Design & Construction of a High Geogrid Reinforced Wall

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Abstract

A housing project on a hill site requires the construction of a 17m high reinforced soil wall supporting a 20m high reinforced soil slope. At the top of the slope were sited double storey terrace houses founded on raft foundations. Beneath the foundation of the wall, a disused sewage treatment pond was reclaimed, with soft slime excavated and replaced with compacted rockfill to form the foundation of the wall. Woven high strength geotextile was used as the base reinforcement immediately above the rock foundation. A 17m high reinforced soil wall of gradient 4v:1h was constructed with geogrids. Immediately above this steep wall was a reinforced soil slope of gradient 1v:1.7h, reinforced with woven high strength geotextile. The structure was designed to limiting differential displacements at the top where the buildings were sited. Hence, extensive monitoring of the displacements was carried out. This paper describes the design concept, construction methodology adopted and the monitoring results recorded.

Keywords: Hill site, reinforced soil wall, woven geotextile, geogrid

1.0 Introduction

The development of housing on a hill site project in Cheras, Selangor, Malaysia necessitated the construction of an earth retaining structure. The base of the structure was to be constructed on the site of a disused sewage treatment pond. The pond was reclaimed whereby soft unsuitable materials were excavated and replaced with rock fill compacted to form a firm base. A 17m high geogrid reinforced earth structure was constructed on the reclaimed foundation. This structure, sloped at 4v:1h, supports an overburden fills of 20m high sloped at 1v:1.7h, above which are sited the double storey terrace houses. The total length of the structure is approximately 120m. Figure 1 shows the layout of the structure.

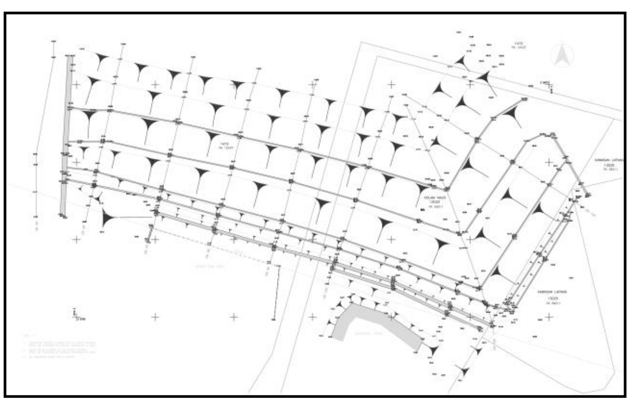

Figure 1: Layout of Geogrid Reinforced Wall

This paper describes a case study of the design and the construction processes in erecting the 37m high reinforced soil structure.

2.0 Overview of Design Concept

The subsoil condition of the foundation generally was treated to ensure the bearing capacity is sufficient to sustain the loads from the structure. The design criteria calls for a factor of safety against bearing failure, based on lower bound shear strength, to be not less than 2.0, and the factor of safety against local and global slope failure to be not less than 1.35. Reasonably conservative shear strength values were adopted for the design: For well compacted fill and retained soil layers, the effective cohesion (c') adopted was 15 kPa and the effective friction angle (ϕ') was 28^o. For the foundation layer, the c' is 0 kPa and the ϕ' is 30^o. Table 1 below provides a summary of the design parameters adopted.

Table 1: Design Parameters

Stratum	Design Parameters		
	Effective Cohesion (kN/m^2)	Effective Friction Angle (^oC)	Bulk Unit Weight (kN/m^3)
Well Compacted fill	15	28	18
Retained layer	15	28	18
Foundation layer	0	30	18

In order to achieve the required stability of the high wall, the use of high strength polyester woven geotextile and high strength knitted geogrid were used to reinforce the structure. KiaraTex high strength woven geotextile KT 400/50 was laid in the founding layer of the structure. The ultimate strength of this material is 400 kN/m, but the working stress adopted in the design is 122.10 kN/m, which is approximately 30% of the ultimate strength. For the remaining layers, KiaraGrid high strength knitted geogrid were used. Grades of the geogrids included KG 75/25, KG 100/25 and KG 150/25. The ultimate strength of these materials were 75 kN/m. 100 kN/m and 150 kN/m, respectively. The working stresses adopted were 24 kN/m, 32 kN/m and 49 kN/m, respectively, representing about 30% of the ultimate strength. Figure 2 shows a typical cross-section detail of the structure. The upper reinforced soil slopes were reinforced with high strength woven geotextile, KT200/50. Table 2 below provides a summary of the design stresses of the geosynthetic materials used.

Table 2: Design Stresses in Geotextiles and Geogrids

Geosynthetics	Ultimate Strength (kN/m)	Actual Design Strength (kN/m)
Geogrid		
KG150/25	150	49
KG100/25	100	32
KG75/25	75	24
Woven Geotextile		
KT400/50	400	122
KT200/50	200	61

The stability analysis was performed using the high strength polyester woven geotextile and high strength knitted geogrid, considering internal stability and overall stability. A minimum factor of safety of 1.40 was adopted for the design. A circular mode of failure was considered for the internal and global stability. The stability analysis was based on Bishop's method of slices. Translational mode of failure was also considered, taking into account the elongation of the geo-reinforcement under the working load adopted.

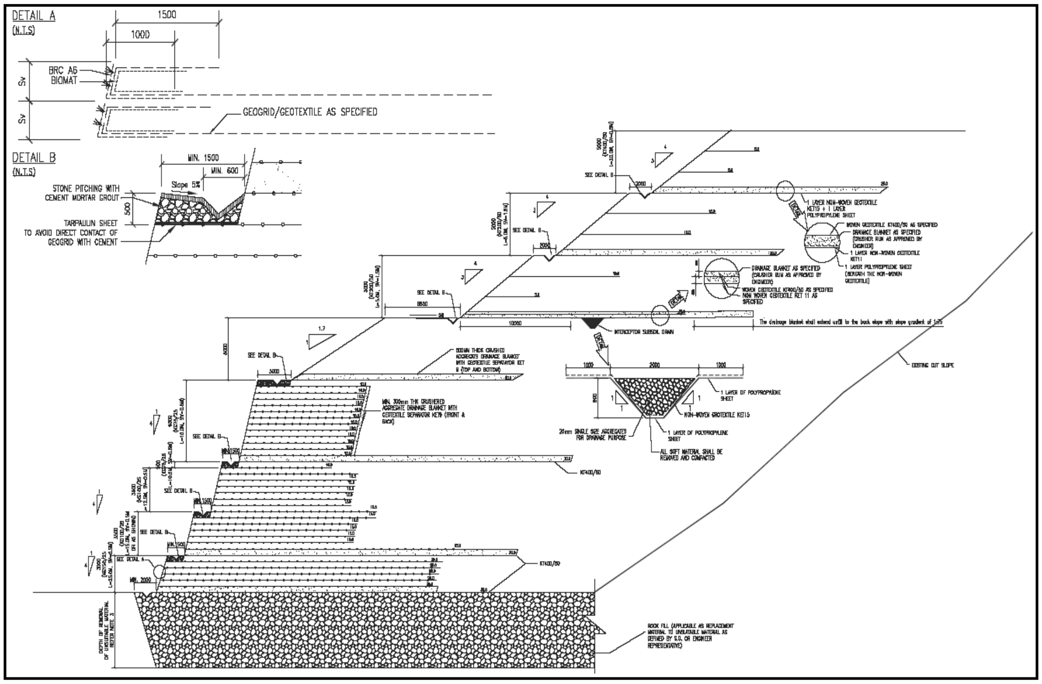

Figure 2: Typical Cross-Section Detail of Structure

3.0 Foundation Preparation

As mentioned in the introduction, the retaining structure was sited on a disused sewage treatment pond. The base of the pond was filled with soft slime up to a depth of about 3m. This soft material was excavated and replaced with compacted rockfill to form the base of the structure. The excavation is terminated when the Mackintosh Probe tests reached a resistance of 75 blows per 300mm penetration. Figures 3 and 4 below show the completed rock-fill base of the structure.

Figure 3: Rock-fill Base of Structure

Figure 4: Base of Structure

4.0 Earthworks and Compaction Control

Selected earthfill materials were compacted into the structure. The backfill materials selected comprise of suitable material and generally of a gradation within the range of granular soils; however a 10% clay content was acceptable. The Plasticity Index of the selected material were not greater than 30% (P.I. < 30%).

All fill materials were compacted in layers not exceeding 300mm. Field density tests, in addition to laboratory tests were carried out to verify the degree of compaction. Generally, a wide scatter of the degree of compaction was observed, with results ranging from 75% to 99% of the maximum dry density, as determined according to BS 1377: 1990 (4.5kg rammer method). In areas where the degree of compaction falls below 90% of the maximum dry density, a specified section of the earthworks was excavated and re-compacted to meet the specifications. Figure 5 below shows the distribution of the degrees of compaction obtained from field density tests. The lower densities obtained were generally associated with incidences of high moisture contents during compaction, i.e. compacting wet of the optimum moisture content.

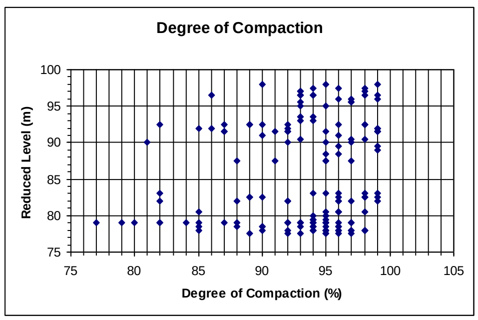

Figure 5: Distribution of Degree of Compaction

The moisture contents of the fill material prior to compaction were monitored. The results show a wide scatter of the values; a significant portion of the field moisture falls between 10% and 20%. Figure 6 below shows the distribution of field moisture contents. The maximum dry density of the selected fill material is 1.925 Mg/m^3 and the corresponding optimum moisture content is 12.82 %. Given a range of ±5% difference in moisture content, the acceptable range of moisture content would be between 7.82 % and 17.82 %. It may be observed from figure 6 below, that a portion of the fill material were compacted at too high a moisture content. This was seen as the most likely reason for the incidences of low densities recorded, as compacting at too high a moisture content will likely to result in low densities and low shear strengths.

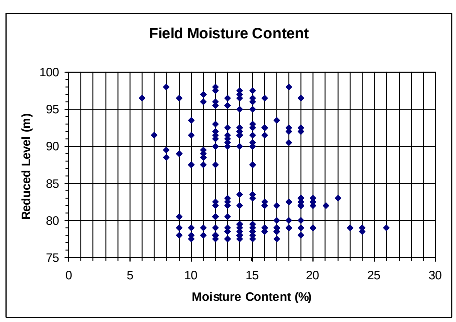

Figure 6: Distribution of Field Moisture Content

Once the foundation layer has been compacted to the level required, the position of the wall was pegged to facilitate the laying of a layer of the high strength woven geotextile KT 400/50 on top of the compacted foundation layer. A layer of granular soil (minimum 50mm) was first placed on top of the woven geotextile before placing 80mm diameter perforated sub-soil UPVC pipe Class D (Rip Loc), wrapped around with nonwoven geotextile (KET9), at 5m spacing interval. All perforated subsoil drains were placed with a layer of granular material sandwiched in between with non-woven geotextiles (KET 15). The granular soils were placed and compacted in layers of not greater than 300mm thickness.

KiaraGrid, KG 150/25, KG 100/25 and KG 75/25 were cut to the required length inclusive that of the wrap-around length. A layer of Eco-Biomat geotextile was placed on the inner side of the geogrid. The function of the Eco-Biomat was to facilitate the germination of vegetation on the facing of the reinforced soil structure.

During the installation process a 150mm thick cover of backfill material was maintained between the tracks of machinery and the geogrid in order to avoid damage to the geotextile material. All rocks and boulders greater than 100mm were also removed from the backfilled materials. Compaction of fill material within 1m of the front face were carried out using light hand-held compactor, including the plate vibrating compactor, while other part of the reinforced block were compacted with vibrating compactor roller.

Hydroseeding of the slope cover was carried out immediately after completion of each berm of the wall to prevent erosion. V-shape berm drains were constructed to drain surface runoff away from the newly built slope.

Figure 7: Compaction of backfill material in progress

5.0 Installation of Geogrid

The reinforced slope with Kiaragrid-geogrid was constructed using the conventional construction methods and equipment. The geogrids were laid in layers vertically spaced at 500mm. The geogrids were placed horizontally with the higher tensile strength direction (warp) perpendicular to the face of the slope on the compacted and levelled fill surface. To prevent slack and to ensure tautness in the geogrids before backfilling, a small tension was applied by pulling the geogrids before pinning with staple pins.

Once the geogrid has been placed horizontally on the compacted fill, the backfill material was spread over the geogrid. No construction equipments were permitted to travel directly on the geogrids to avoid damage to the geogrid. As mentioned earlier, a minimum fill of 150mm thickness is placed over the geogrids before any construction plant were permitted to traverse over it.

Suitable backfill material was then placed on the Geogrids and compacted to at least 90% of its maximum dry density as determined using 4.5kg rammer method as specified in BS1377:1990. A wrap-a-round facing was used to contain the reinforced structure. This was carried out by wrapping the final portion of the grids towards the inner slope and slightly stretch and taut it. This was then anchored to the soil by partly burying the geogrids into the backfill material.

Figures 8 to 12 shows the sequences in the construction of the wall.

Figure 8: Installation of the wrap-around facing of the geogrid

Figure 9: A completed section of the geogrid wall

Figure 10: A side view of wall

Figure 11: A view of fully vegetated facing

Figure 12: Panoramic view of wall

6.0 Construction Practices

There were several aspects in construction practices that will impact on the performance of the reinforced earth wall. The first of these regards the earthworks procedures, especially the selection of suitable fill material. It is necessary that the designer have specific control of the earthworks procedures. The grading limits and the moisture content of the selected fill materials shall be carefully controlled, as variable compaction densities can be the result of non-compliance to this requirement. Generally, compaction procedures are well understood and can be well controlled.

The trafficking of construction equipment and vehicles directly over the geogrid or geotextile shall also be avoided as this will likely cause construction-related damage to the reinforcement materials.

The provision of temporary drainage at the construction site has often been neglected or treated with little importance. The absence of adequate temporary drainage has frequently resulted in severe erosion on the slopes and walls, and if left unattended may even induce failures in the structure. It is thus important to ensure adequate temporary drainage at the construction site.

To enhance the durability of the reinforced structure, a proper and adequate slope cover is essential. The facing shall be quickly hydroseeded as soon as the possible.

7.0 Monitoring

A series of monitoring systems comprising of inclinometers. settlement markers and piezoneters were installed to monitor the performance of the reinforced soil wall. Whilst installing the inclinometers and piezometers, soil tests including the SPT were carried out in the boreholes. Figure 13 below shows records of the SPT N-values measured within the compacted fill. The N-values generally ranged from 5 to about 15 in the fill material. The low values and the scatter is consistent with the compaction densities and moisture contents observed, These results suggests low compaction densities at the locations tested.

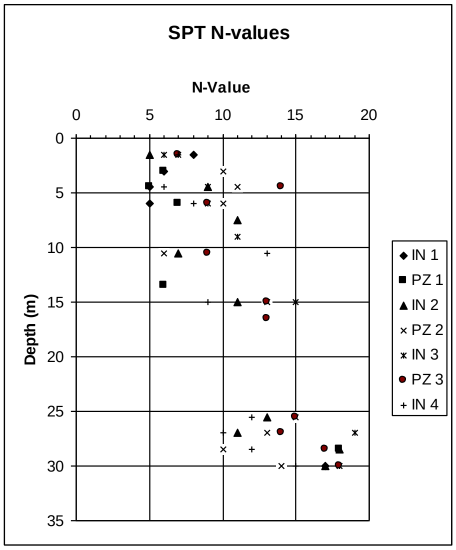

Figure 13: SPT N-values within compacted fill material

Inclinometers and piezometers were installed from the fourth, fifth and sixth berms of the structure. The maximum downslope movements of the inclinometer readings are shown in Figure 14 below:

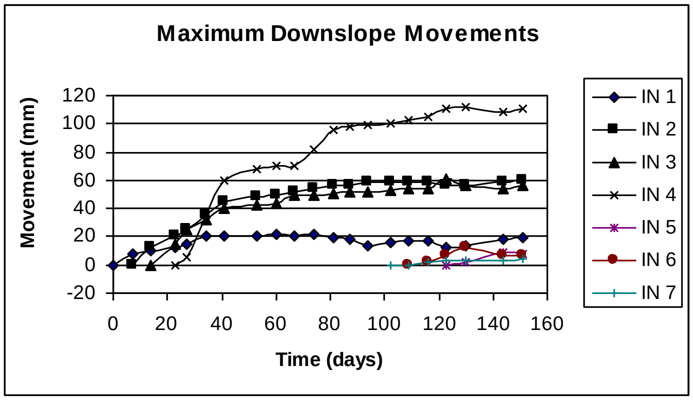

Figure 14: Maximum downslope movements of inclinometers

The inclinometer readings show that the structure moved a significant movement in the initial stages but stabilised towards the end of the monitoring period. The large movements recorded in the early stages of the construction were thought to be due to the straightening and tensioning of the geogrid.

The piezometric levels recorded indicate a stable piezometric level, hovering at about the base of the structure.

The records from the settlement markers are shown in Figure 15 below. The results show that the structure has reached stability with respect to the vertical movements.

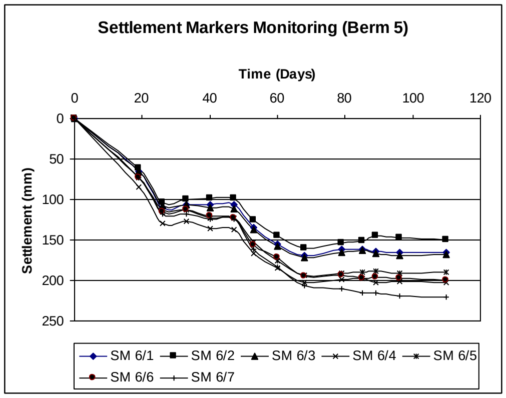

Figure 15: Records from the Settlement Markers

8.0 Conclusion

A case study of the design, construction and monitoring of a 17m high geogrid reinforced soil wall has been described. The construction sequences were described, and the monitoring results suggest that the wall has reached a stable state with small residual horizontal and vertical movements recorded. The case study showed that high reinforced soil walls can be constructed and yield a safe and stable environment.

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