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Analysis of geotextile-soil interaction in pull-out tests

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ABSTRACT: A laboratory research program was undertaken to determine the influence of geotextile fabric structure and geometry on the interfacial shear strength between geotextiles and dry sand. Pullout tests were carried out in a large pullout box. Three types of woven geotextiles (with same tensile strength and different fabric structure) and one nonwoven geotextile were selected for the study. All of the four geotextiles have same polymer composition. Coarse, medium and fine sands were used as the cover material. Effect of fabric structure and geometry on pullout test results were analyzed in terms of peak or ultimate pullout resistance and strain developed at different points along the length of the geotextiles. Pullout tests were conducted at 7, 21, 35 and 49 kPa normal pressures.

1. INTRODUCTION

One of the most important parameters in the performance of a geotextile reinforced structure is the stress-strain behavior of the geotextile when subjected to direct shear or pullout load. Proper understanding of pullout mechanism of geotextiles is necessary for designing reinforced soil structures. For example, if a geotextile is used to reinforce a slope, the stability of the slope depends on the stress that the geotextile can sustain and the displacement it undergoes, as the soil tends to slide downwards. Mechanical interaction between the geotextile and soil is characterized by the shear strength developed between soil and geotextile. A high contact shear strength is required when geotextile is used to reinforce soil and a low contact shear strength is required when soil and geotextile are designed to move against each other. The shear strength is governed by the angle of internal friction developed in between soil and geotextile. Shear strength of the soil-geotextile interface can be characterized by the stress-strain behavior of the geotextile when subjected to pull out force.

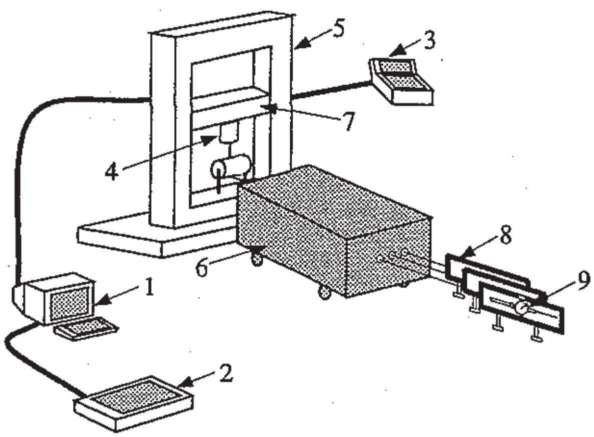
Several researchers (Brand and Duffy, 1987; Rao and Pandey, 1988; Chang et al. 1993; Murthy et al. 1993) have demonstrated the effect of normal pressure and related soil dilatancy on the pullout performance of a soil-geotextile interface. For a soil-geotextile system, the coefficient of friction has been shown to decrease with an increase in normal pressure. Rao and Pandey (1988) and Chang et al (1993) demonstrated that the coefficient of friction of a soil-geotextile interface can exceed the coefficient of friction of soil itself. Ingold (1984) reported that the interface friction angle of a soil-geotextile interface exceeded the coefficient of friction of the soil at low normal pressures. An opposite phenomenon was obtained by Murthy et al (1993), who reported that the pullout coefficients of friction were less than those of sand (as obtained from direct shear test) at three normal pressure levels.

Surface roughness has been found to have a significant effect on bond angle obtained in pullout test (Kabeya and Karmokar, 1993). In that particular pullout test, different sizes of glass beads were used to represent soils with different grain sizes. The coefficient of friction increased with an increase in surface roughness. The interlocking of sand particles was observed to depend primarily on the ratio of the apparent opening size of the geosynthetic to the diameter of the soil particles. Collios et al (1980) studied the effect of soil particle size and the deformability of geotextiles on direct shear and pullout test results. Test results show that the friction angle between the geosynthetic and the cover material increases with an increase in geotextile opening size.

There are three objectives of this study. The objectives are, (1) to evaluate the effect of fabric structure and geometry on the pullout performance of woven fabrics, (2) to evaluate the effect of sand properties on the ultimate pullout resistance of woven and nonwoven fabrics, and (3) to evaluate the effect of normal pressure on the strain developed at different points of woven and nonwoven fabrics.

2. EXPERIMENTAL

An experimental system was developed to study the frictional characteristics of geotextiles with different soils using pullout test method. Figure 1 shows the schematic of the experimental system. A box of 91 cm length × 61 cm width × 46 cm depth was made out of 2.5 cm thick plywood. The box is used in conjunction with the Instron material testing system for pullout testing. The box is filled with 20 cm of soil in four lifts. Geotextile with an unrestrained embedded end is introduced in the box with the help of a clamp through a slit (33 cm × 2.5 cm) in front of the box.



1. computer data acquisition system
2. plotter
3. control panel
4. load cell
5. Instron tensile test frame
6. pullout box
7. moving load head
8. dial gauge frame
9. dial gauge

Figure 1. Schematic of the experimental system

Three high precision dial gages are attached at three different locations along the length of the geotextile. These dial gages are used to measure the progressive mobilization of the geotextile during pullout. It is assumed that normal pressure and interface friction at the soil-geotextile interface is constant along the length of the geotextile. After the geotextile is placed, then the box is filled with 10 cm of soil in two lifts. After placing each lift the soil is compacted with a manual compactor. A steel cable from the clamp is threaded around a pulley and attached to the loading cell on the Instron. Density of the compacted sand was measured with a balloon apparatus (ASTM D2167). An air bag is placed on top of the soil in the box. The box is then covered by a wooden cover. After the cover is bolted on four sides and securely fixed to the box, the air bag is inflated to the required pressure. The loading cell in the Instron is then moved upwards to remove slack in the cable. The load is applied at a prescribed constant displacement rate. The results are recorded with a data acquisition system controlled by a microcomputer. The data include pullout load and front end displacement of the geotextile. Loading was stopped if the displacement exceeded 175 mm or if the geotextile failed in tension.

Three types of woven and one nonwoven geotextile were selected for the study whose properties are shown in Table 1. A coarse, medium and a fine sand were used as the cover material. Table 2 shows the grain size distribution and average density of the sands. Four normal pressures, 7, 21, 35 and 49 kPa and a constant displacement rate of 1 mm/min were selected for the tests.

Table 1. Properties of Geotextiles Tested

	Geotextile Types			
	Woven			*Nonwoven*
	A	B	C	
Properties				
Structure	Plain (M/T)	Plain (T/S)	2 × 1 RHT (S/T)	Needle-punched
Polymer	PP	PP	PP	PP
AOS	40	70	40	70
Grab Tensile Strength (N)	1351	1351	1351	473
Application	E, D, F	R, S/S	E, S/S	D, E, F

Note:
RHT Right Hand Twill
M/T Monofilament in the warp and tape yarn in the filling direction
T/S Tape yarn in the warp and slit film in the filling direction
S/T Slit film yarn in the warp and tape yarn in the filling direction
PP Polypropylene
AOS Apparent Opening Size (Sieve size)
E Environmental
D Drainage
F Filtration
S/S Stabilization
R Reinforcement

Table 2. Sand Properties

	Sand Types		
	Coarse	Medium	Fine
Properties			
Average Diameter (mm)	0.8	0.6	0.3
Compacted Density (gm/cc)	1.46 to 1.63 (for three sands)		
Loose Density (gm/cc)	1.35 (for three sands)		

Geotextiles were marked at four different points along the length of the fabric as shown in Figure 2.

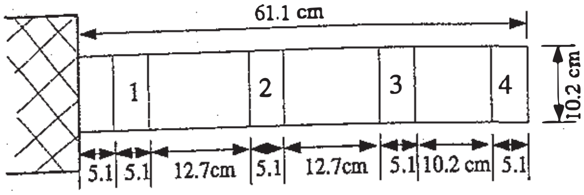


Figure 2. Original mark on the geotextile sample

The initial length of each strip was 5.1 cm. After the test, final length of the strips were measured. From the deformation of the strip, strain at different points along the length of the geotextiles were calculated.

3. RESULTS AND DISCUSSION

3.1 *Effect of fabric structure*

To analyze the effect of fabrics structure, sand properties and normal pressure on the pullout performance of the geotextiles, the following test parameters were selected from the pullout tests:

1. Peak or ultimate pullout resistance
2. Peak or ultimate pullout displacement, and
3. Strain at the points 1, 2, and 3 (Figure 2)

Figure 3, 4 and 5 show the effect of fabrics structure on the peak or ultimate pullout resistance. Definitions of the peak and ultimate pullout resistance are as follows: (Figure 6)

Peak pullout resistance: the maximum load on the pullout load-displacement curve where the curve reached a distinct peak

Ultimate pullout resistance: The maximum load on the pullout load-displacement curve where the curve did not reach any peak. For all the tests, ultimate pullout resistance was achieved at the maximum pullout displacement which was selected as 175 mm for this study.

From the Figures 3 to 5, it can be seen that the peak or ultimate pullout resistance for the geotextile B is larger than the geotextile A and C at all four normal pressures (except in fine sand at 49 kPa). As shown in Table 1, geotextiles A, B and C have the same tensile strength and nearly same elongation. Geotextile;e A is a plain weave with monofilamet warp and tape filling yarn, geotextile B is a plain weave with double tape warp yarn and slit film filling yarn, and sample C is 2 × 1 right hand twill weave with monofilament warp yarn and slit film filling yarn. Pullout resistance of geotextiles is primarily dependent upon three interaction mechanisms: skin friction, interlocking of sand particles and tensile strength of the fabric. As tensile strength of all three fabrics are the same, the difference in pullout resistance is assumed to be caused by the difference in fabric structure and surface properties which are directly related to the development of skin friction and interlocking of sand particles inside the geotextiles.

Skin friction is affected by the fabric surface properties. Geotextile B has the roughest surface and the highest surface area. The slit film filling yarn of fabric B also may have locked the sand particles inside the geotextile during pullout, which resulted in a larger pullout resistance. Geotextiles A and C have relatively smooth surface texture, which resulted in lower pullout resistance.

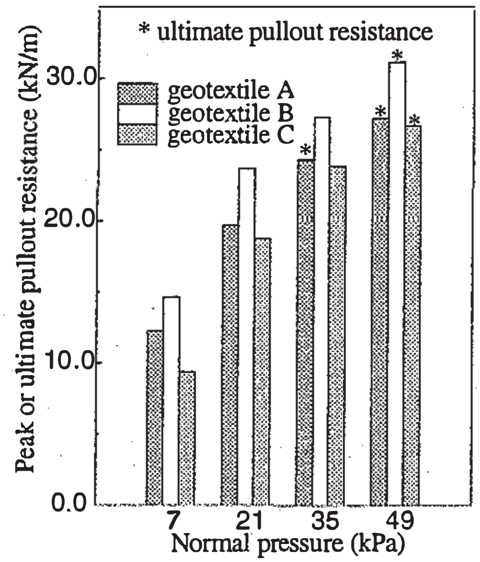


Figure 3. The effect of fabrics structure on the peak or ultimate pullout resistance (coarse sand)

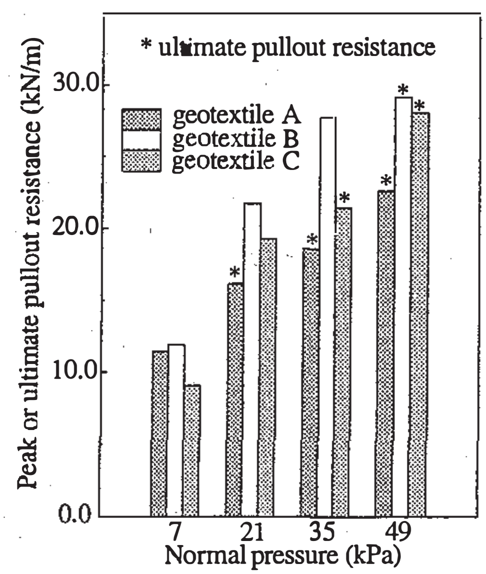


Figure 4. The effect of fabrics structure on the peak or ultimate pullout resistance (medium sand)

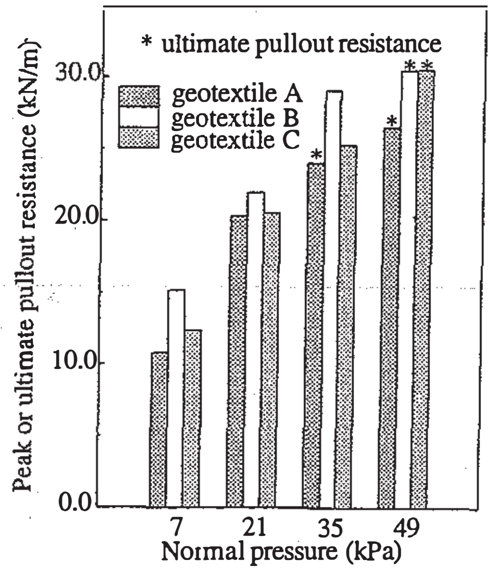


Figure 5. The effect of fabrics structure on the peak or ultimate pullout resistance (fine sand)

Comparison between Geotextiles A and C showed that in the coarse sand, there is no major difference between the pullout resistances developed by the Geotextile A and C. In medium and fine sand, geotextile C demonstrated a larger pullout resistance than Geotextile A, at all four normal pressures (except at 7 kPa in medium sand).

It is also noticed from the test results that the geotextile structure and the normal pressures have major effect on the peak or ultimate shear displacement. As shown in figure 6, under low normal pressures (7 kPa,) all three geotextiles reached a peak pullout load.

At high normal pressures (49 kPa) pullout load-displacement curves did not reach any peak, for all three geotextiles. shear displacement at the maximum pullout resistance sample C reached the peak pullout resistance at short front end displacement than the others for the low normal pressures (Figure 6). It is also noticed from the figure 6, that the geotextile C has the smallest and the geotextile A has the largest peak shear displacement of all three geotextiles. From the reading of dial gage attached to the end of the geotextile sample, it was observed that the end of the sample starts sliding as the sample reaches the peak load. The smallest peak pullout displacement for the geotextile C showed that the sample started sliding much faster than the Geotextile A and B which can also be explained from the fact that the geotextile C has the smoothest surface. Geotextile A has the maximum percent open area of all three geotextiles which may have resulted in a better interlocking between sand particle above and below the geotextile, which in turn resulted in a higher peak shear displacement for the geotextile A.

3.2 *Effect of sand properties*

Figure 7, 8 and 9 show the effect of sand on the pullout resistance of woven fabrics. From Figure 7 and 9 it can be noted that the pullout resistance in fine sand is grater than the pullout resistance in medium sand for the geotextiles A and C. Table 1 and 2 shows that the geotextile A and C have the apparent opening sizes (0.415 mm) slightly larger than the average diameter of fine sand (0.3 mm) and slightly smaller than the average diameter of medium sand (0.6 mm).

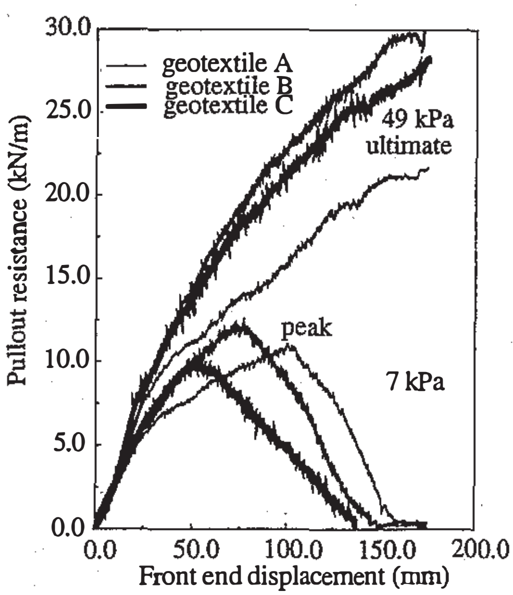


Figure 6. Pullout resistance versus front end displacement at 7 and 49 kPa for sample A, B, C in medium sand

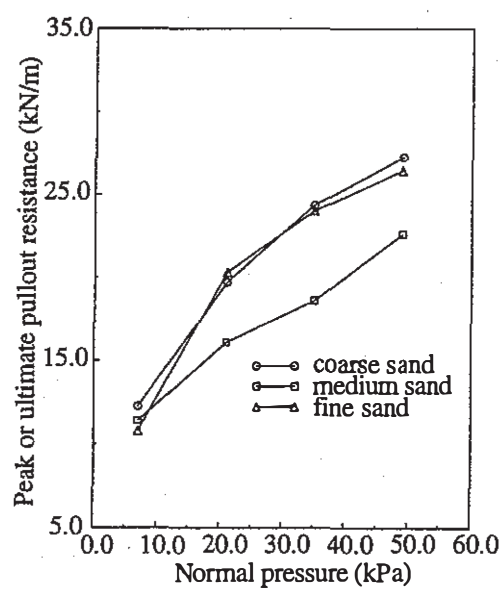


Figure 7. The effect of sand properties on geotextile A

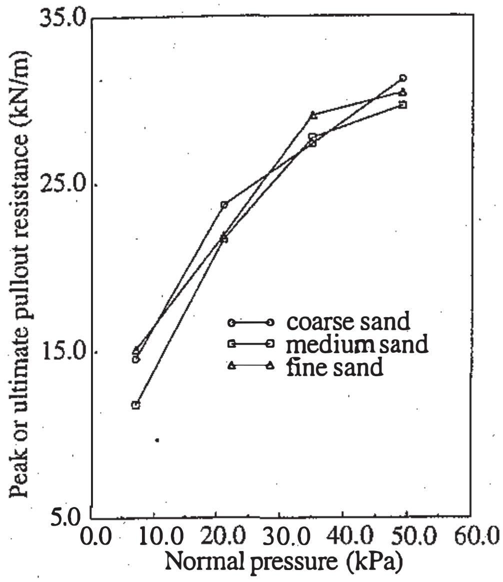


Figure 8. The effect of sand properties on geotextile B

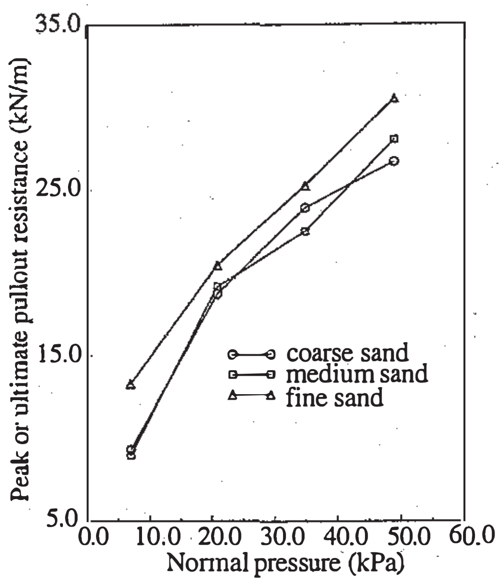


Figure 9. The effect of sand properties on geotextile C

As the geotextile opening size is larger than the average diameter of the fine sand, under normal pressure, indentation of sand particles inside the geotextiles developed an interlock between the sand particles above and below the geotextile, which in this case resulted in a larger pullout resistance in fine sand.

3.3 *Effect of normal pressure on the strain at different points on the geotextiles*

Figure 10, 11 and 12 shows the effect of normal pressure on the strain developed at points 1, 2 and 3 of the woven and nonwoven geotextiles in fine sand. It can be noticed from the figure 10 that, for the woven and nonwoven fabrics, strain at point 1 increased continuously with the increase in normal pressures from 7 to 49 kPa. For the points 2 and 3, in case of woven geotextiles, the strain increased with the increase in the normal pressures from 7 to 35 kPa and then decreased from 35 to 49 kPa. For nonwoven fabrics, the effect is totally different. Strain at the point 2, for nonwoven fabric, decreased continuously with the increase in normal pressures from 7 to 49 kPa. This result shows that the pullout mechanism for the woven and nonwoven fabrics are totally different and the difference is due to the fact that the nonwoven geotextile is much more extensible than the woven geotextiles. When a geotextile is subjected to a pullout load, under low normal pressure, the front part of the fabric stretches under the pullout load, and provides the pullout resistance. As the normal pressure increases, this stretching of the front part of the fabric also increases which is demonstrated by the continuously increasing strain at point 1. For the less extensible woven geotextiles, with the increase in normal pressures, length of the geotextile providing the pullout resistance also increases, which is demonstrated in the increase in the strain at points 2 and 3 from 35 to 49 kPa. For the highly extensible nonwoven geotextiles, under the higher normal pressures the front part of the geotextile continues to stretch and provide the pullout resistance while the strain at points 2 and 3 continues to decrease with the increase in normal pressures.

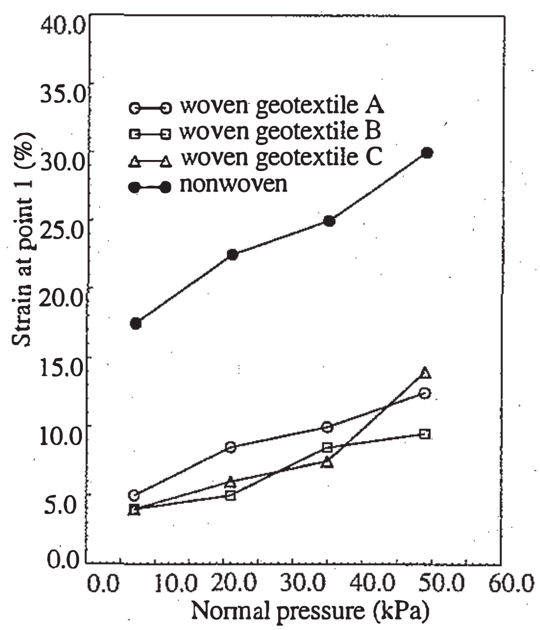


Figure 10. Effect of normal pressure on the strain at point 1

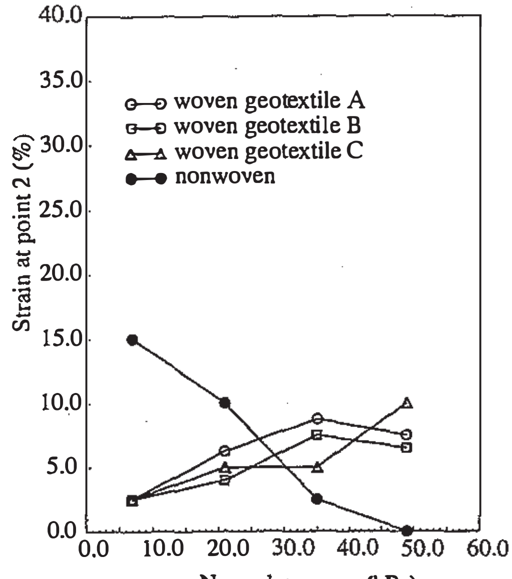


Figure 11. Effect of nonnal pressure on the strain at point 2

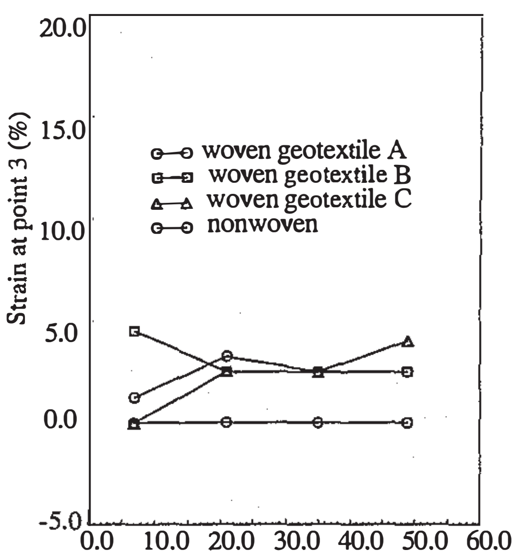


Figure 12. Effect of normal pressure on the strain at point 3

4. CONCLUSIONS

The following conclusions can be drawn from the test results:

1. Fabric structure and surface roughness has an effect on the peak or ultimate pullout load. When two fabrics have same apparent opening sizes, (Geotextile A and C) the geotextile with the slit film filling yarn, (Geotextile C) demonstrated higher pullout resistance.

2. Pullout resistance is higher when soil grain size is smaller than the apparent opening size of the geotextiles (Geotextiles A and C).

3. Effect of sand grain size could not be separated for the geotextile, where the apparent opening size of the geotextile is smaller than the average grain size of coarse, medium and the fine sand.

4. Due to high extensibility of the nonwoven geotextile, strain at points 2 decreased with the increase in nonnal pressures.

5. Strain at point 1 of nonwoven geotextile was much higher than that of all three woven geotextiles.

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