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Experimental investigation of shearing behavior at cohesive soil-geotextile interfaces

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ABSTRACT : The results of direct shear tests on unsaturated silty clay samples reinforced with woven and nonwoven geotextiles were analyzed in terms of both overall strength increase and interface bond development. It was found that the strength increase under low values of normal stress showed a drained behavior whereas higher normal stresses resulted in undrained behavior. The magnitude of interface bond - combined friction and adhesion - increases with the water transmissivity of geotextile and depends on the normal stress. Graphs are presented relating interface friction angles compatible with the expected values of adhesion efficiency for the geotextiles used in the investigation.

INTRODUCTION

Geosynthetics are used with increasing frequency in reinforced soil applications. At the early stage of the earth-reinforcement technique the proposed backfill materials were granular, especially in the case of metallic reinforcements. In the case of geosynthetics, however, several sucessive applications have demonstrated the potential of using cohesive soils as backfill materials (Delmas et al., 1992; Bergado et al., 1993; Wayne and Wilcosky, 1995). As a result of the growing interest in utilizing on-site cohesive soils in reinforced soil structures the research on the subject of the geosynthetic/cohesive soil interface behavior has been intesified during the last decade. This interface behavior is described by a friction angle, δ, and an adhesion, c_α, which are expressed as fractions of the corresponding shear strength parameters of the soil material, φ and c. The corresponding ratios are usually termed efficiencies i.e. the frictional efficiency=δ/φ (or $\tan\delta/\tan\varphi$) and the adhesion efficiency=c_α/c (Ingold, 1994, Koerner, 1994).

In this paper the results are presented of an experimental investigation of the interface behavior between geotextiles and cohesive-frictional soil. The effects of several parameters such as the type of geotextile, its water transmissivity, the normal interfacial stress and the moisture content of the cohesive soil are discussed and conclusions are drawn regarding the practical applications of reinforced cohesive-soil structures.

REVIEW OF LITERATURE

The behavior of clays reinforced with geotextiles was investigated at the beginning of '80s by triaxial tests, direct shear tests, pull-out tests and physical models (Ingold, 1981; Ingold, 1983; Ingold and Miller, 1983). Values of adhesion efficiency were very low in the pull-out mode (0.18) and relatively high (0.89) in the direct shear mode. The triaxial tests indicated that under undrained conditions the use of geotextiles with no capability of in-plane flow actually reduced the shear strength of cohesive soils especially when the degree of saturation was greater than 70%. Under drained conditions, however, the shear strength of reinforced clay was found to increase significantly.

Subsequent investigations by direct shear and pull-out testing showed that the adhesion efficiency ranged from 0.52 to 1.65 for nonwoven and 0.37 to 1.08 for woven geotextiles (Fourie and Fabian, 1987). Bouazza and Djafer-Khodja (1994) reported values of efficiencies equal to 1.23 for friction and 0.68 for adhesion between a peat with water content equal to 250% and a nonwoven geotextile. They also reported that the values of efficiencies were reduced with increasing values of normal interfacial stress. Values of adhesion efficiencies greater than 0.50 were also reported by Nataraj et al. (1995) for clay/geotextile interfaces.

EXPERIMENTAL PROCEDURE

The direct shear tests described in this investigation were conducted in a square shear box measuring 63mm x 63mm. The geotextile reinforcement was placed perpendicular to the plane of shear as shown in Fig. 1. This type of testing has been used by the author in the past for testing granular soils. There are situations, however, where the actual field conditions dictate different test configurations (Murthy et al., 1993).

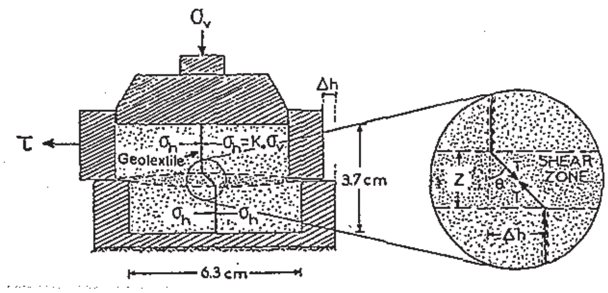

Fig. 1 Direct shear testing of soil sample reinforced with a sheet of geotextile

The soil tested is a silty clay having LL=25, PL= 16, w=17% and G_s=2.68. This soil was compacted in the shear box to obtain the values e=0.50, γ_t=21 kN/m^3 and S_r=91%. The reinforcement sheets were cut from two nonwoven geotextiles (Terram 500, 1500, 4000 and Amoco 4545) and from a woven geotextile (Nicolon 66448). Table 1 summarizes some mechanical and hydraulic properties of the geotextiles.

The rate of shear was 0.4 mm/min. This rate is in the range recommended in the literature (Smith and Criley, 1995; Ingold, 1994). For the cohesive soil used in the tests, this rate of shearing is taken to represent undrained loading conditions. All tests were run immediately after the placemen and compaction of soil in the shear box ; therefore the tests are considered unconsolidated-undrained and represent the short-term conditions developed in the corresponding field applications. The values of normal stress ranged from 25 kPa to 600 kPa.

TEST RESULTS AND DISCUSSION

The results of direct shear tests are analyzed in terms of both overall behavior of reinforced sample and interface interaction between soil/ reinforcement.

Fig. 2 shows the tests results for the unreinforced silty clay. The failure envelope indicates a frictional-cohesive behavior with strength parameters : φ=14.8° and c=43.2 kPa. The vertical displacement/shear displacement curves indicate a contractant behavior which is caused by the consolidation settlement of samples during testing. Fig. 3

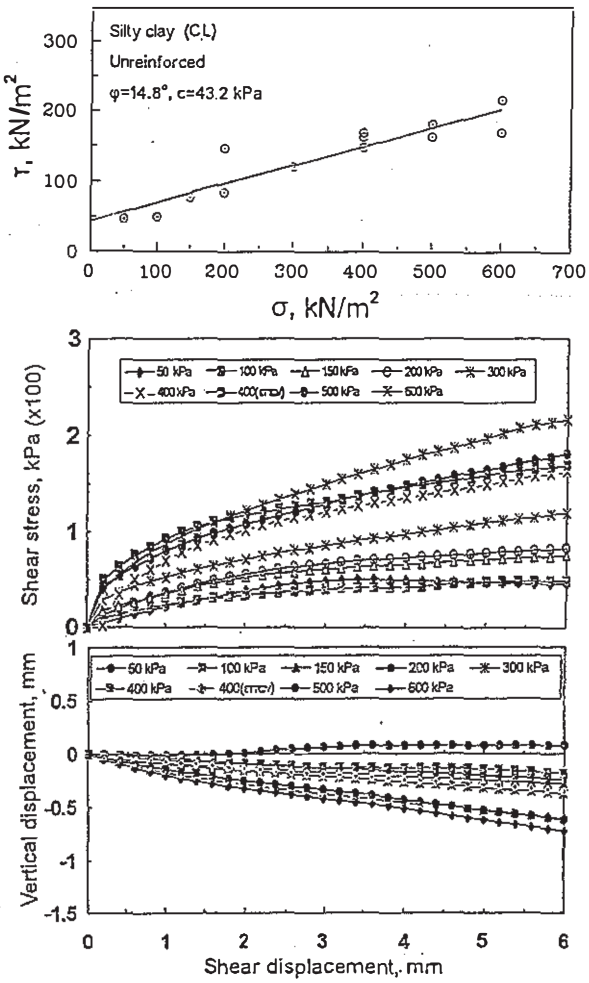

Fig 2 Results of direct shear tests on unreinforced sample of silty clay

Table 1. Geotextile Properties

Geotextile	Structure	Thickness (mm)	Mass per Unit Area (gr/m^2)	Apparent Opening Size (mm)	Tensile Strength		Hydraulic Properties	
					Ultimate Load (kN/m)	Elongation (%)	Permit-tivity (sec^{-1})	Transmis-sivity (mm^2/sec)
Terram 500	NW	0.4	70	0.35	3.5	20	1.50	0.240
Terram 1500	NW	0.8	190	0.06	12.0	25	0.35	0.224
Terram 4000	NW	1.4	350	0.03	23	30	0.25	0.490
Amoco 4545	NW	1.1	172	0.21	4.2	60	2.5	0.847
Nicolon 66448	W	0.9	183	1.25	42.6	31	High	0.000

and Fig. 4 summarize the results of tests for samples reinforced with Terram 4000 and Nicolon 66448 geotextiles. A comparison with the results of unreinforced soil indicates that the nonwoven geotextile increased the shear strength of the samples whereas the pattern of development of shear stresses and volumetric deformations remained unchanged. For low values of normal stress the behavior is frictional (i.e. drained) whereas the opposite is true (i.e. undrained behavior) for higher values of normal stress. It is very interesting to note that the woven geotextile did not offer any strength increase to soil samples (Fig. 4). This is attributed to the pore water pressures developed along the interface; these pressures could not be dissipated due to the zero transmissivity of the particular geotextile. Similar pressures were obviously developed in the case of nonwoven geotextiles. These pressures, however, could be rapidly dissipated by the in-plane flow capability of these fabrics. The above results are in agreement with the findings of previous investigations presented in a previous section.

The results of direct shear tests were further analyzed following the methodology described by Athanasopoulos (1993) for estimating the interface friction angle in granular soils. In this study, however, the interface friction angle δ was expressed as a function of both interfacial normal stress and adhesion efficiency, c_a/c. Fig. 5 summarizes the results of calculations for the nonwoven geotextiles and includes plots of the frictional efficiency (δ/φ) versus the interfacial normal stress for three values of adhesion efficiency : $c_a/c=0.0$, 0.5 and 1.0. According to these plots, the Terram 4000 geotextile developed the highest efficiency ratio (δ/φ) ranging from 2.90 to 2.07 for values of c_a/c ranging from 0.0 to 1.0. The corresponding friction angles are δ=43° to 30.6°. The interface friction angles for the other two Terram and the Amoco geotextiles ranged from 1.5° to 22°. It is interesting to note that the values of friction angle δ for the three Terram geotextiles increased with the thickness of geotextile, a fact that could be explained by the corresponding increase of transmissivity of the fabric.

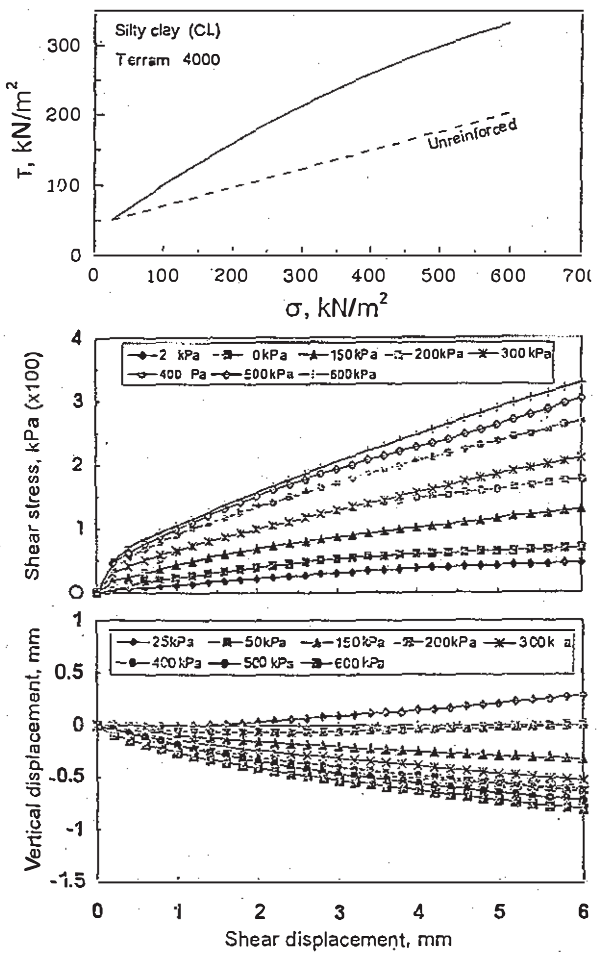

Fig 3 Results of direct shear tests on silty clay reinforced with Terram 4000

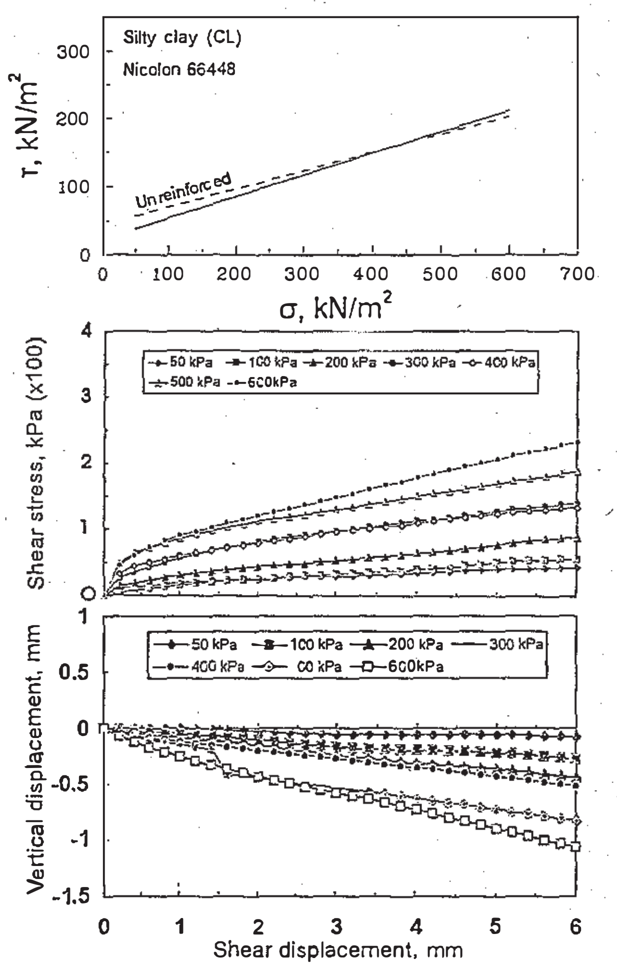

Fig 4 Results of direct shear tests on silty clay reinforced with Nicolon 66448

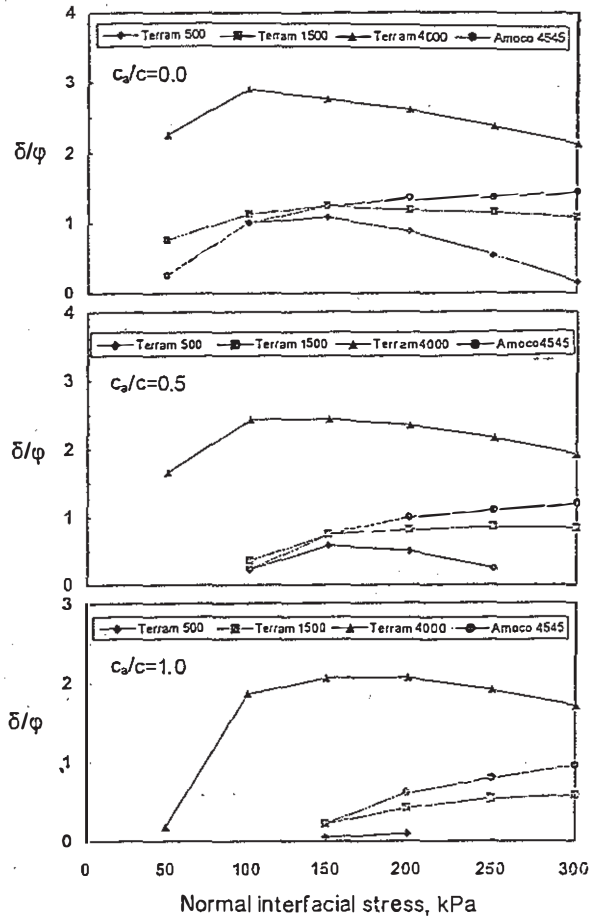

Fig 5 Determined values of δ/φ for various reinforcements as a function of normal interfacial stress and adhesion efficiency ($c_α/c$)

CONCLUSIONS

The cohesive soil used in this investigation was effectively reinforced by geotextiles possesing the capability of in-plane flow of water. It is therefore possible to utilize on-site cohesive soils as backfill materials by appropriately selecting dual function (reinforcement + drainage) geosynthetics.

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