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Behavior of reinforced sand: Effect of triaxial compression testing factors

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ABSTRACT: Triaxial compression tests were conducted in order to investigate the effect of specimen preparation parameters and testing parameters on the mechanical behavior of Ottawa 20–30 sand reinforced with woven and non-woven geotextiles. Strength and failure deformation of reinforced sand are always higher than the ones of unreinforced sand. Strength of reinforced sand increases with increasing number of geotextile layers and cell pressure and is not affected by the rate of axial displacement used in the tests. Axial strain at failure of reinforced sand increases as specimen size and number of geotextile layers increase. An empirical equation is proposed for the computation of the equivalent confining stress increase due to geotextile reinforcement in connection with specimen size, number of geotextile layers and cell pressure. The results obtained by this equation are in good agreement with the experimental results obtained in this investigation.

1 INTRODUCTION

The design of reinforced soil structures requires the knowledge of the mechanical behavior of composite material. The mechanical behavior of sand – geotextile composites has been extensively investigated in the past and several research efforts were based on the results of triaxial compression tests (e.g. Gray et al. 1982, Gray & Al-Refeai 1986, Baykal et al. 1992, Ashmawy & Bourdeau 1998, Haeri et al. 2000). An appropriate selection of parameters related to triaxial compression test is needed, before conducting this test for the study of mechanical behavior of geotextile reinforced sand. Although the effect of specimen preparation and testing parameters, such as specimen size, number and position of reinforcement layers and strain rate, on mechanical behavior of reinforced sand has been evaluated in some research efforts (e.g. Yang & Singh 1974, Gray & Al-Refeai 1986, Moroto 1992, Haeri et al. 2000), it is of merit to make an all-embracing assessment of the effect of all these parameters on strength and deformation characteristics of reinforced sand. The research effort reported herein, aims at the evaluation of the effect of specimen size, number of reinforcement layers, cell pressure and strain rate as well as the combined effect of the first three parameters on the results of triaxial compression tests conducted on sand reinforced with geotextiles. Based on the results of this investigation, the behavior of geotextile reinforced sand could be predicted by selecting the values of the above mentioned parameters.

2 EXPERIMENTAL PROCEDURES

Conventional laboratory triaxial compression equipment was used to conduct tests on geotextile reinforced sand. All tests were conducted using dry and dense Ottawa 20–30 sand. This sand has maximum and minimum void ratios of 0.77 and 0.46, respectively, and angle of internal friction, φ, equal to 36° at an average relative density of 84%. This value of angle of internal friction 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, as well as 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.

Tests were conducted using sand specimens reinforced with a number of geotextile discs, N, equal to 3, 5 or 7 placed as shown in Figure 1. The discs had diameter equal to that of specimens. The specimens had diameter, d, equal to 50 mm and 70 mm and overall height, H, of 101 mm and 141 mm, respectively. Specimen configurations same as that of Figure 1b have been used previously (Atmatzidis & Athanasopoulos 1994, Markou & Droudakis 2005) in laboratory investigations using triaxial compression tests. The sand was compacted using a special hand operated tamper. All tests were conducted at a relative density of sand between 77% and 89%. Triaxial compression tests were conducted with cell pressures, σ_3, equal to 50, 100, 200, 400 and 600 kPa and at a testing rate of axial displacement ranging from 0.1%/min to 5.94%/min.

3 RESULTS AND DISCUSSION

The effect of specimen size on strength and axial strain at failure of reinforced sand is shown in the diagrams of Figure 2. In these diagrams, the maximum deviator stress, $(\sigma_1 - \sigma_3)_{max}$, values and axial strain at failure, ε_f, values obtained from reinforced sand specimens with diameter of 50 mm are directly compared to the values obtained from specimens with diameter of 70 mm. The results were obtained from sand specimens reinforced with 3 and 5 layers of TB2, TTS and NP non-woven geotextiles. It can be seen (Fig. 2a) that, although a significant number of points is very close to the diagonal line, the majority of points is above this line, indicating that specimens of 70 mm in diameter give generally higher strength than the ones of 50 mm in diameter. The observed variations in maximum deviator stress can reach the value of 20% for tests conducted with low cell pressures and are limited to the value of 10% for tests conducted with higher cell pressures (Fig. 2a). It is clearly seen in Figure 2b that specimens with diameter of 70 mm generally present higher values of axial strain at failure than specimens having diameter of 50 mm. Therefore, it is concluded that the effect of specimen size on maximum deviator stress is not very strong, while the effect of it on axial strain at failure is significant.

Table 1. Geotextile properties.

Geotextile	Thickness mm	Mass per unit area g/m^2	Tensile test results: Max tensile load, kN/m	Tensile test results: 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

The strength ratio, S_R, defined as the ratio of maximum deviator stress of reinforced sand to the maximum deviator stress of unreinforced sand for the same cell pressure, is used for the quantification of the strength increase due to reinforcement of sand. Strength ratio values obtained from specimens reinforced with 3, 5 and 7 layers of TTS geotextile are presented in Figure 3. It is observed that strength ratio increases with increasing the number of geotextile layers used for sand reinforcement and with decreasing cell pressure. The S_R values obtained from

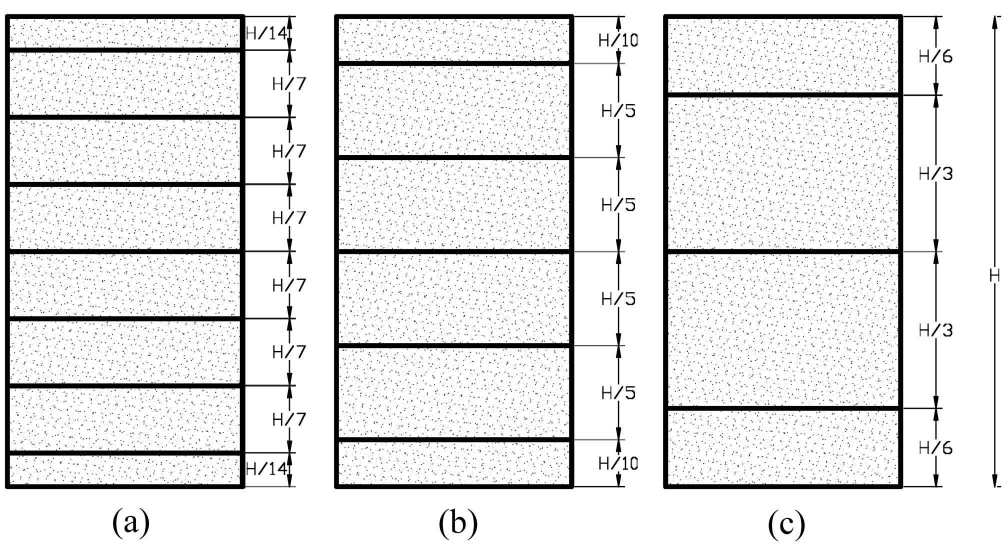

Figure 1. Sand specimens reinforced with (a) 7, (b) 5 and (c) 3 geotextile layers.

all specimen configurations used in this investigation, range between 1.34 (specimen with d = 50 mm, TB2 geotextile, N = 3, $\sigma_3 = 400$ kPa) and 5.97 (specimen with d = 70 mm, NP geotextile, N = 7, $\sigma_3 = 50$ kPa) showing that the use of geotextiles as reinforcement leads to a significant increase in the strength of sand.

Similarly, axial strain at failure values obtained from specimens reinforced with 3, 5 and 7 layers of NP geotextile are presented in Figure 4. Axial strain at failure increases as the number of geotextile layers increases. Furthermore, the axial strain at failure of reinforced sand is always higher than the one of unreinforced sand. Also, it seems that an increase in cell pressure leads to an increase in axial strain at failure. This observation is not always confirmed when a larger number of woven and non-woven geotextiles are considered (Markou et al. 2006a, b).

Yang (1972) presented a semi-empirical equation that relates the equivalent confining stress increase, $\Delta\sigma_3$, to the reinforcement spacing ratio, ΔH/d, in a triaxial compression test. The equation has the form:

$$\frac{\sigma_3 + \Delta\sigma_3}{\sigma_3} = \frac{1}{1 - CK_p\left(\frac{\Delta H}{2d}\right)^m} \qquad (1)$$

where ΔH = spacing between reinforcement layers; d = triaxial specimen diameter; $K_p = \tan^2(45° + \varphi/2)$; and C, m = empirical constants.

It was found that the experimental results and theoretical curve predicted by Equation 1 compare fairly well at large spacing ratios, but diverge at ratios less than 0.5 and that reinforcements placed at ΔH/d ratios more than unity have little effect. (Gray & Al-Refeai 1986).

In the present investigation, ΔH/A ratio (A = specimen cross-sectional area) is preferred than ΔH/d ratio, since it expresses the combined effect of number

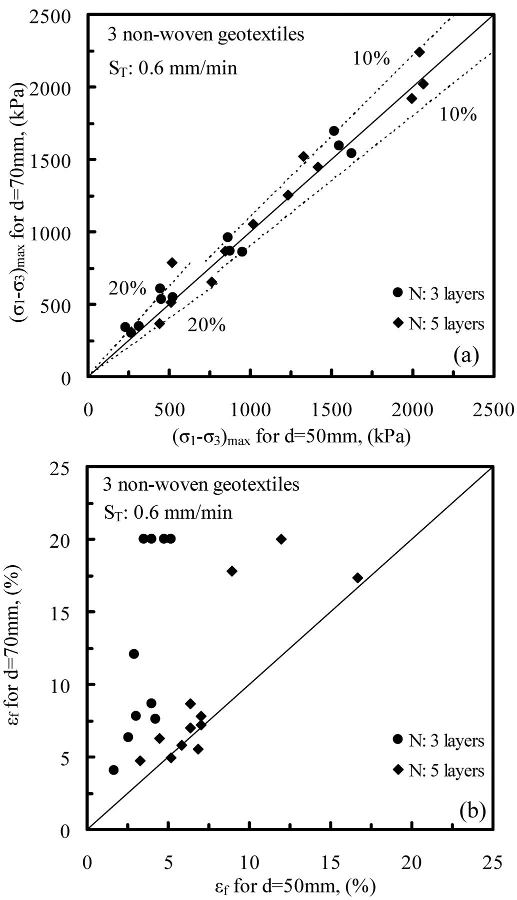

Figure 2. Effect of specimen size on (a) maximum deviator stress and (b) axial strain at failure of reinforced sand.

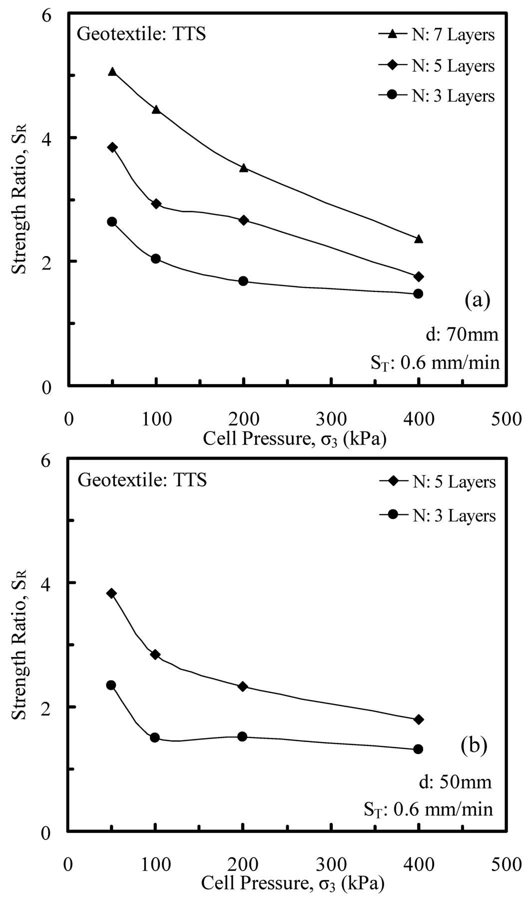

Figure 3. Effect of number of geotextile layers on strength increase of reinforced sand.

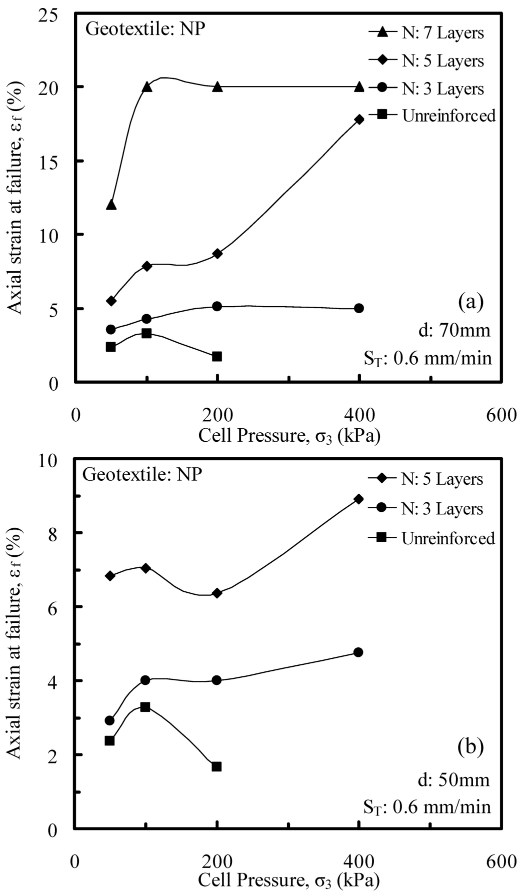

Figure 4. Effect of number of geotextile layers on axial strain at failure of reinforced sand.

of geotextile layers and of specimen size on triaxial compression test results. As it is typically shown in Figure 5, $(\sigma_3 + \Delta\sigma_3)/\sigma_3$ values decrease with increasing $\Delta H/A$ ratio. This behavior is mostly attributed to the number of geotextile layers since it was shown earlier that specimen size does not present a strong effect on reinforced sand strength (Fig. 2a). Based on this observation and on the experimental results obtained in this investigation, an alternative empirical equation is proposed for the quantification of the effect of specimen size, number of geotextile layers and cell pressure on the equivalent confining stress increase:

$$\frac{\sigma_3 + \Delta\sigma_3}{\sigma_3} = (0.0005\sigma_3 + 0.4247)\left(\frac{\Delta H}{A}\right)^{0.001\sigma_3 - 0.754} \quad (2)$$

The comparison between values of $(\sigma_3 + \Delta\sigma_3)/\ \sigma_3$ ratio computed with Equation 2 and values obtained

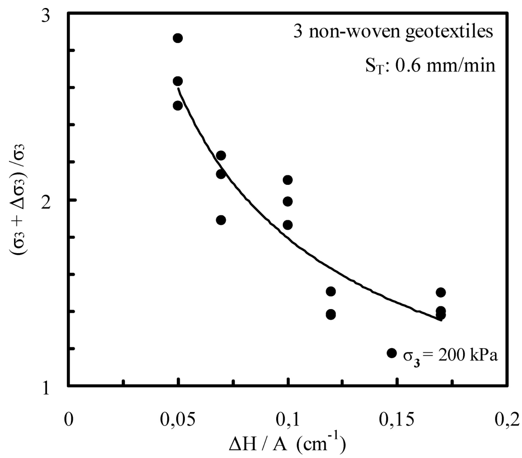

Figure 5. Combined effect of specimen size and number of geotextile layers on $(\sigma_3 + \Delta\sigma_3)/\sigma_3$ ratio.

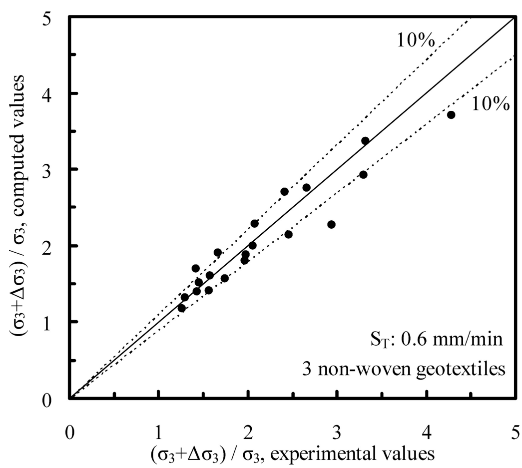

Figure 6. Comparison between computed and experimental values.of $(\sigma_3 + \Delta\sigma_3)/\sigma_3$ ratio.

experimentally is shown in Figure 6. As it can be seen, the results of Equation 2 compare fairly well with the experimental results, since the variation between them is lower than or equal to 10% in most cases.

Shown in Figure 7, is the effect of rate of axial displacement on maximum deviator stress of sand reinforced with a woven (WSG) and a non-woven (TB1) geotextile. For both geotextiles tested and for the range of axial displacement rates used, it is evident that maximum deviator stress is not affected by the axial displacement rate.

Failure envelopes obtained by triaxial compression testing of the unreinforced and reinforced sand, are

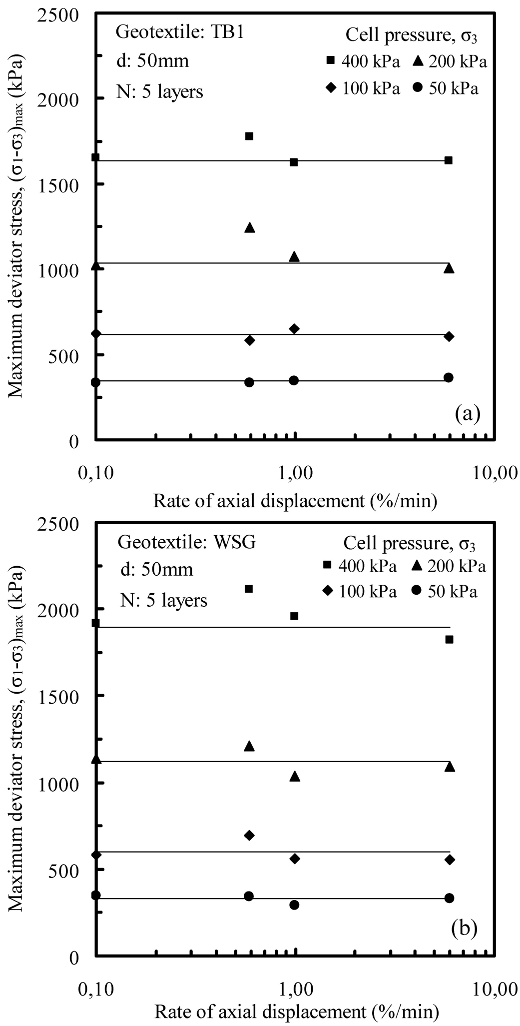

Figure 7. Effect of rate of axial displacement on maximum deviator stress of reinforced sand.

presented in Figure 8. The marks in Figures 8a–d represent the points at which failure envelopes are tangent to Mohr circles resulted from the triaxial compression tests. Such marks were not plotted in Figures 8e, f for clarity reasons. It can be observed that the triaxial compression tests yielded bilinear envelopes for the composite material in good agreement with the observations of other investigators (e.g. Gray et al. 1982, Gray & Al-Refeai 1986). In every case, reinforced sand presents higher shear strength than unreinforced sand (Figs 8a–d). Furthermore, it appears that the specimen sizes (diameter of 50 mm and 70 mm) used, do not affect significantly the shear strength of reinforced sand (Figs 8a, b). It is also observed, that shear strength of reinforced sand increases with increasing number of geotextile layers (Figs 8c, d). Failure envelopes from triaxial compression tests conducted at different testing speeds, S_T, in sand reinforced with a non-woven and a woven geotextile, are presented in Figures 8e, f, respectively. It is seen, that the range of testing speed (rate of axial displacement) used in this investigation has no effect on shear strength of reinforced sand. Consequently, all the above mentioned observations on the effect of triaxial compression testing parameters on the strength of geotextile reinforced sand are also confirmed by the failure envelopes.

4 CONCLUSIONS

Based on the results of this investigation and within the limitations posed by the number of tests conducted and the materials used, the following conclusions may be advanced:

- Strength of reinforced sand increases with increasing number of geotextile layers, specimen size and cell pressure and is unaffected by the rate of axial displacement. However, the effect of specimen size is not considered as strong.
- Axial strain at failure of reinforced sand increases as the number of geotextile layers, specimen size and cell pressure increase. However, the increase of axial strain at failure with increasing cell pressure was not always observed when a larger number of woven and non-woven geotextiles were tested in previous research efforts.
- Strength and axial strain at failure of reinforced sand are always higher than those of unreinforced sand. The increase in maximum deviator stress of sand, due to geotextile reinforcement, ranges from 1.30 to 6.00 times.
- An empirical equation is proposed for the quantification of the effect of specimen size, number of geotextile layers and cell pressure on the equivalent confining stress increase due to geotextile re-inforcement. The results obtained by this equation are in good agreement with the experimental results obtained in this investigation.

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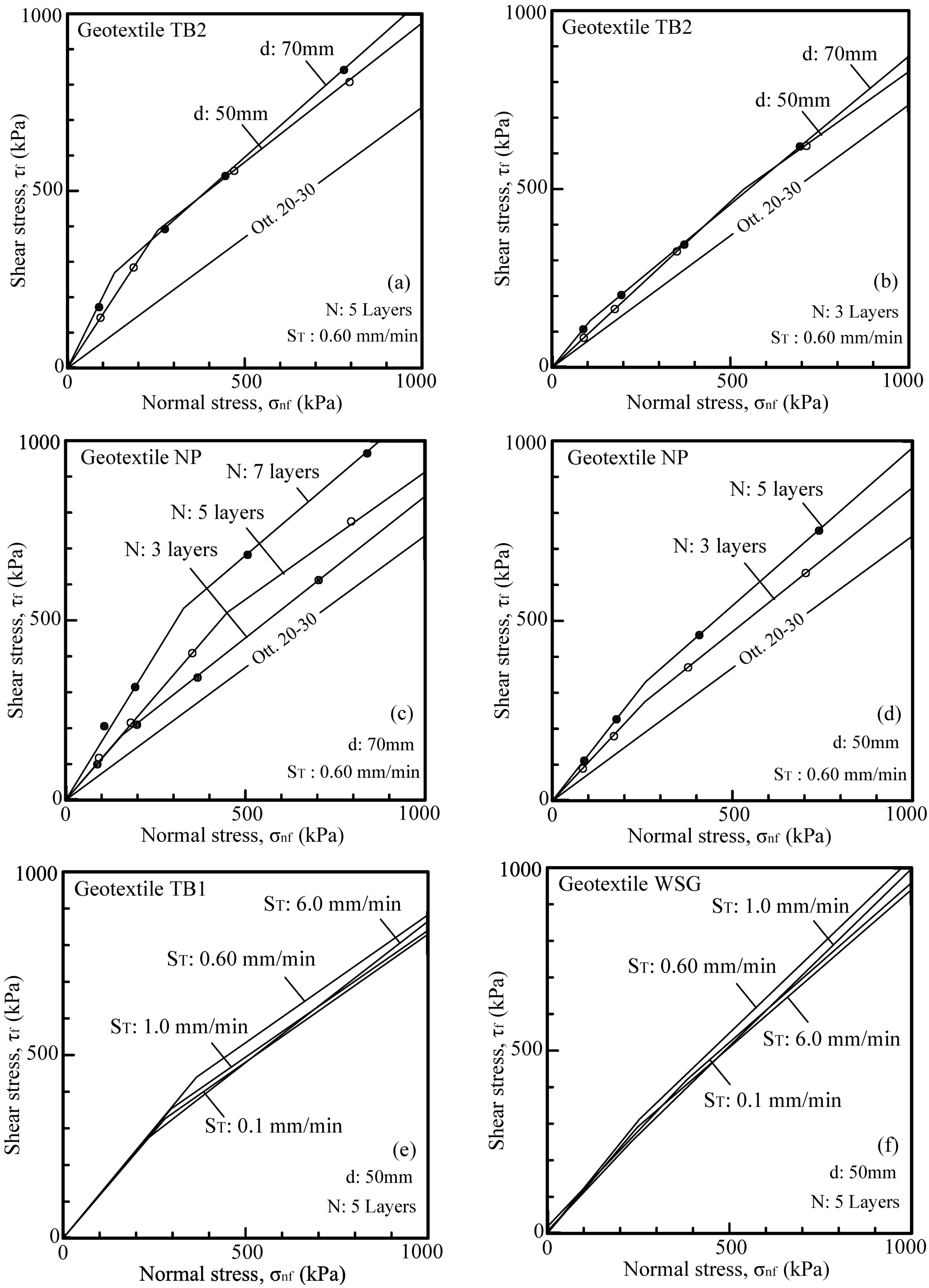

Figure 8. Typical failure envelopes of reinforced sand.

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