Construction of slopes using cohesive fills and a new innovative geosynthetic material

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ABSTRACT: The results of a research program on the effectiveness of a new geosynthetic combining drainage and reinforcement in a geogrid are presented. Dissipation tests in English China Clay show that initial excess pore water pressures of 50 and 100 kPa can both be dissipated to 20 % of their initial values in 36 to 42 hours. Pullout tests in English China Clay show that the new geosynthetic can improve the soil reinforcement bond after only partial dissipation of excess pore water pressure. After full dissipation the pullout resistance at small displacements can increase by as much as 500 % when compared with a conventional geogrid of similar construction but with no drainage component.

1 INTRODUCTION

The design of reinforced slopes is concerned with the provision of an adequate factor of safety on strength and the control of settlements to acceptable limits. Conventional design and construction methods have used granular materials due to their high shear strength and good drainage properties. Recent research (Zornburg, Mitchell, 1994) and long term case histories (Inada et al.,1978 and Fukuoka, 1998) have indicated that cohesive soils can be used in the construction of reinforced slopes if an adequate drainage system is provided in the structure of the slope.

When low permeability fills are loaded excess pore water pressures can be generated. This can result is a reduction in the available shear strength of the cohesive fill and also a reduction in the soil reinforcement bond requiring more reinforcement to provide an adequate bond length. The dissipation of excess pore water pressures results in consolidation and settlement of the reinforced structure, which can continue over time resulting in unacceptable face deflections.

The magnitude of excess pore water pressure present in a slope is a function both of the applied load and also the ability of the drainage system to dissipate the excess pore water pressure. At the base of a slope with no drainage provided large excess pore water pressures can develop. However if drainage is provided and complete dissipation of excess pore water pressure occurs before construction of the next layer the excess pore water pressure in the completed structure would only be a fraction of that otherwise present.

The construction of steep slopes from cohesive fills requires knowledge of the properties of the cohesive material and the dissipation and drainage characteristics of the inclusions. This study presents research on the effectiveness of a new innovative geosynthetic reinforcement and drainage material to reinforce slopes constructed from cohesive fills. The new geosynthetic consists of high tenacity polyester encased in a polyethylene sheath. The sheath both protects the load carrying elements and maintains the shape of the product which is profiled to provide a drainage channel on one side. The profiled strap has a thermally bonded nonwoven geotextile strip bonded on the shoulders of the drainage channel. The geotextile allows excess pore water pressure to dissipate while retaining the cohesive soil.

2 LABORATORY TESTING

A research program was initiated at the University of Newcastle. The program had the following objectives,

1. To evaluate the effectiveness of a new combined drainage and reinforcement geosynthetic in dissipating excess pore water pressures under various confining stresses.
2. To evaluate the pullout resistance of the new geosynthetic when compared with a conventional geogrid of similar construction but with no drainage component.
3. To evaluate the horizontal flow characteristics of the material under various hydraulic gradients and confining pressures.
4. To determine suitable parameters for use in design for constructing steep slopes using cohesive fills.

A laboratory scale apparatus was developed using large 254 mm diameter Rowe Cells. Two Rowe Cells were used to assess the behavior of a single strip of the new geosynthetic material with a cohesive fill consolidating around it. Control of the position of the new geosynthetic material in the consolidating fill was required to allow accurate pore water pressure measurements around the material during consolidation and pullout. To fulfil this requirement a PVC cylinder was produced to house the geosynthetic strip. A Rowe Cell was then clamped on either side of the central PVC cylinder allowing equal consolidation either side resulting in no movement of the geosynthetic strip.

The apparatus was instrumented with 6 probes to measure pore water pressures in the cohesive fill at various offsets above and below the new material. Displacement and volume change traducers were also incorporated to measure displacement of the Rowe Cells during application of load and the volume of water leaving the cell through the geosynthetic during dissipation.

English China Clay, supplied by ECC International Limited, Cornwall, UK, was used as the cohesive fill. English China Clay was chosen due to its low permeability and consistent properties that would allow for repeatability and comparison of test results. The properties of the clay used are given in Table 1 with consolidation and permeability values in Table 2. The coefficient of consolidation, C_V and the coefficient of volume compressibility, m_V were determined from oedometer tests to BSI (1990). The English China Clay was placed at a moisture content of 60 ± 1 % for all tests. The clay was mixed with water and allowed to stand for 24 hours to allow for hydration of the clay before remixing and placing in the test apparatus.

Two principle types of tests were carried out using this apparatus:

1. Dissipation tests at confining pressures of 50 and 100 kPa with continuous measurement of the excess pore water pressure in the cell and the volume of water leaving the cell.
2. Pullout testing after full and partial dissipation of excess pore water pressure at different confining pressures.

Table 1. Properties of English China Clay used in study.

Property	Value
Specific Gravity	2.6
Specific Surface area	6 m^2/g
d_{90}	20 µm
d_{10}	0.6 µm

Table 2. Consolidation and permeability values for English China Clay used in study.

Confining pressure	50 kPa	100 kPa
C_V (m^2/year)	2.323	1.355
m_V (m^2/MN)	0.337	0.255
k (m/s)	2.43 x 10^{-10}	1.07 x 10^{-10}

Dissipation tests were performed in the unit cell by only allowing drainage through the new geosynthetic. A confining pressure was applied and the excess pore water pressure generated was allowed to dissipate while continuous readings of the pore water pressure, the volume change and the displacement of the Rowe Cells were taken. The test results show that the pore water pressure reduces from the applied pressure to 20 % of the applied pressure in a 36 to 42 hour period at confining pressures of both 50 and 100 kPa. Very little difference was observed in the pore water pressure values at various offsets from the drainage material. No noticeable difference was observed in pore water pressure values measured above and below the test specimen even through the drainage channel was only on one side of the new geosynthetic. On the surface of the test specimen the excess pore water pressure reached approximately 40 % and 30 % of the applied load at confining pressures of 50 and 100 kPa respectively. The test results for a confining pressure of 50 kPa are shown in Figure 1.

The volume of water displaced is a reliable indicator of the end of consolidation. Consolidation at confining pressures of 50 and 100 kPa occurs in a 36 to 42 hour period and is consistent with the pore water pressure measurements. The volume of water leaving the cell for a confining pressure of 50 kPa is shown in Figure 2.

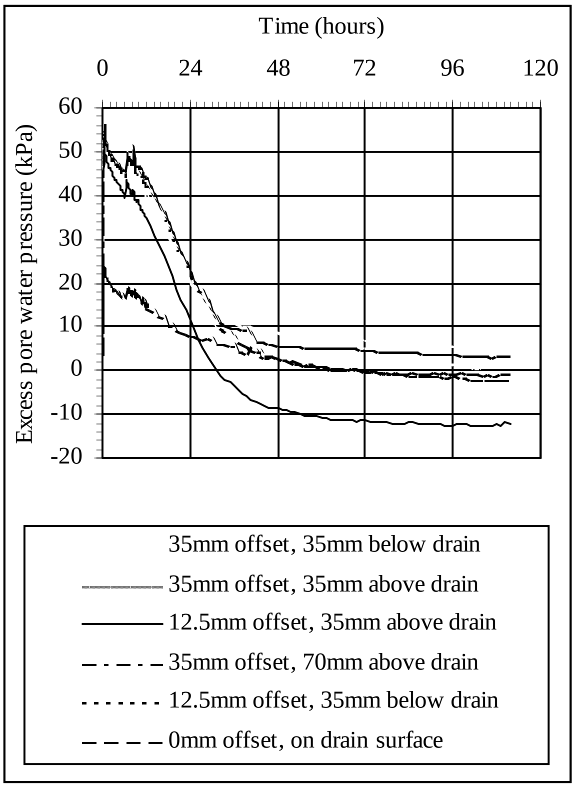

Figure 1. Dissipation of excess pore water pressure for a confining pressure of 50 kPa.

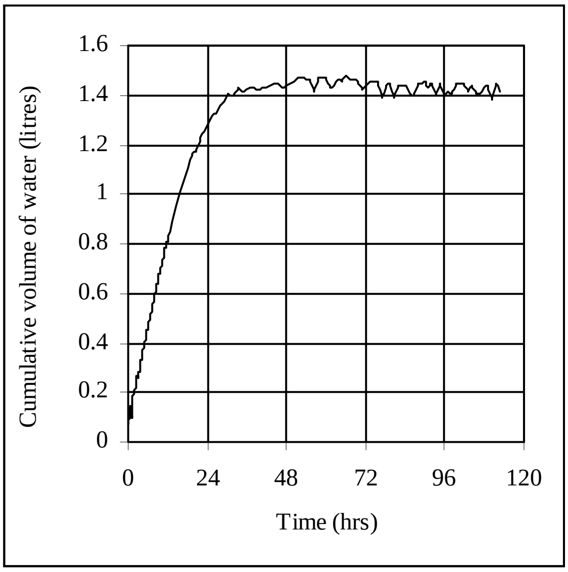

Figure 2. Cumulative volume of water displaced during dissipation of excess pore water pressure under confining pressure of 50 kPa.

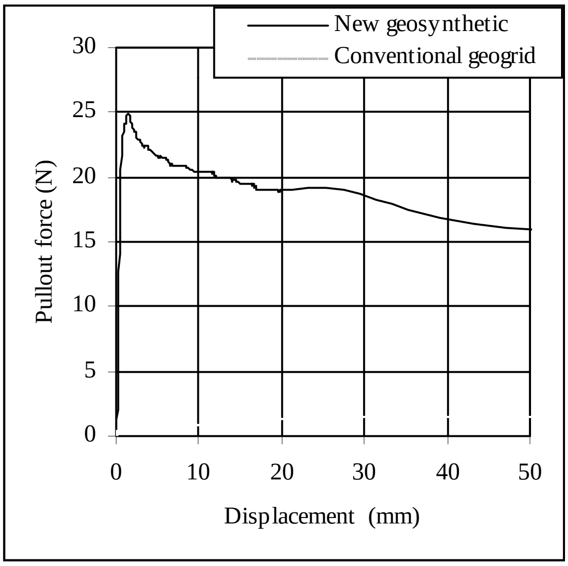

Figure 3. Pullout results for new geosynthetic and conventional geogrid with no drainage component after dissipation of excess pore water pressure for 12 hours.

Pullout testing on the new geosynthetic and on a similar geogrid with no drainage component was conducted after partial and full dissipation of excess pore water pressure in the unit cell. The pullout tests after partial dissipation were carried out after dissipating the excess pore water pressure for 12 hours under a confining pressure of 50 kPa. The new geosynthetic was found to have a much enhanced pullout resistance after partial dissipation, Figure 3. This may be explained by the excess pore water pressure in the immediate vicinity of the new geosynthetic dissipating quickly thus allowing early developed of bond between the reinforcement and the soil. The pullout resistance of the new geosynthetic peaks at a small displacement, 2.0 mm, where the conventional geogrid does not appear to reach a peak pullout load.

Full dissipation of excess pore water pressure was assumed when the pore water pressure values reached 10 % of the applied confining pressure in the immediate vicinity of the geosynthetic. Pullout tests after full dissipation were conducted at confining pressures of 50 kPa and 100 kPa. A substantial increase in pullout resistance of the new geosynthetic over a similar conventional geogrid with no drainage component was observed with the peak pullout resistance increased by approximately 33 % while at smaller strains a 500 % increase in pullout resistance was observed, Figure 4. The peak pullout resistance for the new geosynthetic was reached at a displacement of 3.5 mm whereas the conventional geogrid reached a peak pullout load at 7 mm.

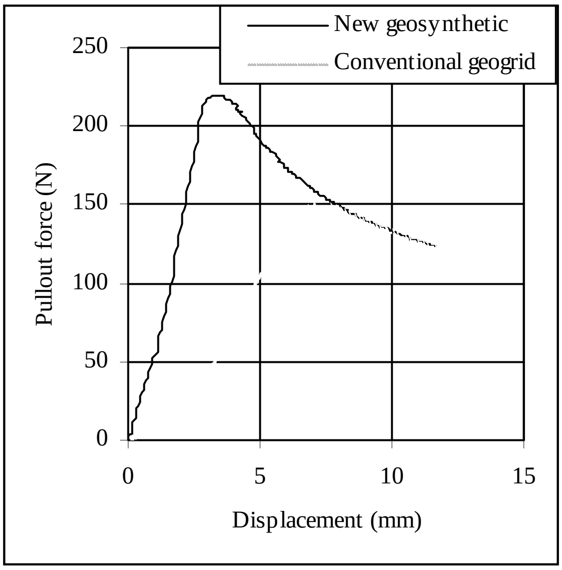

Figure 4. Pullout results for new geosynthetic and conventional geogrid with no drainage component after full dissipation of excess pore water pressure.

The water flow or transmissivity of the new geosynthetic is of importance in removing the dissipated water from the soil. The ability of a drainage material to remove water from a soil structure is a function of the confining pressure, length of drainage channel, permeability of soil and magnitude of excess pore water pressure in the soil. In a reinforced slope the hydraulic gradient along any drainage path will vary according to its proximity to the face of the slope and the magnitude of the excess pore water pressure present.

The transmissivity of the new geosynthetic was measured over a 1 m long strip under confining pressures of 50, 100 and 200 kPa and at hydraulic gradients of 0.1, 0.5 and 1.0. The test apparatus consisted of a channel that held a strip of the new geosynthetic. A confining pressure could be applied over the full length of the strip and water introduced under different hydraulic gradients. The test results are presented in Figure 5.

Samples of the new geosynthetic removed from the test apparatus after consolidation testing showed minimal signs of clogging and very little wash through of fines into the drain.

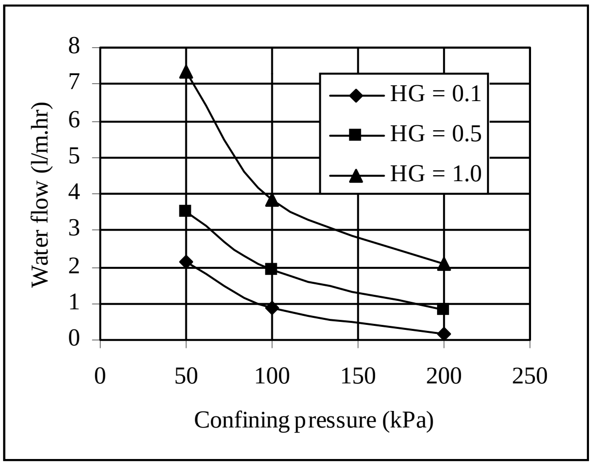

Figure 5. Water flow through new geosynthetic under various confining pressures and hydraulic gradients

3 DESIGN IMPLICATION

The research program has indicated that that the new geosynthetic can dissipate excess pore water pressures in English China Clay of low permeability in 36 to 42 hours. For a cohesive fill with a higher permeability it is anticipated that the excess pore water pressure would be dissipated in a shorter time period. In this situation the excess pore water pressure would be fully dissipated during the construction phase of the structure. For the design of such a slope an effective stress analysis could be used.

The dissipation of excess pore water pressure as each layer is placed would result in the consolidation of the structure occurring during the construction phase. Any face deflection due to excess pore water pressure could be corrected during construction resulting in the structure meeting its serviceability limit state criteria at the end of construction.

4 CONCLUSIONS

The research program has shown that the new geosynthetic combining drainage and reinforcement in a geogrid form is capable of dissipating excess pore water pressures in English China Clay to 20 % of their initial values in approximately 32 hours. The pullout resistance of the new geosynthetic is increased even after partial dissipation of the pore water pressures. The transmissivity of the material has been found to be more than adequate even at low hydraulic gradients to remove water from the soil. No clogging or wash through of fines into the drain was observed.

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