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Field performance and pullout tests of geosynthetics reinforced soil slope using residual soil in Singapore

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ABSTRACT: A geosynthetics reinforced soil slope was built for the repairing of a failed slope at Bukit Batok district in Singapore. This slope is adjacent to a proposed high-rise housing development. The implication of further slope failure, if any, is very serious in this case. Efforts were also made to maintain the environmental friendliness of the slope such that it will then blend well with the natural park nearby as well as providing a "green" environment for the residents. Thus, the proposed solution consists of a series of 3-tier slope of 1V:3H with geotextile reinforcement. The maximum height of the slope is about 21.5 m and in-situ poorly draining residual soil is used as the backfill material as free draining importing sand as fill material is too costly. Layers of high strength composite geotextile with high in-plane permeability are then needed as not only reinforcement function but also drainage function has to be provided in such a poorly draining soil. Extensive instruments were installed to monitor not only the construction stage but also the long term performance of the repaired slope. In addition, the actual in-situ interface properties between the geosynthetics and the backfill soil were evaluated by performing field pullout tests. This paper will focus on the field performance of the slope during the 2 years after construction. The soil-geosynthetics interaction of geotextile and geogrid in residual backfill soil was investigated using a series of field pullout tests.

1 INTRODUCTION

A geosynthetics reinforced soil slope was built with the intention of repairing a failed slope at Bukit Batok district in Singapore. The slope consisted of a heterogeneous mixture of residual soil and loose rock fragments from granite rock blasting operation in the past. The slope used to displace emerging water springs due to high water in the upstream of the slope fed by a pond. The failure of the slope had been a recurrent feature during the monsoon periods. The total height of the repaired slope was about 21.5 m.

This slope is adjacent to a proposed high-rise housing development. The implication of further slope failure, if any, is very serious in this case, hence, the proposed solution must possess high factor of safety with a large degree of redundancy. Efforts were also made to maintain the environmental friendliness of the slope such that it will then blend well with the natural park nearby as well as providing a "green" environment for the residents. Thus, the proposed solution consists of a series of 3-tier slope of 1V:3H with geotextile reinforcement. The lower 2 tiers were also constructed with a 1 m height modular block facing wall.

The maximum height of the slope is about 21.5 m and in-situ poorly draining residual soil is used as the backfill material. Importing sand as fill material will make the project too costly. Layers of high strength composite geotextile with high in-plane permeability are then needed as not only reinforcement function but also drainage function has to be provided in such a poorly draining soil.

The consolidated-drained (CD) test results of the residual soil shows that the soil friction angle, ø equals to 36° and the soil cohesion, c equals to 6 kPa. The silt and clay content of the residual soil is about 45%. Its average bulk density is 21.0 kN/m^3 and its in-situ moisture content is 20%. The main tensile strength of the geotextile in its machine direction is 200 kN/m and in its cross machine direction is 14 kN/m.

2 SLOPE MONITORING SYSTEM

As this slope is very important, extensive instruments were installed to monitor not only the construction stage but also the long term performance of the repaired slope. Seven types of instruments have been installed for real time monitoring. They are resistance type strain gauge, vibrating wire strain gauge, pore pressure transducer, total pressure cell, tensiometer, piezometer and in-place inclinometer. They were installed and connected to the 3 data loggers which are collecting the real-time data triggered by the computer program (shown in Figure 1 and Figure 2). Except these, fiber optic type strain gauges were also installed to monitor the slope performance (shown in Figure 3).

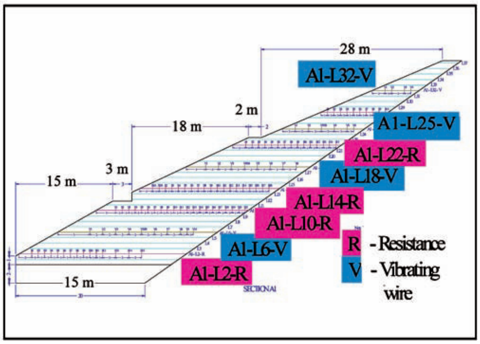

Figure 1. Instrumentation section 1 – Resistance and vibrating wire types strain gauges.

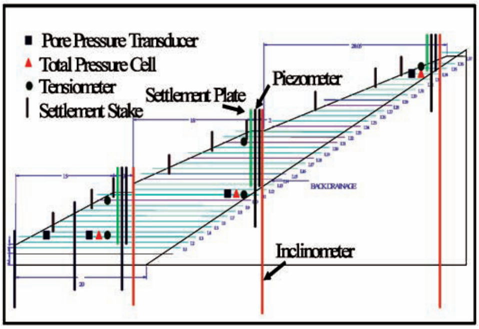

Figure 2. Instrumentation section 2.

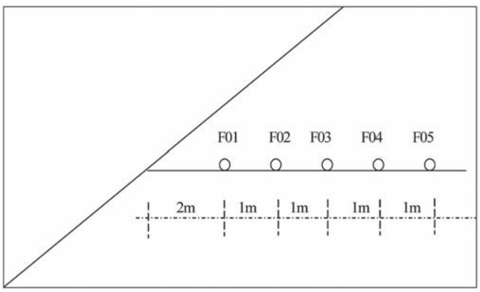

Figure 3. Instrumentation section 3 – Fibre optic type strain gauges.

3 SLOPE PERFORMANCE

In this project, two sections of slope had a single layer geotextile being installed with fibre optic type strain gauges. Since the slope had been designed to high factor of safety, high strain was not expected. Figure 3 shows the location of the fibre optic strain gauges. By referring to Figure 4, it is seen that the strain registered is lower than 1%. Nevertheless, the results show that fibre optic type strain gauge is a feasible alternative to resistance and vibrating wire types strain gauges.

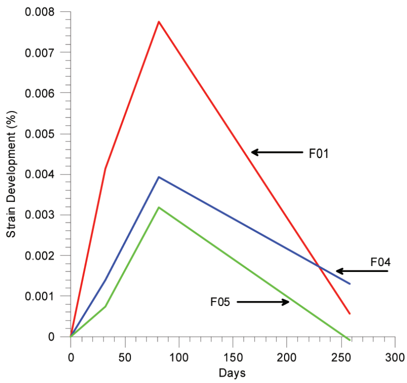

Figure 4. Strain development for fibre optic type strain gauge for section 1 slope.

4 FIELD PULLOUT TESTS PERFORMED

One of the major design considerations for geosynthetics reinforced soil slopes is the interface properties between the geosynthetics and the backfill soil. These interface properties ideally should be obtained by performing field pullout tests. As geotextile and geogrid behave differently in reinforced soil slope, two types of field pullout tests were performed for these two materials.

As geosynthetics behave differently in "dry" and "wet" soil condition in reinforced soil slope, field pullout tests were also performed in "dry" condition (soil with at in-situ moisture content), and in "wet" condition which simulates the ponded condition where the slope would experience tropical rainfall and possible mal-functioning of back drainage.

The width and length of the test pieces were 0.5 m and 2.15 m respectively. The embedded length was 1.65 m and the height of the surcharge at the test location was 2 m.

The pullout test system consisted of a high-precision pulling machine, a special clamping device, supporting frame and a telltale setup. The pullout machine is a hydraulically powered system which could provide a pull at a slow but high precision constant rate as low as 1 mm/min throughout the duration of the test. A special clamping device was designed and constructed following pullout tests of Chew et al. (2002).

An extensive set of instruments were installed in the soil and on the geotextile or geogrid test pieces to capture the behaviour and mechanism of the geosynthetics during the pullout test.

In this paper, Test-F1 (geotextile in "dry" condition) and Test-F2 (geotextile in "wet' condition) will be discussed. The typical recordings from the instrumentation will also be presented.

5 FIELD PULLOUT TEST RESULTS AND DISCUSSION

5.1 *The interface property*

Soil-geosynthetics interface friction angle, δ can be calculated from the Mohr-Coulomb stress equation:

$$\tau = \sigma' \tan \delta + c \tag{1}$$

Where τ is the pullout shear stress, σ' is the effective normal stress at soil-geosynthetics interface, δ is the soil-geosynthetics friction angle and c is the soil-geosynthetics cohesion. By substituting $\tau = F/2A$ into Equation (1), Equation (2) is obtained:

$$F = 2\,A(\sigma' \tan \delta + c) \tag{2}$$

Where F is the pullout force and A is the area of geosynthetics embedded in soil.

The effective stress, $\sigma' = \sigma - u$. The total stress, σ and the pore water pressure, u were measured during the tests.

Figure 5 shows the stress development of Test-*F*1. At the start of the test, TPC1, TPC3 and TPC4 recorded 69.50 kPa, 43.99 kPa and 56.34 kPa respectively. The reading of TPC2 is not taken into account as it seems illogical.

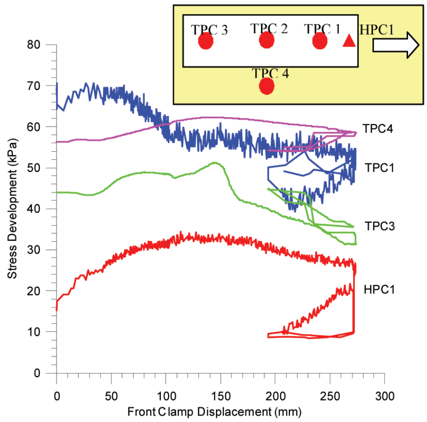

Figure 5. Stress development versus front clamp displacement, Test-F1.

The peak pullout force obtained for Test-F1 is 43.31 kN. The soil cohesion c obtained from triaxial tests is 6 kPa. Cohesion of soil-geotextile interface is assumed to be 6 kPa also. During the pullout test, the soil is sheared. This results the soil to dilate and brings changes to the effective stress. It can be seen in the changes of vertical pressure and pore pressure. When the peak pullout force occurred, TPC1, TPC3 and TPC4 registered 57.23 kPa, 50.41 kPa and 62.27 kPa respectively. As for the calculations of soil-geotextile interface properties, the average total pressure 55.63 kPa is used. Therefore, with soil suction of 2 kPa, peak pullout force of 43.31 kN and c to be 6 kPa, the friction angle at the occurrence of peak pullout force, δ obtained is 19.4°.

Figure 6 shows the stress development versus clamp displacement curves of Test-F2. At the beginning of the pullout test, TPC2, TPC3 and TPC4 captured the total vertical pressure as 46.22 kPa, 53.33 kPa and 46.10 kPa respectively. TPC1 recorded unusual low pressure which is not making sense. Thus, TPC1 readings are discarded.

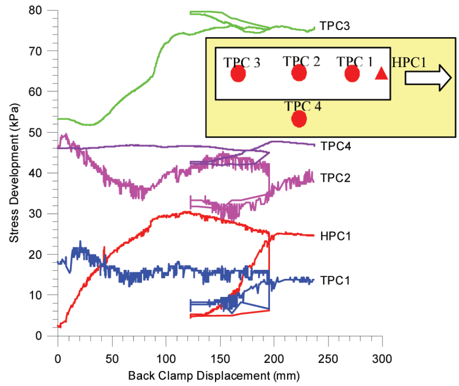

Figure 6. Stress development versus front clamp displacement, Test-F2.

Pore pressure 5.74 kPa was recorded at the occurrence of peak pullout force. The peak pullout force achieved for this geotextile "wet" test is 31.25 kN. As for the "wet" test, the effective cohesion, c is assumed to be 6 kPa. At the peak pullout force, TPC2 and TPC3 recorded 40.75 kPa and 74.12 kPa respectively. As for the computations of soil-geotextile interface properties, the average total pressure of 55.63 kPa is used. Thus the friction angle δ at the occurrence of peak pullout force was calculated to be 14.5°.

TPC4 registered 46.62 kPa at the peak pullout force. This is not much different from 46.10 kPa that TPC4 measured at the start of the pullout test. This shows that TPC4 that is located outside of the geotextile test piece is not affected by the process of the pullout test.

Kharchafi & Dysli (1993) showed that the interface friction angle between non-woven geotextile and silt was 17.8°. Test-F1 was conducted between composite geotextile and residual soil. The silt and clay content of the residual soil is as high as 46%. Therefore, the interface friction angle of Test-F1 can be compared to that of Kharchafi & Dysli (1993). The interface friction angle of 19.4° of TestF1 is quite matching with what was obtained by Kharchafi & Dysli (1993). Hence, the major contribution of friction is borne by the non-woven portion of the geotextile.

In order to study the effect of different backfill soil conditions, i.e. in "dry" and "wet" soil conditions, Test-F1 and F2 are compared. The effective stress, σ' of Test-F2 is lower than that of Test-F1 because the soil of Test-F2 has high excess pore water pressure. Consequently, the pullout force achieved by Test-F2 is lower than that of Test-F1. The geotextile in "wet" soil condition could retain about 72% of the pullout force of geotextile in "dry" soil condition. The soil-geotextile interface friction angle, δ of Test-F2 is lower than that of Test-F1. This is because the backfill soil of Test-F2 has softened. However, the geotextile in "wet" soil condition could still retain more than 70% of its pullout resistance because of this particular type of geotextile has high in-plane drainage capability.

Table 1 shows the summary of the soil-geosynthetics interface friction angles, δ calculated for the field pullout tests.

Table 1. Summary of field soil-geosynthetics interface.

Test	F (kN)	A(m^2)	σ'(kPa)	Δ	δ/ϕ
F1	43.31	1.65	57.63	19.4°	0.53
F2	31.25	1.65	49.89	14.5°	0.40

6 CONCLUSIONS

A 21.5 m height failed slope was repaired by a geotextile reinforced slope. The residual soil which has high silt and clay content was used as backfill material. The repair work was successfully conducted and a wide variety of instruments were installed to monitor the performance of the slope during the construction period and as well as in the long term. During the last two years, the data recorded show that the slope had very small deformations.

Large scale field pullout tests were conducted to investigate the geotextile-soil interface property. The tests were conducted in both "dry" and "wet" soil conditions. For the geotextile in "dry" condition, the peak friction angle δ obtained is 19.4°. For geotextile in "wet" condition, the peak friction angle δ obtained is 14.5°. The geotextile in "wet" soil condition could still retain more than 70% of its pullout resistance because of this particular type of geotextile has high in-plane drainage capability.

It was also found that the major contribution of friction between geotextile and soil is borne by the non-woven portion of the composite geotextile.

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