Design and Construction of A12m High Reinforced Soil Segmental Retaining Wall for Hillside Development: A Malaysian Perspective

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ABSTRACT: Reinforced soil segmental retaining wall system has gained popularity in hillside luxury end property development against the conventional rigid retaining wall system in Malaysia. This system was chosen because of the fascia aesthetics and also the wall can be designed to meet stringent engineering standards with construction efficiency and cost advantages. The geosynthetics reinforcement used for the wall reinforcement consisted of a composite continuous filament fiber nonwoven geotextile reinforced with high tenacity polyester yarns. The nonwoven component provides in plane drainage capacity while the high tenacity polyester yarns provide tensile strength. An important highlight of this paper is the wall design methodology according to NCMA (National Concrete Masonary Association Method) and large scale pullout tests carried out on the geotextile reinforcement in poor drainage soil.

1 INTRODUCTION

Moonlight Bay is a luxury end, gated property development on Penang Island in Malaysia. The development consists of condominiums and exclusive villas blended into the hill slope with breathtaking sea views of the renowned Batu Ferringhi beaches and the Andaman Sea. Moonlight Bay can be described as a terraced development conforming to the existing hill slope with minimized earthworks. An access road snakes its way up the hill side climbing gently along the contours of the slope while hairpin turns at specific locations. In this way, the environmental impact is optimized while the geotechnical stability of the hill side development is ensured.

A series of retaining walls are designed for the road carriageway. The villas are then built in-between rows of road beside the retaining walls. As this is luxury end property development, wall aesthetics is a very important consideration. Reinforced soil segmental retaining wall system was chosen for this development for very compelling reasons. The fascia gives very good aesthetics while the wall can be de sign with soil reinforcements to meet stringent engineering standards and practice.

Steep cuts have to be made into the existing slope to accommodate the construction of the retaining walls.

Being in the tropics where rainfalls are frequent and intense it is important to keep the time exposure of the temporary steep cuts to a minimum. Conventional reinforced concrete wall systems are time consuming because it requires onsite formwork erection, steel reinforcement assembly, casting and curing of concrete and formwork removal before backfilling. Another important advantage of the reinforced soil segmental wall system is that the temporary steep cuts exposure can be kept to a minimum as components like concrete fascia units and soil reinforcements are manufactured offsite and backfilling as the wall is built.

Figure 1: Existing site contour after site clearing.

2 SOIL INVESTIGATION

In the proposed site, 15 numbers of boreholes was carried out to indentify the ground condition. From the soil investigation result, it shows that the major hill slope profile consist layers of medium dense to very dense silty SAND and stiff to hard sandy SILT. This soil is the weathering product of its parental granitic rock, thus it is not uncommon the original relics texture of the rock components still visible in the soil matrix. These soil layers often found containing traces of gravels. A layer of Completely Decomposed Granite or CDG containing very dense (N>50) mixture of silt, sand and gravel formed at the bottom-most level in contact with rock deposit. The thickness of this soil formation varies from 1.5m to 15m depth. The granitic residual soil has effective shear strength mean properties of friction angle of 28^o and cohesion of 8 kN/m^2. The composition of gravel and sand ratio average at 72% while silt and clay are 24% and 4% respectively.

3 EVALUATION OF REINFORCED SOIL WALL SYSTEM

3.1 *Allowable tensile strength of composite geotextile reinforcement*

Reinforcing composite geotextile consisting of high tenacity polyester yarns and continuous filament nonwoven geotextile. The high tenacity yarns provide the tensile strength required for the reinforcement while the nonwoven geotextile facilitates in plane drainage and optimum reinforcement soil friction interface. The nonwoven also provide a/protection to the polyester reinforcing yarns against installation damage and UV. Due to the composite nature of the geotextile, reinforcing composite geotextile is suitable for the reinforcement of both poor draining and granular soils.

To use reinforcing composite geotextile in long term soil reinforcement application an assessment of their load carrying capabilities is required. Several assessment procedures are in practice, each adopting the use of the partial factor approach to describe the behaviour of the reinforcement material over time under specific load and environment regimes. The procedures adopted for reinforcing composite geotextile is compatible with the procedures adopted by various national codes of practice such as the US Federal Highway of Administration, the British Code of Practice BS 8006: 1995 and the Australian Standard. The procedure utilizes the following partial factor approach to determine the long term design strengths for the reinforcement materials at different design life:

$$T_d = \frac{T_c}{f_c\, f_d\, f_e\, f_m} \qquad (1)$$

where,

T_d is the long term design strength of the reinforcement at the required design life,

T_c is the characteristic short term tensile strength of the reinforcement,

f_c is the partial factor relating to creep effects over the required design life of the reinforcement,

f_d is the partial factor relating to the installation damage of the reinforcement,

f_e is the partial factor relating to environmental effects on the reinforcement,

f_m is the partial factor relating to consistency of manufacture of the reinforcement

In order to justify the allowable long-term design strength of the reinforcing composite geotextile various tests such as durability test, field installation damage test and creep test had been carried out.

3.2 *Segmental blocks facing unit*

The facing system is a mortarless, stackable, concrete block retaining wall system. The dimensions of the segmental blocks unit are approximately 203mm height, 457mm length and 304mm width with a unit weight of 34kg/block. The compressive strength required for the segmental blocks unit at 28 days is 20MPa. The hollow cores in the block are infilled with 20mm single size aggregate for free draining properties and higher interlocking properties between the block and reinforcing composite geotextile. The patented interlocking lip automatically locks each row of blocks in place as they are stacked. With mortarless construction technique, the segmental block requires no grouting, no mortar and no concrete footing. The inherent benefits include site adaptability, easy installation and lower cost.

The hollow core design combines with mortarless construction to allow water to drain freely from behind the wall. A vertical “drained field” is formed by layer of crusher rock placed behind the rock and in the blocks cores. Water moves easily down through the drained field. The dry-stacked construction technique allows the water to escape by flowing around the blocks and out of the wall surface. This built-in drainage system prevents any major build-up of hydrostatic pressure.

4 DESIGN AND ANALYSIS

The design of the segmental retaining wall requires two different analyses namely the wall stability and global stability. The recommended minimum factors of safety for reinforced soil segmental retaining wall specified by NCMA are given in Table 1 and Table 2.

Table 1: External stability factors of safety.

Mode of failure	Factor of safety
Base sliding	1.5
Overturning	2.0
Bearing	2.0
Global	1.3-1.5

Table 2: Wall internal stability factors of safety.

Mode of failure	Factor of safety
Tensile overstress	1.0
Pullout	1.5
Facing connection capacity	1.5
Interface shear capacity	1.5

4.1 *Wall stability*

Simac et al (1993) reported that the wall stability mode of failure (Figure 2) can be divided into:

- External stability
- Internal stability
- Local stability
- Global stability

4.1.1 *External stability*

External stability analysis examines the stability of the facing units and reinforced soil zone with respect to active earth forces generated by the self-weight of the retained soil and distributed surcharge pressures beyond the reinforced zone. These analyses determine the minimum length L of the geosynthetics reinforcement by checking:

4.1.1.1 Base sliding

This is related to the outward movement along the base of the reinforced soil mass due to insufficient shear resistance in the soil.

4.1.1.2 Overturning

Rotation of the reinforced soil mass about the toe of the wall.

4.1.1.3 Bearing capacity

The bearing imposed by a reinforced soil structure should be compared with the ultimate bearing capacity of the foundation soil and the factor of safety is 2.

4.1.2 *Internal stability*

This is related to the effectiveness of the geosynthetic reinforcement in holding the reinforced soil mass together. The internal stability analyses determine the minimum tensile strength, number and vertical spacing of reinforcement layers by checking:

4.1.2.1 Tensile stress

This is to ensure that the geosynthetic reinforcement does not exceed the product allowable working stress.

4.1.2.2 Pullout

According to NCMA, the recommended minimum factor of safety for pullout is 1.5.

4.1.2.3 Internal sliding

Geosynthetic reinforcement layers may create preferred plane of sliding at elevations along the height of the wall.

4.1.3 *Local stability*

The local stability analysis limits the vertical spacing of geosynthetic reinforcement by checking:

4.1.3.1 Facing connection

This is to check the integrity of the composite system. Both the connection strength and the serviceability capacity of the segmental blocks – reinforcing geotextile are checked. The allowable tensile strength of the reinforcing geotextile must be greater or equal than the connection strength / serviceability capacity and LTDS developed.

Allowable tensile strength ≥ connection strength / 1.5 = serviceability capacity = LTDS

4.1.3.2 Bulging

The vertical spacing of geosynthetics reinforcement layers must be restricted and the interface shear capacity between units must be adequate to prevent excessive shear deformation.

4.2 *Global stability*

Stability analysis study was carried out to ensure the global stability of the reinforced soil structure. Global stability analysis was performed by Slope-W computer program using Morgenstern Price method.

5 CONSTRUCTION METHODOLOGY FOR REINFORCED SOIL SEGMENTAL RETAINING WALL

Mackintosh probe at every 10m to 15m spacing was carried out along the alignment of the proposed wall

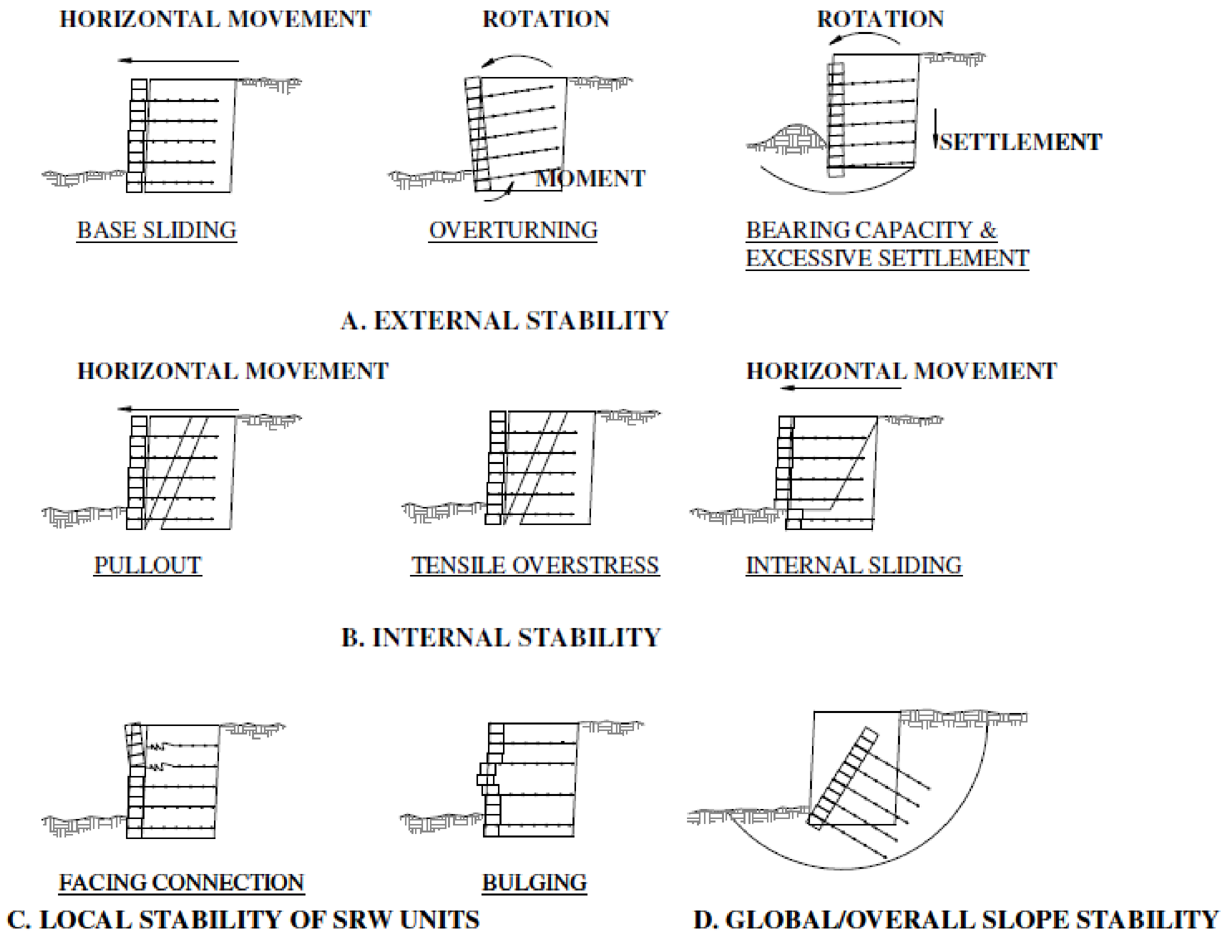

Figure 2: Modes of failure (adapted from Simac et al. 1993).

to ensure that the bearing capacity of the underlying soil is greater than pressure of the wall before excavation for the base of the wall. Soil treatment was required for the underlying soil with MP<80 blows. Ground replacement method with well compacted granular fill and reinforced with reinforcing geotextile was adopted in this proposed site.

The minimum embedment depth required for the reinforced soil segmental wall is 0.45m and increases according to the wall height and site condition. The first roll of segmental blocks was installed on top of the minimum 150mm thick granular fill leveling pad with the aid of a leveling rule and a string for the wall alignment. The hollow cores in the block are infilled with 20mm single size aggregate for free draining properties and higher interlocking properties between the block and reinforcing composite geotextile. To eliminate the problem of the blocks movement during compaction, a layer of 0.3m thick aggregate blanket was installed behind the blocks and it also permits free drainage of water through the blocks.

The composite reinforcing geotextile was installed at the required elevation as per in the construction drawing. The composite reinforcing geotextile is placed on top of the segmental blocks and the patented interlocking lip automatically locks each row of the blocks in place as they are stacked. The composite reinforcing geotextile are then pulled toward the end to the required anchorage length and pretension prior to soil backfilling placement.

The granular fill material which consists of granular and coarse sand are spread on top of the composite reinforcing geotextile and compacted in lift height of maximum 0.3m. To minimize movement of the segmental block during compaction, plate compactor was used to compact the backfilling material less than 1m from the edge of the wall. For the rest of the reinforced zone area, compaction can be done by using a minimum 1 ton roller compacter. Subsequent layers of the blocks, composite reinforcing geotextile and backfilling was installed till the full height of the wall was achieved.

6 LABORATORY IN-PLANE DRAINAGE TEST AND LARGE SCALE PULLOUT TEST

In-plane drainage and large scale pullout test was carried out to verified the properties of the geotextile composite reinforcement when subjected to full water saturation soil as Penang Island is subjected to heavy rainfall intensity during the month of Nov.-Dec.

Figure 3: Ground replacement with well compacted granular fill and reinforced with composite reinforcing geotextile.

Figure 4: Installation of the composite reinforcing geotextile.

Figure 5: Construction of the reinforced soil segmental wall in progress.

Figure 6: Overview of completed reinforced segmental retaining wall.

6.1 *Laboratory in-plane drainage test*

The pullout capacity of high strength composite geotextile in residual soils had been investigated and the results have shown good pull-out resistance provided by the geotextile even at fully saturated soil condition compared to that at in-situ moisture content at compaction (Chew et al., 1998). The test result indicated that while the average strength of the soil reduced almost 75% at saturated condition, the reduction of peak pull-out strength recorded was only about 16% when tested in saturated soil condition.

The ability of the geotextile to maintain adequate pull-out resistance under saturated soil condition was attributed to it ability to drain water in the plane of the geotextile as shown by pore water pressure transducers placed at different locations during the pull-out test. At some 15cm away from the geotextile layer, excess pore water pressure was recorded while at the interface of the geotextile, pore water pressure was negligible.

Laboratory seepage flow and consolidation tests were carried out to evaluate the drainage capability of the high strength geotextiles embedded in residual soil. Figure 7 shows the set-up and the schematic diagram of the test apparatus. The set-up allowed uniform surcharge loading to be applied at the top by means of a hydraulic jack loader. The tests were conducted by first ponding the soil surface to allow infiltration of water into the soil and subsequently apply different surcharge loading in stages.

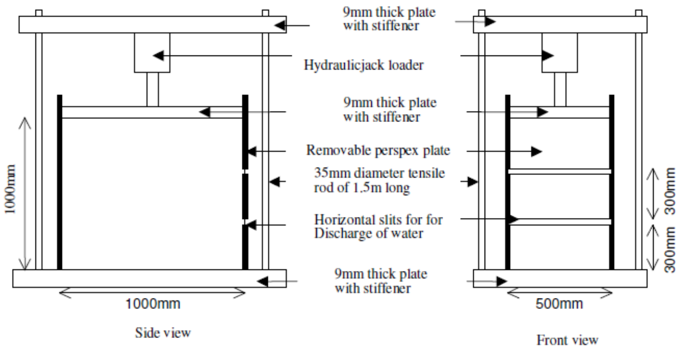

Figure 7: Test apparatus and schematic diagram.

Figure 8 shows the dissipation of pore water pressure versus time of the test using soil alone (control test) and that with different geosynthetics reinforcement. The geosynthetics were placed horizontally at the level of the slit openings to allow drainage of water. Pore water pressure transducers were installed at different location to measure the pressure development in the test. The upper figure shows the pore water pressure dissipation at 50kPa surcharge load. The lower figure shows the normalized pore water pressure, which is the ratio of measured pore water pressure to the surcharge load increment.

The results clearly indicate that dissipation of pore water pressure was much faster when the soil was reinforced with the composite geotextile than without as in the control test. Dissipation of pore water pressure was similar to the control test when the soil was reinforced with geogrid. This clearly indicates the ability of the high strength composite geotextile to drain water in the plane of the geotextile and the advantage of in-plane permeability to reduce pore water pressure.

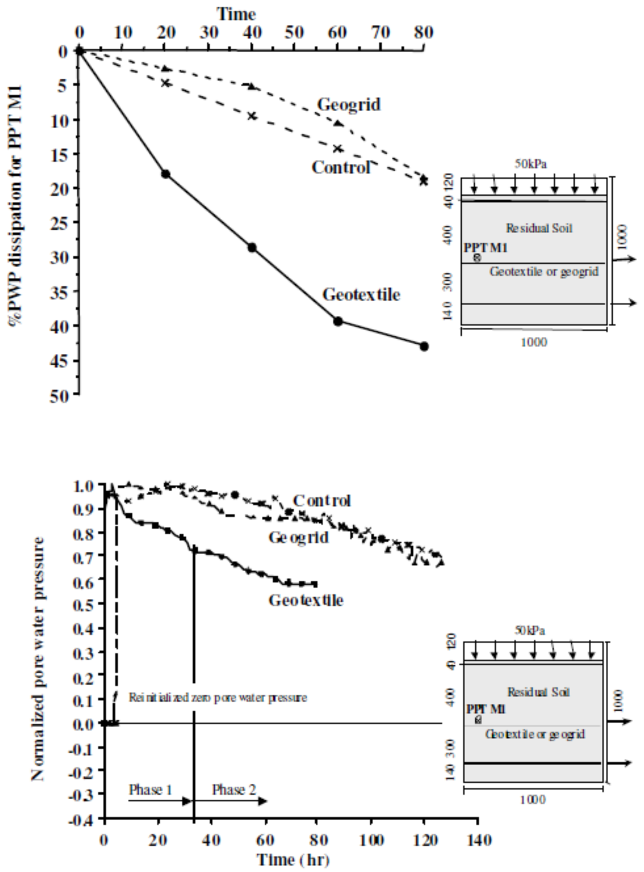

Figure 8: Dissipation of pore water pressure with time.

6.2 *Large-scale pullout test*

A large scale experimental wall was constructed to further verify laboratory studies and also to simulate actual wall construction and conditions. The wall was about 3m high and 6m long, constructed using segmental modular blocks as the facing as shown in Figures 9 and 10. Six layers of high strength composite geotextile with 50kN/m ultimate tensile strength at vertical spacing of 0.4m were used to reinforce the wall retaining laterite soil backfill. The base of the wall was filled with gravel to provide a bottom drainage layer. This drainage layer extended vertically at the back of the wall to form a vertical back drain.

The modular block used was hollow in the inside and the opening was filled with gravel. Connection of the geotextile to the modular blocks was achieved by placing the geotextile in between the modular blocks and filled with gravel in the hollow opening. Figure 11 shows the particle size distribution of the laterite soil. The plastic limit of the soil was in the range of 22% to 24% while the liquid limit was 42% to 45%. The in-situ moisture content of the soil was about 20% to 28%. Compaction tests carried out on a few soil samples showed optimum moisture content of around 19% with a maximum dry density of around 1.73g/cm^3.

Figure 9: Top of large-scale wall with some instrumentation.

Figure 10: Portion of the front wall.

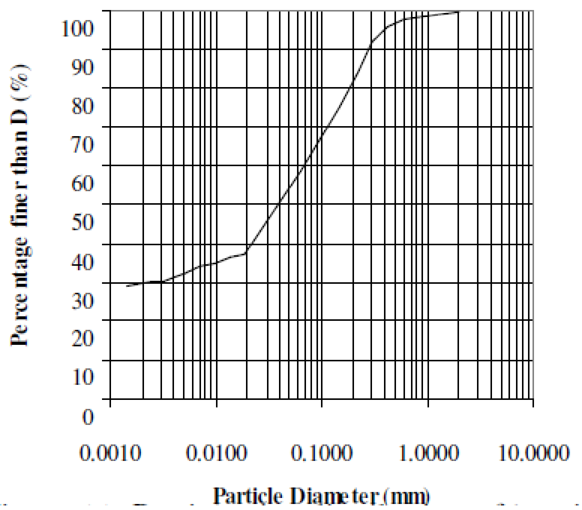

Figure 11: Particle size distribution of laterite soil.

The pull-out tests were carried out on small strips 0.3m wide laid in the soil during construction. Figure 12 and Figure 13 shows the pull-out test setup. A modified compression machine with a pulling capacity of 20kN and constant displacement rate of 1.25mm/min was used for the tests. A steel structure was fabricated to support the compression machine and to align the machine to the level of the geotextile strips. Potentiometers were used to capture the real-time displacement of the tell-tales as well as the clamp.

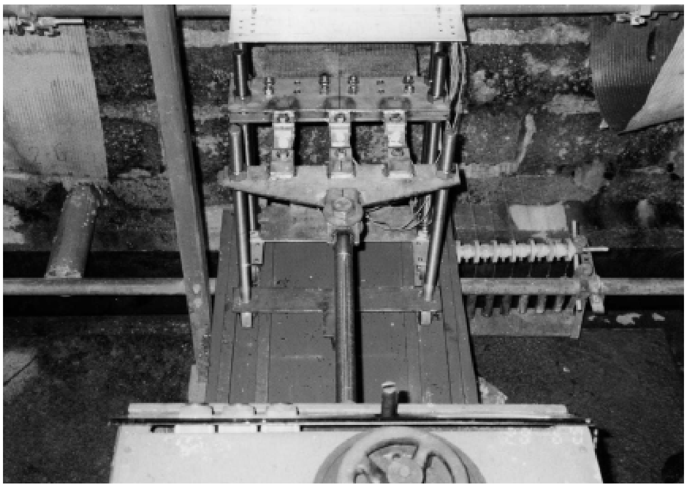

Figure 12: Pull-out test setup in front of large-scale wall.

The embedded area of the pullout strip was 1.85m by 0.3m and the overburden pressure on the geotextile was 7.5kPa during the pullout test. The soil condition was saturated. Figures 14 and 15 show the results from one of the pullout tests. Pullout resistance attained was rather high even at low overburden pressure and wet soil condition. The peak pullout strength achieved was 8.74kN per 0.3m width or 29.15kN/m as shown in Figure 11. Back calculations were carried out to evaluate the effective interface parameters. With an assumed adhesion value of 5kPa, the friction angle between the soil and the geotextile was calculated to be around 21°. The internal friction angle of the soil was about 27°. Hence, the efficiency of 0.80 was achieved. The measured tensiometer readings also indicated that the effective stress at the geotextile interface was not significantly affected by the saturation of the soil carried out prior to the test.

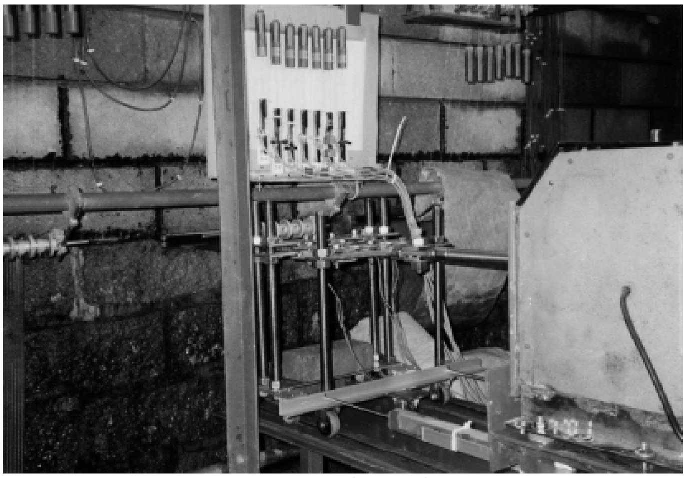

Figure 13: Pull-out test setup in front of large-scale wall.

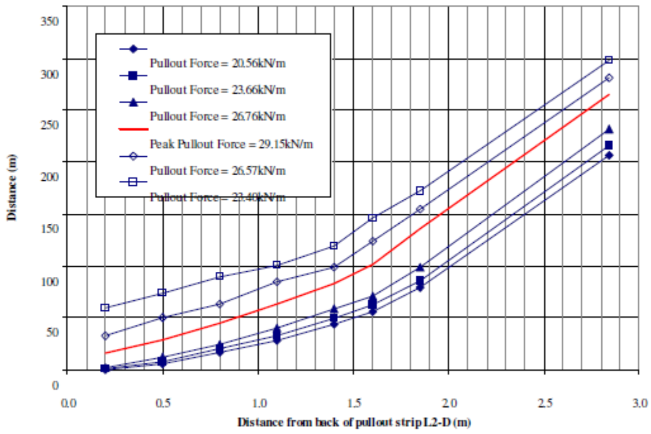

Figure 14: Geotextile displacement at various stages of pull-out test.

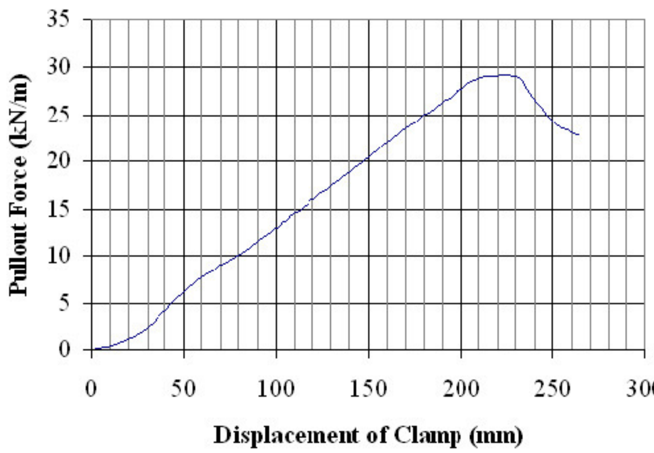

Figure 15: Force versus front displacement for the pullout test.

7 SUMMARY AND CONCLUSION

For the design and construction of Segmental Retaining Wall (SRW) system, NCMA design guideline and methodology should be adopted. However, to justify the design parameters for a safe and economical design, the long term design strength has to be adopted in the design. In order to justify the allowable long-term design strength of the reinforcing composite geotextile various tests such as durability test, field installation damage test and creep test had been carried out at accredited testing institutes.

SRW units have been designed for rapid and easy installation and can be executed using unskilled labours compared to conventional earth retaining structure. They can be placed by a single construction worker without the aid of construction equipment. The mortarless construction allows installation to proceed quickly. These minimize the impact of retaining wall construction on project scheduling, shorten overall construction time and are economical compared to conventional earth retaining structure. SRWs are relatively flexible structures which are typically founded on leveling pad foundations. SRWs are dry-stacked systems that can tolerate movement and settlement without causing visual distress at the face since the SRW units may move and adjust relative to each other. This contrasts with more rigid retaining structures such as cast-in-place concrete and conventional mortared masonry walls.

From the research, it shown that geotextile composite with nonwoven component reinforced with high tenacity polyester yarn is suitable for use with poor draining soil in providing both in-plane drainage and reinforcement functions. High strength composite geotextile effectively reinforced poor draining soil used in the construction of walls without affecting its stability. It provided addition factors of safety under conditions of poor back drainage system and rapid draw down. The large scale experimental wall showed that the combination of high strength composite geotextile with segmental blocks as facing is an ideal and viable system for wall constructions, especially in areas where poor draining soil is abundant and can be economically used as the backfill material.

REFERENCES

Lim, L.K., Lee,L & Siau, L.S. 2005. Design and construction of 8m high geogrid reinforced segmental wall in Malaysia using NCMA design method. Proc. of Geotechnical Engineering 2005, Petaling Jaya, Malaysia.

Loke,K.H., Lim,C.S., Chew, S.H., Karunaratne, G.P., Tan,.S.A. & Loh, S.L.2002 Large-scale studies on contribution of high strength composite geotextile reinforcing poor draining backfill. Proceedings of 7th International Geosynthetics Conference- Delmas, Gourc and Girard(eds), Nice, Vol, PP 1047- 1050.

British Standards Institution, BS8006: 1995 Code of Practice for Strengthened / Reinforced Soils and Other Fills.

National Concrete Masonry, Second Edition Design Manual for Segmental Retaining Wall