level. The fill slopes were formed with slope drainage and vegetation based on the satellite imagery. In year 2005, a 120 m long RS wall with heights varying from 4m to 10m was constructed on the northern most slope to create space for the construction of the access road at RL 63.20 m to the residential units.

Part of the wall about 11m stretch collapsed on 20 May 2011. The collapsed wall is 9m high with exposed wall height of 25 m. The top 6 m of the RS wall with 4 panels vertical and 7 panels horizontal collapsed. The location and photograph of the collapsed wall is shown in Figure 1 and Figure 2.

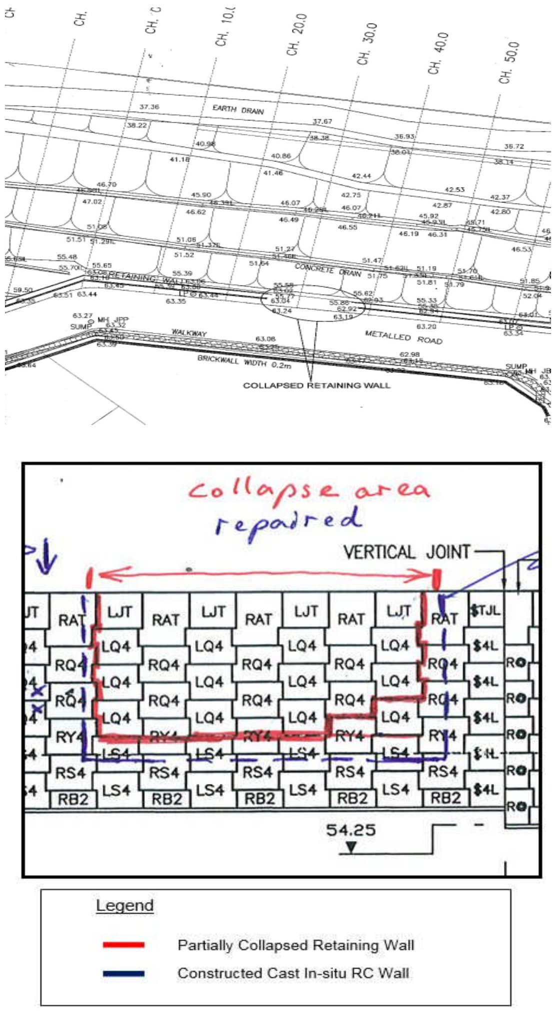


Figure 1 Location of collapse wall

Figure 2 Partial collapsed of reinforced soil wall on 20th May 2011

The collapsed wall is founded on a fill ground of maximum 19 m high with 4 fill slopes below the wall. Based on the survey drawings and detail site inspection, variations in the slope height and gradients were observed. The slope height was not consistent with heights varying from 3.5 m to 7 m. The slope gradient also was inconsistent with varying values of 1(V):1.2(H) to 1(V): 2(H). The slope berms also vary from 1 m to 2 m. The slopes were generally covered with vegetation with shrubs and small tress have grown on the slopes. The fill slopes have shown signs of erosion over the years with some locations only resulting in three (3) slopes with the bottom slope has been eroded badly. Water seepage was observed coming out from behind the wall after collapse and continuous flow at the toe of the thick embankment fill as shown in Figure 3. The topography and drainage pattern of the study area are shown in Figure 4.

Figure 3 Copious flow of water seeping out from the toe of embankment

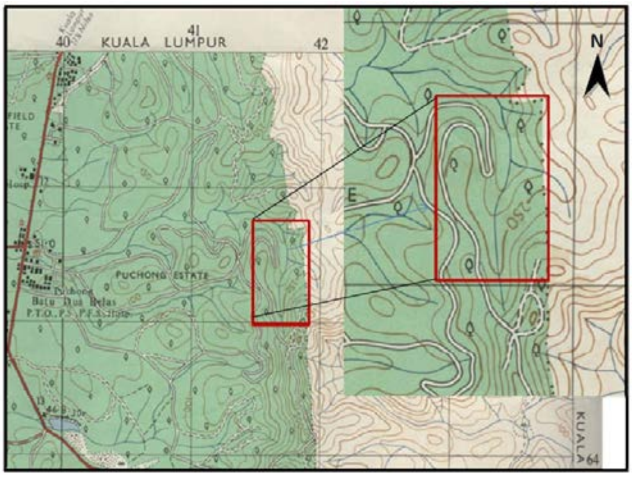


Figure 4 Original topography and drainage pattern of the site

This paper will address the subsoil conditions together with the ground water conditions, the topographical changes over the period at this site, subsoil design parameters interpreted from the laboratory tests, likely reasons for the wall collapse, the short term & long term remedial works carried out, the geotechnical instrumentation monitored during and after the works and finally outline the lessons learned from this case study on the failure of a RS wall.

2. SUBSOIL CONDITIONS AND PROPERTIES

Based on published Geological Map of Kuala Lumpur, the site is underlain by Kenny Hill Formation of Permian Carboniferous age. Kenny Hill formation consists of monotonous sequence of interbedded sedimentary rocks such as sandstone, siltstone, shale and mudstone. The damp tropical climate with average annual rainfall of more than 2500 mm has resulted in extensive chemical weathering of these rocks to produce weathered profile above the rocks. Variations in the weathering profile are mainly due to differences in the parent material and site morphology.

Ground investigation comprising of boreholes (7 Nos), trial pits, seismic refraction and electrical resistivity survey were carried out under different agencies involved in this project. Standpipe piezometers installed in all boreholes to monitor the groundwater levels over a period. Appropriate laboratory tests were carried out on disturbed, undisturbed and trial pit samples.

Based on the soil investigation and laboratory testing results, the subsoil profile is identified to be 3 distinct layers. The first layer consist of fill material with thickness varies between 1m and 25m. This layer consists of a mixture of soft to stiff sandy SILT and loose to dense silty SAND with high content of granular materials. The next layer consists of residual soil of medium stiff to hard sandy SILT with SPT-N value less than 50 blows. The thickness varies from 4 m to 12 m. The final layer consists of hard layer with SPT-N more than 50 blows and generally made up of hard sandy SILT. The SPT-N versus depth plot is shown in Figure 5. The properties of these layers are summarized in Table 1.

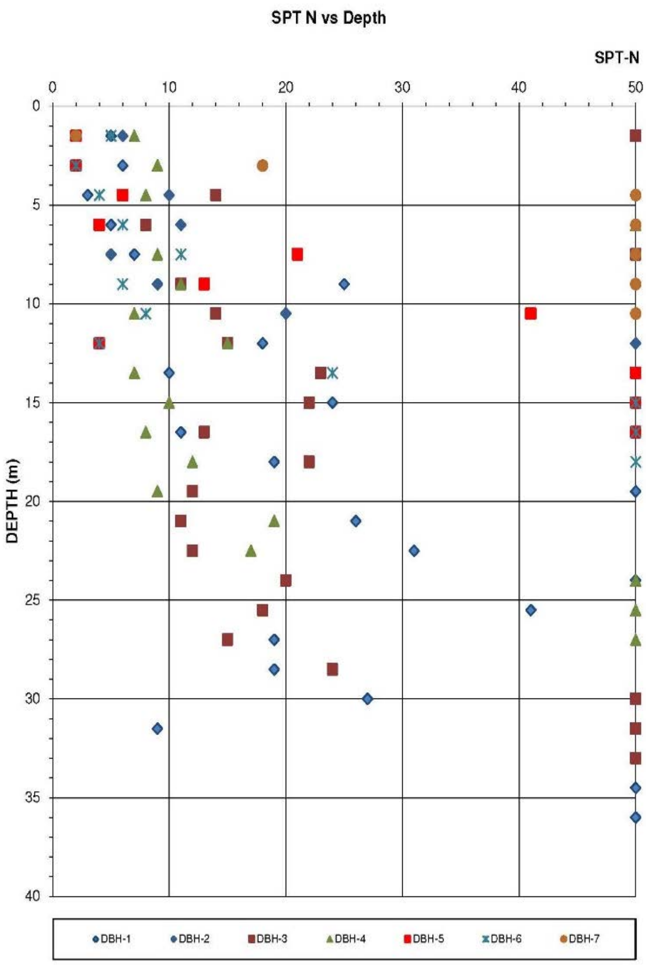


Figure 5 SPT-N versus Depth plot

Table 1 Typical Properties of Subsoil Layers

Layer	Description	SPT – N Blows	Thickness (m)	Moisture Content (%)	Bulk Density (kN/m^3)	Atterberg Limits (%)			Grain Size (%)	
						LL	PL	PI	Coarse	Fine
1	Fill	2 – 31 (varies)	1 - 25	10 - 25	19.7 – 20.8	20 - 40	15 - 25	5 – 15	45 - 90	10 - 55
2	Residual Soil	< 50	4 - 12	10 - 35	15.8 – 21.5	25 - 50	15 - 35	10 - 15	20 - 75	25 - 80
3	Weathered Soil	> 50	> 10	15 - 25	-	20 - 40	15 - 20	10 - 25	50 - 80	30 - 50

The typical t-s plots for the fill material and the residual weathered formation to obtain the effective strength parameters are shown in Figure 6a and 6b.

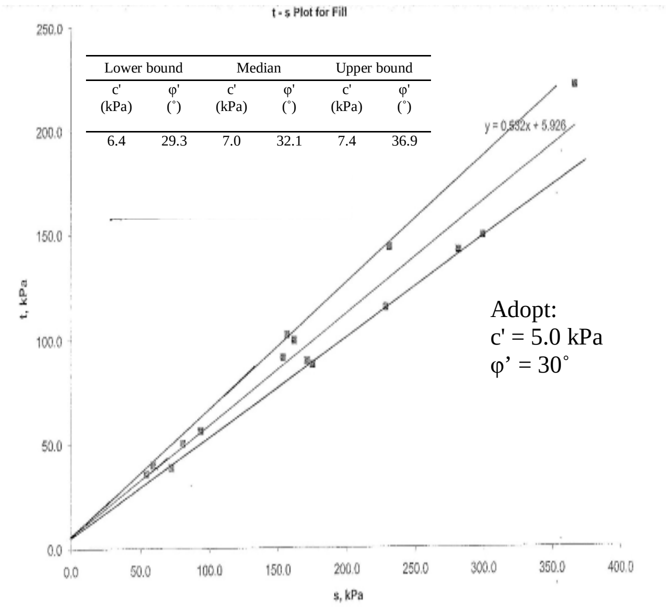


Figure 6a t-s Plot for fill

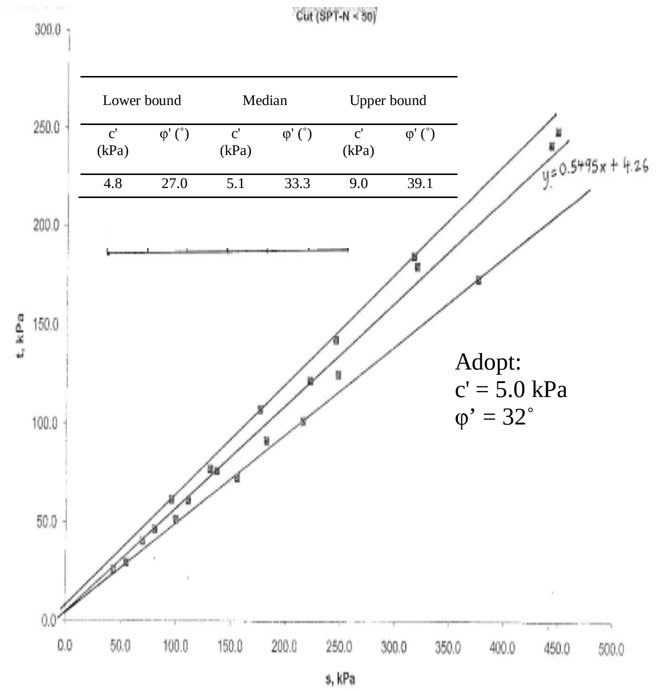


Figure 6b t-s Plot for cut (SPT-N < 50)

Block samples from the trail pits were also obtained to validate the effective strength parameters consolidated undrained (CIU) and drained (CD) triaxial tests. The summary of these results shown in Table 2 validated the values used in the analysis.

Table 2 Design Parameters of Subsoil Layers

Subsoil Layer	Description	Thickness (M)	Bulk Density (kN/M^3)	Effective Strength Parameters	
				C' (kPa)	Φ' (°)
1	Fill	1.0 - 25.0	19.0	5	30
2	Residual Soil (SPT – N < 50)	4.0 – 12.0	18.0	5	32
3	Weathered Soil (SPT – N > 50)	> 10	20.0	7	34

The groundwater levels vary from 3 m to 21 m below existing ground level with closer to the surface at the toe of the slopes. The typical subsoil profile at the distress area is shown in Figure 7.

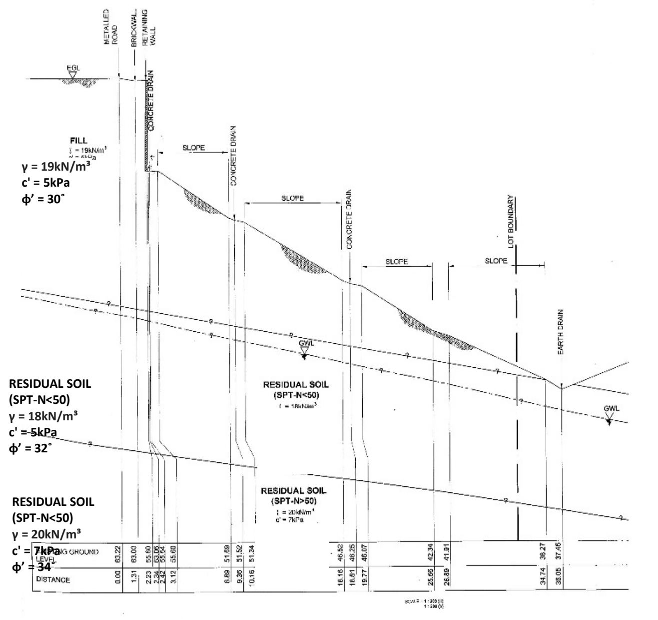


Figure 7 Typical subsoil profile at distress area

Seismic refraction survey was carried out along the wall line as shown in Figure 8 and the results in shown in Figure 9. The seismic refraction survey indicates two distinct layers based on the contrast of the velocities. The upper layer is characterized by low p-wave velocity representing the fill materials of sandy SILT or silty SAND. Underlying this fill layer is the highly weathered meta-sedimentary profile with higher p-wave velocity. These results conform closely to the findings of the boreholes.

Figure 8 Location of seismic profiles

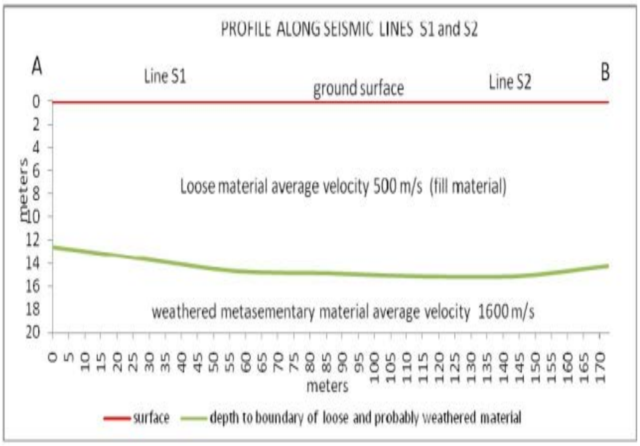


Figure 9 Seismic profile along seismic lines S1 and S2

Three lines of resistivity survey were carried out at the first berm from the base of slope, base of the RS wall and at the roadside near to the houses. Typical resistivity profile is shown in Figure 10. These profiles show the presence of partial saturated soil layers indicating presence of groundwater seepage.

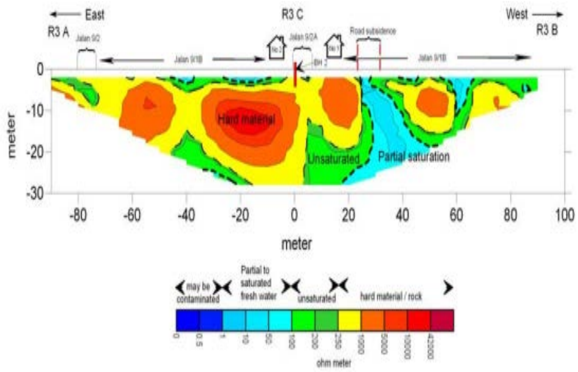


Figure 10 Typical resistivity profile along the affected area

3. POSTULATION ON THE WALL FAILURE

The partial collapse of the RS wall can be attributed to the following factors:

- Leakages of fluids from certain sources which could indirectly increase the hydrostatic pressure behind the RS Wall. These leakages may not be from recent incidents and may have been occurring over a long period. The potential sources would be from concealed drains, water supply pipes and sewerage pipes. 2 out of 3 sources have been confirmed by the respective owners that leakages have been detected in the nearby pipes. These pipes could have been damaged over the time due to the post construction settlement of the fill materials not properly placed and compacted.
- Regular water ponding after each heavy downpour on the road next to the collapsed wall area. Due to the water ponding and delayed dissipation of surface runoff, water could have infiltrate into the ground and cause an increase in hydrostatic pressure behind the wall especially over a prolonged period of time.
- From the site visit, it is observed that a lot of shrubs and some trees growing between the RS Wall panels. This could be another contribution factor to the failure as the roots growing from the shrubs and trees may cause the wall panel to be displaced and instill additional stresses in the reinforcing tendons.

The RS wall has been designed in accordance to the code of practice BS 8006 (1995). Flooding and leakages of the water carrying services near to the wall has caused an increase of pore water pressure. This has caused the overstressing of the tendons. A detail analysis simulating the buildup water pressure show that reinforced wall tendons in layers 5 to 8 were overstressed and the final collapse took place due to the failure of the tendon T12 at layer 8 which has the highest stress. The settlement of the fill under the wall could have further aggravated the situation. The likely postulation of the failure is shown in Figure 11.

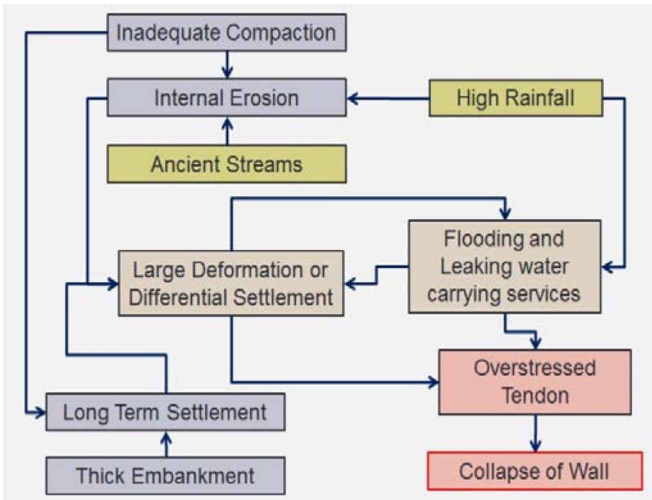


Figure 11 Flow Chart of possible factors for the wall collapse

4. REMEDIAL WORKS

The remedial works were carried out in two stages viz short term and long term. The details of the remedial works are elaborated in the following sections.

4.1 Short Term Remedial Works

Immediately after the wall failure, a short term remedial of reconstructing the wall using cast insitu RC wall was carried out. After removal of the collapsed RS panels, an RS wall was built with the existing tendons were extended into the RC wall. Damaged or bend tendons were replaced with new tendons. This allows the road to be constructed immediately for the residents to use. This is the only road for the residents to access their homes. One (1) row of horizontal drains of 12m length were also installed at about 4m from the top of wall to mitigate any buildup of water and allow flow of any trapped water behind the wall. Figure 12 illustrated the short term remedial works using RC wall.

Figure 12 Short term remedial work using RC wall

Another short-term measure proposed and constructed at the site is the permanent drain channel along the forest reserve to allow water from the forest reserve to flow to the toe drain. This will reduce the ground water seepage due to surface runoff from the Forest Reserve. Figure 13 indicated the drainage path.

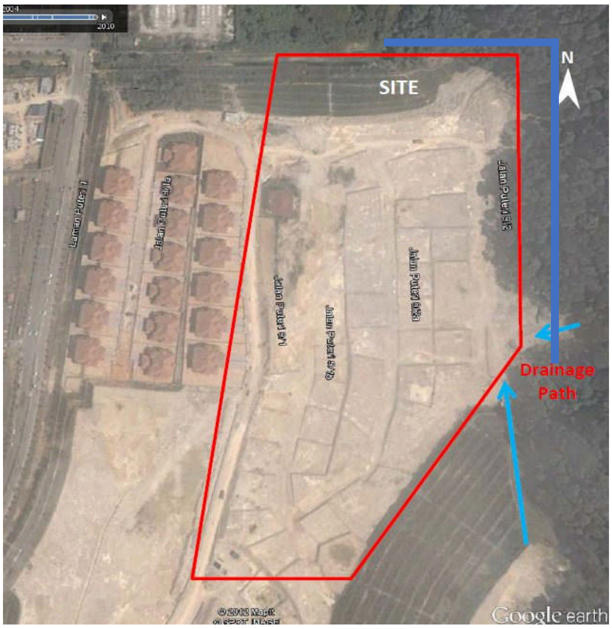


Figure 13 Drainage path for short term measure

4.2 Long Term Remedial Works

The entire slope system with the existing wall need to be strengthened to achieve higher factor of safety of minimum 1.4 as recommended in the Hong Kong Slope Manual for high risk slope. An extract of the GEO 84 which provides some guidelines on the Factor of Safety (FOS) based on risks to the economy loss and lives is shown in Table 3.

Table 3 Guidelines on the Factor of Safety (FOS) based on risks to the economy loss and lives (GEO 1984)

Economic Risk	Risk to Lives		
	Negligible	Low	High
Negligible	>1.0	1.2	1.4
Low	1.2	1.2	1.4
High	1.4	1.4	1.4

Without strengthening works, the current embankment slope shows FOS of about 1.06 to 1.14. The embankment slope has been strengthened using soil nails, horizontal drains and rock fill buttress to enhance the FOS to the required levels. The analysis output for slope without and with strengthening are shown in Figure 14a and 14b.

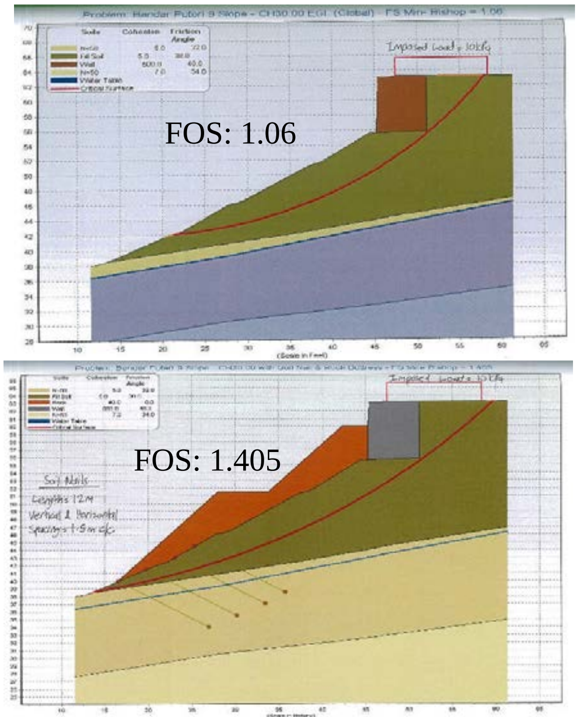


Figure 14 Typical slope analysis output (a) without strengthening (b) with strengthening

The typical strengthening details is shown in Figure 15. The details of the strengthening works are:

- Significant rise in the ground water table may adversely affect the stability of the slopes and the wall and cause potential failures. In order to mitigate the ground water fluctuations, horizontal drains have been installed. One row of drains at a spacing of 4 m centers and 12 m length installed along the bottom berm. A total of forty horizontal drains of 12 m length and four (4) no's of 7 m to 8 m length due to rock were installed.
- Additional soil nails of 100 mm dimeter and 12 m length at horizontal and vertical spacing of 1.5 m centres at the bottom slope to enhance the FOS of deep seated failure. Galvanized T25 reinforcement bar with working load of 100kN and cement grout of minimum compressive strength of 30 N/mm^2 was used. The nails were inclined at 30 degree from horizontal. A total of 249 no's of soil nails were installed with some socketed into rock. Pull out tests were performed on 4 soil nails up to 150 kN, i.e. 1.5 times the working load. The values are within the acceptable limits of 12.5 mm.
- A rock fill buttress of compacted stones were placed on the existing slopes after the soil nails and horizontal drain works. The stone used consist of hard durable inert rocks of granite origin. The rock fill was well graded from 150 mm to 400 mm. The rock fill was placed in layers of 500 mm and compacted by at least 12 passes of vibrating roller. The gradient of the rock slopes was initially fixed at 1; (V): 1(H) but later amended to 1(V): 1.5 (H) upon review of the independent consultant to avoid any localized failure of the rock fill.

- To mitigate erosion problems on slopes, close turfing and mortared stone pitching were used on slopes not covered by the rockfill.
- As failure of the reinforced soil wall involved leakages of the water carrying services and soaking of the cohesive soil behind the wall, free draining material was used to backfill behind the wall. By doing so, water will be easily drained out from behind the wall and the probability of another failure would be much reduced. The existing precast drainage system along the wall and part of the site road, which is currently leaking was replaced with cast in situ drains to reduce or avoid leakages. The water supply pipes along the wall was totally exposed and installed inside a RC channel with measure to drain the water from the pipe if any leakage. Sewage pipes along the wall was also redesigned and replaced with a more robust system that could withstand large differential settlement.

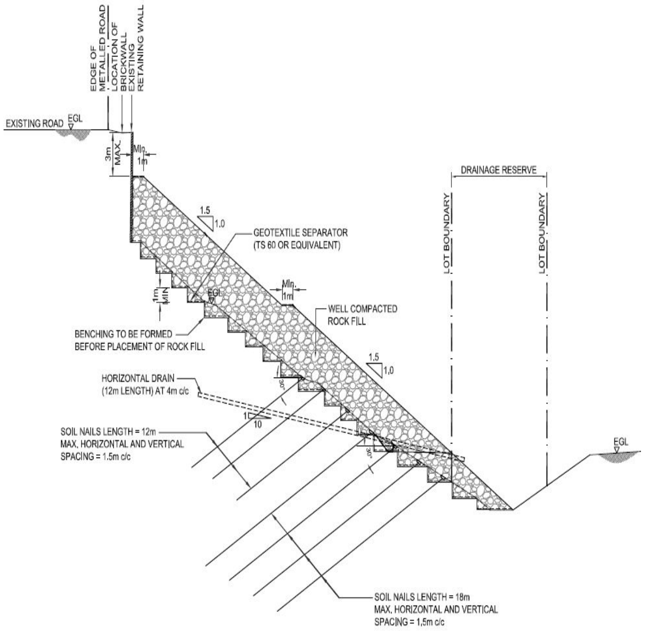


Figure 15 Typical strengthening details

The damaged water and sewer pipes were repaired with special allowance for damage. The final completed remedial work is shown in Figure 16.

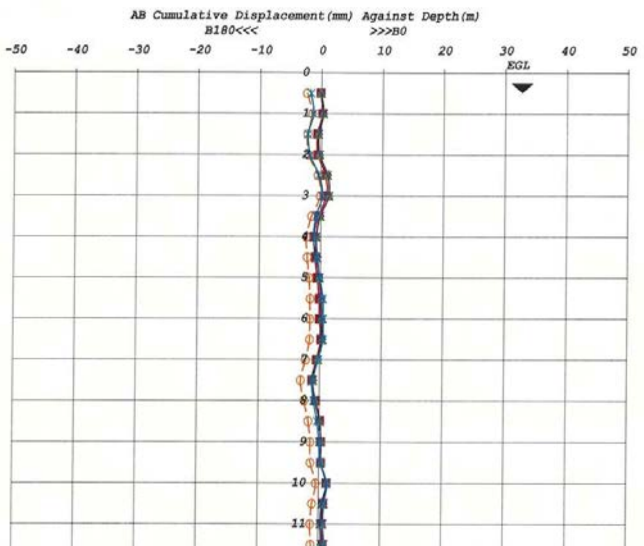
Figure 16 Final view of completed rectification work

Geotechnical Instrumentation

Instrumentation were installed during the remedial works to monitor the performance of the slopes stabilization measures during and upon completion of construction works. The instrumentation plan is shown in Figure 17.

Figure 17 Instrumentation Layout

The instrumentation readings showed that the constructed remedial works have performed as expected and all the readings are well within the acceptable limits. Typical results of the instrumentation readings are shown in Figure 18a and 18b.



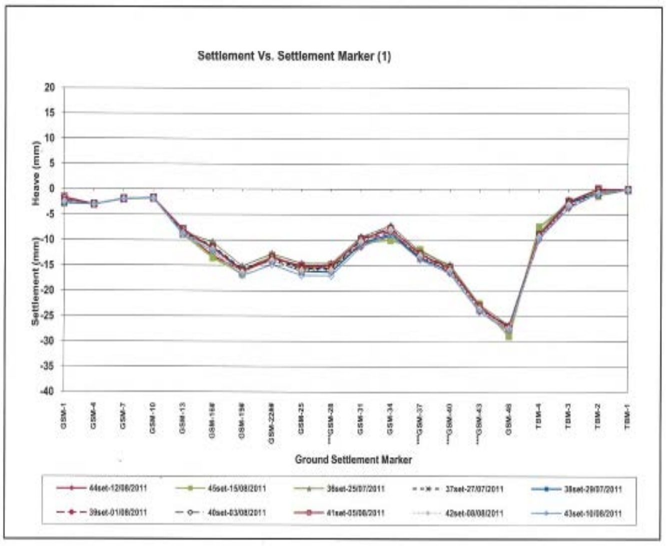


Figure 18 Typical instrumentation results (a) Inclinometer reading (b) Ground Settlement Marker reading

5. MAINTENANCE OF SLOPES

It is crucial that a routine slope inspection be conducted on the embankment and its slope to ensure that the remedial works are performing according to design and to detect any signs of instabilities. For a start, the inspection should be conducted every 6 months. Its frequency could be revised later by the consultant, depending on findings from the routine inspection. The slope maintenance guidelines issued by the Public Works Department could be referred to for this purpose. However, a few important maintenance items specific to the study site shall also be carried out, such as measuring the total dissolved solid and flow rate of water seepage from the horizontal drains and springs at the toe of embankment, checking on the buried water carrying services, taking the inclinometer readings at the reinforced soil wall and checking on the functionality of the monitoring and relief wells. The maintenance report should be submitted to the consultant and relevant authority for reference and further action, if required. Routine maintenance works, such as clearing and sealing the drainage system, repairing or replacing the pump or sensor and replacing the horizontal drains, if necessary, shall be conducted immediately after the inspection.

6. LESSONS LEARNED

From this case study of a RS wall failure at a residential housing site occurring about 7 years after the installation of the wall, the following lessons learned can be summarized so that such failure will not occur in other similar projects.

1. During any site development (earthworks), adequate study shall be carried out on the existing drainage patterns and proper drain diversion shall be provided for stream flowing from the area outside the development area and into the development area. This will minimize future seepage of groundwater due to the infiltration of surface runoff into the ground.
2. Proper selection of the cut materials shall be used for the filling works. Rocks bigger than the sizes allowed in the specification shall be broken into smaller sizes and used with soil fill. This will ensure adequate compaction of the fill soils. All fill shall be placed and compacted as per specification to minimize long term consolidation settlement of the fill due to self-weight particularly for high fill.
3. Proper cut-off drains shall be provided at the top of fill to divert the water from the fill slopes. Preferably use open drains at hill site to facilitate easy maintenance in the event of any clog gage in the drains.
4. RS wall can be constructed on thick fill ground provided all the measures as highlighted above are strictly adhered.
5. The combination of soil nails, horizontal drains and rock fill mattress can be successfully implemented on the distress areas of thick fill of unconsolidated fill with large rock fragments and underground seepage. This system allows the free flow of the seepage water whilst maintaining the required stability at any slip failures.
6. Adequate ground investigation is very important in such high fill area to determine the subsoil conditions and properties.
7. Adequate routine maintenance of high slopes must be carried out covering the slope drains, slope vegetation, retaining wall, horizontal drains, utilities on slopes, etc.

7. REFFERENCES

Atkinson, J. H. (2007). *The Mechanics of Soils and Foundation.* 2nd Edition, Taylor and Francis (Publishers).

Bittelli et al. (2012). *Monitoring soil – water and displacement conditions leading to landslide occurrence in partially saturated clay.* Geomorphology 173- 173, 161 – 173.

Geotechnical Engineering Office, The Government of the Hong Kong Special Administrative Region. (1984). *Geotechnical Manual for Slopes.*

IKRAM & Geo Solution Resources. (2012). *Geophysical Assessment Study Report.*

Krahn, J. Geoslope software manual

Mineral and Geoscience Department, Malaysia. (1993). *Geological Map of Kuala Lumpur*