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Drained Triaxial Behaviour of Geotextile Reinforced Sand

G. Venkatappa Rao
Professor of Civil Engg.,

J.M. Kate
Asst. Prof. of Civil Engg.,

P.D.R. Yemen
Currently Research Scholar,

Indian Institute of Technology, Delhi, India

Faisal Shamsher
Senior Lecturer, Civil Engg.,
Faculty of Engineering, University of Aden.

Synopsis

In order to understand the behaviour of sand reinforced with geotextile, series of large diameter (100mm) drained triaxial compression tests have been conducted using confining pressure upto 400 kPa. Two types of Indian made woven and nonwoven geotextiles were used as a reinforcement. The resulting changes in stress-strain, volume changes, strength and strength parameters have been presented and analysed in detail. The reinforcement induced confining stress has been found to vary hyperbolically with applied confining pressure for both types of reinforcements.

Introduction

The use of geotextile as a civil engineering material has gained widespread application through.ou the world. Reinforced soil is an effective and reliable technique for improving the strength and stability of soil. This technique is used in a variety of applications ranging from earth retaining structures to subgrade stabilization beneath pavements.

In India, reinforced soil construction has enormous potential. Various types of geosynthetics have begun to be manufactured in the country. Thus it is imperative to understand the behaviour of reinforced soil structures thoroughly, so that their analysis, design and construction can be carried out with confidence. In view of this, the present laboratory studies were planned in which an attempt was made to understand the strength and volume change behaviour of sand reinforced with layers of geotextiles in triaxial tests.

Literature Review

Inextensible inclusions (eg. G.I. strips) when embedded in soil develop tensile stresses which will have an analogous but fundamentally different effect of increasing the lateral confining stresses. When extensible inclusions (like - geotextiles) are used in the same manner as the inextensible inclusions, they will also inhibit the development of internal tensile strain in the soil and develop tensile stresses. McGown and Andrawes (1977) observed that in case of extensible inclusions this further increases boundary stresses at any boundary strain range. However, in case of inextensible inclusions, post-rupture, post peak strength of the system and intense local shear planes have been observed to develop. The extensible inclusions due to their lower modulus, higher elongation at break, and generally high frictional properties, are far less likely to be either pulled out or to break, instead they simply yield or stretch with only limited local slippage occuring where tangential stress exceeds skin friction at the inclusion-sand interface Tumay (1979). The overall stress-deformation behaviour of the reinforced composite will depend upon the rupture strength, tensile modulus, and elongatin properties of reinforcement Gray et al (1982), Gray and Ohashi (1983).

Confining Stress Concept: In order to define the basic mechanism of reinforced soil, laboratory studies have been conducted by Yang, (1972), Schlosser and Long (1974), and McGown et al. (1978). They reported the results of triaxial compression tests on cylinderical samples of dry sand containing thin, horizontal layers of tensile reinforcing materials. These studies concluded that strength increases with increase in confining pressure and amount of reinforcement, and that the failure of samples is due to rupture of reinforcement. The result, of these triaxial tests on reinforced sand have been interpreted in two different yet related ways. Yang (1972) suggested that the tensile stresses built up in horizontal reinforcing layers were transferred to the soil through sliding friction and caused an increase in confining pressure σ_3. It follows that:

$$\sigma_{1f} = (\sigma_3 + \Delta\sigma_3) N_\phi \qquad (1)$$

where σ_{1f} = major principal stress at failure,

σ_3 = applied confining pressure on the specimen,

N_ϕ = $\tan^2 (45 + \phi/2)$, and

ϕ = friction angle of unreinforced sand.

Thus for a measured value of σ_{1f} and known applied value of σ_3 it was possible to evaluate $\Delta\sigma_3$

$$\Delta\sigma_3 = Ka\, \sigma_{1f} - \sigma_3 \qquad (2)$$

Cohesion Concept : It was noticed by Schlosser and Long (1974) that the reinforcement induced an anisotropic or pseudo-cohesion (C') which was a function of spacing of reinforcement and its tensile strength. The strength of reinforced soil accordingly is given by:

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$$\sigma_{1f} = \sigma_3 N_\Phi + 2C' \sqrt{N_\Phi} \quad (3)$$

The anisotropic or pseudo-cohesion (C') was computed from a force-equilibrium analysis of a reinforced composite. The following expressions were derived:

Horizontal Reinforcement: $$C' = \frac{R_T}{\Delta H} \frac{\sqrt{N_\Phi}}{2} \quad (4)$$

where, R_T=force per unit width of reinforcement at failure, and
ΔH=spacing between reinforcements.

From Eqn. (1), (3) the following relationship is obtained:

$$C' = \frac{\Delta\sigma_3}{2} \sqrt{N_\Phi} \quad (5)$$

Rearrangement of the coefficient from Eqn. (4) and Eqn.(5) leads to

$$\Delta\sigma_3 = R_T/\Delta H \quad (6)$$

Thus either the ($\Delta\sigma_3$) or the (C') approach could be used equally well for analysing the behaviour of reinforced sand for maximum strength conditions where failure occurs by breaking of the reinforcement. Hausmann's (1976) and Brom's (1977), investigations confirm the hypothesis that slippage failure leads to increased friction angle. In this paper the analysis is carried out using the former approach.

Previous work at I.I.T. Delhi :

Venkatappa Rao et al (1987) conducted a study on triaxial behaviour of geotextile reinforced dense Yamuna sand using specimens of size 38.1 mm diameter X 76.2mm height. One to two discs of wovem geotextles are used as a reinforcing material. It was observed that, at low confining pressures (σ_3) the increase in strength with reinforcement is significant, but at σ_3 upto 64 kg/cm^2, there is little improvement. They generally observed an increase in C' and Φ' with addition of reinforcement. They reported that no geotextile rupture occured even at high confining pressures.

Experimental Programme

(i) Materials Used

(a) Soil

The soil chosen was a locally available sand known as "Yamuna sand" containing 100% fine sand particles (mostly quartizitic but with some flakes). Properties of the sand are summarized in Table 1.

Table 1. Properties of Sand

D_{50} (mm)	Cu	γ_d (g/cc) max.	γ_d (g/cc) min.	e max.	e min.	G
0.23	1.62	1.67	1.35	1.04	0.64	2.67

(b) Reinforcement

Two types of geotextiles one of them woven and the other nonwoven, as described below were used as reinforcement.

(i) Indian polypropylene multifilament woven fabric, manufactured by Bombay Dyeing and marketed by AIMIL New Delhi as GEOLON 499 have been used as reinforcement.

(ii) Indian polypropylene nonwoven geotextile is a needle punched manufactured by Shri Dinesh Mills Vadodara Commercially known as Dineshmat (GPB 132) has been used.

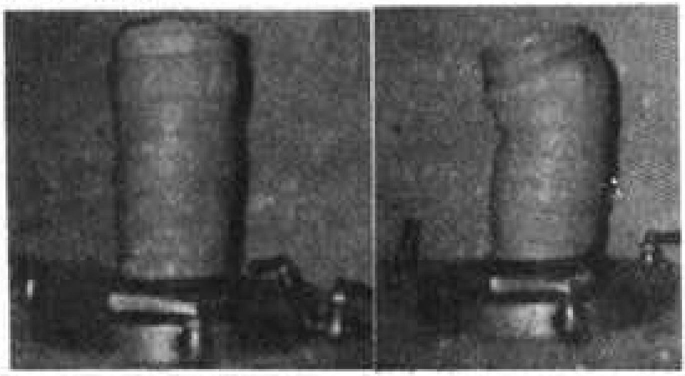
Their physical and mechanical properties have been presented in Tables (2).

Table 2 : Physical and Mechanical Properties of Geotextiles.

Property		Sample No. Geolon 499	Sample No. Dineshmat GPB 132
Colour		Black	White
Mass per unit area (g/m^2)		270	275
Thickness at 20 g/cm^2			
Pressure (mm)		0.70	2.86
Pore size in micron(mean)		25	75
Secant Modulus @ 10%	warp	17000 side A	110
Elongation (kg/m)	weft	9150 side B	76
Wide width tensile (kg/m)	warp	3700 side A	1440.6
	weft	3390 side B	1403.0
Extension at failure	warp	28 side A	56.6
	weft	26 side B	66.5
CBR push through (kg/cm^2)		67.75	14.93
Angle of soil fabric friction (degree)		34.0	35.0

(ii) Experimental Procedure

The procedure adopted to conduct these tests was similar to that for conducting consolidated drained triaxial tests. The size of the triaxial cell used in the present study was 100mm diameter and 200mm high. The saturated sand was deposited in layers into the membrane using a split mould former. Each sand layer was compacted to achieve required density by vibration at constant frequency. The reinforcement geotextile disc of 100mm diameter were placed on the levelled sand layer, the next layer of sand was then placed and compacted. The procedure was repeated till the full height of the sample was reached. The number of layers of reinforcement varied were 1, 3, 5 & 7 and accordingly the number of sand layers and their corresponding thicknesses were calculated and compacted. The samples were also prepared with sand in which, the dry density of the samples were maintained at 1.48 ± 0.02 g/cc. Conventional consolidated drained triaxial tests were conducted on both reinforced and unreinforced specimens. The cell pressures applied were 25,50,100,200 and 400 kPa and each test was conducted at a deformation rate of 0.2 mm/minute. At the end of the test the failure pattern of reinforced sand were also observed. These were mainly of two types as illustrated in Fig. 1 (a and b). A bulging pattern as shown in (a) was observed at high confining pressures whereas the other pattern (b) was observed for low confining pressures.



(a) (b)
Figure 1 Failure Pattern of Reinforced Sand.

Presentation and Discussion

(i) Stress Strain Relationship

The typical stress-strain curves are presented in Figs. 2 and 3 for confining pressures of 25 kPa and 400 kPa respectively for both woven (Geolon 499) and nonwoven (Dineshmat GPB132) geotextiles. The comparison between the curves of reinforced and unreinforced sand very clearly shows improvement in strength of reinforced sand with number of reinforcement. This is true for both types of geotextiles used. The ratios of strength between reinforced and unreinforced sand are presented in Table 3 for both woven and nonwoven geotextiles. It can be seen from this table that with increase in confining pressure the strength ratios increase. This has been observed for both woven and nonwoven geotextile and also for varying number of layers. It may be noted that for any given confining pressures the strength ratios increase with increase in number of reinforcement. The comparison between woven and nowoven geotextile reinforcement indicates that for the same number of layers and magnitude of confining pressure the nonwoven geotextile exhibits higher strength ratios than that of woven geotextile.

The increase in strength due to introduction of an extensible reinforced material is derived by virtue of interface friction and the tensile

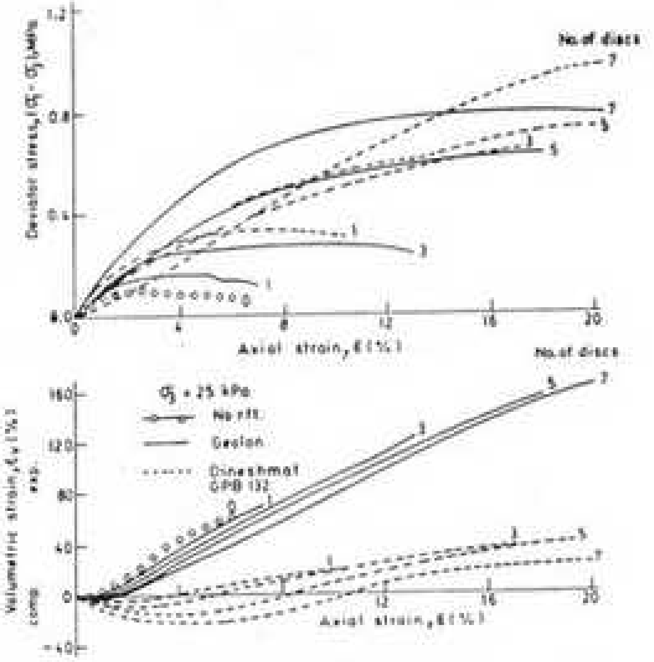


Figure 2 Stress-Strain-Volume Change Relationship for Reinforced Sand, (σ_3=25 kPa)

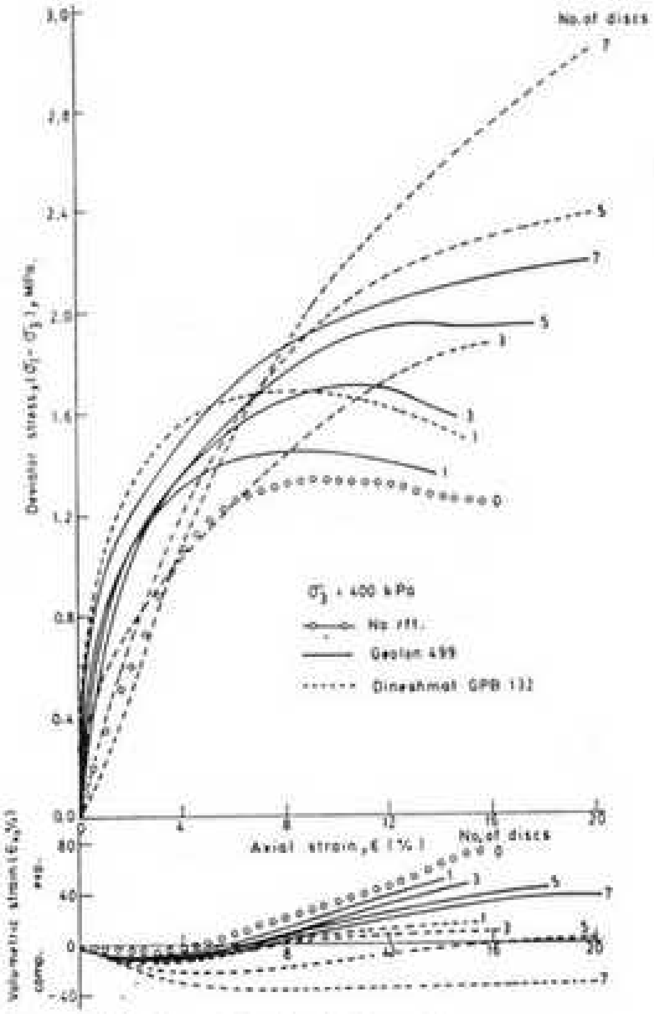


Figure 3 Stress-Strain-Volume Change Relationships for Reinforced Sand, (σ_3=400 kPa).

strength of the reinforcement. It has been already noted that there has been no rupture of the reinforcement at the end of shearing even in a single case. It is thus imperative that it is not the strength but the interface friction which is critical and it is likely that the specimen having large interface friction would have large strength increase. From, table 2 it is seen that the non.woven geotextile exhibited a slightly larger value of friction than the woven geotextile. Perhaps this has caused the larger increase in the strength of the nonwoven geotextile reinforced composite,compared to the woven geotextile.

Table 3 : Variation of Strength Ratio with Confining Pressure.

σ_3 kPa	No. of Reinforcement layers							
	Fabric Geolon 499				Fabric Dineshmat GPB132			
	1	3	5	7	1	3	5	7
25	1.63	2.86	5.87	8.10	3.50	6.50	7.35	9.75
50	1.21	2.20	2.96	4.22	2.28	3.12	4.08	5.92
100	1.10	1.56	1.67	2.85	1.51	2.03	2.79	3.65
200	1.01	1.22	1.46	2.01	1.24	1.55	1.89	2.98
400	1.08	1.27	1.46	1.63	1.27	1.42	1.82	2.29

(ii) Volume Change Behaviour

The variation between volumetric strain and axial strain for reinforced sand with woven and non.woven geotextile are shown in Fig. 2 and 3. They show that the volume change behaviour of reinforced sand in qualitatively similar to that of unreinforced sand. It has been observed that, after initial compression unreinforced sand dilates at low confining pressures. Whereas at higher confining pressures compression takes place with increase of axial strain. At particular confining pressure the effect of reinforcement is to shift these curves towards compression side.

(iii) Strength Characteristic of Reinforcement

Typical results of triaxial tests are plotted in Figs.4 and 5 for reinforced sand with woven and nonwovern geotextile respectively. These results for unreinforced sand are also presented in these figures for comparison. It can be seen from these figures that with increase in number of reinforcement layers the strength increases. The break in the curves corresponds to critical confining stresses; below this critical stress the reinforcement, tends to slip or pulled out as opposed to stretching. This behaviour has been discussed by Hausmann (1976) for the case when the failure is due to slippage between soil and reinforcement. The critical confining stress was typically about 100 kPa for both fabrics. Above this confining stress, all failure envelopes become paralle to the envelope for unreinforced sand.

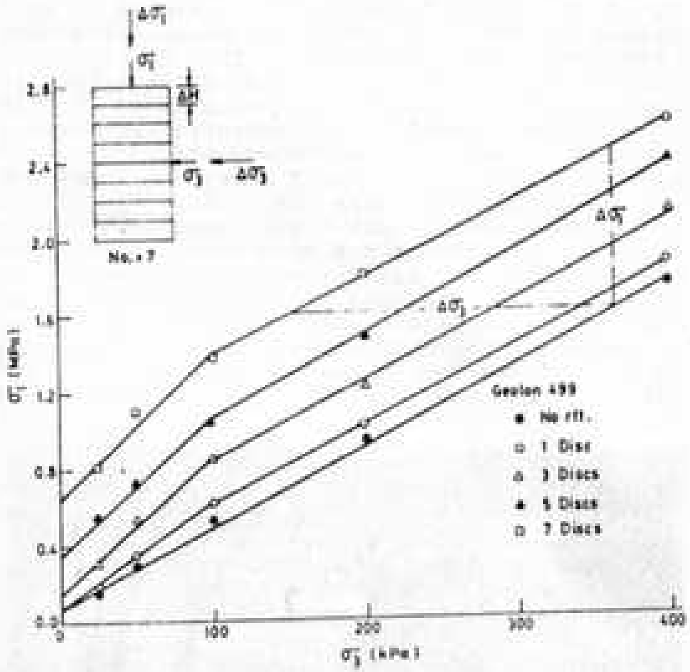


Figure 4 σ_1 Vs. σ_3 Plot for Sand Reinforced with Geolon 499.

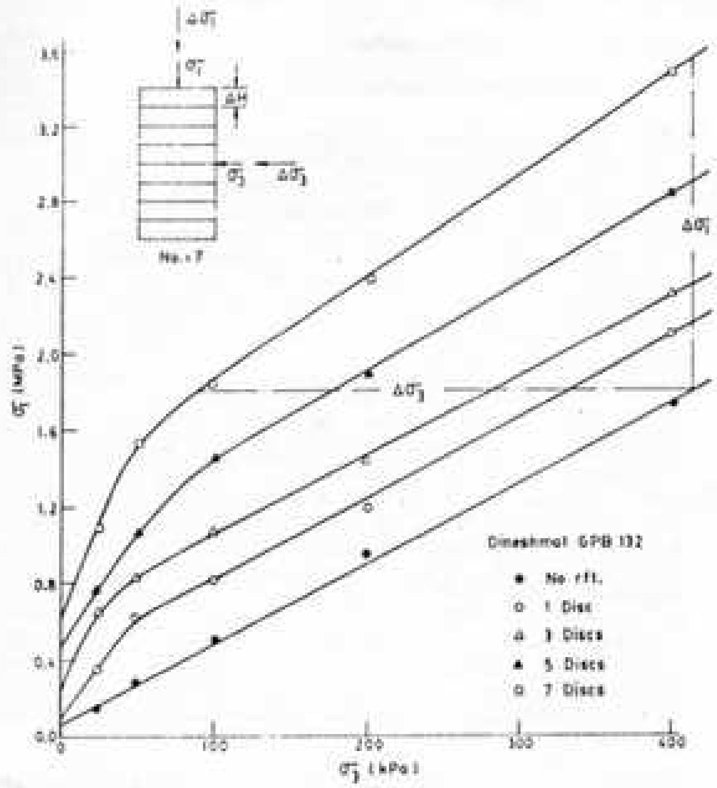


Figure 5 σ_1 Vs. σ_3 Plot for Sand Reinforced with Dineshmat GPB 132.

(iv) Strength Parameters (C' and ϕ')

The p-q plots for reinforced and unreinforced sand for different ranges of confining pressures are presented in Figs.6 and 7 for woven and nonwoven geotextile respectively. The failure envelopes are observed to be bilinear in nature. A visual eximination of these figures indicates that the range of confining pressures upto 100 kPa corresponds to initial linear portion, whereas the second linear portion corresponds to the value of 100-400 kPa. The values of C' and Φ' for these ranges are presented in Tables 4 and 5 for woven and nonwoven geotextiles respectively. A study of these tables reveals the followings:

- For unreinforced sand the values of C' is zero upto confining pressures equal 400 kPa which confirms to previous work reported (Venkatappa Rao et al. 1987).

- For woven geotextile reinforced sand for σ_3 upto 100 kPa, C' is found to increase to 119 kPa and Φ' increases to the maximum value of 54°. Similar increase is observed in case of nonwoven geotextile reinforced sand, C' increases to 171 kPa and Φ' to 53°, when reinforced with 7 discs of both geotextiles.

- For woven geotextile reinforced sand when σ_3 equals 400 kPa the values of Φ' nearly remains constant at value of 35°, whereas the value of C' increases to maximum of 256 kPa. In case of nonwoven geotextile reinforced sand, similar results found where Φ' nearly remains constant at 38°. However, the value of C' increases upto 279 kPa for 7 discs of reinforcement.

It is observed that the value of C' in nonwoven geotextile reinforced sand is higher than that of woven geotextile reinforced sand.

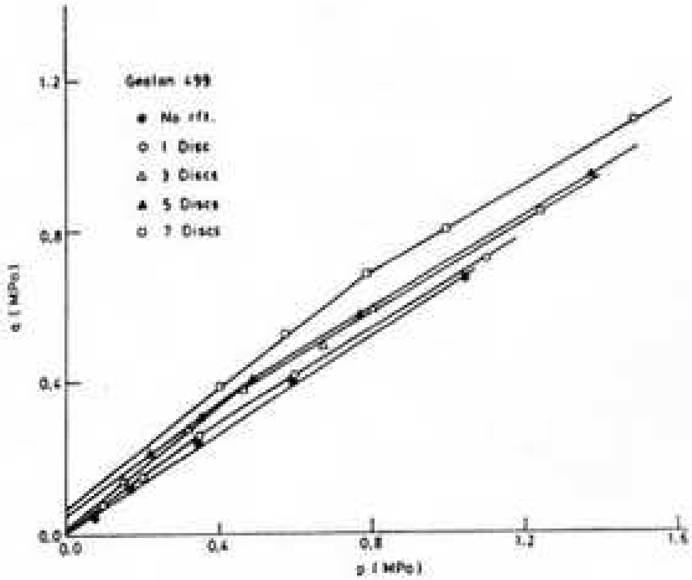


Figure 6 p-q Plots for Sand Reinforced with Geolon 499.

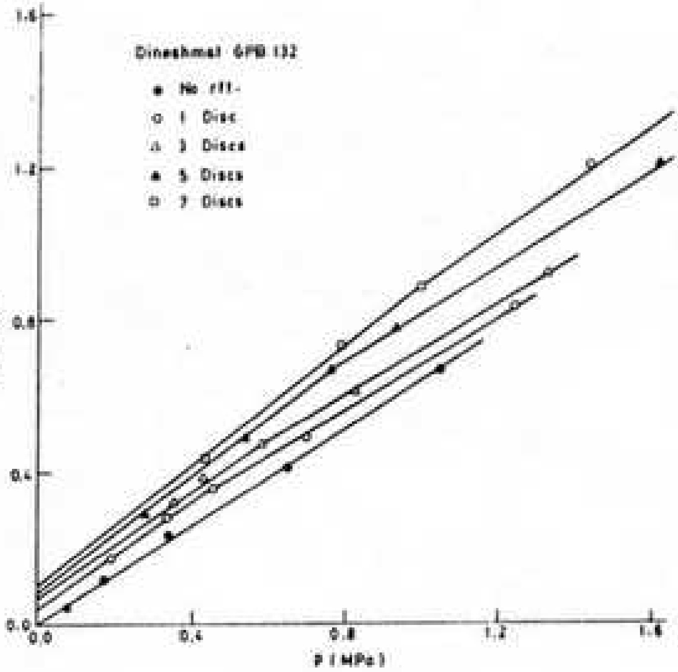


Figure 7 p-q Plots for Sand Reinforced with Dineshmat GPB 132.

Table 4 : Strength Parameters for Sand Reinforced with Geolon 499.

σ_3 kPa	Strength parameter	No. of Reinforcement layers 0	1	3	5	7
<100	C'(kPa)	0	0	32	81	119
	Φ'(deg.)	40	46.6	49	52	54
100 - 400	C'(kPa)	0	49	89	122	256
	Φ'(deg.)	40	35	36	35	35

Table 5 : Strength Parameters for Sand Reinforced with Dineshmat GPB132.

σ_3 kPa	Strength parameter	No. of Reinforcement layers 0	1	3	5	7
<100	C'(kPa)	0	55	98	128	171
	Φ'(deg.)	40	44.4	45.5	51	53
100 - 400	C'(kPa)	0	113	160	263	279
	Φ'(deg.)	40	36.9	36.9	37.8	38

(v) Variation of $(\Delta\sigma_3)_i$ with Confining Pressure

The relationship between confining pressure (σ_3) and increase in confining pressures $(\Delta\sigma_3)_i$ due to reinforcement has been plotted in Figs. 8 and 9 for both woven and nonwoven geotextile reinforcements. The reinforcement induced confining stress $(\Delta\sigma_3)_i$ was obtained directly from experimental data shown by dotted lines and also from eqn. (2) shown in full lines. It is observed that in general $(\Delta\sigma_3)_i$ increases initially linearly with applied cell pressure σ_3, upto a critial pressure caused by increase in frictional resistance. Beyond this the pressure envelope becomes nearly asymptotic as the reinforcement tends to stretch. The ratios of reinforcement induced confining stress $(\Delta\sigma_3)_i$ between experimental data and theoretical results (by use of eqn.2) are presented in Table 6, for both woven and nowoven geotextiles reinforced. From this table it is clear that the ratio in general is found to be approaching unity for both types of geotextiles except for the reinforcement with one disc.

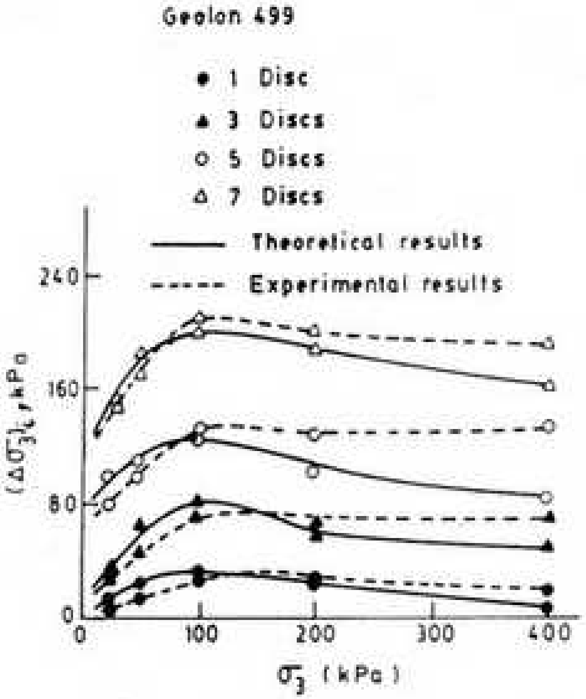


Figure 8 Variation of Reinforcement Induced Confining Stress with σ_3 for Geolon 499.

Table 6 : Ratios of experimental and theoretical induce confining stress with confining pressures.

σ_3 kPa	No. of Reinforcement layers							
	Fabric Geolon 499				Fabric Dineshmat GPB132			
	1	3	5	7	1	3	5	7
25	0.49	0.85	0.76	1.02	0.80	0.99	0.980	1.05
50	0.47	0.70	0.90	0.91	0.90	0.996	1.003	1.07
100	0.70	0.88	1.07	1.05	1.04	1.02	1.014	1.08
200	1.25	0.97	1.08	1.08	1.21	1.11	1.056	1.06
400	4.00	1.24	1.59	1.20	1.54	1.35	1.083	1.06

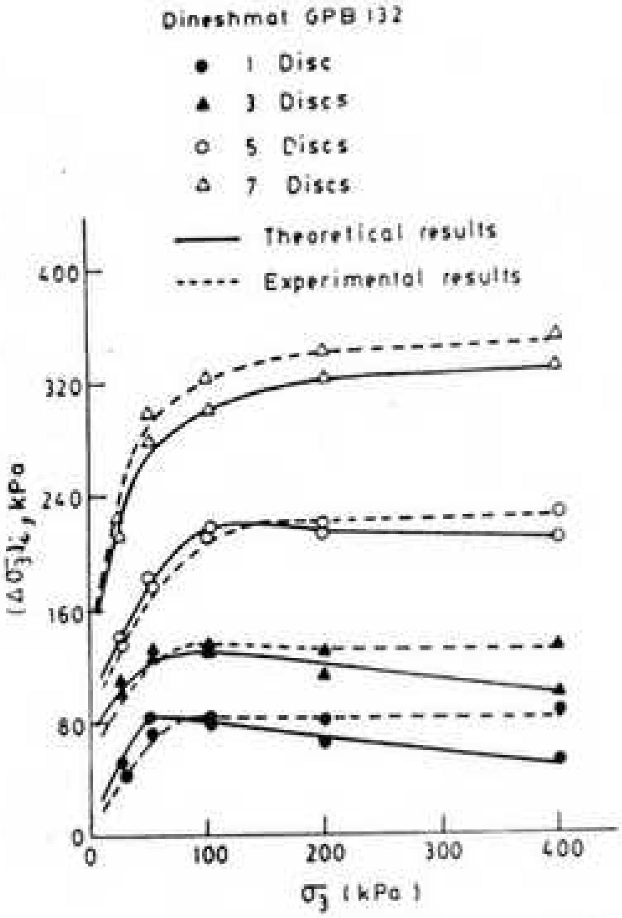


Figure 9 Variation of Reinforcement Induced Confining Stress with σ_3 for Dineshmat GBP 132

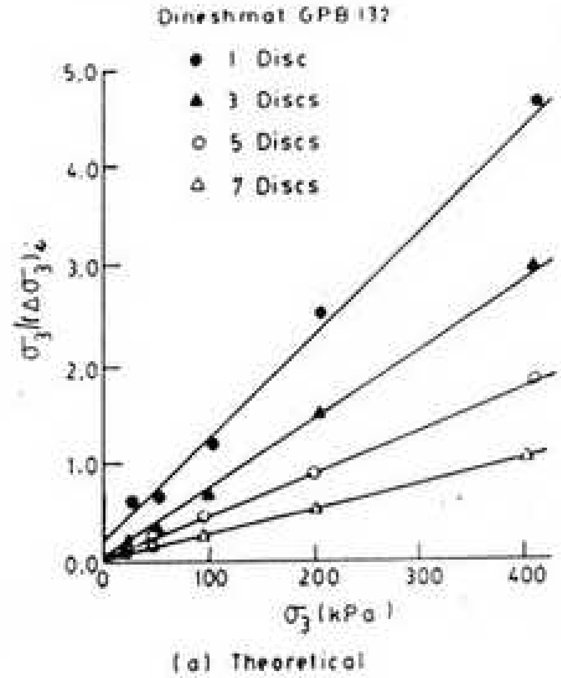
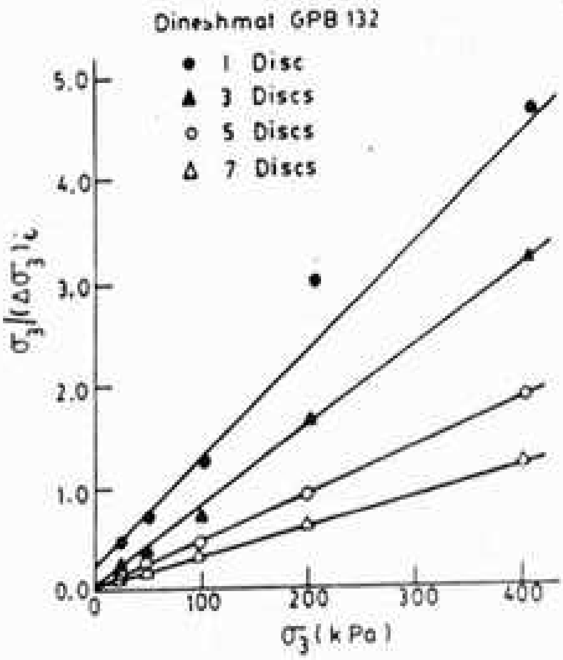


Figure 10(a) Hyperbolic Plot for Reinforced Sand with Dineshmat GPB 132.



(b) Experimental

Figure 10(b) Hyperbolic Plot for Reinforced Sand with Dineshmat GPB 132.

The relationship between the ratio of confining pressure (σ_3) to the induced confining stress $(\Delta\sigma_3)_i$ and confining pressure (σ_3) is a straight line as shown in Fig.10 and 11. From this relationship of the hyperbolic form the following equation is obtained as:

$$\frac{\sigma_3}{(\Delta\sigma_3)_i} = a + b\sigma_3 \qquad (7)$$

where a and b are constants.

Thus for any given confining pressure it is possible to predict the induced confining stress.

Conclusions

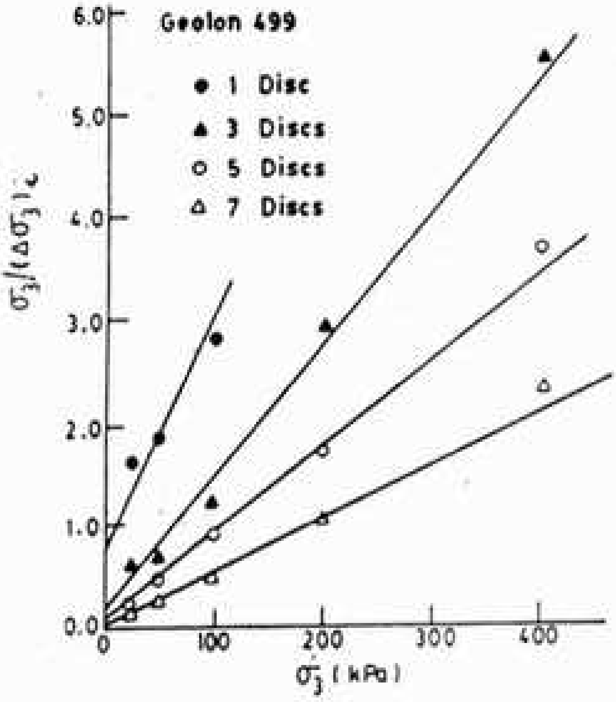
- The results of reinforced sand indicates improvement in strength with number of reinforcement discs, for both types of geotextiles. This is inline with the work reported earlier.

- For σ_3 upto 100 kPa, C' and Φ' increases, when σ_3 = 400 kPa C' increases and Φ' nearly remain constant in both types of geotextiles with number of reinforcement.

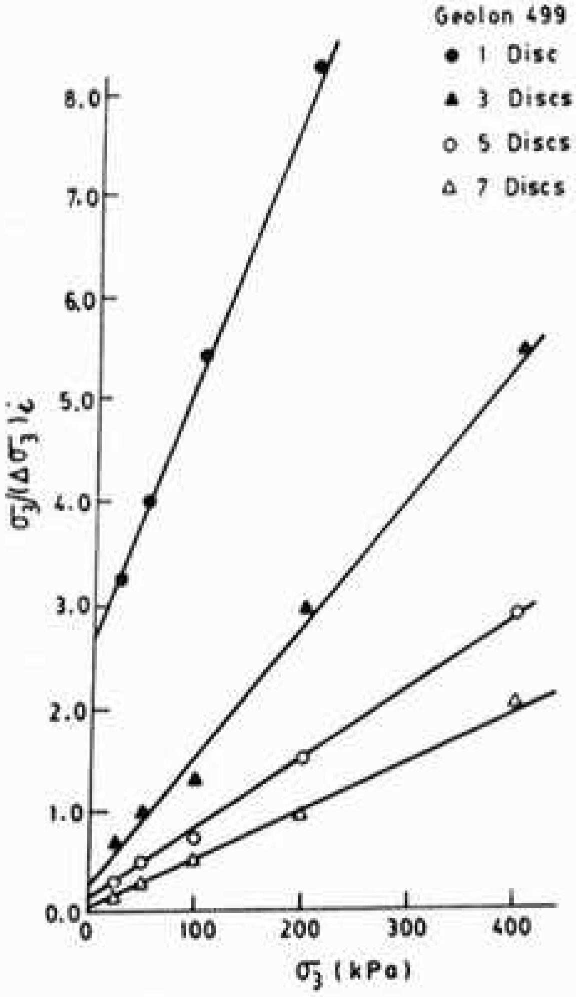
  Intially the induced confining stress increases linearly with σ_3 upto critical pressure. Beyond this the envelope becomes nearly asymptotic as the reinforcement tends to stretch.

  The variation in reinforcement induced confining stress $(\Delta\sigma_3)_i$ with σ_3 is found to be hyperbolic in nature.

  The ratio of calculated and measured values of $(\Delta\sigma_3)_i$ is ingeneral found to approach unity.



(a) Theoretical



(b) Experimental

Figure 11 (a) and (b) Hyperbolic Plots for Reinforced Sand with Geolon 499.

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