HOLTZ, R. D.
Purdue University, West Lafayette, Indiana, U S A.
TOBIN, W. R.
McClelland Engineers, Houston, Texas, U S A
BURKE, W. W.
Rittenhouse-Zeman & Associates, Bellevue, Washington, U S A

Creep Characteristics and Stress-Strain Behavior of a Geotextile-Reinforced Sand

La fluage et le comportement contrainte-déformation de sable renforcé par des géotextiles

Laboratory investigations evaluated the creep behavior of woven and nonwoven geotextile-reinforced triaxial test samples. Short-term tests were performed on samples reinforced with evenly spaced horizontal circular disks of three common geotextiles to obtain stress-strain relationships. Long-term creep tests were conducted on similar specimens subjected to a constant load of 90% of the corresponding short-term ultimate strength. It was found that the inclusion of fabric reinforcement markedly increased both the maximum principal stress difference and the initial deformation modulus. Specimens reinforced with nonwoven geotextiles exhibit creep behavior similar to specimens reinforced with woven geotextiles.

Des essais de laboratoire ont été effectués pour évaluer la réponse au fluage de sable renforcés par des geotextiles. Des échantillons de sable dense renforcés par des disques horizontaux, également séparés, et faits de géotextiles communs, tissés et nontissés, ont été soumis à la compression dans l'appareil triaxial. Des échantillons similaires ont été soumis à des essais de fluage sous une charge égale à 90% de la resistance maximale immédiate. L'insertion de l'armature de renforcement a accru singulièrement l'écart maximum entre les contraintes principales et le module initial de deformation. Les échantillons avec armature nontissée ont montré une résponse au fluage similaire à celle des échantillons renforcés avec une armature tissée.

INTRODUCTION

The application of geotextiles to permanent construction requires that fabric properties be sufficiently stable to permit acceptable performance of the structure throughout its design life. However, there are many uncertainties concerning the long-term reliability of geotextiles, particularly their resistance to sustained loading. Knowledge of the long-term behavior of geotextiles is essential for the safe and economic design of fabric-reinforced retaining structures and embankments as well as fabric containment systems.

There is little published information on the creep characteristics of geotextiles in typical geotechnical environments. Studies have been conducted to determine the creep properties of both fibers (1) and fabrics (2, 3), but they have not included the effects of soil-reinforcement interaction. It is recognized that geotextiles tested in isolation may exhibit different behavior than geotextiles tested in soils (4). Koerner et al. (5) proposed a tentative design procedure to consider the creep of fabric-reinforced cohesive soils.

The objective of this study was to examine the response of woven and nonwoven geotextiles confined in dense sand when subjected to short-term and long-term loadings. A conventional triaxial test configuration was chosen for simplicity. Therefore, the tests provide only a qualitative indicator of in-situ geotextile stress-strain-time behavior.

TEST PROCEDURES

Laboratory investigations were conducted in two phases. An initial series of short-term triaxial tests was followed by a second series of long-term or creep tests. Samples were typically 36 mm in diameter and 73 mm in height. They were composed of a dry sand compacted to approximately 90% relative density (D_r) by tamping. Unreinforced control samples were used in both test series.

The reinforced specimens were constructed with circular fabric disks placed horizontally at the upper and lower third points and on the top and bottom platens. The diameter of the disks was the same as the triaxial samples. Similar tests have been conducted by Broms (6) and Schlosser and Long (7).

Sand

The soil was an oven dried, fine to medium, poorly-graded, angular sand with a trace of fines. This material is locally known as Lafayette Concrete Sand and is classified SP. Typical properties are shown in Table I.

Table I. Properties of Lafayette Concrete Sand

D_{10}	0.25 mm
C_u	2.36
ρ_s	2.70 Mg/m^3
e_{max}	0.70
e_{min}	0.37
ϕ_{triax}	46^0 at D_r = 90%

Geotextiles

Three common geotextiles, one woven and two nonwovens, were selected for testing. A comparison of fabric properties is shown in Table II.

Table II. Properties of Geotextiles Tested*

Item	Supac 5-P	Mirafi 140S	Mirafi 500X
Manufacturer	Phillips	Celanese	Celanese
Composition	Nonwoven	Nonwoven	Woven
Fiber Type	Polypropylene	Polypropylene, Polyethylene	Polypropylene
Process Type	Needle-punched, heat fused	Melt Bonded	Slit film
Unit Weight (g/m^2) ASTM D-1910	180	140	136
Thickness (mm) ASTM D-1777	1.3	0.8	0.6
Grab Tensile Strength (N) ASTM D-1682	667	556	890
Grab Tensile Elongation (%) ASTM D-1682	80	65	24

*Source: Manufacturer's Literature

Short Term Tests

These tests were conducted to determine the short term stress-strain relationships and the strengths to be used for the subsequent creep tests. All tests were consolidated-drained (CD) on dry samples using air as the cell fluid. Confining pressures of 35 kPa, 69 kPa, and 276 kPa were chosen to simulate loadings in small to moderate embankments and walls.

A conventional loading press with proving ring was used to apply the axial stress at a constant rate of strain. Failure was defined as the maximum principal stress difference. Since volumetric strain of the dry specimens could not be measured, the principal stress difference was calculated using the initial specimen cross sectional area.

Long Term Tests

The long-term triaxial tests were conducted to determine the creep behavior of various geotextile-reinforced samples. The long-term test samples were constructed in the same manner as the short-term test samples.

A sustained, axial compressive stress was applied by a hangar and weight system on a loading frame. Confining pressures of 35 kPa and 69 kPa were maintained by air pressure regulators arranged in parallel. The maximum capacity of the hangar system did not permit creep tests to be conducted at higher confining pressures. The magnitude of the applied principal stress difference was 90% of the maximum principal stress difference determined from corresponding short-term tests. After creep loading of about 35 days, the samples were loaded rapidly to failure.

RESULTS

Short Term Tests

The reinforcing effect of inclusions on the short-term behavior of sands has been well documented (6,7,8, 9). The introduction of extensible inclusions (geotextiles) into a geotechnical environment will inhibit the development of soil tensile strains, thus producing a composite material of greater strength and modulus than an unreinforced soil at the same deformation.

The results of the short-term testing program are shown in Table III. The stress-strain relationships for fabric-reinforced and unreinforced specimens are shown by Figs. 1, 2, and 3. It can be seen that the geotextile inclusions markedly increased the maximum principal stress difference and the initial deformation modulus (E_i). However, at higher confining pressures the initial tangent modulus was found to decrease. The average increase in maximum principal stress difference due to reinforcing also decreased with higher confining pressures (211% increase at 35 kPa, 100% increase at 69 kPa, and 63% increase at 276 kPa). In addition, the fabric-reinforced samples exhibited a larger axial strain at failure (ε_f) than corresponding unreinforced samples. Consistent with the increase in maximum principal stress difference due to reinforcing, the Mohr-Coulomb relationships show a corresponding increase in the angle of internal friction (ϕ) from 46° to 54°, at a zero intercept (c' = 0).

Table III. Summary of Short-Term Triaxial Test Results for Various Reinforcement Materials (D_r = 90%)

Reinforcement	Type	σ_3 (kPa)	$(\sigma_1-\sigma_3)_f$ (kPa)	ε_f (%)	E_i (kPa)
Unreinforced	--	35	183	3.4	11,000
Supac 5-P	Nonwoven	35	464	4.6	16,500
Mirafi 140S	Nonwoven	35	646	4.8	23,500
Mirafi 500X	Woven	35	597	2.9	33,500
Unreinforced	--	69	376	3.8	18,000
Supac 5-P	Nonwoven	69	733	5.0	21,500
Mirafi 140S	Nonwoven	69	754	7.4	18,000
Mirafi 500X	Woven	69	762	7.4	19,000
Unreinforced	--	276	1401	6.6	92,000
Supac 5-P	Nonwoven	276	2180	8.4	64,000
Mirafi 140S	Nonwoven	276	2183	18	42,000
Mirafi 500X	Woven	276	2503	16	50,000

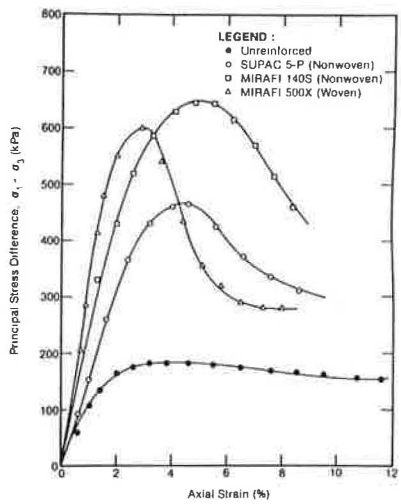

Figure 1. Stress-Strain Relationships for Various Reinforcement Materials (σ_3 = 35 kPa, D_r = 90%)

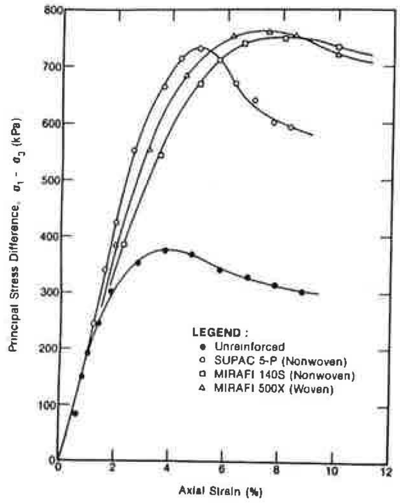

Figure 2. Stress-Strain Relationships for Various Reinforcement Materials (σ_3 = 69 kPa, D_r = 90%)

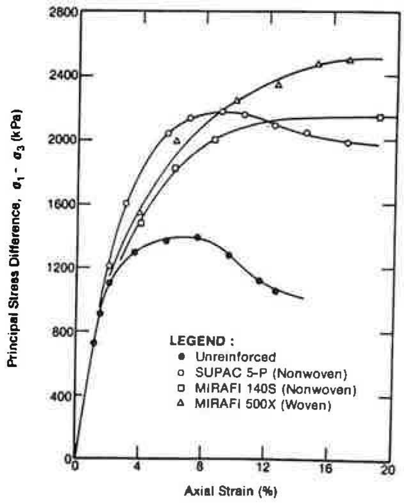

Figure 3. Stress-Strain Relationships for Various Reinforcement Materials (σ_3 = 276 kPa, D_r = 90%)

Long Term Tests

The results of the long-term testing program are shown in Table IV and Figs. 4 and 5. Consistent with the short-term testing behavior, it was found that at high relative densities (e.g., D_r = 90%), differences in geotextile properties did not greatly affect creep behavior.

Table IV. Summary of Long-Term Triaxial Creep Test Results for Various Reinforcement Materials (D_r = 90%)

Reinforcement		σ_3 (kPa)	$(\sigma_1-\sigma_3)_f$ (kPa)	Initial Strain (%)	Creep Strain (%)	Failure Strain (%)	Creep Duration (Days)
Unreinforced	--	35	231	0.7	0.1	1.1	35
Supac 5-P	Nonwoven	35	580	2.2	0.8	4.9	35
Unreinforced	--	69	535	1.0	0.05	2.1	35
Supac 5-P	Nonwoven	69	958	1.9	0.8	7.2	35
Mirafi 140S	Nonwoven	69	>1000	5.0	1.8	>10	42
Mirafi 500X	Woven	69	996	2.5	0.85	6.7	32

When fabric-reinforced samples are subjected to sustained loading conditions, the strain response consists of an immediate or "elastic" strain followed by a time-dependent creep strain. Figs. 4 and 5 show the creep strain versus time for reinforced and unreinforced specimens at two different confining pressures. Approximately 70% of the total creep strain occurred in less than three days of sustained loading. In all cases the observed creep response resulted in a nonlinear creep curve when plotted as a function of logarithmic time. Finnigan (1) and Van Leeuwen (2) reported a linear creep response when fabrics were tested in isolation.

Although the geotextiles tested had different properties, the stress-strain behavior (Figs. 1-3) for the majority of the specimens was very similar. In fact, it appears that at high relative densities (e.g., D_r = 90%), fabric properties do not greatly influence the behavior of reinforced sands. McGown and Andrawes (10) reported that at low initial placement densities, the improvement derived from fabric inclusions was greater than observed at high densities.

The effect of soil density influencing sample behavior becomes further apparent when considering the mode of sample failure. Hausmann and Vagneron (11) stated that an increase in the angle of internal friction, as a result of the addition of reinforcement to a sample, would indicate a failure controlled by slippage along the fabric surface. Conversely, failure controlled by rupture of the fabric material would result in an apparent cohesion (c'). Results of the short-term testing program indicate that failure of the reinforced samples was caused by particle slippage at the sand fabric interface. A slight bulging of the specimens occurred between reinforcing layers. Examination of the fabric disks after failure showed no evidence of ruptured filaments. It is believed that at high relative densities, soil-fabric frictional properties have the greatest influence on reinforced soil systems.

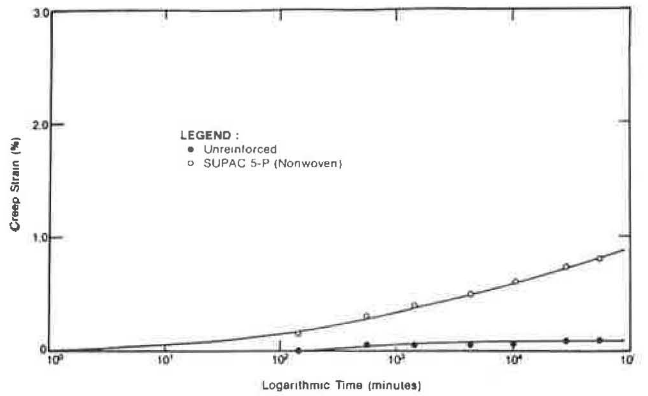

Figure 4. Creep Strain Relationships for Fabric-Reinforced and Unreinforced Triaxial Specimens (σ_3 = 35 kPa, D_r = 90%)

The long-term test results showed no significant differences in creep behavior due to confining pressure or geotextile properties. As expected, the lighter weight nonwoven (Mirafi 140S) exhibited a somewhat greater creep response than the heavier nonwoven (Supac 5-P). However, the woven geotextile (Mirafi 500X) showed a greater creep response than the heavier nonwoven (Supac 5-P). This result verifies the importance of soil-fabric frictional properties. It is possible that quite different behavior would be observed for fabric-reinforced samples at lower relative densities where fabric properties are likely to have a greater influence (8).

At the conclusion of creep testing, the samples were rapidly loaded to failure to evaluate stress-strain characteristics after creep loading. It was observed that the long-term stress-strain behavior resulted in an increase in strength (about 30%) and tangent modulus when compared to corresponding short-term tests. Similar results are reported by Haliburton, et al. (3). This behavior was exhibited by both unreinforced and reinforced samples.

Consistent with the short-term tests, all of the samples tended to bulge slightly between reinforcing layers. After testing, the fabric disks were examined and no evidence of ruptured filaments was observed. However, the nonwoven fabrics appeared to be "dished" in the center area of the disks. No "dishing" was noted with any of the woven fabrics although some scratches and striations were evident.

CONCLUSIONS

1. The inclusion of geotextile reinforcement increases the ultimate strength, deformation modulus, and the angle of internal friction of triaxial samples composed of dense, angular sand.
2. The increase in short-term maximum principal stress difference for geotextile-reinforced triaxial test samples of a dense, angular sand decreases with increasing confining pressure.
3. Geotextile-reinforced sands exhibit a larger axial strain at failure and more creep than corresponding unreinforced samples.
4. Approximately 70% of the total creep strain occurs within 3 days of sustained loading.

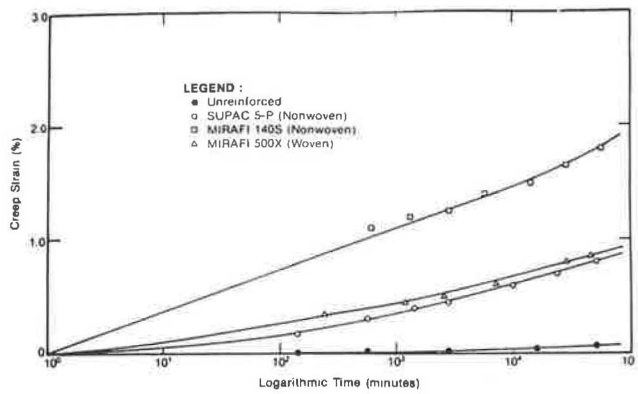

Figure 5. Creep Strain Relationships for Fabric-Reinforced and Unreinforced Triaxial Specimens (σ_3 = 69 kPa, D_r = 90%)

5. At high relative densities (D_r = 90%) geotextile properties do not appear to greatly influence the stress-strain or creep behavior of reinforced samples.
6. At confining pressures of 35 and 69 kPa, failure for both long-term and short-term samples is apparently controlled by slippage along the soil-geotextile interface.

ACKNOWLEDGEMENTS

We thank M. W. Oakland for his assistance with the laboratory work. The manuscript was typed by Nancy Warren.

REFERENCES

(1) Finnigan, J. A., "The Creep Behaviour of High Tenacity Yarns and Fabrics Used in Civil Engineering Applications", Proceedings of the International Conference on the Use of Fabrics in Geotechnics, Ecole Nationale des Ponts et Chaussées, Paris, Vol. II, April 1977.

(2) Van Leeuwen, J. H., "New Methods of Determining the Stress-Strain Behaviour of Woven and Non-Woven Fabrics in the Laboratory and in Practice", Proceedings of the International Conference on the Use of Fabrics in Geotechnics, Ecole Nationale des Ponts et Chaussées, Paris, Vol. II, April 1977.

(3) Haliburton, T. A., Anglin, C. C. and Lawmaster, J. D., "Testing of Geotechnical Fabric for Use as Reinforcement", Geotechnical Testing Journal, ASTM, Vol. 1, Dec. 1978.

(4) McGown, A. and Andrawes, K. Z., "In-Isolation and In-Soil Behaviour of Geotextiles", Unpublished, Dept. of Civil Engineering, University of Strathclyde, Glasgow, U.K.

(5) Koerner, R. M., Rosenfarb, J. L., Dougherty, W. W. and McElroy, J. J., "Stress-Strain-Time Behavior of Geotextiles", The Use of Geotextiles for Soil Improvement, ASCE National Convention, Portland, Oregon, April 1980.

(6) Broms, B. B., "Triaxial Tests with Fabric-Reinforced Soil", Proceedings of the International Conference on the Use of Fabrics in Geotechnics, Ecole Nationale des Ponts et Chaussées, Paris, Vol. III, April 1977.

(7) Schlosser, F. and Long, N. T., "Comportement de la Terre Armée Ouvrages de Soutènement", Proceedings of the Fifth European Conference on Soil Mechanics and Foundation Engineering, Madrid, Vol. 1, 1972.

(8) McGown, A., Andrawes, K. and Al-Hasani, M. M., "Effect of Inclusion Properties on the Behavior of Sand", Geotechnique, Vol. 28, No. 3, 1978.

(9) Singh, A. and Yang, Z., "Strength and Deformation Characteristics of Reinforced Sand", presented at the ASCE National Meeting on Water Resources Engineering (preprint) Los Angeles, January 1974.

(10) McGown, A. and Andrawes, K. Z., "The Influences of Non-Woven Fabric Inclusions on the Stress-Strain Behaviour of a Soil Mass", Proceedings of the International Conference on the Use of Fabrics in Geotechnics, Ecole Nationale des Ponts et Chaussées, Paris, Vol. I, April 1977.

(11) Hausmann, M. R. and Vagneron, J. M., "Analysis of Soil-Fabric Interaction", Proceedings of the International Conference on the Use of Fabrics in Geotechnics, Ecole Nationale des Ponts et Chaussées, Paris, Vol. III, April 1977.