Pullout resistance of a novel multifunctional geosynthetic in fine grained marginal fills

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Keywords: steep slopes, reinforcement, geocomposite, pullout, marginal fill

ABSTRACT: Free draining granular fills have been the preferred choice for backfill materials for reinforced soil structures such as steep slopes owing to their good strength characteristics and ability to minimise the development of excess pore water pressures in the reinforced fill. Excess pore water pressures may result in possible stability and settlement problems. Large quantities of poor quality fine grained fills are excavated on construction sites each year. These materials can be effectively used to construct reinforced soil structures if adequate drainage is provided in the reinforced zone. This can be achieved through the use of novel multifunctional geocomposites which combine reinforcement and drainage functions. This paper presents the results of pullout testing on a combined reinforcement and drainage geosynthetic in a novel pullout test apparatus. Details of the test arrangement and operating procedures are presented. The pullout testing was performed on a marginal fill at a variety of confining pressures and moisture contents. Testing of a conventional reinforcement only geosynthetic was also performed for comparative purposes. Increasing confining stress and moisture content of the soil was shown to reduce pullout resistance while higher pullout rates resulted in greater pullout resistances. The reinforcement-drainage geocomposite was seen to produce higher pullout resistances than a conventional geosynthetic.

1 INTRODUCTION

Traditionally free draining granular fills are used in the construction of reinforced soil structures. This is due to their high strength and ability to prevent the development of excess pore water pressures. Zeynep & Tezcan (1992) reported the use of granular fill to cost about 40% of the total construction cost.

Potential build up of pore water pressure in the reinforced block is the main concern when using fine grained fills in reinforced soil structures resulting in lower shear strength than granular fill and reduced bond between the soil and the reinforcement which may result in deformation and settlement of the structure. Fine grained soils are also more difficult to compact when the moisture content is high, resulting in longer construction periods (Zornberg & Mitchell, 1994). Large volumes of fine grained soils are disposed of each year as there are little uses for them on site. The estimated volume of construction and demolition waste (CDW) for the twenty five members of the European Union (EU) for 2002 was 1,126kg/capita resulting in a total of 5.1m tons (Eurostat, 2005). The estimated volume of CDW generated per capita in Brazil for 1999 was 500kg/year, totalling 68.5 million tons/year (John et al, 2004). Significant proportions of this waste stream was soil waste, comprising 38% (2001 value) of Irelands total CDW (Annon, 2007) and 33% (1999 value) of England and Wales total CDW volumes. (<www.wasteonline.org.uk>).

Design codes treat coarse and fine grained soil backfills differently. BS 8006 (1995) does not restrict the type of material that can be used, stating that cohesive fills are permitted providing adequate reinforcement is used. The Federal Highway Administrations (FHWA, 2001) design document does provide a gradation limit for a maximum proportion of fines, as does Geoguide 6 (2002) although its limits are not as stringent.

2 RESEARCH ON THE USE OF A DRAINAGE COMPONENT WITH MARGINAL FILLS

Considerable research has been undertaken into the inclusion of a drainage component in reinforced soil structures (Kempton et al, 2000, Zornberg & Kang, 2005, O'Kelly & Naughton, 2008, Boardman, 1998, Naughton and Kempton, 2004, Clancy & Naughton, 2008).

Results of shear box and pullout analysis reported by Kempton et al (2000), Zornberg & Kang (2005) and O'Kelly & Naughton (2008) showed improved pullout resistance and shear strength at the soil-geosynthetic interface, where multifunctional geosynthetics have been used.

Naughton and Kempton (2004) reported on the use of the same geocomposite in the reinstatement of a failed slope in Taiwan. For the reinstatement the silty clay from the failed slope was reused in combination with the geocomposite meaning considerable cost saving, as expensive granular fill did not have to be imported. The geocomposite allowed rapid dissipation of the pore water pressures and permitted the work to be carried out in only three weeks.

Boardman (1998) studied the change in the rate of consolidation associated with the geocomposite using a modified Rowe cell apparatus. It was shown that the inclusion of the composite reinforcement resulted in reducing the drainage path by half, in turn increasing the rate of consolidation. Improved pullout resistance was recorded for the geocomposite.

The effectiveness of reusing fine grained fill combined with multifunctional geosynthetics in steep slope construction was demonstrated by Clancy & Naughton (2008). A parametric study was presented that determine the quantity of reinforcement required to stabilise a 10m high steep slope inclined at 70° to the horizontal. The parametric study highlighted the important of understating the pore pressure distribution throughout the entire slope. Dissipation of pore pressures may be induced by incorporating a drainage element into the reinforcement. The required transmissivity of the geogrid was also determined for each of the soil types and a maximum value of 0.4l/m.hr established. Marginal fills with high percentage of fines and low angles of shearing resistance required longer lengths of reinforcement placed at closer vertical spacings than that expected from the use of granular free draining fills Clancy & Naughton (2008).

3 PULLOUT TESTING PROGRAMME

An experimental model was developed to examine the pullout behaviour of geosynthetic strips with and without drain elements under different loading conditions. A cylindrical PVC pipe, 300 mm inside diameter and 550 mm long was sealed top and bottom with steel caps and O rings. The bottom cap could slide inside the pipe. A pneumatic ram was used to displace the bottom cap, thus generating an excess pore pressure in the soil contained in the sealed cell. Pore water transducers measured the pore pressures generated in the soil around the geosynthetics during a test and a 100N load cell recorded the pullout force mobilised in the reinforcement. The geogrid strip, 350 mm in length, was placed longitudinally in the pipe, projecting out thought a slot in the top cap. The whole apparatus was placed inside a conventional triaxial load frame. The geogrid was connected to the load cell, which was in turn connected to the cross beam of the triaxial load frame. Pullout was achieved by lowering the platen of the triaxial apparatus, causing the geogrid to pullout of the soil. The advantages of the experimental model include the development, control and continuous monitoring of excess pore water pressures in the soil mass and around the geosynthetic. Dissipation of excess pore water pressures can also be facilitated to simulate various consolidation conditions.

Calibration of the load cell and all transducers was carried out and the pore water pressure transducers were de-aired before use. The soil, at the desired moisture content for the test, was placed into the cylinder and tamped in layers of approximately 200mm using a tamping rod. The pore water pressure probes were placed at sample mid-height and measured the pore pressure at different radii from the geosynthetic. In the test series discussed here pullout commenced almost immediately after the confining stress was applied to the soil mass. Values of pore pressures, displacement and pullout resistance were recorded for the duration of the test using a data acquisition system. Pullout resistance was defined in this study as pullout force per width of geosynthetic strip.

3.1 *Material Properties*

Two geosynthetics were used in the testing programme. The conventional geogrid used was a 34mm wide strip of geogrid which consisted of discrete bundles of closely packed high strength synthetic fibres, lying parallel to each other, encased in a tough and durable polyethylene sheath. The reinforcement-drainage geocomposite was 24mm wide and manufactured from the same material but incorporating a drainage channel. The drainage component included a thermally bonded nonwoven geotextile that was fixed to the shoulders of the drainage channel, filtering the pore water and retaining the soil particles.

The engineering properties of the soil used in the study are summarised in Table 1. Further information on the soil properties are contained in Clancy & Naughton (2008).

4 PULLOUT TEST RESULTS AND DISCUSSION

Pullout testing was performed at different combinations of confining stress, moisture content and pullout rate. For quick identification of the properties of each test, the following labelling system was adopted which showed the applied normal load in kPa (first numbers in code), followed by the rate of pullout (S = slow, R = regular and F = fast) followed by the percentage moisture content of the soil used in the pullout apparatus. The rates of pullout used were 0.2mm/min, 2.0mm/min and 10mm/min. The regular pullout rate of 2mm/min was that used in similar pullout tests reported by Zornberg & Kang (2005). The pullout resistance was defined as the maximum forced recorded by the load cell during a test.

Table 1: Engineering properties of soil used in pullout tests

Liquid Limit	52.5%
Plasticity Index	26.8%
Angle of friction ϕ'	18.6°
Cohesion c'	21.5kN/m^2
Maximum dry density†	1.580 Mg/m^3
Optimum Moisture Content†	19.5%
% Passing 63μm	58%
† Determined using standard compaction to BS 1377 (1990)	

Testing of the conventional geogrid indicated the presence of multiple peaks in the pullout resistance, Figure 1. This generally occurred at higher moisture contents and faster pullout rates. A similar response was observed by Richardson et al. (2009) in pullout testing of scaled prototypes of offshore anchors in clays at high moisture contents. Richardson et al. (2009) attributed the multiple peak response to the development of suction immediately behind the anchor during pullout.

The effect of soil moisture content can be seen in the results presented in Figure 2. A comparison of tests 25R56 and 25R58, in which there was a small increase in the moisture content (from 56 % to 58%) resulted in a very significant decrease in pullout resistance from 1071 N/m to 782 N/m. This was again evident in tests 90R38, 90R48 and 90R58 where an increase in moisture content reduced the pullout resistance. The higher moisture contents were possibly lubricating the inclusion. In general as the moisture content increased the pullout resistance decrease irrespective of confining stress. In Figure 3 the solid and hollow data points represent the conventional and geocomposite geogrids, respectively.

The influence of confining stress on pullout resistance was evident in tests 25R56, 50R56 and 90R58, where a general downward trend of pullout resistance with increasing confining stress was observed. Greater confining stresses could generate higher pore water pressures possibility leading to a reduced bond at the soil geosynthetic interface.

The effect of rate of pullout on the pullout resistance was also examined. A comparison of the tests 50R55 and 50F54, Figure 2, conducted at the regular and fast rates, respectively, for similar confining pressure and moisture content showed an almost threefold increase in pullout resistance at the faster rate. The increase appears to be even greater in magnitude at higher confining stresses, tests 90R58 and 90F54 where the faster rate of pullout (90F54) resulted in a five-fold increase in pullout resistance. However a proportion of this increase may be attributed to the lower moisture content and the possible development of suction forces behind the geosynthetic during pullout.

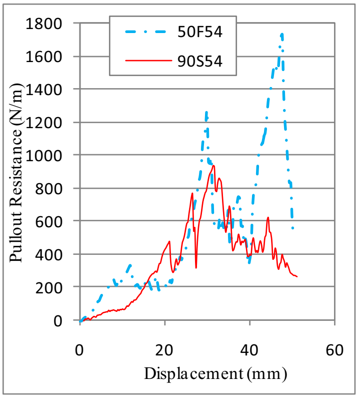

Figure 1. Pullout resistance versus displacement for the conventional geogrid for tests 50F54 & 90S54

Testing was also preformed on a combined reinforcement-drainage geocomposite at similar conditions to those for the conventional geogrid. Figure 2 provides an illustrated comparison of peak pullout resistances for the two geosynthetics. Tests at the regular pullout rate for all confining stresses showed a marked increase in pullout resistance. This increase was greatest at higher confining stresses, Figure 2, which was attributed higher excess pore water pressures which were dissipated more rapidly by the geocomposite, due to a high hydraulic gradient locally around the drainage element of the geogrid, thus increasing the pullout resistance. Testing the geocomposite at the faster pullout rate significantly reduced the pullout resistance compared with the conventional geogrid at the same rate. This could be attributed to the drainage aspect of the geocomposite limiting the development of suction forces immediately behind the conventional geogrid. No multiple peak response in the pullout resistance of the geocomposite was observed. No significant change in pore water pressure response was evident for either the conventional geogrid or geocomposite, during the pullout tests performed, although overall values fell slightly during pullout.

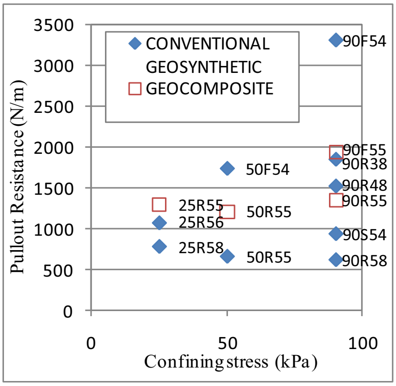

Figure 2: Maximum pullout resistance for range of confining stresses and moisture contents examined

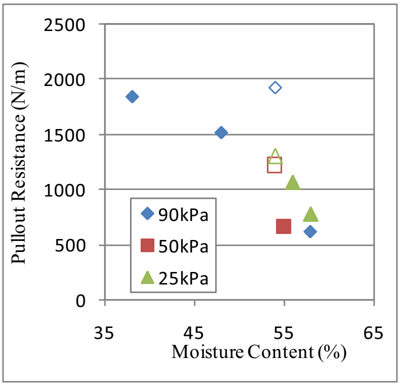

Figure 3: Relationship between pullout resistance and moisture content at confining stresses of 25kPa, 50kPa & 90kPa.

5 CONCLUSIONS

Large volumes of fine grained marginal fills are excavated each year and a significant proportion of this material is sent to landfill as there are few recognised uses for it on site. Research (Kempton et al, 2000, Zornberg & Kang, 2005, Boardman, 1998 & Clancy & Naughton, 2008) has shown that fine grained soil can be successfully used as backfill material provided adequate drainage is provided in the body of the structure. Excess pore water pressures, generated using construction, can be rapidly dissipated resulting in increased strength and deformations occurring during the construction period (Naughton et al, 2001).

A programme of pullout testing was presented which examined the effect of soil moisture content, pullout rate and confining stress on pullout resistance of both a conventional and multi-functional geogrid. It was found that increased moisture content and confining stress resulted in a decreased pullout resistance while higher pullout rates increased the pullout resistance. The improvement in pullout resistance provided by a reinforcement-drainage geocomposite was also examined. It was found that peak pullout resistances were increased for all confining stresses, with greater increases at higher stresses. However a higher pullout resistance was measured in the conventional geogrid when a faster pullout rate was used which may be attributed to suction forces developing immediately behind the geogrid during pullout.

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