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Effect of triaxial compression testing factors on sand – geotextile interface friction

Markou, I. & Droudakis, A.
Department of Civil Engineering, Democritus University of Thrace, Greece

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ABSTRACT: Conventional triaxial compression tests are conducted on Ottawa 20-30 sand reinforced with woven and non-woven geotextiles, in order to estimate the apparent angle of friction, $\phi_{S/GTX}$, at the sand – geotextile interface, using a special computation method. The effect of specimen preparation parameters and of testing parameters is investigated. The failure envelopes of reinforced sand are bilinear. The maximum values of friction angle are obtained from specimens with diameters of 70 mm and 50 mm containing 5 geotextile layers. Also, the friction angle values decrease with increasing cell pressure and appear to be unaffected by the rate of axial displacement used in tests.

1 INTRODUCTION

Design procedures for reinforced soil structures require quantification of the interaction behavior at the soil – reinforcement interface which is accomplished by conducting direct shear and pull-out tests and is expressed in terms of an apparent friction angle, $\phi_{S/GTX}$. These experimental procedures require the use of special large-size direct shear or pull-out boxes and specialized personnel and are rather costly. Therefore, a methodology for obtaining $\phi_{S/GTX}$ values from the results of conventional triaxial compression tests was developed (Atmatzidis et al. 1992, 1994, Atmatzidis & Athanasopoulos 1994). The triaxial compression testing techniques used in these investigations appear to offer a feasible alternative to pull-out and direct shear tests. It is, therefore, of merit to investigate the effect of specimen preparation and testing parameters on $\phi_{S/GTX}$ values obtained using this methodology. Toward this end, triaxial compression tests were conducted on sand specimens reinforced with different geotextiles. Based on these tests, the effect of specimen size, number of reinforcement layers, cell pressure and rate of axial displacement was investigated and the results obtained, are reported herein.

2 EXPERIMENTAL PROCEDURES

Conventional laboratory triaxial compression equipment without modifications was used to conduct tests on geotextile reinforced sand in order to investigate the mechanical behavior of the composite material and to evaluate the interface friction angle, $\phi_{S/GTX}$. All tests were conducted using dry dense Ottawa 20-30 sand. This sand has maximum and minimum void ratio of 0.77 and 0.46, respectively, and angle of internal friction, ϕ, equal to 36° at an average relative density of 84%. This ϕ value was found to be unaffected by the rate of axial displacement values used for conducting triaxial compression tests in this investigation. Two thermally bonded (TYPAR SF 56 and TYPAR SF 77), one needle-punched with thermally treated surfaces (FIBERTEX F 400) and one needle-punched (POLYFELT TS 65) non-woven polypropylene geotextiles, and one standard grade woven polypropylene geotextile (BONAR SG 80/80), were tested. These geotextiles are designated as TB1, TB2, TTS, NP and WSG, respectively. Properties according to the manufacturers of the geotextiles, are presented in Table 1.

Table 1. Geotextile properties.

GTX	Thickness (mm)	Mass per unit area (g/m^2)	Tensile Test Results	
			Max tensile load (kN/m)	Extension at max load (%)
TB1	0.54	190	12.8	65
TB2	0.65	260	20.0	70
TTS	1.80	275	16.5/17.5 $	52/55 $
NP	1.10	285	21.5	80/40 $
WSG	1.35	360	82.0/86.0 $	20/11 $

$ Machine direction/Cross machine direction

Triaxial compression tests were conducted using specimens with diameter, d, of 50 mm and 70 mm and overall heights of 101 mm and 141 mm, respectively. The specimens were reinforced with a number of geotextile discs, N, equal to 3, 5 or 7. The discs had diameter equal to that of specimens and were placed as shown in Figures 1(a), 1(b) and 1(c). The sand was compacted using a special hand operated tamper. All tests were conducted at a relative density of the sand between 77% and 89%. Tests were conducted with confining pressures, σ_3, equal to 50, 100, 200, and 400 kPa and at a testing speed, S_T, ranging from 0.1 mm/min to 6.0 mm/min. Duplicate tests were conducted on specimens prepared with 2, 4 and 6 geotextile discs placed as shown in Figures 1(d), 1(e) and 1(f) respectively, in order to determine the effect of the reinforcement disc placed at the mid-height of the sample. This was dictated by consistent observations indicating that slippage between sand and geotextile occurred definitely at least on this reinforcement disc. Reinforced sample configurations same as that of Figures 1(b) and 1(e) have been used previously (Atmatzidis et al. 1992, 1994, Atmatzidis & Athanasopoulos 1994, Markou & Droudakis 2005) in an attempt to separate the effect of the central reinforcement layer and to estimate the values of the interface friction angle, $\phi_{S/GTX}$.

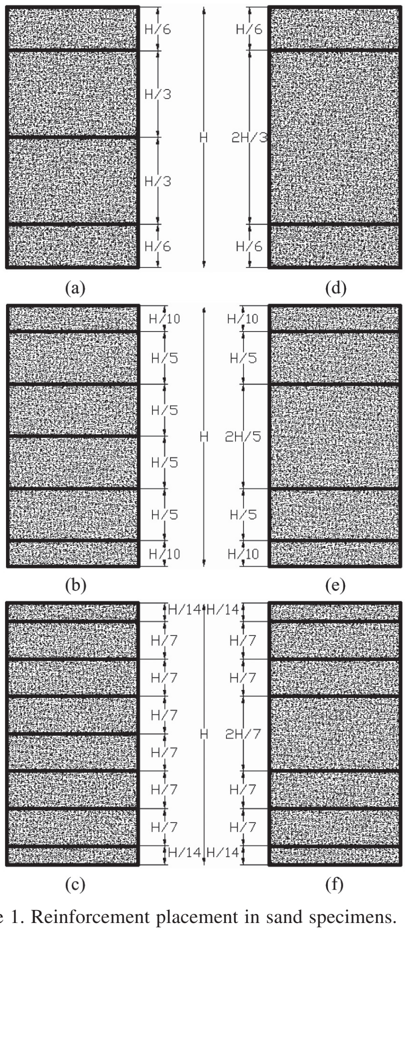

Figure 1. Reinforcement placement in sand specimens.

3 FRICTION ANGLE COMPUTATION

A method developed for computing values of the angle of friction, $\phi_{S/GTX}$, from the results of triaxial compression tests (Atmatzidis et al. 1992, 1994, Atmatzidis & Athanasopoulos 1994), was used in this investigation. More specifically, the equivalent confining stress increase, $\Delta\sigma_3$, concept (Ingold 1982) attributes the observed shear strength increase, due to reinforcement, to the development of an additional confining pressure, $\Delta\sigma_3$, which is considered uniformly distributed over the entire cylindrical surface of the sample and is expressed, for failure conditions, as (Gray & Al-Refeai 1986):

$$\Delta\sigma_3 = \frac{\sigma_3}{\sigma_1} \cdot \Delta\sigma_1 \qquad (1)$$

where σ_3 is the same minor principal stress for tests on reinforced and unreinforced soil, σ_1 is the major principal stress at failure of the unreinforced soil and $\Delta\sigma_1$ is the major principal stress difference at failure between reinforced and unreinforced soil. Therefore, the contribution of the geotextile disc at the mid-height of the specimens to the shear strength increase was quantified by determining the corresponding confining stress increase, $\Delta\sigma_3$. This was achieved by (a) conducting tests with the same confining pressure, σ_3, for unreinforced sand and sand reinforced as shown in Fig. 1, (b) determining $\Delta\sigma_{3,N}$ and $\Delta\sigma_{3,N-1}$ for N (3, 5, 7) and N-1 (2, 4, 6) layers of reinforcement, respectively, by applying Equation (1) and (c) setting $\Delta\sigma_3 = \Delta\sigma_{3,N} - \Delta\sigma_{3,N-1}$. The value of the angle of friction, $\phi_{S/GTX}$, is then computed by applying Equation (2) (Atmatzidis et al. 1992, 1994, Atmatzidis & Athanasopoulos 1994):

$$\tan\varphi_{S/GTX} = \frac{\Delta\sigma_3}{\sigma_{1r}} \cdot \frac{3H}{2R_0} \qquad (2)$$

where R_0 is the radius of the reinforcement disc, H is the overall height of the sample and σ_{1r} is the major principal stress at failure which is set equal to the axial stress at failure of the sand sample reinforced with N layers of geotextile.

4 RESULTS AND DISCUSSION

Failure envelopes obtained by triaxial compression testing of the unreinforced and reinforced sand, are presented in Fig. 2. It can be observed that the triaxial

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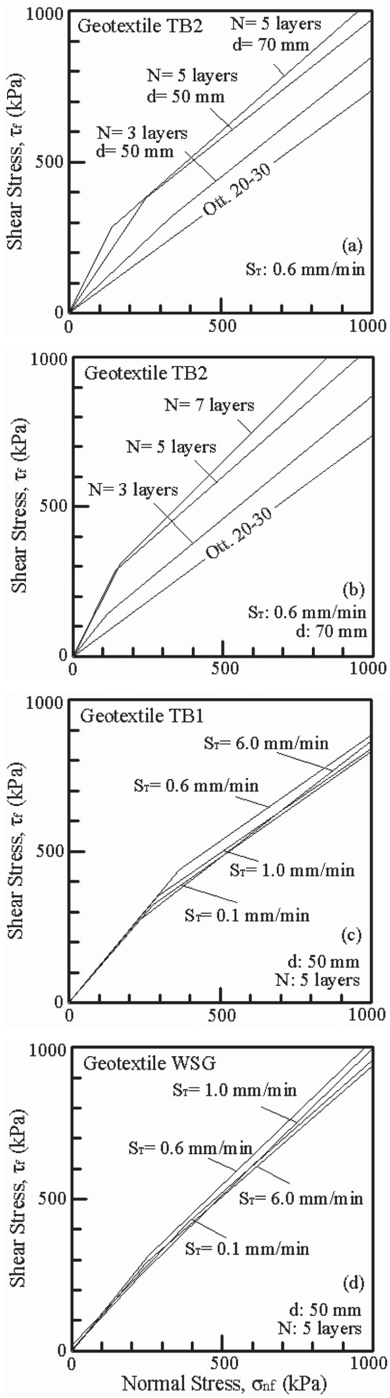

Figure 2. Failure envelopes of reinforced sand.

compression tests yielded bilinear envelopes for the composite material in good agreement with the observations of other investigators (e.g. Gray & Al-Refeai 1986). In every case, reinforced sand presents higher shear strength than unreinforced sand. It is also observed, that shear strength of reinforced sand increases with increasing number of geotextile layers (Fig. 2(a) and 2(b)). However, the increase in strength gained by increasing the number of geotextile layers from 5 to 7 is considered as low (Fig. 2(b)). Furthermore, it appears that the specimen sizes (diameter of 50 mm and 70 mm) used, do not affect the shear strength of reinforced sand (Fig. 2(a)). Failure envelopes from triaxial compression tests conducted at different testing speeds in sand reinforced with non-woven and woven geotextile, are presented in Fig. 2(c) and 2(d), respectively. It is seen that the range of testing speeds (rate of axial displacement) used in this investigation, has no effect on shear strength of reinforced sand.

Values of the interface friction angle were computed by applying the methodology presented in paragraph 3, for triaxial compression tests in which the failure of composite material was caused by the slippage of geotextile with regard to the surrounding soil (Mohr circles tangent to the part of the failure envelope before the break point). The combined influence of specimen preparation parameters (specimen size and number of geotextile layers) on friction angle is presented in Fig. 3 from the results obtained by triaxial compression testing on sand reinforced with 3 different non-woven geotextiles (TB2, NP and TTS). The ratio

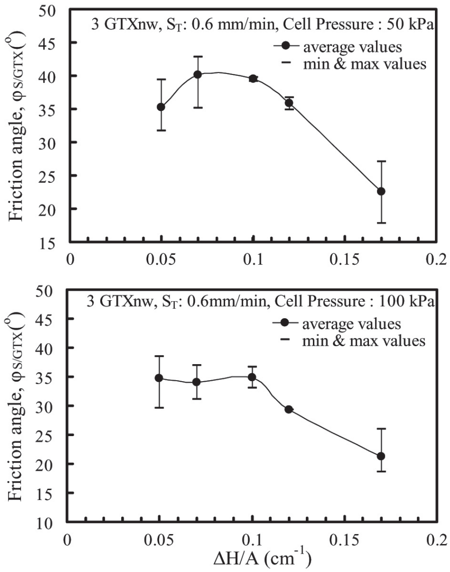

Figure 3. Relationship of friction angle with ΔH/A ratio.

of distance between geotextile layers to specimen cross-sectional area, ΔH/A, is adopted for this purpose. For every ΔH/A value, the minimum, maximum and average values of friction angle obtained from the three geotextiles, are included in Fig. 3. For both cell pressures under consideration, the maximum values of $\phi_{S/GTX}$ are obtained for ΔH/A values equal to 0.07 cm^{-1} and 0.10 cm^{-1} which correspond to specimens with diameters of 70 mm and 50 mm, respectively, reinforced with 5 geotextile layers. Therefore, it appears that these two combinations give the best results. The effectiveness of rate of axial displacement used in triaxial compression tests, on interface friction angle is shown in Fig. 4. For the two geotextiles tested, the interface friction angle values are independent from the rate of axial displacement. This observation is limited to the range of rate of axial displacement used in this investigation (0.1 %/min to 5.94 %/min).

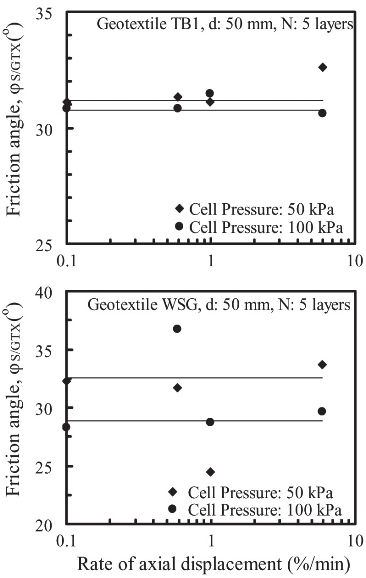

Figure 4. Effect of rate of axial displacement on friction angle.

Based on the observations mentioned above, friction angle values from triaxial compression test conducted at a rate of axial displacement equal to 0.59%/min, on specimens of 50 mm in diameter reinforced with 5 geotextile layers, are presented in Table 2. These values were also normalized with regard to the angle of internal friction, ϕ, of the sand. The values of $\phi_{S/GTX}/\phi$ range generally between 0.80 and 1.10 and are in good agreement with the typical range of friction property of geotextiles which is equal to 60 – 100% of soil friction (Koerner 1994). In addition, the friction angle values from triaxial compression tests were found to be comparable to the values obtained from direct shear tests conducted on the same sand – geotextile interfaces (Markou & Droudakis 2005). It is also observed that the value of friction angle decreases with increasing cell pressure (good indicator of normal interfacial stress) in agreement with other studies (Ingold 1982).

Table 2. Values of friction angle and friction coefficient.

GTX	σ_3 [kPa]	$\phi_{S/GTX}$ [°]	$\mu_{S/GTX}$	$\phi_{S/GTX}/\phi$	$f_{S/GTX}$
TB1	50	31.19	0.61	0.87	0.84
	100	30.75	0.59	0.85	0.81
TB2	50	39.61	0.83	1.10	1.14
	100	36.66	0.74	1.02	1.02
TTS	50	39.18	0.81	1.09	1.12
	100	33.11	0.65	0.92	0.89
NP	50	39.74	0.83	1.10	1.14
	100	34.86	0.70	0.97	0.96
	200	29.62	0.57	0.82	0.79
WSG	50	32.55	0.64	0.90	0.88
	100	28.90	0.55	0.80	0.76

5 CONCLUSIONS

Based on the results of this investigation the following conclusions may be advanced:

- Shear strength of reinforced sand increases with increasing number of geotextile layers and is unaffected by the specimen size and testing speed.
- The interface friction angle obtained by triaxial compression tests, becomes maximum for ΔH/A values equal to 0.07 cm^{-1} and 0.10 cm^{-1}, is unaffected from the rate of axial displacement and decreases with increasing normal interfacial stress.

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