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# Effect of Grain Shape and Size on the Mechanical Behavior of Reinforced Sand

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**Abstract**
The effect of sand grain shape and size on the mechanical behavior of geotextile-reinforced sands is investigated in the present research, based on the results of triaxial compression tests. Six clean uniform sands differing in grain shape (subangular or rounded grains) and/or grain size as well as one non-woven and three woven geotextiles with or without apertures, were used in this experimental investigation. Triaxial compression tests were conducted on specimens with a diameter of 70 mm and a height of 144 mm, consisting of dry and dense sands reinforced with 3, 5 and 7 horizontal geotextile disks. The geotextile-reinforced sands present higher strength and axial strain at failure than the unreinforced sands. The strength of reinforced sands increases with decreasing sand grain size, with increasing number of geotextile layers and is affected by the grain shape of sand, since it was observed that reinforced sands with subangular grains attain higher strength values than the reinforced sands with rounded grains. The triaxial compression tests yielded bilinear failure envelopes for all geotextile-reinforced sands.

*Keywords:* reinforced sands, geotextiles, mechanical behavior, shear strength, triaxial compression tests

## 1 Introduction

Reinforced soil structures, such as reinforced slopes, embankments and retaining walls, are frequently part of transportation infrastructure projects. Also, geotextiles are used as reinforcement for the cost-effective construction of roads, airfields and railroads. The safe and economical design of reinforced soil structures requires the knowledge of the mechanical behavior of the composite material. As free draining granular materials, e.g. sands, are specified as backfill material for reinforced soil structures, the mechanical behavior of sand – geotextile composites has been investigated in the past by conducting triaxial compression tests on sand specimens reinforced with sheets of geotextiles (e.g. Gray et al., 1982; Gray and Al-Refeai, 1986; Chandrasekaran et al., 1989; Baykal et al., 1992; Ashmawy and Bourdeau, 1998; Haeri et al., 2000; Wu et al., 2002; Madhavi Latha

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and Murthy, 2007; Nguyen et al., 2013). Although the results of these investigations have provided valuable information on the effects of several important parameters, the effect of sand grain shape and size on the mechanical behavior of geotextile-reinforced sand needs further experimental documentation. This need is enhanced by the fact that the results of triaxial compression tests are also used for the understanding of the behavior of granular columns reinforced with horizontal reinforcement layers and used for the improvement of weak or soft soils (Wu and Hong, 2008; Hong and Wu, 2013).

It is, therefore, of merit to investigate the effect of sand characteristics (grain shape and size) on the mechanical behavior of the composite material. Toward this end, an experimental investigation was conducted on a variety of sands reinforced with different geotextiles and the results obtained, are reported herein. The 131 triaxial compression tests on geotextile-reinforced sands, required for the present study, were conducted using conventional testing equipment.

# 2 Materials and Procedures

Conventional laboratory triaxial compression equipment without modifications was used to conduct tests on geotextile reinforced sands in order to investigate the mechanical behavior of the composite material. The tests were conducted using six clean uniform sands in dry and dense condition with grain sizes limited between ASTM sieve sizes Nos. 4 and 10, 16 and 20, 20 and 30, 30 and 40, and 40 and 100. From the properties of sands presented in Table 1, it can be seen that the sands also differ in grain shape since three of them (designated as S 4-10, S 16-20 and S 20-30) consist of subangular grains while the other three (designated as R 20-30, R 30-40 and R 40-100) are standard Ottawa quartz sands with rounded grains. The values of angle of internal friction, φ, of the sands in dry and dense condition are also shown in Table 1, together with the average relative density values of the specimens tested in triaxial compression for the determination of them.

| Sand | Grain shape | Grain sizes (mm) | | | Void ratios | | Shear strength characteristics | |
|---|---|---|---|---|---|---|---|---|
| | | $D_{max}$ | $D_{50}$ | $D_{min}$ | $e_{max}$ | $e_{min}$ | Friction angle φ ($^o$) | Rel. density $D_r$ (%) |
| S 4-10 | Subangular | 4.75 | 3.00 | 2.00 | 0.81 | 0.51 | 45.0 | 76 |
| S 16-20 | Subangular | 1.18 | 1.00 | 0.85 | 0.92 | 0.58 | 48.5 | 92 |
| S 20-30 | Subangular | 0.85 | 0.71 | 0.60 | 0.96 | 0.62 | 47.0 | 83 |
| R 20-30 | Rounded | 0.85 | 0.71 | 0.60 | 0.77 | 0.46 | 36.0 | 82 |
| R 30-40 | Rounded | 0.60 | 0.51 | 0.43 | 0.85 | 0.52 | 35.0 | 92 |
| R 40-100 | Rounded | 0.43 | 0.25 | 0.15 | 0.79 | 0.52 | 37.0 | 90 |

**Table 1:** Soil properties

Four different commercially available geotextiles were used during this investigation. These geotextiles were selected in order to test non-woven and woven products with or without apertures. More specifically, one thermally bonded non-woven polypropylene geotextile (TYPAR SF 56), one standard grade woven polypropylene geotextile without apertures (BONAR SG 80/80), one woven polyethylene geotextile with apertures (NICOLON 66447) and one woven polyester with PVC coating geotextile with apertures (HUESKER HaTe 50.145), were tested. These geotextiles are designated as SF 56, SG 80/80, N 66447 and H 50.145, respectively. Pertinent geotextile properties, according to the manufacturers, are presented in Table 2.

Triaxial compression tests were conducted using samples with a diameter of 70 mm and an overall height of 144 mm. A schematic representation of the reinforced sand samples with 3, 5 and 7 horizontal geotextile layers is shown in Figure 1. The geotextile reinforcement discs had a diameter equal to the diameter of the sample and were placed at equal distances perpendicular to the axis of the

| Geotextile | Type | Thickness (mm) | Mass per unit area (g/m²) | Aperture size, A (mm) | Tensile test results | |
|---|---|---|---|---|---|---|
| | | | | | Max. tensile load (kN/m) | Extension at max. load (%) |
| SF 56 | Non-woven | 0.54 | 190.0 | - | 12.8 | 65 |
| SG 80/80 | Woven | 1.35 | 360.0 | - | 82.0 / 86.0 * | 20 / 11 * |
| H 50.145 | Woven | 1.15 | 225.0 | 1.20 | 32.0 / 32.0 * | 15 / 18 * |
| N 66447 | Woven | 0.90 | 194.4 | 0.77 | 2.2/2.0 kN/5cm * | 27 / 22 * |

* Machine direction / Cross machine direction

**Table 2:** Geotextile properties

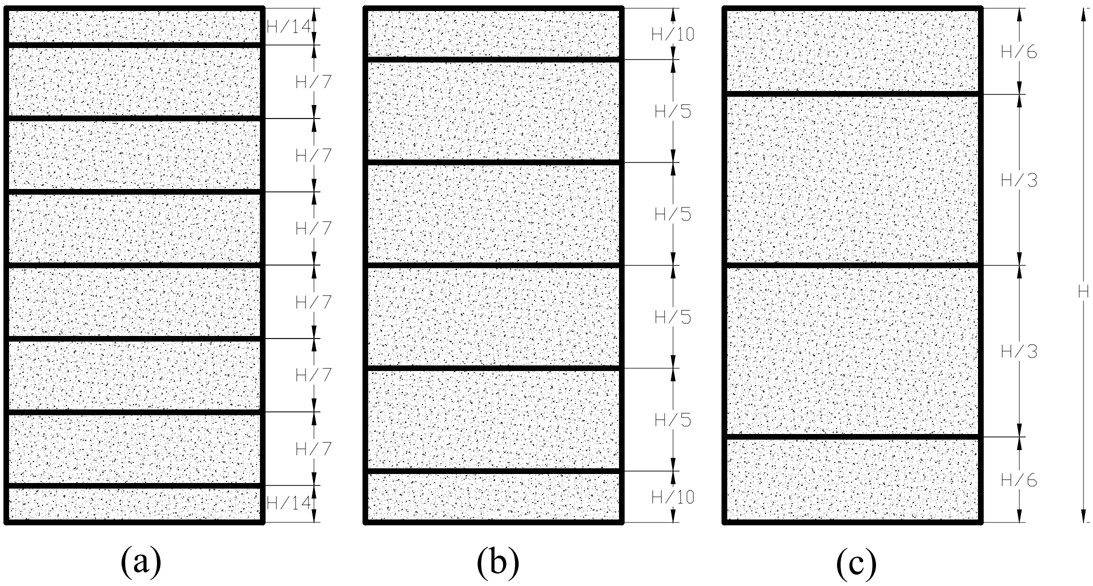


**Figure 1:** Sand specimens reinforced with (a) 7, (b) 5 and (c) 3 geotextile layers

sample. The sands were compacted using a special hand operated tamper and extreme care was taken in order to produce sand layers with constant density. The tests were conducted at a relative density of the sands between 76% and 99%, with confining pressures, $\sigma_3$, equal to 10, 25, 50, 100, 200 and 400 kPa and at a constant rate of axial displacement equal to 0.6 mm/min.

# 3 Results and Discussion

The effect that reinforcement has on the strength of the sands is presented in Figure 2, in terms of the peak (failure) deviator stress, $(\sigma_1\text{-}\sigma_3)_{max}$, and the strength ratio, $S_R$, as a function of the confining pressure used in the tests. The strength ratio is defined as the ratio of the maximum deviator stress (stress at failure) of the reinforced sand to the maximum deviator stress obtained for the unreinforced sand at the same confining pressure. The values of the strength ratio are always higher than unity, are in the most cases higher than 2 and can be as high as 15 (Figure 2a), indicating that the geotextile reinforced sands have higher strength and, in many cases, considerably higher strength than the unreinforced sands. The peak deviator stress increases with increasing confining pressure. On the contrary, the strength ratio and, consequently, the positive effect of reinforcement on the strength of sands increase as the confining pressure decreases. This behavior is attributed to the fact that the failure envelopes of the reinforced sands are, as concluded below, bilinear and approximately parallel to the failure envelopes of the corresponding unreinforced sands for normal stress values greater than the critical normal stress. Accordingly, the difference between the diameters (maximum deviator stresses) of the two Mohr semicircles, which are tangent to the failure envelopes of reinforced and unreinforced sand at the same confining pressure, increases with decreasing confining pressure.

As shown in Figure 2a, strength improvement of sand increases considerably with increasing number of geotextile layers. Although the tensile strength of H 50.145 woven geotextile is lower than that of SG 80/80 woven geotextile (Table 2), the strength ratio values obtained with H 50.145 geotextile are higher than the ones obtained with SG 80/80 geotextile (Figure 2b). This behavior can be attributed to the existence of apertures in H 50.145 geotextile, which activate the interlocking

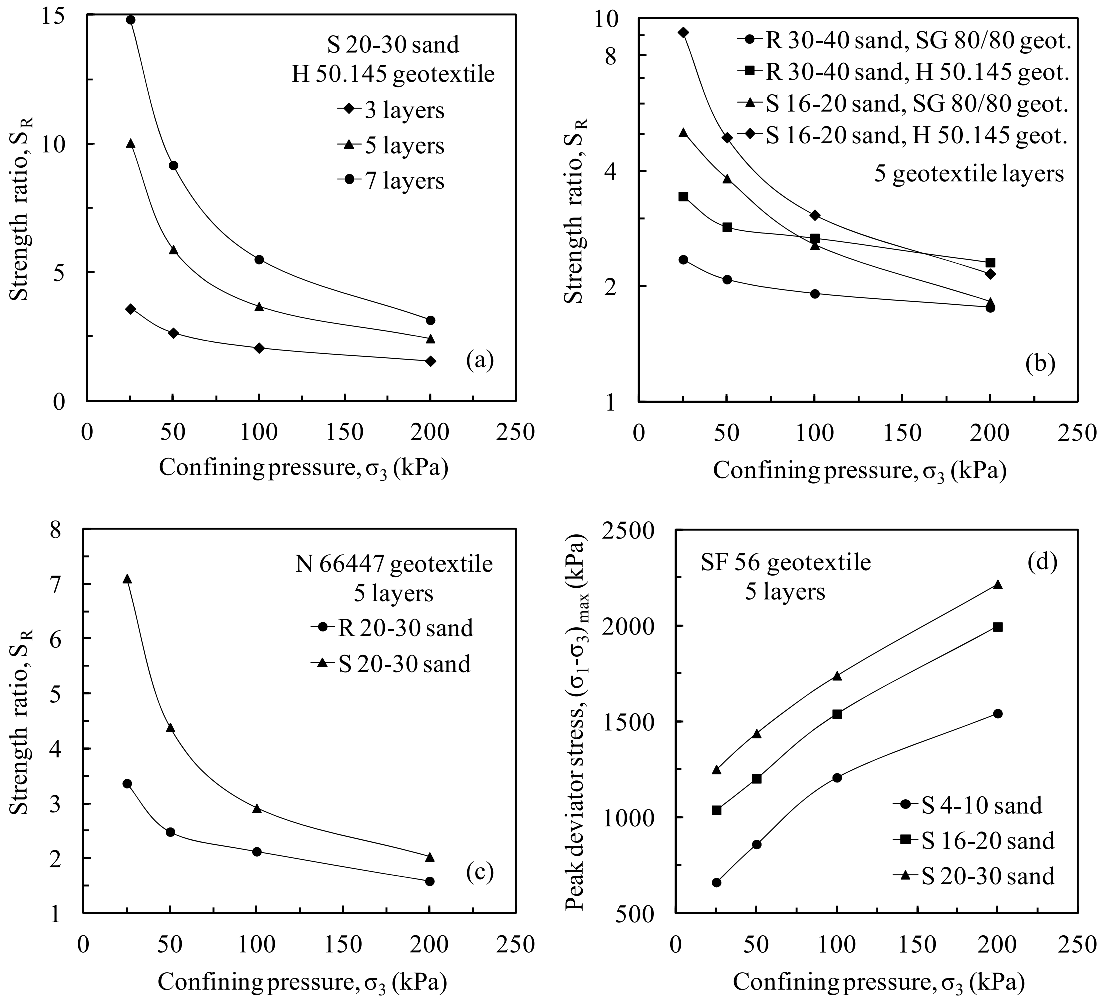


**Figure 2:** Effect of (a) number of geotextile layers, (b) geotextile properties, (c) sand grain shape and (d) sand grain size on the strength of reinforced sands

mechanism with the sand grains. The grain shape has a significant effect on the strength improvement of sand, with sand consisting of subangular grains yielding higher strength ratio values than sand with the same gradation and rounded grains (Figure 2c). As shown in Figure 2d, sand gradation has an effect on the strength of the reinforced sands, which increases with decreasing sand grain size.

In order to quantify and compare the deformability of reinforced sands, the axial strain at failure (point of peak deviator stress), $\varepsilon_{fr}$, of the sand specimens reinforced with geotextiles, is used. Reinforced sands present higher values of axial strain at failure (higher deformability) than unreinforced sands. However, the $\varepsilon_{fr}$ values do not present a consistent variation with confining pressure. For this reason, the average $\varepsilon_{fr}$ values obtained for the tests with all confining pressures conducted on each reinforced sand, are summarized in Table 3. It can be seen that the sand with subangular grains (S 20-30) yields generally higher average $\varepsilon_{fr}$ values than the sand with the same gradation and rounded grains (R 20-30). Also, the greatest average $\varepsilon_{fr}$ values are obtained for sands reinforced with SF 56 or N 66447 geotextile.

| Geotextile | Layers | S 4-10 | S 16-20 | S 20-30 | R 20-30 | R 30-40 | R 40-100 |
|---|---|---|---|---|---|---|---|
| H 50.145 | 3 | - | - | 11.5 | - | - | - |
| | 5 | 11.8 | 13.2 | 13.5 | 11.7 | 12.4 | 12.7 |
| | 7 | - | - | 13.5 | - | - | - |
| SF 56 | 5 | 12.0 | 15.0 | 16.8 | 10.6 | 18.9 | 15.9 |
| SG 80/80 | 5 | 13.0 | 15.0 | 14.6 | 7.4 | 9.3 | 9.0 |
| N 66447 | 5 | 16.6 | 16.9 | 14.2 | 14.3 | 16.7 | 14.4 |

**Table 3:** Average values of axial strain at failure (%) of reinforced sands

Shown in Figure 3 are the failure envelopes obtained by triaxial compression testing of the reinforced sands with 5 layers of all geotextiles tested. It can be observed that the triaxial compression tests yielded bilinear envelopes for the composite material, which is in good agreement with the observations of other investigators (e.g. Gray et al., 1982; Gray and Al-Refeai, 1986). The reinforced sands present higher shear strength than unreinforced sands for all geotextiles tested. It is also observed (Figure 3) that reinforced sands with subangular grains present higher shear strength than reinforced sands with rounded grains, which can be attributed to the higher angles of internal friction of the sands with subangular grains compared to those of the sands with rounded grains (Table 1). The decrease of the sand grain size generally causes an increase of the shear strength of reinforced sand, which is generally not as pronounced as that effected by the sand grain shape. The break point of the bilinear envelopes corresponds to critical values of interface normal stress, $\sigma_{vcr}$, ranging from 70 kPa to 330 kPa. The values of $\sigma_{vcr}$ depend on the type and the mechanical properties of the geotextiles. In the part of the bilinear failure envelopes before the break point, failure of the composite material is due to slippage of the geotextile with regard to the surrounding soil (type I failure). After the break point, failure occurs by excessive deformation during which the geotextile is stretched in unison with the surrounding soil (type II failure). The failure envelopes of S 20-30 sand reinforced with 3 and 7 layers of H 50.145 geotextile are also bilinear. The shear strength of reinforced sand and the value of $\sigma_{vcr}$ increase with increasing number of geotextile layers.

# 4 Conclusions

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

1. The geotextile-reinforced sands have always higher strength and, in many cases, considerably higher strength than the unreinforced sands. The strength of reinforced sand increases with decreasing sand grain size and can be equal to 15 times the strength of the unreinforced sand.

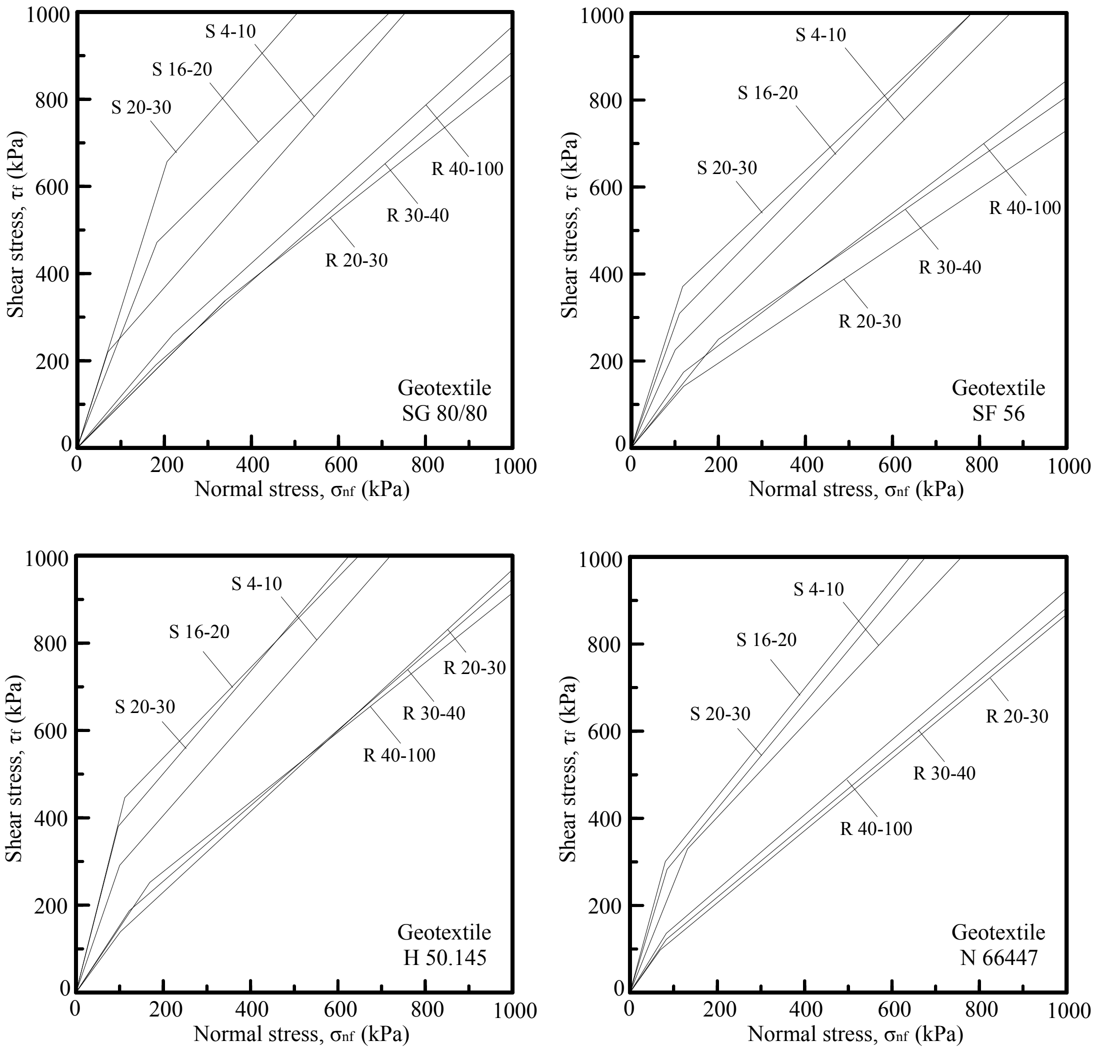


**Figure 3:** Failure envelopes from triaxial compression tests on sands reinforced with 5 geotextile layers

2. The strength improvement of sand due to geotextile reinforcement increases in sands with subangular grains, for geotextiles with apertures, with increasing number of geotextile layers and with decreasing confining pressure.
3. The reinforced sands present higher deformability than the unreinforced sands. The values of axial strain at failure of reinforced sands with subangular grains are generally higher than those of reinforced sands with rounded grains.
4. Triaxial compression tests yield bilinear failure envelopes for the geotextile-reinforced sands. Reinforced sands with subangular grains present higher shear strength than reinforced sands with rounded grains, which is attributed to the difference in angle of internal friction between sands with subangular and rounded grains. The decrease of sand grain size and the increase of geotextile layers also have a positive effect on the shear strength of reinforced sands.

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# References


Ashmawy, A.K. and Bourdeau, P.L. (1998). *Effect of geotextile reinforcement on the stress – strain and volumetric behavior of sand*. Proceedings, 6th International Conference on Geosynthetics, Atlanta. 2: 1079-1082.

Baykal, G., Guler, E. and Akkol, O. (1992). *Comparison of woven and nonwoven geotextile reinforcement using stress path tests*. Proceedings, International Symposium on Earth Reinforcement Practice, Fukuoka. 1: 23-28.

Chandrasekaran, B., Broms, B.B. and Wong, K.S. (1989). *Strength of fabric reinforced sand under axisymmetric loading*. Geotextiles and Geomembranes 8: 293-310.

Gray, D.H., Athanasopoulos, G.A. and Ohashi, H. (1982). *Internal / external fabric reinforcement of sand*. Proceedings, 2nd International Conference on Geotextiles, Las Vegas. 3: 611-616.

Gray, D.H. and Al-Refeai, T. (1986). *Behavior of fabric- vs. fiber- reinforced sand*. Journal of Geotechnical Engineering 112: 804-820.

Haeri, S.M., Noorzad, R. and Oskoorouchi, A.M. (2000). *Effect of geotextile reinforcement on the mechanical behavior of sand*. Geotextiles and Geomembranes 18: 385-402.

Hong, Y.-S. and Wu, C.-S. (2013). *The performance of a sand column internally reinforced with horizontal reinforcement layers*. Geotextiles and Geomembranes 41: 36-49.

Madhavi Latha, G. and Murthy, V.S. (2007). *Effects of reinforcement form on the behavior of geosynthetic reinforced sand*. Geotextiles and Geomembranes 25: 23-32.

Nguyen, M.D., Yang, K.H., Lee, S.H., Wu, C.S. and Tsai, M.H. (2013). *Behavior of nonwoven-geotextile-reinforced sand and mobilization of reinforcement strain under triaxial compression*. Geosynthetics International 20: 207-225.

Wu, C.-S. and Hong, Y.-S. (2008). *The behavior of a laminated reinforced granular column*. Geotextiles and Geomembranes 26: 302-316.

Wu, J.H., Wang, D.Q. and Wang, L.J. (2002). *Experimental study on geosynthetic reinforcement*. Proceedings, 7th International Conference on Geosynthetics, Nice. 4: 1285-1288.