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Clay geotextile interaction in in-soil tensile tests

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ABSTRACT: In-soil tensile tests were carried out on woven and non-woven needle punched geotextile specimens in clay confinement. It was found that the geotextile modulus greatly increased due to the confinement. The increase of the modulus was inversely proportional to the geotextile strain. Due to the different mechanism of the clay geotextile interaction the increase on the non-woven geotextile was considerably larger (up to ten times) than on the woven geotextile (up to three times).

1 INTRODUCTION

The applicability of cohesive backfill in geotextile reinforced retaining walls is a economically important research topic in areas where good quality backfill is not readily available. Previous research has shown that those geotextiles which have high transmissivity and are able therefore to drain cohesive soil can be effectively used to increase the load bearing capacity of clay: Fabian and Fourie (1985), Ingold (1981), Tatsuoka and al (1986). Non-woven needle-punched geotextiles have high transmissivity as the fibres of the fabric are oriented randomly and relatively loosely, providing large void content and seepage paths in the fabric. These characteristics of the manufacturing of the non-woven geotextiles are also the cause of the large deformability which is an important mechanical property of non-wovens.

In certain applications, where the displacements and deformations are normally required to be kept low such as retaining walls, the large deformability is not advantageous.

In-soil tensile tests using granular soil have shown that the soil confinement decreases the deformability of both woven and non-woven geotextiles: McGown and al (1982), Leshchinsky and Field (1987).

It is important to investigate this phenomenon in the case of clay backfill with particular emphasis on non-woven geotextiles which otherwise could be very effectively used in cohesive backfill.

2 MATERIALS USED IN THE TESTS

The soil used in the tests was a silty clay (CL) with the soil indices given in Table 1.

Table 1. Soil Indices of Silty Clay

Plastic Limit	PL = 14%
Liquid Limit	LL = 28%
Plasticity Index	PI = 14%
Linear Shrinkage	LS = 4%
Unified Classification = CL	

The particle size distribution curve of the soil is shown on Figure 1.

Standard compaction tests were carried out on the silty clay and the maximum dry density was obtained as MDD = $1.95/m^3$ at the optimum moisture content of OMC = 12%. The Standard compaction curve of the silty clay is shown on Figure 2.

In the tests the soil was prepared at 19% moisture content. The soil layers -300,500,700 mm long; 100 mm thick; and 500 mm wide, were compacted with 110,190 and 270 blows, respectively, using a 15 kg mass dropped from 0.5 m height to provide a compaction effort 57 kg.m/litre which is equivalent to the compaction effort of the Standard compaction. At 19% moisture content and using Standard compaction the degree of saturation of the soil was about 95%. Thus the soil was deemed to be saturated.

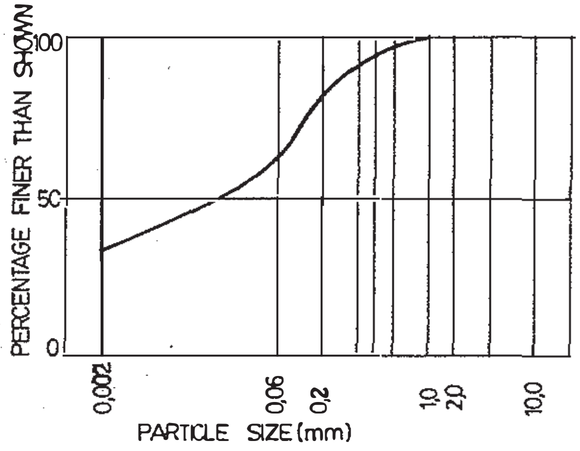


Figure 1: Particle Size Distribution Curve

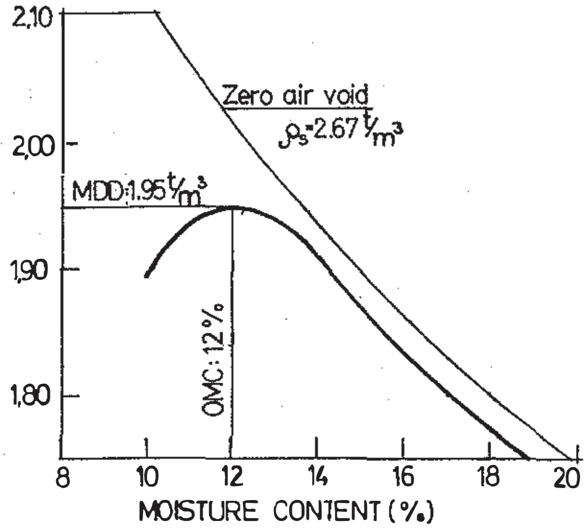


Figure 2: Standard Compaction Curve

Two geotextiles: a woven polypropylene and a non-woven, needle punched polyester were used in the tests. The most important parameters are summarised in Table 2. The results of tensile tests carried out on 200 mm wide strip specimens are collected on Figure 3.

Table 2. Parameters of Geotextiles

Type	Non-woven	Woven
Thickness (mm)	1.8/0.8*	1.6
Weight (g/m^2)	210	155
EOS (5m)**	60	250
Permeability (cm/s)	0.3/0.07*	0.003
Transmissivity (cm/s)	0.06/0.04*	N/A
Break load (kN/m)	10	25
Tangent modulus (kN/m)	28	197

* at 0.5,200 kPa normal stress, respectively

** equivalent opening size

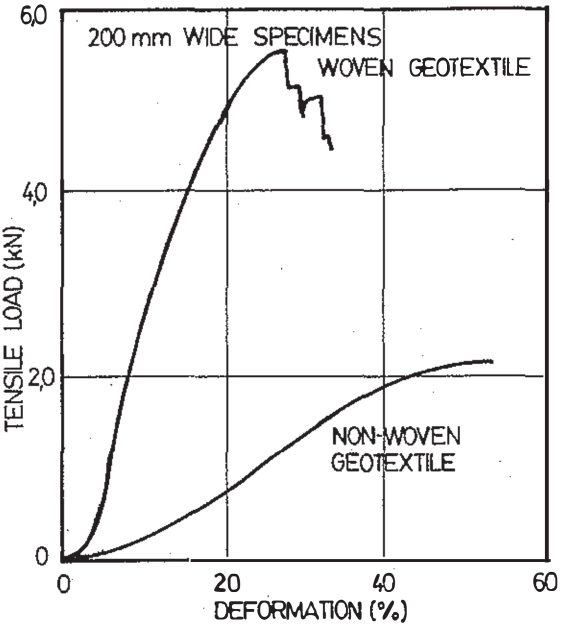
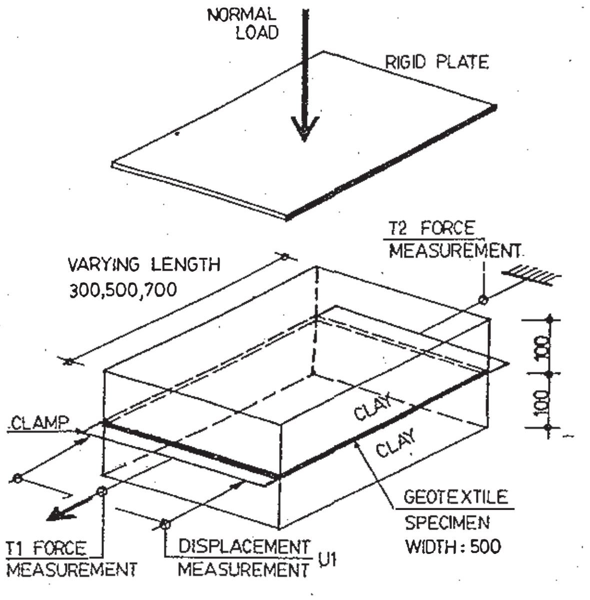


Figure 3: Results of Wide Strip Tensile Tests

3 TESTING PROCEDURE

To carry out the large scale pull-out (in-soil tensile) tests a large steel box was built. It allowed no relative lateral displacement between the soil layers on the two sides of the geotextile. The schematic diagram of the testing configuration is shown on Figure 4. The vertical load was applied from a load frame using a hydraulic ram and the load was distributed over the soil by a rigid steel plate.



(ALL DIMENSIONS IN MM)

Figure 4: Schematic Diagram of Test Configuration

After the preparation and placement of the soil the geotextile sample was clamped on both ends. The in-soil tensile tests of this research were intended to investigate the effect of soil confinement on the geotextile modulus at low strains (max 10%) which are typical in retaining wall problems. The steel clamps were placed adjacent to the soil. Considering the width of the geotextile specimens (500 mm) and the small elongation (less than 35 mm) the aspect ratio of the unconfined section of the geotextile specimen was very large, the in-soil clamping was not regarded therefore important. No necking of the geotextile was evident in any of the tests carried out.

The clamps were attached to two proving rings to measure the load on both ends of the goetextile. The first proving ring (on the side of the application of the tensile force) measured the pull-out force (T1) exerted by a hydraulic pulling ram. The second proving ring anchored the other side of the geotextile specimen and measured the T2 anchoring force.

Two dial gauges were attached to the first clamp at equal distances from the point of application of the tensile (pull-out) force to measure the displacement-U1.

After preparation the normal load was applied using a hydraulic ram. Tests were carried out at 15,50 and 100 kPa normal stresses. The dial gauges and proving rings were zeroed and then the lateral tensile force was applied. The rate of loading was 300 N/min. The tests were terminated at the failure of the geotextile specimen or at bond failure or at 4.2 kN tensile force, whichever was reached first. The loading rate was considered rapid enough to simulate undrained loading.

Before and after every test the length of the geotextile specimens were measured to determine whether any plastic deformation occured. No plastic deformation was detected on any of the specimens.

4 TESTING RESULTS

Typical measured load displacement curves are shown for the non-woven geotextile on Figure 5, and for the woven geotextile on Figure 6. From the load displacement curves the geotextile modulus can be determined using the method introduced by Leshchinsky and Field (1987). In this method it is assumed that the geotextile tensile strain has its maximum at the point of application of the tensile force and that it decreases linearly away from this maximum to zero at the other end of the textile specimen. The maximum geotextile strain may be calculated as:

$$\gamma = 2 * U1 / (L + U1) \qquad (1)$$

where L - length of geotextile specimen
U1 - displacement of geotextile at the point of application of the load

Assuming that the tensile force in the geotextile is linearly proportional to the geotextile strain, the geotextile modulus can be determined as:

$$E = (-L *(T1 + T2)/2U1 \qquad (2)$$

where E - geotextile modulus (kN/m)
T1 - force at the point of application of the load (kN/m)
T2 - force at the other end of the geotextile specimen (kN/m)

From the testing results obtained on the different length geotextile specimens the tensile moduli values were determined using Equation (2). The tensile modulus tensile strain relationships were then collected and summarised on Figures 7 and 8 for non-woven and woven geotextile specimens, respectively. Even though the above calculation technique may not be rigorously correct, i.e. the strain distribution along the geotextile may be non-linear, it provides a useful procedure for comparing the variation of the modulus with strain and normal stress.

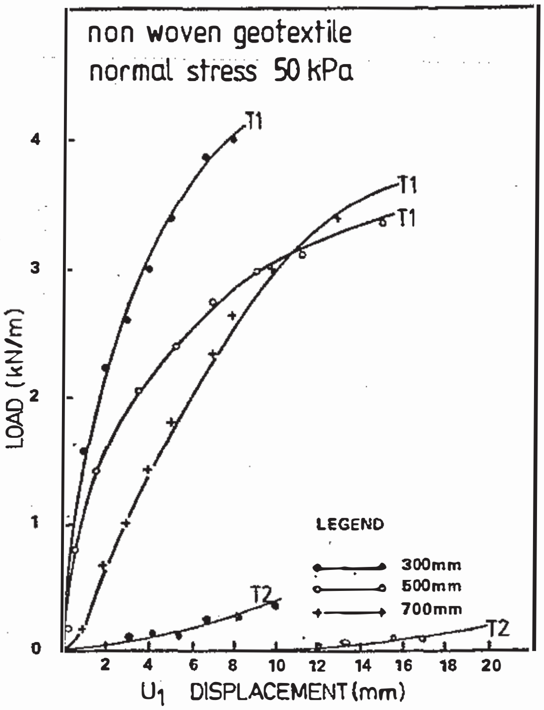


Figure 5: Load Displacement Curves

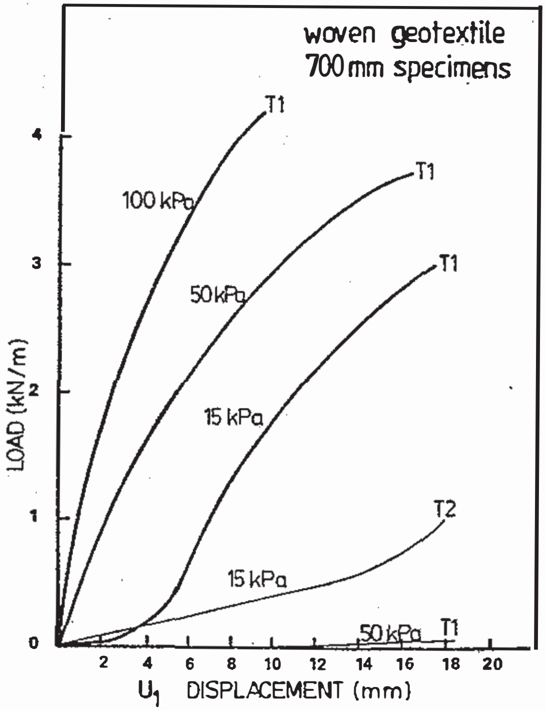


Figure 6: Load Displacement Curves

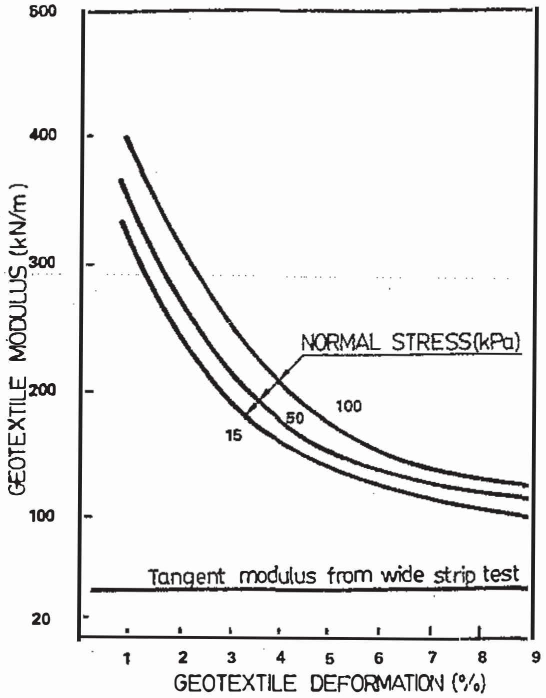


Figure 7: Geotextile Modulus vs. Geotextile Strain Non-Woven Geotextile

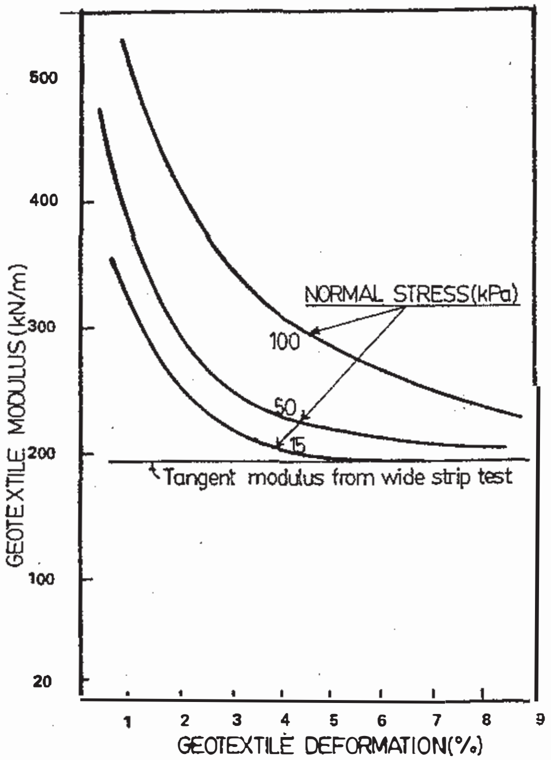


Figure 8: Geotextile Modulus vs. Geotextile Strain Woven Geotextile

5. DISCUSSION OF TESTING RESULTS

5.1 Observations

Studying the results of the tests carried out on geotextile specimens the following conclusions can be drawn:

1. The geotextile tensile modulus is inversely proportional to the geotextile strain in both woven and non-woven geotextiles. At low strains (1%) the tensile modulus can be considerably higher than the unconfined modulus. In the case of the non-woven geotextile this increase can be up to ten times, while in the case of woven geotextile the increase is just up to about three times.

2. The modulus of the non-woven geotextile was increased by soil confinement over the whole range of strains measured in the tests (0 to 9%) for all normal stress values.

3. The geotextile tensile modulus depends on the applied normal stress. An increase in the normal stress results in an increase in the value of the geotextile modulus.

4. In non-woven geotextile the normal stress affects the modulus only slightly. For the woven geotextile the normal stress has a more significant effect than for the non-woven geotextiles. The increase of the modulus is almost proportional to the normal stress. Furthermore at higher normal stresses the range of geotextile strain over which modulus increase can be expected, is wider.

5. A comparison of the load displacement curves in the in-soil tests (Figures 5,6) and in the wide strip tests (Figure 3) shows that the soil confinement reduces the offset and changes the shape and slope of the load displacement curve.

5.2 Mechanism of Clay Geotextile Interaction

The mechanism of the clay geotextile interaction in the in-soil tensile tests is governed by the following major factors:

1. During the application of the normal stress and tensile force, interlocking develops between the particles of the soil and the fibres of the geotextile. Due to this interlocking a high frictional resistance develops on the clay geotextile interface, which appears in the pull-out tests as a highly improved tensile response i.e. an improved tensile modulus.

2. The normal stress acting on the interface increases the frictional resistance between the clay particles and the geotextile fibres as well as the friction among the fibres inside the geotextile. This increased inter-fibre friction also contributes to the improvement of the tensile response of the geotextile. As the opening size of the non-woven geotextile is more akin to the particle size of the clay particles than that of the woven geotextile, the interlocking effect is more efficient on the non-woven geotextile. It is further enhanced by the disoriented nature of the fibres in the non-woven geotextile.

3. When applying the tensile force the point of application of the pull-out force is displaced and therefore strain develops in the geotextile. This results in relative displacement between the geotextile fibres and the clay particles, thus mobilising frictional resistance. At higher displacement (and thus strain) the relative displacement between the geotextile and the clay can be high enough to cause local slippage either through the breaking out of clay particles or through the unrevelling of the surface of the geotextile. This local slippage has two consequences.

1st: the load is transferred further away from the point of locad application and longer sections of the geotextile participate in the pull-out resistance. If the geotextile is not long enough full-scale bond failure occurs.

2nd: the fibres of the geotextile orient themselves in the direction of the pull-out force, hence reducing the frictional resistance inside the fabric itself. This leads to a deteriorated tensile response, or reduced tensile modulus.

It may be concluded that in woven geotextiles the improvement of the tensile modulus is caused fundamentally by the increased interfibre friction, and to a lesser extent by the mobilized bond strength. In non-woven fabrics the improvement of the modulus is caused primarily by the interlocking of the particles and the fibres of the geotextile, which is the source of the bond strength, and partly by the increased inter-fibre friction.

A further factor affecting clay geotextile interaction is the development of excess pore water pressure during the application of load. As the clay in this study was saturated, and the normal and tensile forces were applied rapidly an excess pore pressure developed in the clay.

As a hydraulic gradient is set up between the geotextile and the clay the pore water begins migrating towards the geotextile. Considering the length of the geotextile specimens and the rate of loading it can be assumed that only very small drainage can develop. Therefore a small increase of the bond strength results, which appears as a further increase of the tensile modulus.

Based on the results of previous research it can be assumed that there is no drainage in the plane of the woven fabric: Fourie and Fabian (1987). Consequently there is no increase in the bond strength on the woven geotextile clay interface during testing. The above observation that the effect of the normal stress on the tensile modulus of the geotextiles is stronger in the case of woven than non-woven geotextile verifies this hypothesis. The increase of tensile modulus is fundamentally caused by the improved interfibre friction-factor which is relatively unaffected by excess pore pressure.

6 CONCLUSIONS

The in-soil tensile tests carried out in the way as described gave valuable information on the effects of soil confinement on the geotextile modulus in the case of woven and non-woven geotextile specimens.

The tensile modulus of the non-woven needle punched geotextile increases in soil confinement due to

1. improved interfibre friction

2. interlocking between the soil particles and the fibres of the geotextile which results in the development of increased bond strength.

3. bond strength mobilized when the geotextile is in tension.

4. obstructed reorientation of the fibres when in tension.

The tensile modulus of the woven geotextile increases in soil confinement due to

1. improved interfibre friction and to a small extent due to

2. interlocking between the soil particles and the fibres of the geotextile which results in the development of

3. bond strength mobilized when the geotextile is in tension.

The confined modulus depends largely on the geotextile strain. Due to the difference in the mechanism of the clay geotextile interaction the soil confinement can significantly increase the modulus up to 10% strain on non-woven geotextiles, but only up to 3-4% strain on the woven geotextiles.

The extent of the increase is also different. At low strains the confined modulus of the non-woven geotextile was up to ten times higher than the unconfined modulus, while that of the woven geotextile was up to three times higher than the unconfined modulus.

The phenomenon the of modulus increase due to soil confinement should be taken into account in applications where the geotextile strain is relatively low.

7 REFERENCES

Fabian, K. and Fourie, A. 1986. Performance of geotextile reinforced clay samples in undrained triaxial tests . Geotextiles and Geomembranes, Vol. 4, p. 53-63.

Fourie, A. and Fabian, K. 1987. Laboratory determination of clay geotextile interaction. Geotextiles and Geomembranes, Vol 7 (in print).

Ingold, T.S. 1981. A laboratory simulation of reinforced clay walls. Geotechnique, Vol. 31, p. 399-412.

Leshchinsky, D. and Field, D.A. 1987. In-soil load elongation, tensile strength and interface friction of non-woven geotextiles. Proc. Geosynthetics '87 p. 238-249.

McGown, A, Andrawes, K.Z. and Kabir, M.H. 1982. Load extension testing of geotextiles confined in sand. Proc. 2nd Int. Conf. on Geotextiles, p. 793-798.