Landmarks in Earth Reinforcement, Ochiai et al. (eds),
© 2001 Swets & Zeitlinger, ISBN 90 2651 863 3

A 12-m high geosynthetic-reinforced residual soil slope

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ABSTRACT: A 12-m high steep slope was to be cut in residual soil to make way for the construction of a new road in the Bukit Panjang district, Singapore. Numerous technical and environmental requirements imposed construction of a retaining structure for the resulting steep soil slope. Being in the vicinity of a nature park, the proposed structure should blend aesthetically with its environment. It, too, had to be inclined at about 60 degrees to create the needed space. Field instrumentation comprising total pressure cells, piezometers, standpipes, tensiometers, inclinometers and settlement devices were installed and monitored regularly. A large number of strain gauges were also installed on the geotextiles to monitor the strain development with construction and subsequent slope behavior. This paper presents the monitored construction, field pullout tests and preliminary short-term performance of the 12m high geosynthetics reinforced slope in residual soil.

1 INTRODUCTION

Geosynthetic-reinforced slope systems have become a popular choice over many traditional earth-retaining systems. Recent research (e.g. Rao et al., 2000; Koerner, 1998) has shown realization of substantial cost savings with geosynthetic-reinforced systems when compared with reinforced concrete wall systems especially for tall wall heights more than 3m. In this project, a 12m high slope inclined at about 60 degrees to the horizontal and spanning over a length of 60m was proposed in conjunction with a road widening project associated with a nature park.

A study conducted at the National University of Singapore (Chew et al., 1998) on the use of geotextiles in poorly draining residual soil revealed the feasibility of using composite geotextiles with adequate in-plane transmissivity to reinforce soil slopes in cohesive soils. Therefore, composite geotextiles with less-than-high-quality fill has a high potential for success.

In the current project the excavated in-situ residual soil was considered as backfill to save cost and endorse waste minimization, while encouraging plant growth for the nature park, which creates an aesthetically pleasing "green" slope, and minimal environmental impact.

In the course of construction, the geotextiles reinforcement as well as the soil slope was heavily instrumented for monitoring the behavior of the system during construction and in the long term. Field pullout tests were conducted and preliminary results from these observations are reported in this paper.

2 SITE DESCRIPTION

This project is situated in the Bukit Panjang district in Singapore (Figure 1) and the underlying soil profile is developed on *Bukit Timah Granite formation. Bukit Timah Granite* consists of igneous plutonic rocks, mainly granite, adamellite and granodiorite, while its top portion comprises heavily weathered residual soils. A thorough soil investigation was conducted prior to the commencement of the project. The soil borings revealed that the site consists of up to 3m of fill at the surface (RL 140.7m), a yellowish silty sand subsoil of about 6m, followed by 7m of reddish sandy silt with granite as the bedrock. The soil above the bedrock was considered to be residual soils evolved from weathering of granitic rock. In-

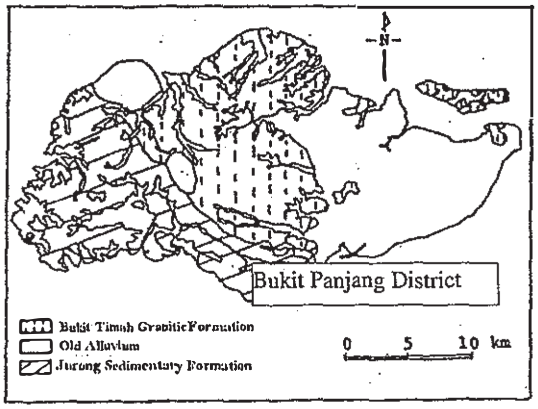

Figure 1. Geology of Singapore and the location of Bukit Panjang District.

stallation of standpipes showed that water level is found at a depth of about 9m (RL132m).

Table 1 summarizes the effective shear strength parameter (c' and ϕ') obtained from high quality consolidated drained test with undistributed soil samples.

Table 1. Soil and rock properties

Soil Type	Depth (m)	ϕ' (degrees)	Cohesion, c' (kPa).
Residual soil	0-3	Organic humus soil	
Silty sand	3-9	33	23
Sandy silt	9-11	34	18
	11-16	31	15
Granite	>16	--	--

3 CONSTRUCTION SEQUENCE

The designed slope, consisting of three 4m-high terraced reinforced slopes, is 12m in height, and spans over a length of 60m. The slope is 1(h): 2(v) with berms of 1.5m width. The reinforcement used was a composite material consisting of a mechanically bonded non-woven geotextile reinforced by a series of uni-directional high strength polyester yarns. Three different grades of geotextile are employed in this project. The geotextile Type C with the highest tensile strength (200kN/m) is used in the lowest terrace, Type B (150kN/m) in the middle terrace, and Type A (75kN/m) on the top. Each terrace has 7 layers of geotextiles installed at a spacing of 600mm. A sketch of the proposed slope is shown in Figure 2.

The existing slope was first excavated to level of the proposed road extension (RL 130.7). A filter drain with granite aggregates wrapped in a filter geotextile was then laid to grade with provision connection to an inclined filter at the back of the fill. The backfill was then placed and compacted with 60 Ton vibratory rollers. The backfill soil was compacted in lifts of 300mm to a minimum 90% dry density of modified AASHTO compaction test. After compaction, reinforcements were placed with the principal strength direction perpendicular to the face of the slope. This procedure was repeated for each successive layer of soil (See Figure 3). Around instruments lightweight compaction equipment was used to prevent damage. At the end of construction, instead of a face wrap, geosynthetics cells with turfing would be installed on the slope to minimize sloughing and erosion, and in addition to encourage greenery.

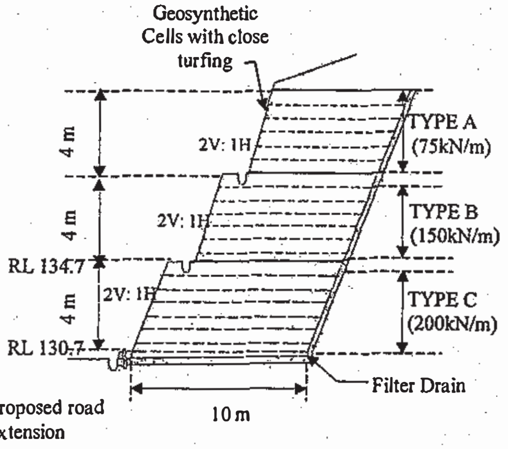

Figure 2. Schematic diagram of the proposed slope.

Throughout the construction process, precautions have been taken to ensure proper handling of geosynthetics during delivery, storage and construction. Quality control testing has been emphasized. Sensitive instrumentation including stain gauges mounted on the geotextiles would be protected from damage due to construction.

4 FIELD INSTRUMENTATION

In this project, an extensive array of field instruments for monitoring ground conditions were installed and monitored regularly. Total pressure cells, pneumatic piezometers, standpipes and tensiometers were used to monitor soil pressure and pore pressure in the reinforced soil slope.

Soil movements were captured with inclinometers and settlement plates. Furthermore, strain gauges also mounted onto the geotextiles to examine the strain development with construction and subsequent performance of the slope.

Not only does the strain measurement in the geotextile allow the evaluation of the geotextile performance, but it also provides an alternative method of assessing the behavior of the reinforced slope. A total of 146 post-yield large-strain electrical resistance gauges, capable of reading strains up to 20%,

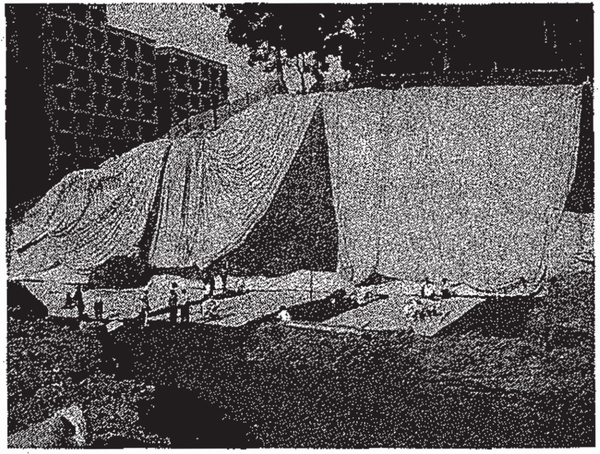

Figure 3. Laying of geotextiles at the base while protecting the cut slope in the front of the nature park.

were installed in the geotextile. The reliability of these gauges would depend on the effectiveness of the waterproofing barrier, the capacity to withstand construction stresses during backfilling and the installation technique.

5 FIELD PULLOUT TESTS

A series of field pullout tests were designed right from the outset of this project. Three pieces of geotextiles of 0.3 m wide and 3 m long were extensively instrumented with strain gauges and horizontal telltales, and were placed midway between two reinforcement layers. The main objective of this test was to evaluate the actual pullout capacity of the soil-geosynthetics interface. Many factors such as degree of compaction, soil properties, strain rate, in-situ water content and suction in the soil would affect this interface behavior. Hence, the interaction coefficients obtained from the in-situ tests can be used to evaluate the correlation between field and large-scale pullout tests conducted concurrently in the laboratory using the same soils and reinforcements. The three series of pullout tests conducted covered the soil at its relatively dry condition (with back filter drain working properly) as well as the soil subjected to adverse ponding condition simulating clogged up inclined filter drain during the lifetime of the slope. All the field pullout tests were conducted with an overburden of about 2.5 m of backfill soil above the test pieces. A pullout resistance at this small overburden pressure will thus yield a conservative estimate of the ultimate capacity under actual site conditions where the overburden will be much larger.

6 RESULTS

The construction of the wall is progressing at the time of this publication with the first terrace of 4m constructed and the three pullout tests completed. Therefore, the results presented here will be based on the progress made up to this stage.

In the tropical climate of Singapore, one of the biggest concerns in slope construction is the high rainfall intensity and water table. Especially in this reinforced slope project where poorly draining residual soil is used, rainfall and groundwater are likely to pose a problem in terms of slope stability during and after construction. After the first 4m-high terrace was built, the slope experienced the tropical monsoon for 2 moths amounting to a rainfall of about 835mm. With the objective of studying the effect of excessive rainfall and high groundwater on the reinforced slope throughout this period, all instruments were monitored regularly.

Behind the reinforced slope, a water standpipe installed to a depth RL124.4 registered no water initially but after 2 months, water rose to 7.4m to RL131.8 where the base level of the slope is at RL130.7. Within the geosynthetics reinforced slope, no water had been registered throughout the entire 2-month period. This would probably be due to the effective drainage system that was constructed behind the slope. A total of 9 piezometers, pneumatic and vibrating wire type, installed at several levels all registered 0 kPa. However, tensiometers recorded an initial average reading of about 18 kPa of suction, which gradually increased to about 34 kPa of suction in the first month where weather was still relatively dry. At the end of the second month, the tensiometers registered about 23 kPa of suction.

Settlement plates were placed to monitor the vertical displacement of the 4m terrace. An average of 8mm settlement was recorded during construction. The inclinometer behind the slope registered a movement of 20mm over the entire construction period of approximately 3 months. The inclinometers within the reinforced slope had registered about 5mm. These movements were within the allowable limits.

Total pressure cells were placed at 2 levels in the reinforced slope. The total pressure cells at RL131.6, with an overburden of 3.1m of surcharge upon completion of the 4m terrace, registered 24 kPa, whereas at RL132.1, with a surcharge of 2.6m registered 36 kPa. One possible explanation for this phenomenon where the total pressure cells at a lower level (with a higher surcharge) registered a lower pressure than one at a higher level (with a lower surcharge), could be due to the non-uniform compaction of the soil at these two locations if not for the differences in soil stiffness. Due to the presence tensiometers and pore pressure transducers near the area where the total pressure cells are located, hand held roller compactor was employed which hindered proper compaction as compared with pneumatic rollers.

The results obtained from the strain gauges are presented in Figure 4. Only selective layers of geotextile had been instrumented. It can be seen that the lower layers of geotextile experienced a higher strain increment where the maximum force was about 62 kN/m. Maximum strain occurred at about 2~4m from the face of the slope. The potential failure plane would follow the locus of the peak strain across the geotextile layers.

Field pullout tests showed that 0.3m wide test specimens registered a displacement up to a distance of 1500mm within the soil slope. The maximum pullout loads exerted at the pullout clamp are found to be 70 kN and 55 kN for dry and wet conditions of soil respectively. A more complete analysis of these tests is out of the scope of this paper.

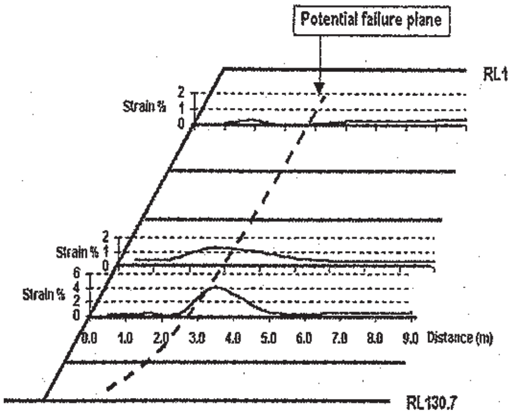

Figure 4. Strain development across geotextile

7 CONCLUSIONS

Despite the partial completion of the project, several conclusions could be drawn from the instrumentation and pullout tests. From the two months of intensive tropical rainfall, the usage of non-free-draining fills, which was a major concern since the dissipation of pore pressure is critical in slope stability, did not affect the pore pressure build up unnecessarily. When a geotextile reinforcement with high in-plane permeability is deployed together with a filter drain at the back of the slope, problems of high ground water could be alleviated. This observation is supported by the reasonably low pore pressure readings from the tensiometers throughout the entire two-month period.

The trend in the strain developed in the geotextile yields not only the force experienced in the geotextile (essential in assessing the breakage capacity of the geotextile); it is also a good indicator of the potential failure plane of the slope.

A sub-objective of this project is also to study the long-term survivability of the electrical resistance gauges. Generally, strain gauges in the field do not last for a substantially long period. The survivability of the strain gauges depends significantly on the installation technique (which will determine the effectiveness of the moisture barrier and adhesive) and the level of construction stresses. An improved technique from the strain gauging technique proposed by Chew et al. (1999) had been adopted in this project. To date, 90% of the gauges had survived the three months of construction period.

Preliminary pullout tests at low overburden pressure demonstrated that the pullout capacities not less than 233 kN/m and 183 kN/m can be realized with a 3m long geotextile for dry and 80% saturated residual soil respectively. The high strength and permeable geotextiles should be used in such soils.

8 ACKNOWLEDGEMENTS

The co-operation of Wee Poh Construction Co (Pte) Ltd, the main contractor, in carrying out the construction, instrumentation and pullout tests for the project is gratefully acknowledged. Assistance given by the specialist contractor Presscrete Engineering Pte Ltd for the successful pullout test is also acknowledged.

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