Failure Investigation of Crib Wall, Piled Reinforced Concrete Wall And Geosynthetic Reinforced Soil Wall

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ABSTRACT: This paper presents two case histories on the collapse of 10m high crib wall with 4m high piled reinforced concrete wall on top and excessive creep movement of 3m high geosynthetic reinforced soil wall. In both cases, the walls were built to retain a filled batter slope with gradient of 1V:1.5H. Investigating processes consisting of site reconnaissance, topography survey, subsurface investigation, laboratory testing and assessment of both external and internal wall stabilities will be briefly discussed in this paper. Rainfall records spanning the period before failure incident were gathered to reveal the relationship between the failure and the rainfall. This paper also presents the ineffectiveness of reinforced concrete (RC) piles in taking bending moment and lateral load from earth pressure. Finite element analyses were also performed to verify the inherent failure mechanism of the lower crib wall, the upper piled reinforced concrete wall and the geosynthetic reinforced soil wall. In addition, remedial solutions are also presented in this paper to demonstrate its effectiveness.

1. INTRODUCTION

Various types of high retaining walls with height ranging from 10m to 15m are inevitably required for hill site development in order to provide the required building platform and to maximise land use. This paper presents two case histories on the collapse of 10m high crib wall and excessive movement on geosynthetic reinforced soil wall in a hill site development.

2. CASE HISTORY 1 – FAILURE OF CRIB WALL WITH PILED REINFORCED CONCRETE WALL

In March 2006, a newly constructed crib wall with piled reinforced concrete (RC) wall seated atop collapsed during a raining season in Kuala Lumpur, Malaysia. The crib wall, piled RC wall and backfilled batter slope (about 62m long) with total height of about 15m had been built at the site to retain the building platform at reduced level RL 213.13m. The 3 headers crib wall at the collapsed section has a height of about 9.4m to 10.6m. A 4m high piled reinforced concrete (RC) wall was constructed on top of the crib wall with an offset of 4m away from the crib wall. The RC wall was built with a 2.4m width base and supported by two rows of vertical 150 x 150mm RC square piles at 1.25m centre-to-centre spacing. A filled batter slope with gradient of 1V:1.5H was then constructed above the RC wall. Figure 1 shows the condition of the collapsed crib wall and piled RC wall whereas Figure 2 shows the subsurface investigation (SI) layout plan.

Figure 1 Collapsed Crib Wall and Piled RC Wall

2.1 General Geology and Subsoil Condition

Based on the Geological Map of Selangor, Sheet 94 Kuala Lumpur published by the Geological Survey Department, the site is underlain by Granite formation. Generally, the subsoil strata below the wall backfill consist of a layer of weathered residual soils with primarily silty SAND and sandy SILT overlying the granite bedrock as shown in Figure 3. Whilst the backfilled material with average SPT-N values of 5 was found on top of the residual soils.

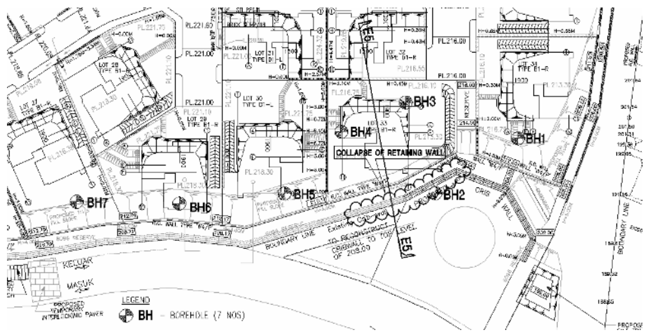

Figure 2 SI Layout Plan

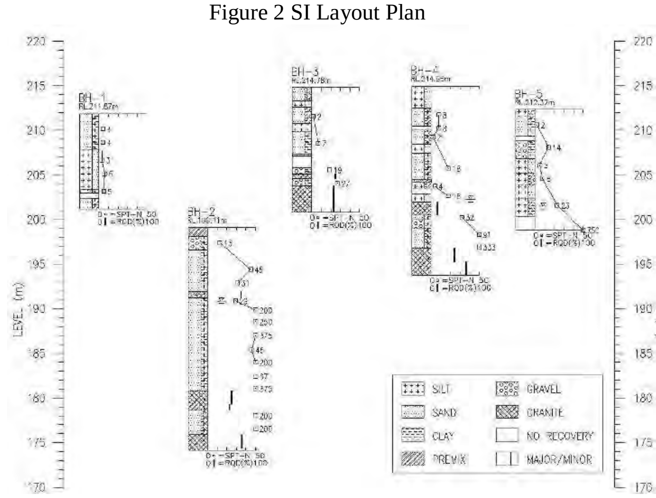

Figure 3 Subsoil Profile

2.2 Assessment of Retaining Wall Stability

An earthwork section of the collapsed crib wall and piled RC wall is shown in Figure 4. External stabilities (overturning, sliding, bearing capacity and global stability) of the crib wall and piled RC wall were examined in investigating the probable causes of the failure. Two (2) cases of groundwater levels are considered in the assessment where the first case assumes that any groundwater seepage would be effectively drained out and no water pressure would be present behind the wall as the cribwall was backfilled with granular material. Notwithstanding the above, the second case considers the groundwater level is at 1/3 of the wall retained height.

The abovementioned stability aspects have been assessed and the computed factors of safety (FOS) from limit equilibrium are summarised in Tables 1 and 2. The computed FOS was compared with the required FOS based on Hong Kong Geotechnical Manual of Slope (GCO 1984).

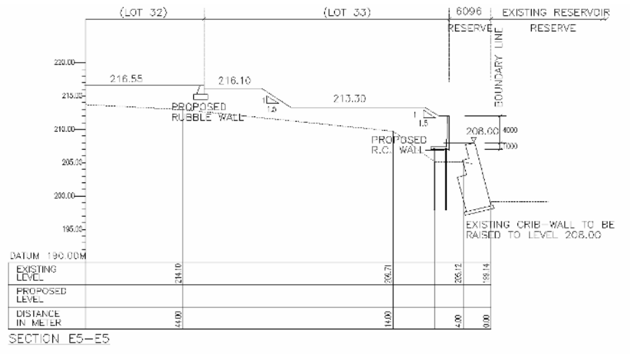

Figure 4 Earthwork Section of Collapsed Retaining Wall

Table 1 Factors of Safety for Retaining Wall External Stability

Wall	Ground Water Condition	Overturn-ing(> 2.0)	Sliding (>1.5) Case A	Sliding (>1.5) Case B	Bearing Capacity (>3.0)
Piled RC Wall	Without GWT	1.53	0.27	2.09	N.A (Supported by RC piles)
	GWT at 1/3 Wall Height	1.48	0.24	1.52	
Crib Wall	Without GWT	1.72	0.93		5.74
	GWT at 1/3 Wall Height	1.71	0.85		2.89

* Case A denotes lateral resistance from RC piles
* Case B denotes shearing resistance from earth contact at RC wall base

Table 2 Factors of Safety for Global Slope Stability

Earthwork Section	Ground Water Condition	Global Slope Stability (>1.4) Case 1	Global Slope Stability (>1.4) Case 2
Collapsed Section	GWT based on SI results	1.72	1.14
	High GWT (3m below upper platform)	1.33	1.12

* Case 1 denotes global slip circle underneath crib wall
* Case 2 denotes global slip circle cut through crib wall

2.3 Finite Element Analysis

In order to verify the inherent failure mechanism of retaining wall failure, Finite Element Method (FEM) analysis using PLAXIS software was performed. The results show that the failure slip surfaces were formed behind the crib wall and RC wall as shown in Figure 5.

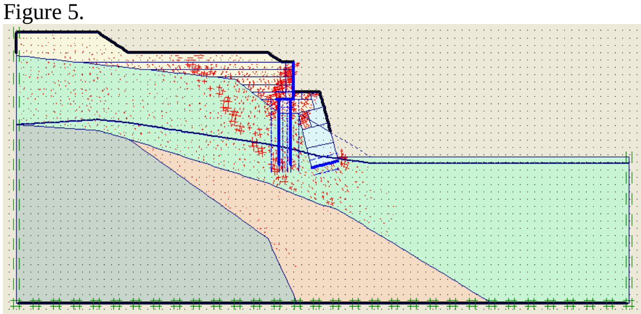

Figure 5 FEM analysis result

The analysis results reveal that the maximum movement of the retaining structures is about 95mm and the FOS obtained from strength reduction analysis against limit equilibrium is about 1.17. Therefore, both the limit equilibrium and finite element analysis reveal that the marginal FOS for the retaining structures constructed at site is apparently inadequate.

2.4 Investigation Findings

Based on the assessment, the following findings can be deduced:

a) FOS on overturning stability, bearing failure and overall stability for both types of retaining wall are less than the required values especially when groundwater table is at 1/3 of the wall height. However, the FOS is greater than 1.0 indicating that the crib wall and piled RC wall shall not fail in overturning, bearing failure and overall stability.

b) RC wall supported by pile foundation (vertical piles) is ineffective in taking lateral load. This is because overburden pressure from the wall backfill will be transferred directly to the pile foundation as the pile element is much stiffer than the soil underneath the wall base preventing development of the base contact resistance. As a result, the soil beneath the wall base would not experience much build up of overburden pressure from the backfilling of retaining wall until the piles had failed. Therefore, the lateral resistance offered at the wall base to soil contact is insignificant. This concurs with the findings published in a paper by Liew (2007).

c) The FOS against sliding on the crib wall without considering groundwater table is marginally lower than 1.0. When groundwater is at 1/3 of the wall height, the sliding resistance of the crib wall is even lower. Therefore, the collapse of the cribwall was most probably triggered by the rise of groundwater table behind the wall backfill. This can be evidenced by the rainfall record as shown in Figure 6, which indicated high volume of antecedent rainfall before the collapse. The impact of antecedent rainfall will cause gradual rise of groundwater table reducing the wall stability.

d) The low SPT-N values observed at the backfilled layer indicated that fairly poor compaction was achieved during construction. The dry density of undisturbed samples of BH1-UD1, BH1-MZ1 and BH3-UD2 ranges from 1.323Mg/m^3 to 1.511Mg/m^3, which was only about 80% of the maximum dry density obtained from standard Proctor test. Therefore it was evidenced that the backfill material had not been compacted to fulfil the normal engineering fill requirement at site and thus infiltration of surface runoff into backfill can be reasonably expected.

e) In view of insufficient FOS of the cribwall against sliding, the collapse of the crib wall likely occurred prior to the RC wall, in which the ribs of the crib wall were found at the front portion of the collapsed debris.

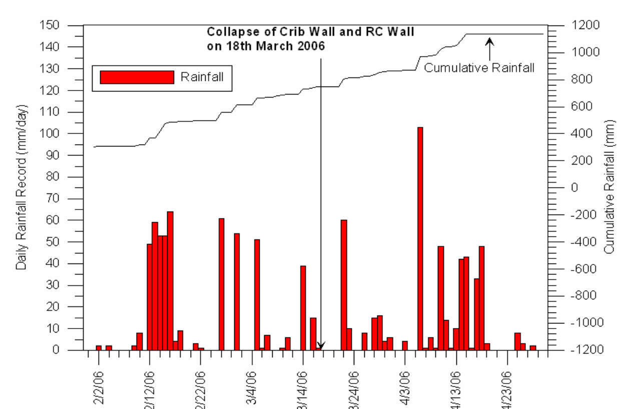

Figure 6 Rainfall Data

2.5 Remedial Design

The following remedial works were carried out at site:

a. Construct a 10m high reinforced soil (RS) wall after the debris removal of the collapsed cribwall.
b. Provision of subsoil drainage behind the reinforced soil wall to prevent built up of water pressure within the retaining wall.
c. The building platform is re-profiled to a lower platform level to reduce the RC wall height and the RC wall is designed directly founded on the retained backfill of RS wall instead of pile foundation.

3. CASE HISTORY 2 – EXCESSIVE MOVEMENT OF GEOSYNTHETIC REINFORCED SOIL WALL

A geosynthetic reinforced soil (RS) wall located at the same project site had experienced excessive creep movement after the wall completion. The geosynthetic RS wall and backfilled batter slope above the wall with total height about 10m had been built at the back of bungalow under construction to retain a higher road platform as shown in Figure 7. Figure 8 shows the bulging of geosynthetic RS wall.

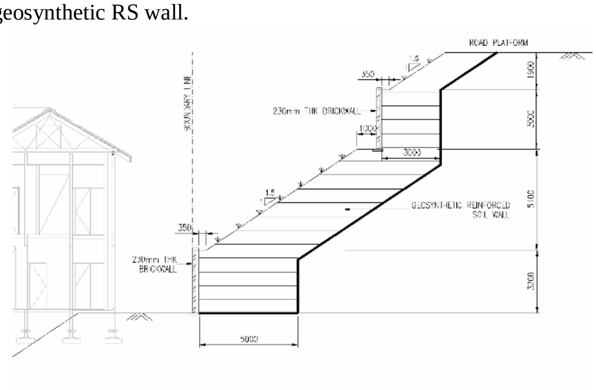

Figure 7 Earthwork Section of Geosynthetic RS wall

3.1 General Geology and Subsoil Condition

Similar to Case History 1, the site is overlain by Granite formation. The subsoil generally consists of silty SAND. The subsoil profiles and soil conditions of the project site are summarised in Figure 9.

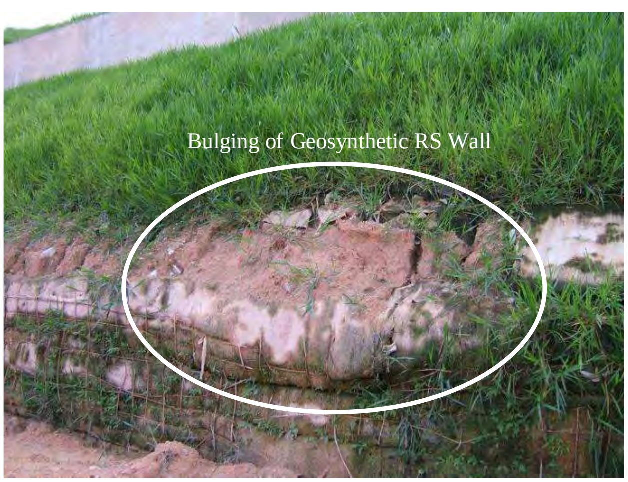

Figure 8 Bulging of Geosynthetic RS wall

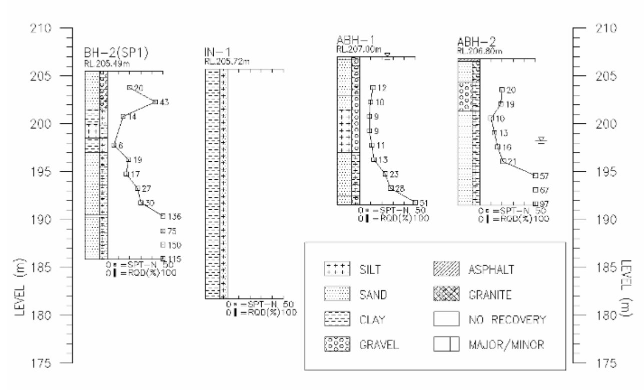

Figure 9 Borehole Profile

3.2 Site Observations

The following observations during the construction and after the distress were summarised from the construction records:

a) A 15m high temporary cut slope, which was formed to facilitate the construction of geosynthetic RS wall, collapsed affecting the road shoulder and roadside drain. The construction of geosynthetic RS wall continued after the removal of the collapsed debris.
b) A layer of strip drain was laid on the collapsed temporary cut slope prior to the construction of geosynthetic RS wall as shown in Figure 10.
c) The backfill materials for the geosynthetic RS wall consist of high moisture content as shown in Figure 11.
d) Bulging and outward movements of the geosynthetic RS wall at the lowest berm were observed as shown in Figure 8. The bulged wall alignment had encroached into the property boundary. In addition, it was also observed from site inspection that the wall surface was very wet.
e) The geosynthetic textile cloths at the lowest berm had been punctured and damaged.
f) At the top layer of the geosynthetic RS wall, the geosynthetic was found not properly wrapped back and anchored into the fill slope. Sign of soil erosion had been found at the top of the geosynthetic RS wall.

3.2 Assessment of Geosynthetic RS Wall Stability

Limit equilibrium assessments had been carried out on the external stability (overturning, sliding, bearing capacity and global stability) and internal stability (geotextile rupture and pull out resistance) of the geosynthetic RS wall. The achieved FOS based on the above assessments are summarised in Table 3 and 4.

Figure 10 Laying of Strip Drain

Figure 11 Wet Backfill Material

Table 3 Factors of Safety for External and Internal Stabilities (Limit equilibrium)

External Stability			Internal Stability	
Overturn-ing(> 2.0)	Sliding (>1.5)	Bearing Capacity (>3.0)	Rupture (>2.0)	Pull Out Resistance (>2.0)
2.04	1.55	>3.0	1.60	2.78

Table 4 Factors of Safety for Global Stability (Limit equilibrium)

Global Stability (>1.4)	
Circular	Wedge
1.27	1.24

3.3 Finite Element Analysis

In order to verify the inherent failure mechanism of retaining wall failure, Finite Element Method analysis using PLAXIS software was again performed. Two finite element models (FEM) were established, where the first model was without any strip drain behind the geosynthetic RS wall and slope and the second model was modelled with the closely spaced strip drain.

The analysis results showed that the maximum movement of the geosysthetic RS wall and slope was about 100mm and the FOS yielded from the analysis was about 1.18 which is slightly lower than the FOS computed using limit equilibrium stability programme. For the second model where the strip drain was included in the model, the maximum geosynthetic RS wall and slope movement is about 145mm and the FOS yielded from the analysis is about 1.08.

3.4 Investigation Findings

Based on the assessment, the following findings can be deduced:

a. The external stability (overturning, sliding and bearing capacity) and internal stability of the geosynthetic RS wall are adequate.
b. Both the limit equilibrium and finite element analyses results revealed that the FOS against global stability are marginally inadequate, with the FOS against global stability of about 1.30, which is less than the required FOS of 1.4.
c. Although lower FOS does not imply that the geosynthetic RS wall and slope will fail, large creeping movement of the wall and slope could be expected, which may exceed the serviceability limit and certainly can not be captured by the limit equilibrium analyses. The finite element analysis had actually shown large movement of the geosynthetic RS wall.
d. The rainy weather continued to prevail during the construction of the geosynthetic RS wall and batter slope. Therefore, it can be reasonably expected that the compaction to achieve the required compaction effort was difficult due to high moisture content of the fill material.
e. The finite element analysis also revealed that the use of closely spaced strip drain behind the geosynthetic RS wall and batter slope will promote tendency of developing preferential slip surface and induce further instability to the geosynthetic RS wall and slope, thus lowering the FOS. This is due to the reason that the interface friction between the strip drain and soil is lower than internal friction between soil particles.

3.4 Proposed Remedial Design

The following remedial works were carried out at site:

a. Install 10 rows of soil nail with various lengths ranging from 6 to 12m to strengthen the batter slope. The batter slope was then protected by a layer of shotcrete.
b. Subsequently, trimming of the bulged geosynthetic RS wall by removing the excessive soil and re-wrapping of the geotextile.
c. Constructing a 4m high RC wall by casting the concrete against the geosynthetic RS wall to retain the soil and batter slope.
d. Provision of proper drainage system including subsoil drains and berm drains.

4. CONCLUSIONS

The following conclusions can be made from the investigation of these two cases histories:

a) Proper compaction on the backfill material is crucial in retaining wall construction as this will minimise the infiltration of surface runoff and thus prevent of built up of groundwater table behind the retaining wall especially during monsoon season. Therefore, full time supervision on the wall construction is vital to ensure works compliance in accordance to required specification and thus to prevent unnecessary failure, which will lead to costly remedial works.
b) RC wall supported by pile foundation (vertical piles) is ineffective in taking lateral load and bending moment.
c) The use of strip drain behind the geosynthetic RS wall and slope will promote preferential slip surface and induce further instability. Hence, it shall be used with caution.

5. REFERENCES

[1] GCO (1984). “Geotechnical Manual for Slopes”. (Second edition). Geotechnical Control Office, Hong Kong, 295 p.

[2] Liew S.S (2007), “Lessons Learnt on Stability of Piled Retaining Wall in Weak Soils”, 10th ANZ Conference on Geomechanics, Brisbane, October 2007.