Long Term Performance Monitoring of a Reinforced Soil Structure Constructed over a Reclaimed Sewage Pond

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ABSTRACT: The construction of a reinforced soil structure for a housing project in Cheras, Selangor, Malaysia was continuously monitored during the construction period as well as in the post-construction period. The base of the structure was partially constructed over a reclaimed sewage pond. The total height of the structure is 37m and was constructed on a rock-fill foundation. The reinforced soil structure was constructed as a wrap-around system for the lower four berms where geogrid was used and where the facing was hydroseeded with suitable vegetation. The gradient of the lower 4 berms was 4v:1h with a height of 17m. The upper berms were constructed with high strength woven geotextile with a slope gradient of 1v:1.7h. The backfill material used in the construction of the structure is composed of weathered residual soil and weathered rockfill of granite. Instrumentation consisting of inclinometers, pneumatic piezometers and settlement markers were installed at various locations in the structure to monitor the performance of the structure, both during construction and post-construction. This paper discusses the post-construction monitoring of the structure derived primarily from the inclinometer readings and examines the long term performance of the reinforced soil structure in relation to its design intent.

1 INTRODUCTION

A 37m high reinforced earth structure was constructed in Cheras, Selangor, Malaysia to facilitate the development of a housing project. This structure consisted on two distinct sections, with the lower section consisting of 17m high geogrid reinforced earth structure constructed on a compacted rockfill foundation. This lower section was sloped at 4v:1h and supports an upper section comprising of a 20m high geotextile reinforced earth slope with a slope gradient of 1v:1.7h. The base of the entire structure was partially founded on a disused sewage treatment pond which was reclaimed whereby the soft unsuitable materials were excavated and replaced with compacted rock fill materials. The total length of the structure is approximately 120m. Figure 1 shows the layout of the structure and Figure 2 shows a typical cross section detail of the reinforced earth structure.

Geotechnical instrumentation in the form of inclinometers, piezometers and settlement markers were installed during the construction of the structure. The construction of the structure commenced in the year 2003 was completed in the year 2005. Records of the instrumentation readings were taken during the construction of the structure to monitor the performance of the geogrid and geotextile reinforcement. Upon successful completion of the construction, these readings were continued up to the present moment (year 2010). This paper describes the details of these long term monitoring and discusses the long term performance of the geogrid and geotextile reinforcement in a reinforced earth structure.

2 OVERVIEW OF DESIGN CONCEPT

The subsoil condition of the foundation generally was treated to ensure the bearing capacity is sufficient to sustain the load from the structure. Soft unsuitable materials up to a depth of about 3m were removed from the base of the disused sewage treatment pond. These were replaced with selected compacted rockfill to form a stable rock toe.

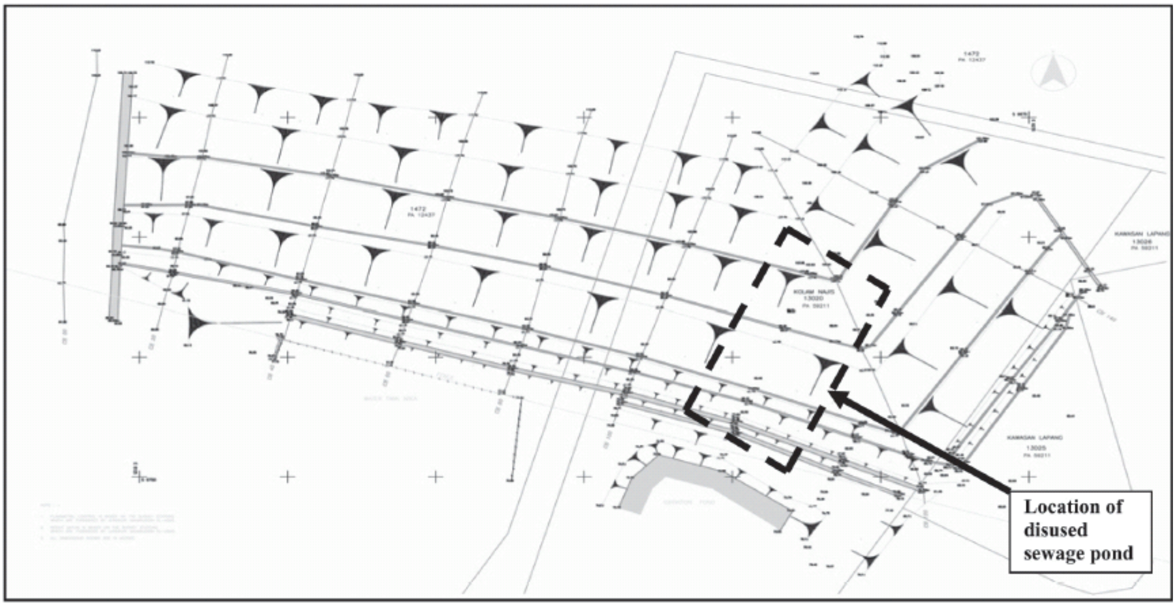

Figure 1: Layout of reinforced earth structure.

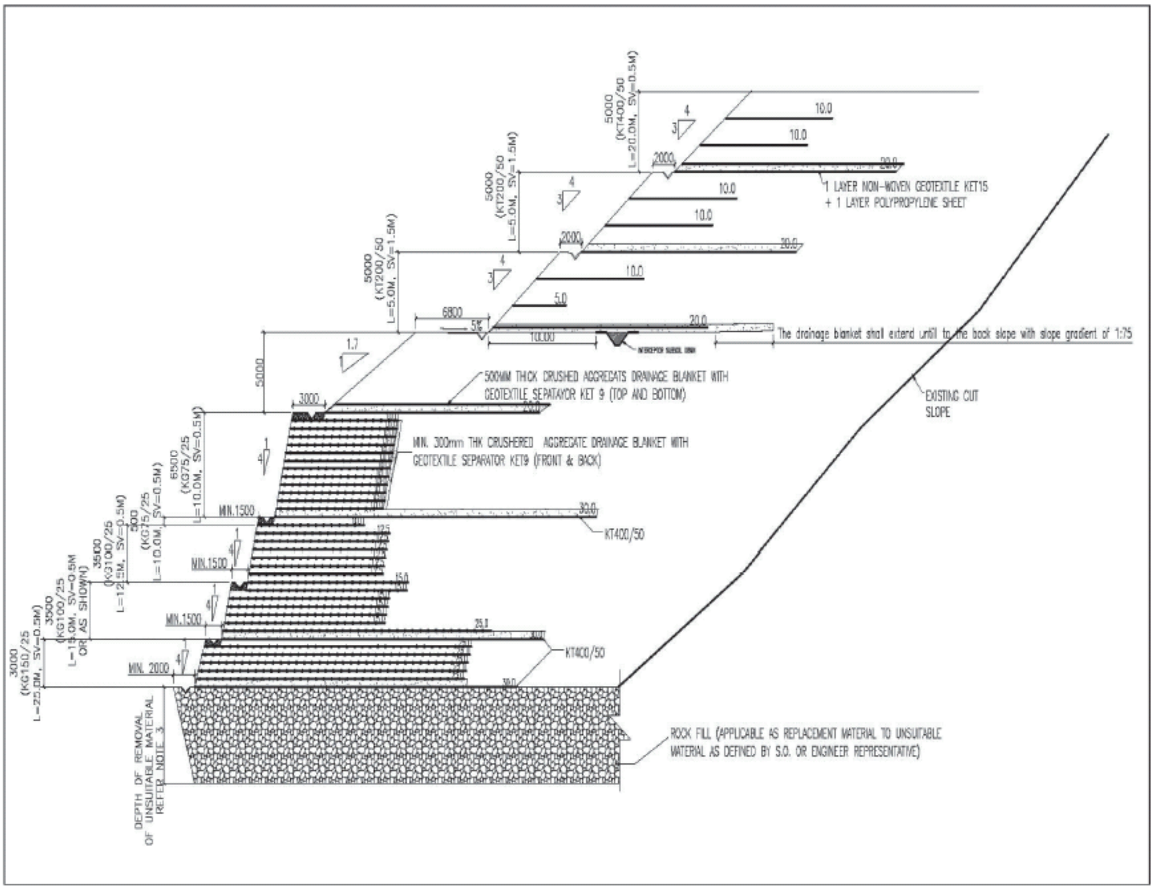

Figure 2: Typical cross detail of structure.

The design criteria calls a factor of safety against bearing failure to be not less than 2.0, based on lower bound shear strength, and the factor of safety against local and global failure to be not less than 1.4. Both the circular and translational modes of failure were investigated for the internal and global stability. The stability analysis was based on Bishop's Method of Slices.

Residual soils derived from the weathering of a granitic profile were used as fill material for the reinforced earth structure. Its composition comprise predominantly of clayey silty sand. Reasonably conservative shear strength values were adopted for the design. For well compacted fill of residual soils of granite and the retained soil layers, the effective cohesion (c') adopted was 5 kPa and the effective friction angle (ϕ')was 32°. For the foundation layer, the c' adopted was 0 kPa and the value of ϕ' adopted was 30°. The shear strength parameters of the fill material were verify by carrying out large shear box tests, with the shear box measuring 300mm x 300mm. This size of the shear box was used to take account of the maximum grain size of the soil particle of 10mm. Table 1 below provides a summary of the design parameters adopted.

High strength knitted geogrid and high strength woven polyester geotextile were used as reinforcements for the reinforced earth structure. Kiaratex high strength woven geotextile KT400/50 was laid in the founding layer of the structure. The ultimate tensile strength of this material was 400 kN/m, and the global reduction factor was 3. For the remaining geogrid layers KiaraGrid high strength knitted geogrids of various grades were used; these included geogrids of grades KG 75/25, KG 100/25, and KG 150/25. The long term design strength of the geogrids were investigated by carrying out SIM creep tests, the results of which indicated that the long term design strength of the material well exceeded 80% of its initial ultimate tensile strength. Table 2 below provides a summary of the design strength adopted for the various grades of woven geotextile and geogrids.

Table 1: Summary of design parameters adopted.

Stratum	Design Parameters		
	Effective Cohesion (kN/m^2)	Effective Friction Angle (deg)	Bulk Unit Weight (kN/m^3)
Well compacted fill	5	32	18
Retained layer	5	32	18
Foundation layer	0	30	20

Table 2: Design strength in woven geotextiles and geogrids.

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

Figures 3 and 4 show visuals of the completed structure. As shown in the figure the facing of the structure was hydroseeded.

Figure 3: A view of a completed section of the structure.


Figure 4: A view of another section of the completed structure.

3 RESULTS OF MONITORING

The monitoring system installed included inclinometers, surface settlement markers, and pneumatic piezometers. The piezometeric levels recorded indicate a stable piezometric level hovering at about the base of the structure, and will be discussed in this paper. The surface settlement markers recorded the settlement of the structure with most of the settlement recorded during the construction period. The post-construction monitoring of the settlement markers indicated that there is negligible settlement of the structure indicating that the compression of the fill occurred predominantly during the construction period. These measurements will not be discussed in this paper.

The inclinometer readings in the post-construction period were closely monitored up until March 2010. Figures 5 and 6 illustrate the position of these inclinometers on the structure. The inclinometer IN1 is sited at the 5^{th} berm of the structure, whereas inclinometers IN2, IN3 and IN4 were sited at the 6^{th} berm of the structure. Inclinometers IN5, IN6 and IN7 were disturbed after the completion of the construction works and hence monitoring of these instruments were not continued in the post-construction period.

The results of the monitoring of the inclinometers are illustrated in Figure 7. The post-construction monitoring extended over a 5-year period from 2005 to 2010.

4 DISCUSSIONS

The lateral displacement recorded ranged from 45mm to a maximum of 160mm. The maximum displacement was recorded on IN4 sited at Berm No. 6. This recorded displacement occurred at a depth of 3m below the berm level, which correspond to a layer of woven geotextile KT200/50 of a length of 100m (see Figure 2). The recorded maximum displacement corresponded to a strain of 0.16%, which is well below the maximum strain of 10%. The stability of the structure is observed to be acceptable. The rate of creep movement observed is negligible and within the limits of instrumentation error.

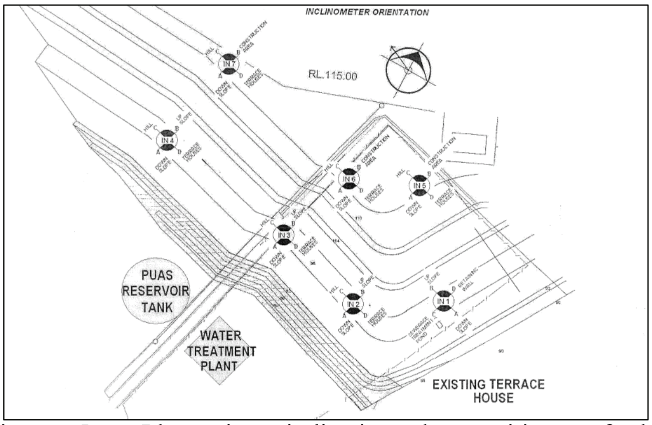

Figure 5: Plan view indicating the positions of the inclinometers.

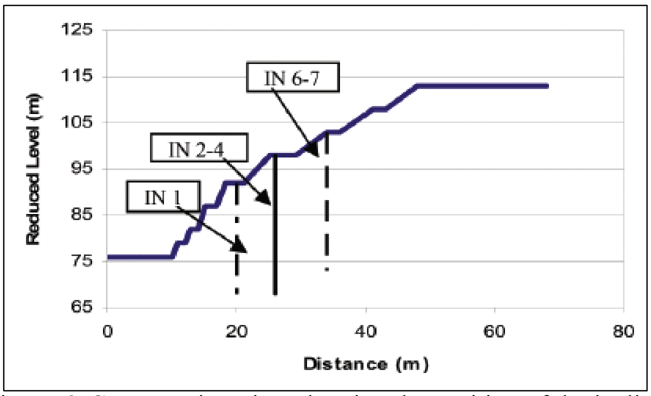

Figure 6: Cross section view showing the position of the inclinometers.

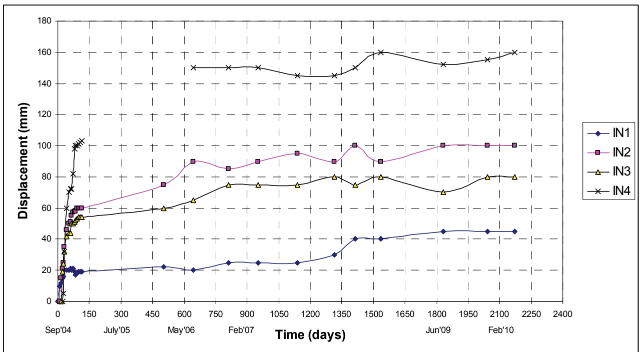

Figure 7: Monitoring Results of the Inclinometers.

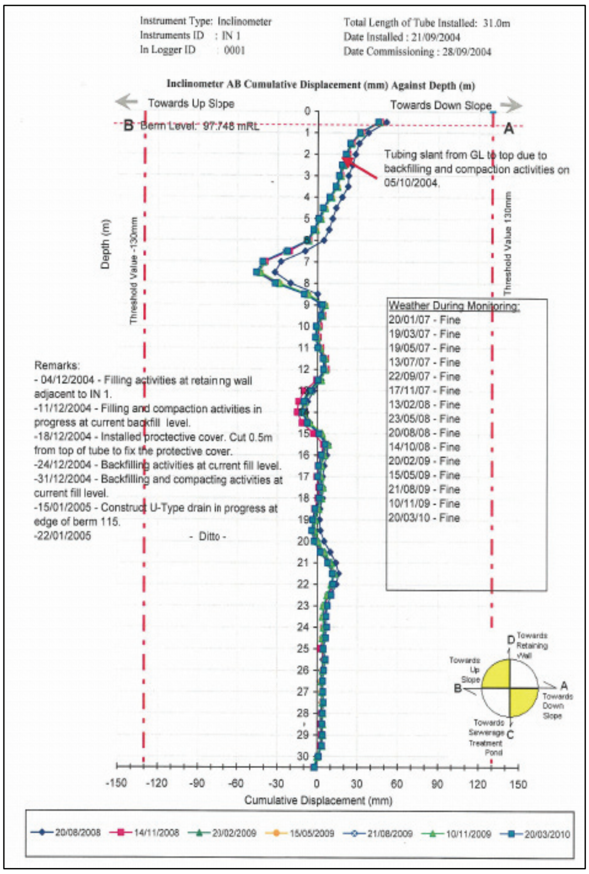

Figure 8a: Displacement readings from IN 1.

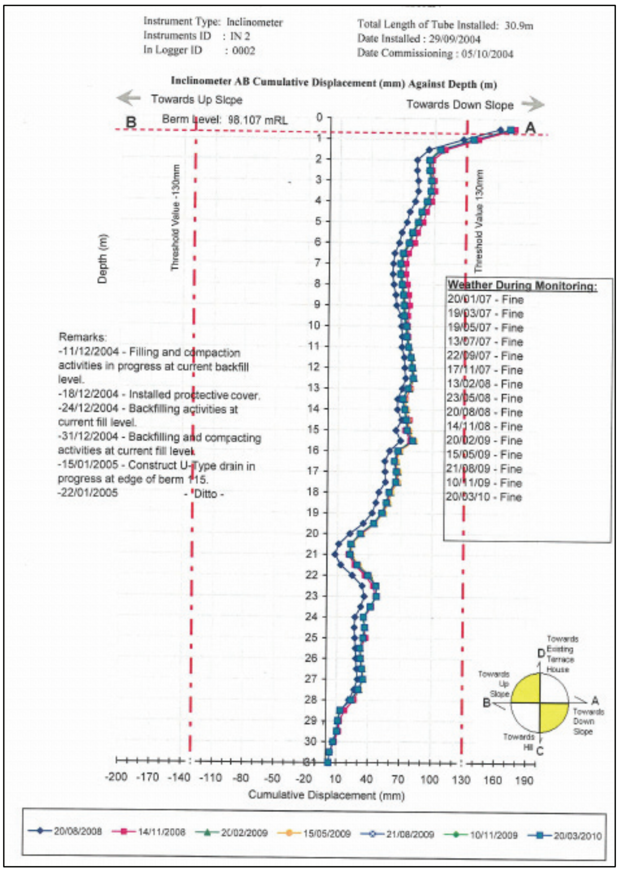

Figure 8b: Displacement readings from IN 2.

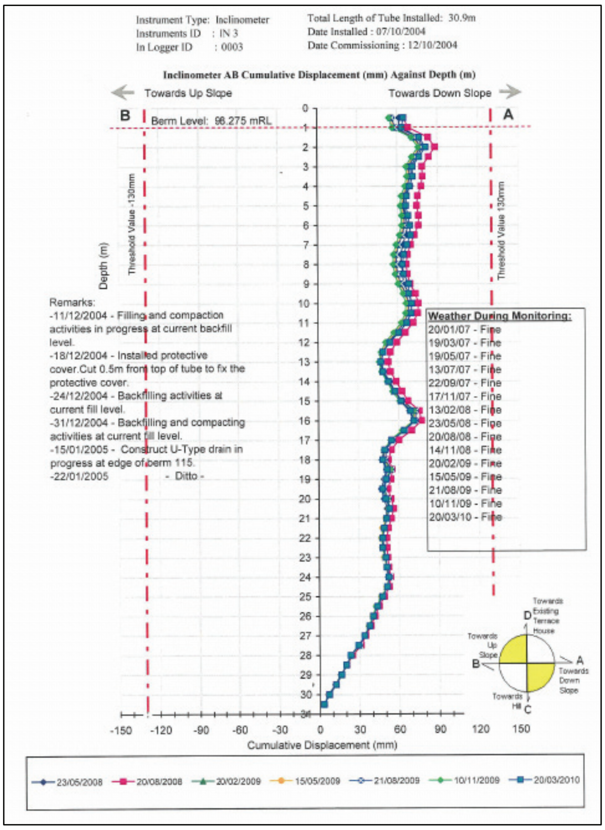

Figure 8c: Displacement readings from IN 3.

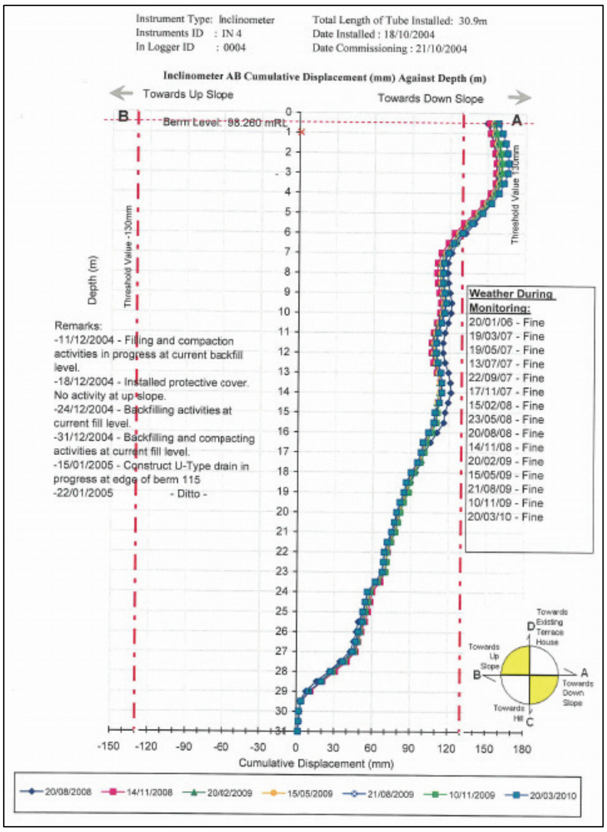

Figure 8d: Displacement readings from IN 4.

5 CONCLUSIONS

The construction of a 37m high reinforced soil structure over a disused sewage pond has been successfully executed. Instrumentation has been installed to monitor the displacement and pore pressure developments during the construction period and the monitoring was extended to cover an extended post-construction period of more than 5 years. The post-construction instrumentation has indicated that the structure is essentially stable and showed minimal lateral displacement with the maximum reinforcement strain of 0.16%.