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Strength Behaviour of Geotextile Reinforced Sand under Axisymmetric Loading

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Introduction

The technique of soil reinforcement is being extensively used since the last two decades in the construction of embankments, retaining walls, etc. As a result of this, large varieties of reinforcing materials have emerged, which include, metallic strips, bars, mats and geosynthetics. 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 studies were planned primarily to assess the influence of reinforcement on the overall behaviour of geotextile reinforced sand under triaxial conditions. The studies consist of conducting drained triaxial tests on large diameter sand specimens with and without reinforcement under different confining pressures in which the types and spacing of geotextile and types of sands have been varied. An attempt has also been made to compare the experimental values thus obtained with the corresponding theoretically computed values based on different models suggested by earlier researchers.

Literature Review

Several investigators (Yang, 1972; Schlosser and Long, 1974; Broms, 1977; McGown et al., 1978 and Mandal, 1987) have reported the results of

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triaxial and plane strain compression tests on cylindrical specimens of sand containing thin horizontal layers of extensible reinforcing material. The behaviour of fabric reinforced sand has been explained by the concept of enhanced confining pressure. 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 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. Experimental findings of Hausmann (1976), Broms (1977), Venkatappa Rao et al. (1987, 1989) are in general agreement with the hypothesis that slippage failure results in increased friction angle. Test results of Long et al. (1972) and Saran et al. (1978) indicated development of pseudo-cohesion where failure was due to the rupture of reinforcement. However, investigations by Subba Rao and Parsad (1987) and Venkatappa Rao et al. (1989) revealed an increase in angle of shearing resistance along with the cohesion intercept even in the slippage mode of failure.

Broms (1977) proposed a semi-empirical equation relating the force in the fabric to increased strength. The total axial load (P_{max}) on the specimen was calculated by the following equation, hence forth referred to as the original model.

$$P_{max} = \frac{\pi \sigma'_{ho} K_b (\Delta H)^2}{2 \tan^2 \phi'_a} \left[\exp \frac{2 \tan \phi'_a R}{\Delta H K_b} - \frac{2 \tan \phi'_a R}{\Delta H K_b} - 1 \right] \tag{1}$$

wherein σ'_{ho} = lateral confining pressure at the perimeter of the specimen,

R = radius of the triaxial specimen,

K_b = coefficient of earth pressure, next to the fabric estimated as $1/(1 + 2\tan^2 \phi'_a)$, and

ϕ'_a = is the effective interface friction angle.

More recently Chandrasekaran et al., (1989) suggested the following equation (referred as modified model) for computing P_{max}.

$$P_{max} = \pi \sigma'_{ho} \frac{K_{av}}{K_a} \frac{R \Delta H}{\tan(\alpha \phi'_a)} \left[\exp\left\{ \frac{\tan(\alpha \phi'_a) R}{\Delta H K_{av}} \right\} - 1 \right] \tag{2}$$

wherein $K_{av} = \frac{1}{2}(k_a + k_b)$,

$K_a = (1-\sin\phi')/(1+\sin\phi')$,

ϕ' = angle of internal friction of sand,

$K_b = 1/\left(1+2\tan^2\phi'\right)$, and

α = multiplication factor, $0 < \alpha \leq 1$

Experimental Work

Material Properties

The present investigation was carried out on two sands viz., Yamuna sand and Ottawa sand. Yamuna sand is a fine grained sand whereas Ottawa sand is medium to coarse grained. The relative density, uniformity coefficient and coefficient of curvature for Yamuna sand are 0.60, 1.67 and 1.01 respectively whereas for Ottawa sand these are 0.72, 0.83 and 0.92 respectively.

Two types of geotextiles (woven and nonwoven) manufactured in India are used as reinforcements. These are a multifilament plain woven geotextile of polypropylene and polypropylene staple fibre needle punched geotextile. The physical and mechanical properties of these geotextiles are presented in Table 1.

Experimental Procedure

The specimens have been prepared by a procedure similar to that adopted for preparing specimens of saturated cohesionless soil for

Table 1: Properties of Geotextiles

Property		*Woven* G499	*Non-woven* GPB132
Mass per unit area (g/m^2)		270	275
Thickness at 2kPa pressure (mm)		0.70	4.02
Pore size "mean" (micron)		25	75
Secant modulus @ 10% Elongation (kN/m)	(MD)	170.5	1.1
	(CD)	91.5	0.76
Wide width tensile (kN/m)	(MD)	37.0	14.41
	(CD)	33.9	14.03
Extension at failure (%)	(MD)	28.0	56.6
	(CD)	26.0	66.5
CBR push through (kPa)		0.68	0.149

(MD) = Machine Direction
(CD) = Cross Machine Direction

conventional consolidated drained triaxial tests (Bishop and Henkel, 1962). The specimens prepared for the present study were 100 mm in diameter and 200 mm high. The saturated sand was deposited in layers into the rubber membrane inside a split mould former. Each sand layer was compacted to achieve the required density through vibration at constant frequency. The circular reinforcement discs of 100 mm diameter were cut from the fabric sheets by rotating a heated, sharpened brass tube on fabric spread on a wooden block. Such a reinforcement disc was placed on already compacted and levelled sand layer of predetermined height The procedure was repeated till the full height of the sample was reached. Thus the reinforced sand specimens were built up layer by layer with circular discs of reinforcement placed at predetermined intervals. Care was taken to see that the density of the specimens is uniform throughout. Conventional consolidated drained triaxial tests were then conducted.

Parameters Varied

The compaction density of Yamuna sand was maintained at 15 ± 0.2 kN/m^3 whereas, Ottawa sand was compacted at 16 ± 0.2 kN/m^3. The number of reinforcement layers varied were 1, 3, 5 and 7 and accordingly the thicknesses of sand layers were adjusted. The ratios of specimen radius (r) to reinforcement spacing (ΔH) worked out to be 0.5, 1.0, 1.5 and 2.0. For each of the case studied, the cell pressures applied were 25, 50, 100, 200 and 400 kPa. The specimens, after consolidation were sheared at a deformation rate of 0.2 mm/minute.

Results and Discussions

Stress-Strain Relationship

The typical stress-strain curves obtained under confining pressures σ_3 of 25 kPa and 400 kPa for Yamuna sand reinforced with woven fabric are illustrated in Fig. 1. This figure also presents the curves for the unreinforced sand. It can be seen from this figure that, both the peak stress and corresponding axial strain increases with increase in confining pressure. These values are found to be higher for reinforced sand than those corresponding to unreinforced sand. For example, Yamuna sand reinforced with one disc of woven geotextile at $\sigma_3 = 25$ kPa exhibits a peak stress of 154 kPa and a failure axial strain of 4% whereas these values for unreinforced sand are 95 kPa and 2% respectively. Similar is the case at other confining pressures. Similar results have been observed for all the cases studied here.

The values of strength ratio defined as the ratio of the strength of a reinforced specimen to that of an unreinforced specimen, under different confining pressures are given in Tables 2 and 3. These tables reveal a definite

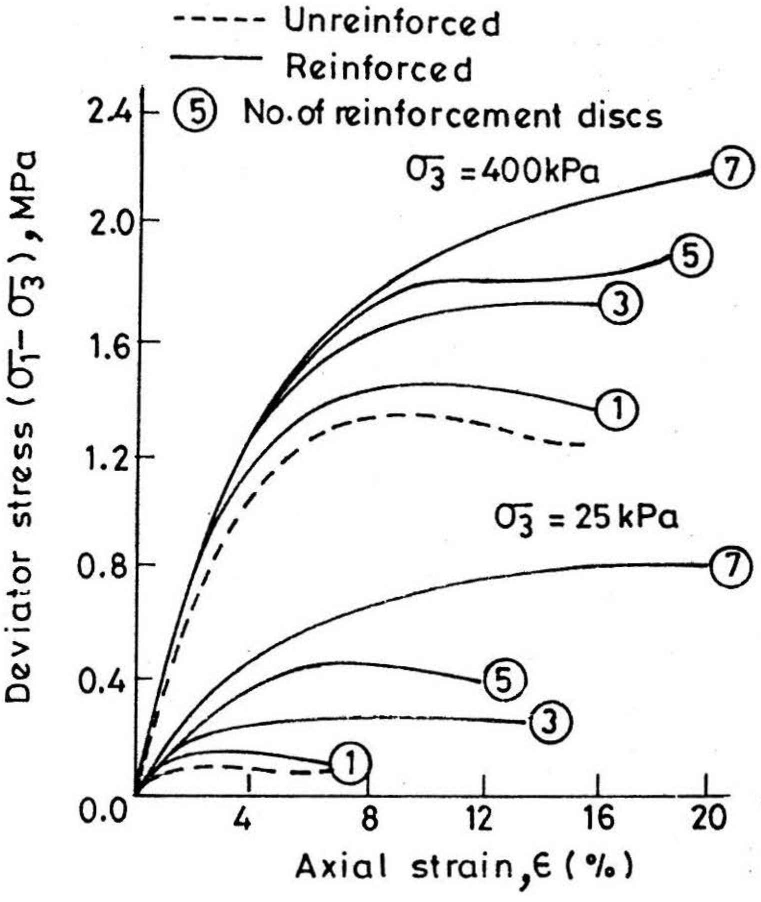


Figure 1 : Stress-Strain Relationship for Yamuna Sand Reinforced with Woven Fabric

pattern indicating an increase in strength ratios with increase in number of reinforcements and a decrease with increase in confining pressure. The same sand when reinforced with nonwoven fabric exhibit higher strength ratio than with woven fabric. Further, for the same type of fabric, reinforced Yamuna sand exhibited higher strength ratios than reinforced Ottawa sand.

Volume Change Behaviour

The typical stress-strain-volume change behaviour for sands, unreinforced as well as reinforced with 5 discs under different confining pressures is illustrated in Fig. 2 for Ottawa sand. This figure in general depicts that both reinforced as well as unreinforced sands exhibit nearly similar trends of axial strain versus volume change curves indicating an initial compression and then dilation as the axial strain increases. Similar

Table 2 : Variation of Strength Ratio with Confining Pressures for Yamuna Sand

σ_3 (kPa)	Strength Ratio for							
	Woven Fabric with Reinforcement Discs Numberings				Non-woven Fabric with Reinforcement Discs Numberings			
	1	3	5	7	1	3	5	7
25	1.62	2.70	4.60	8.10	3.49	6.46	7.35	8.38
50	1.21	2.72	2.36	4.19	2.24	3.15	4.08	5.32
100	1.33	1.88	2.18	3.49	1.88	2.51	3.39	4.59
200	1.22	1.41	1.62	2.16	1.43	1.73	2.11	3.02
400	1.08	1.26	1.34	1.62	1.27	1.42	1.57	2.32

Table 3 : Variation of Strength Ratio with Confining Pressures for Ottawa Sand

σ_3 (kPa)	Strength Ratio for							
	Woven Fabric with Reinforcement Discs Numberings				Non-woven Fabric with Reinforcement Discs Numberings			
	1	3	5	7	1	3	5	7
25	1.04	2.24	4.44	7.40	1.64	2.76	5.10	8.90
50	1.04	1.86	2.57	3.99	1.28	1.84	2.50	4.43
100	1.22	1.72	2.54	3.61	1.42	1.95	2.75	4.29
200	1.09	1.23	1.69	2.35	1.22	1.37	2.06	2.72
400	1.02	1.15	1.38	1.80	1.08	1.24	1.59	2.13

trends have been noticed in all other cases irrespective of the number of reinforcement discs as well as type of reinforcing fabric for both the sands. In general, it may be inferred that the effect of reinforcement is to decrease the volumetric expansion. The decrease in volumetric expansion is much more pronounced in Ottawa sand reinforced with nonwoven geotextile compared with all other cases. It may also be seen that the volumetric expansion decreases with increase in confining pressures.

Strength Characteristics

The typical variation between σ_{1f} and corresponding σ_3 for unreinforced as well as reinforced sands with varying number of discs are shown in Figs. 3 and 4 for Yamuna sand and Ottawa sand respectively, both reinforced with woven fabric. It is interesting to note from these figures that, the failure envelopes are linear for unreinforced sand whereas they become bilinear with

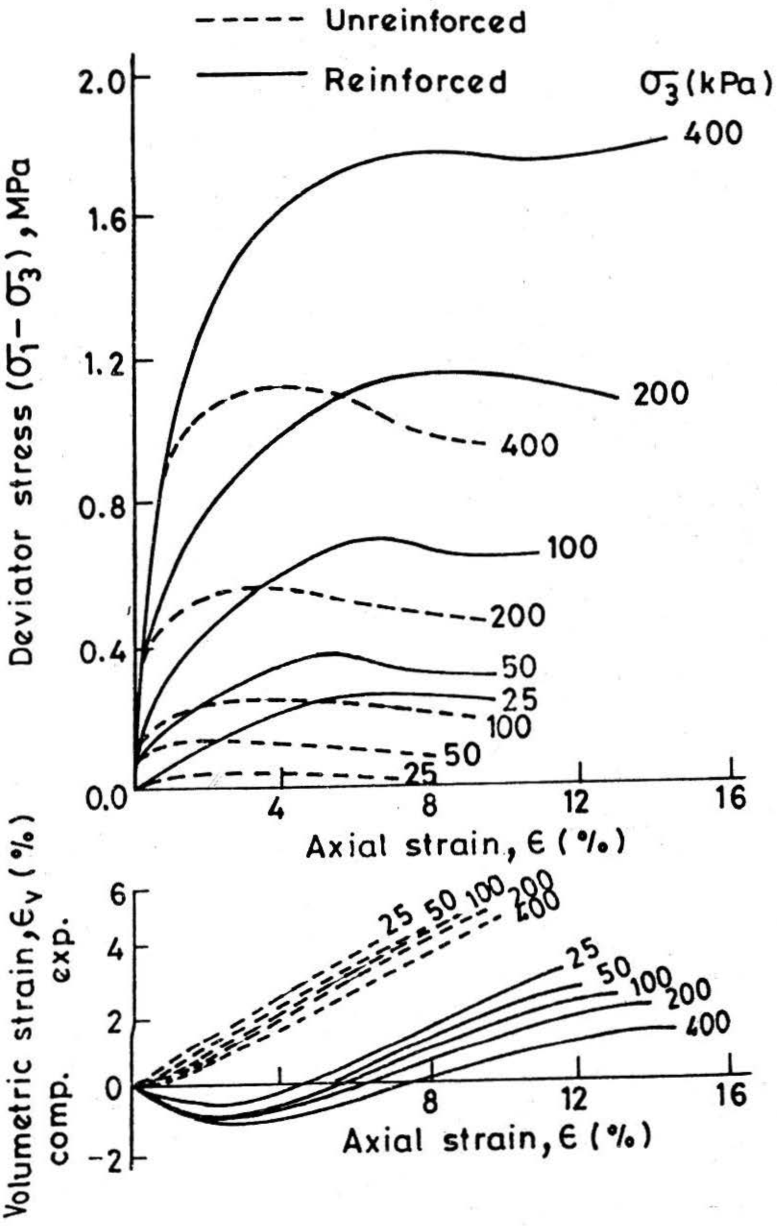


Figure 2 : Stress-Strain Volume Change Relationship for Ottawa Sand Reinforced with Non-woven Fabric

reinforcements. Similar trends have also been noticed for these sands with nonwoven fabric. The value of σ_3 corresponding to the intersection point of these linear segments has been referred as critical confining pressure (σ_c). Interestingly the values of σ_c have been observed to be around 100 kPa for all the cases. For the values of σ_3 more than σ_c, all the failure envelopes for

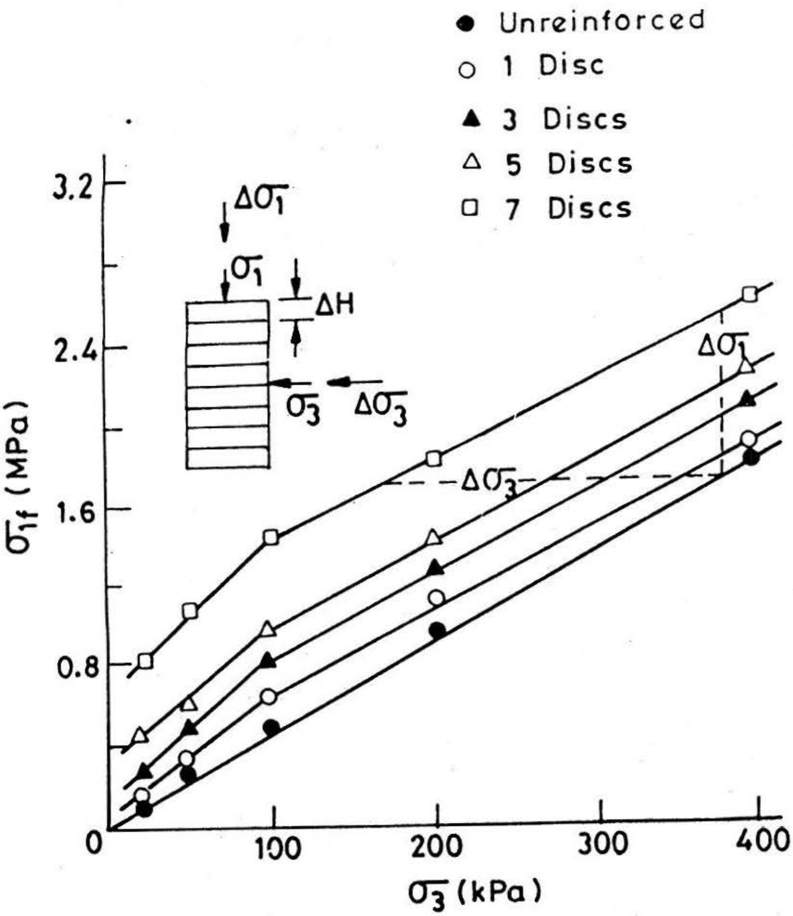


Figure 3 : Variation between σ_{1f} and σ_3 for Yamuna Sand Reinforced with Woven Fabric

reinforced sands are nearly parallel to the envelopes of unreinforced sand. Such behaviour has also been reported by Gray et al. (1982) which has been attributed to the slippage between sand and reinforcement.

The typical p-q plots for Ottawa sand reinforced with woven fabric are illustrated in Fig. 5. The values of c′ and ϕ' evaluated from these plots within and beyond the critical confining pressure of 100 kPa are presented in Table 4. It can be seen from these tables that the ϕ' values exhibited by unreinforced sand is 35° with c′ = 0, in the entire range of σ_3 applied in the study. The values of both c′ and ϕ' increase with number of reinforcement discs, upto σ_3 = 100 kPa. Beyond this the values of c′ increase with number of reinforcement whereas ϕ' remains nearly constant. Similar results have

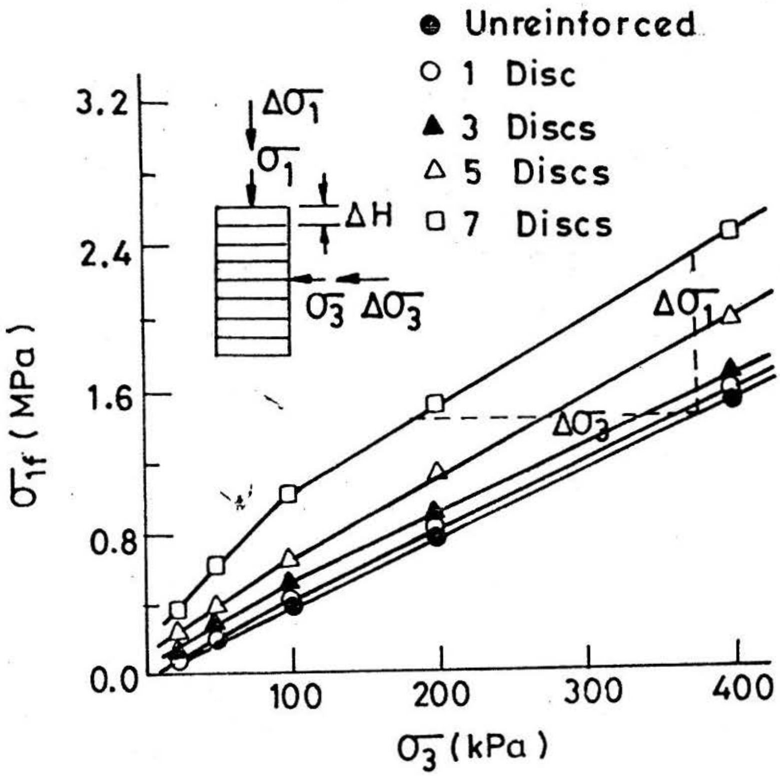


Figure 4 : Variation between σ_{1f} and σ_3 for Ottawa Sand Reinforced with Woven Fabric

been observed in all other cases studied. The unreinforced Yamuna sand *exhibited a ϕ' value of 39°.* The higher strength ratios for reinforced Yamuna sand noticed earlier may be attributed to its higher value of ϕ' compared to Ottawa sand.

Table 4: Strength Parameters for Ottawa Sand Reinforced with Woven Geotextile

σ_3 (kPa)	Strength Parameter	No. of Reinforced Discs				
		0	1	3	5	7
<100	ϕ' (deg)	35	39	41	44	46
	c' (kPa)	0	12	26	42	62
100-400	ϕ' (deg)	35	35	35	35	38
	c' (kPa)	0	36	49	92	136

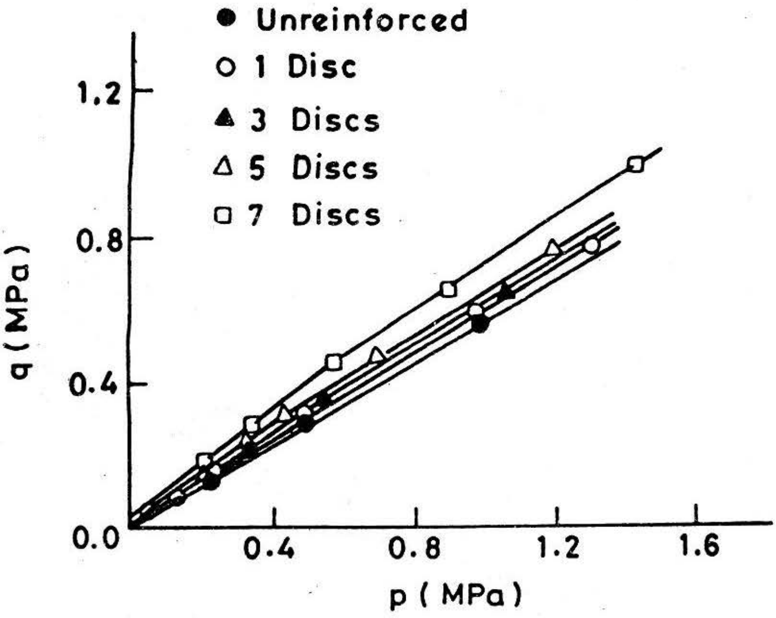


Figure 5 : p–q Plots for Ottawa Sand Reinforced with Woven Fabric

Induced Confining Stress due to Reinforcement

It can be seen from Figs. 3 and 4 that for any particular magnitude of peak failure stress (σ_{1f}) the corresponding confining pressures (σ_3) are different for reinforced and unreinforced sand. For example, for σ_{1f} of 1.68 MPa the corresponding σ_3 values are 375 kPa and 170 kPa for unreinforced Yamuna sand and when it is reinforced with 7 discs of woven fabric. For the same magnitude of σ_{1f}, the σ_3 values required are always lower for reinforced sand than the unreinforced one. The difference in confining pressures between the reinforced and unreinforced sands corresponding to same σ_{1f} is considered and unreinforced sands corresponding to same is considered as induced confining stress $\Delta\sigma_3$ due to the reinforcement. The values of such $\Delta\sigma_3$ for different values of applied σ_3 have been extracted from Figs. 3 and 4 under different test conditions. The theoretical values of such $\Delta\sigma_3$ have been computed by using Eqn. 3, suggested by Yang (1972) :

$$\Delta\sigma_3 = K_a\sigma_{1f} - \sigma_3 \quad (3)$$

where $\Delta\sigma_3$ = increase in confining pressure,

K_a = Rankine's coefficient of active earth pressure,

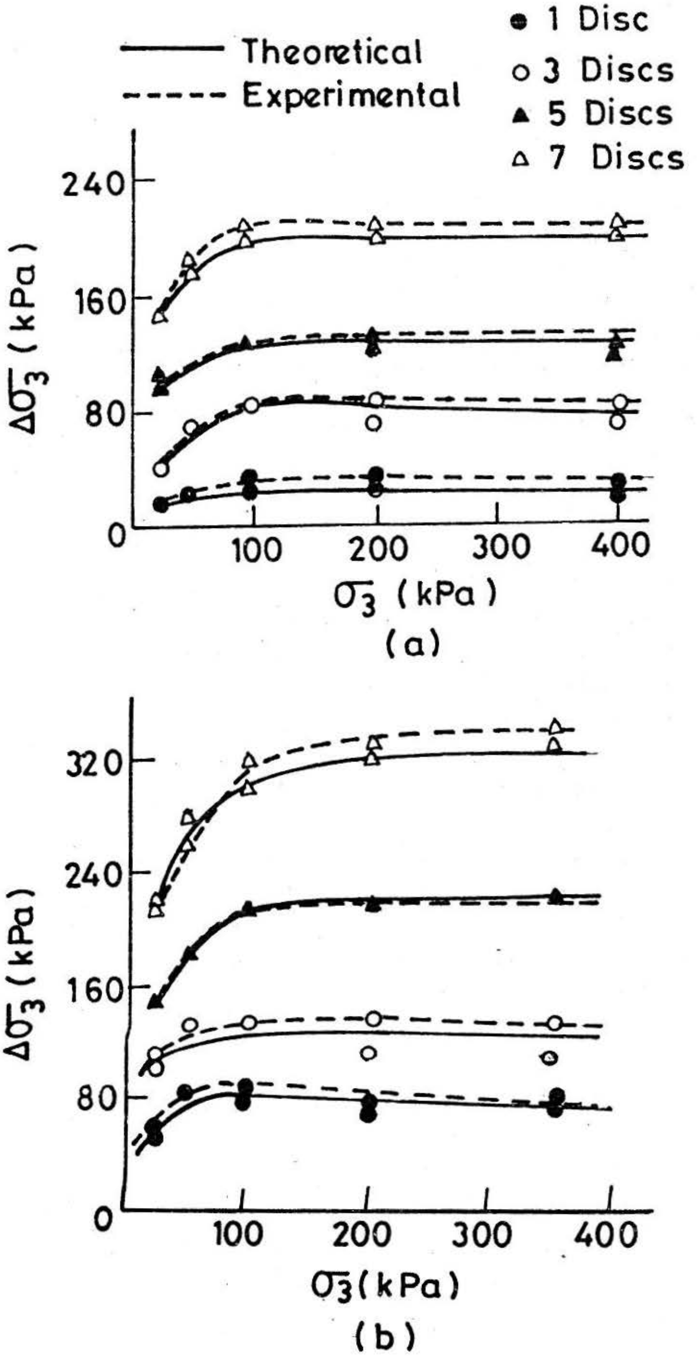


Figure 6 : Variation between $\Delta\sigma_3$ and σ_3 for Reinforced Yamuna Sand with (a) Woven Fabric, (b) Non-woven Fabric

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

σ_3 = applied confining pressure on the specimen.

The theoretical and experimental relationships between confining pressure and induced confining stress due to reinforcement are shown in Fig. 6 for Yamuna sand. In general, this figure show that $\Delta\sigma_3$ increases with σ_3 upto critical confining pressure (σ_c) and beyond this $\Delta\sigma_3$, remains almost constant with σ_3. The theoretical as well as experimental curves are in good agreement. Similar trends have been noticed for other cases studied here. The asymptotic behaviour observed beyond critical confining pressure may be as a result of reinforcement tending to stretch.

The typical values of ratio between experimental $\Delta\sigma_3$ and theoretical $\Delta\sigma_3$ calculated under different test conditions are presented in Table 5 for Ottawa sand. This table clearly indicate that the ratios in general are approaching unity. Similar results have been noticed for Yamuna sand also.

The experimental as well as theoretical hyperbolic plots between the ratio of confining pressure to the induced confining stress $\sigma_3/\Delta\sigma_3$ and confining pressure σ_3 are shown typically in Figs. 7 and 8 for Yamuna and Ottawa sands reinforced with nonwoven fabric. In general, these variations are linear and can be expressed by the following equation

$$\sigma_3/\Delta\sigma_3 = a + b\,\sigma_3 \tag{4}$$

where a and b are constants and their magnitude depends both on the quality as well as the quantity of reinforcements and the type of sand. These sands reinforced with woven fabric exhibited similar trends. The ranges of the constants a and b obtained theoretically and experimentally for both the reinforced sands are given in Table 6. In general, the table shows that the experimental values are some what higher than their theoretical values.

Table 5 : Ratio of Experimental and Theoratical $\Delta\sigma_3$ for Different σ_3 for Ottawa Sand

σ_3 (kPa)	No. of Reinforced Discs							
	Woven Fabric				Non-woven Fabric			
	1	3	5	7	1	3	5	7
25	-	0.83	0.92	1.02	1.00	1.05	0.95	0.90
50	1.0	1.10	0.95	1.00	1.09	1.03	1.02	0.96
100	1.0	1.03	1.03	0.97	1.14	1.09	1.10	0.98
200	1.6	0.95	1.09	0.95	0.96	0.92	1.11	0.96
400	1.6	0.90	1.10	1.08	0.90	0.92	1.09	0.95

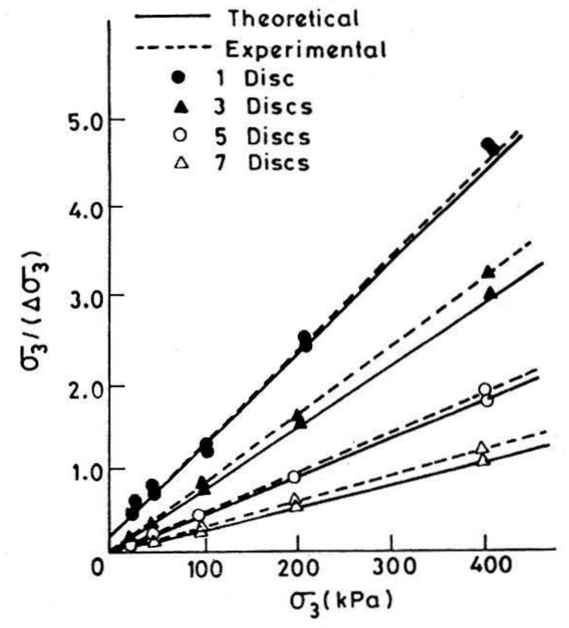


Figure 7 : Hyperbolic Plots for Yamuna Sand Reinforced with Non-woven Fabric

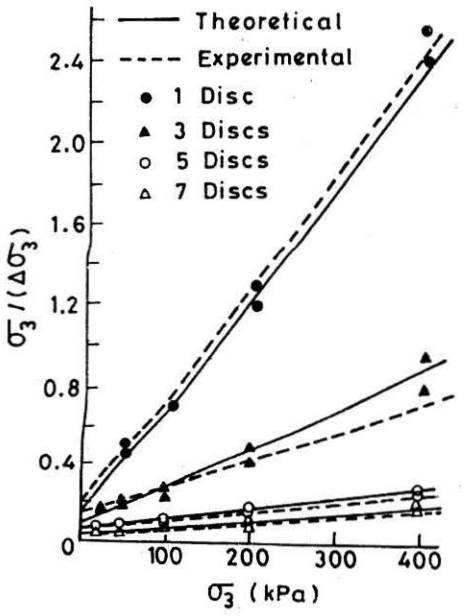


Figure 8 : Hyperbolic Plots for Ottawa Sand Reinforced with Non-woven Fabric

Influence of Reinforcement Spacing on Stress Ratios

The typical variation between the maximum stress ratio σ_{if}/σ_3 and the ratios of specimen radius to reinforcement spacing $(r/\Delta H)$ under different confining pressures are illustrated in Fig. 9 for Yamuna sand reinforced with woven geotextile. Such variation for unreinforced sand has also been shown by dotted lines in this figure for comparison. These variations in general exhibit curvilinear trends indicating an increase in maximum stress ratios with increasing $r/\Delta H$ ratio. Similar results have been noticed for other cases studied here. It is evident from these curves that the maximum stress ratio increases rapidly with increase in $r/\Delta H$ ratios for lower confining pressures. However, with increase in confining pressure the change in σ_{if}/σ_3 decreases and at higher confining pressure it becomes marginal. For instance, in the case of Yamuna sand reinforced with woven geotextile when $r/\Delta H$ is changed from 1.0 to 1.5 the corresponding changes in σ_{if}/σ_3 are 7.5, 3.75, 1.5, 0.5 and 0.25 under the confining pressures of 25, 50, 100, 200 and 400 kPa respectively. The significant increase in maximum stress ratios $r/\Delta H$ with at low confining pressures suggest that geotextile reinforcement in sand are more effective for the construction of soil structure of relatively low heights.

The influence of $r/\Delta H$ on equivalent strength ratios $(\sigma_3 + \Delta\sigma_3)/\sigma_3$ obtained experimentally and theoretically (Yang, 1972) is illustrated in Fig. 10. It is clear that all these results compare fairly well and when $r/\Delta H$ is less than 0.5 the equivalent strength ratio is not affected.

Constitutive Relationship

Typical plots of $\varepsilon/(\sigma_1 - \sigma_3)$ versus are shown in Fig. 11 for reinforced as well as reinforced sands with 7 discs under different confining pressures. This figure which correspond to Yamuna sand shows a linear variation for

Table 6 : Range of Constants in the Hyperbolic Equation

Sand	Reinforcement			
			a	b
Yamuna	Woven	Theo.	0.025-0.750	0.005-0.02299
		Expt.	0.030-2.650	0.005-0.02650
	Non-woven	Theo.	0.025-0.225	0.003-0.01050
		Expt.	0.013-0.225	0.003-0.01078
Ottawa	Woven	Theo.	0.200-25.000	0.004-0.08000
		Expt.	0.298-25.000	0.004-0.08000
	Non-woven	Theo.	0.400-1.650	0.004-0.05200
		Expt.	0.300-2.130	0.004-0.05600

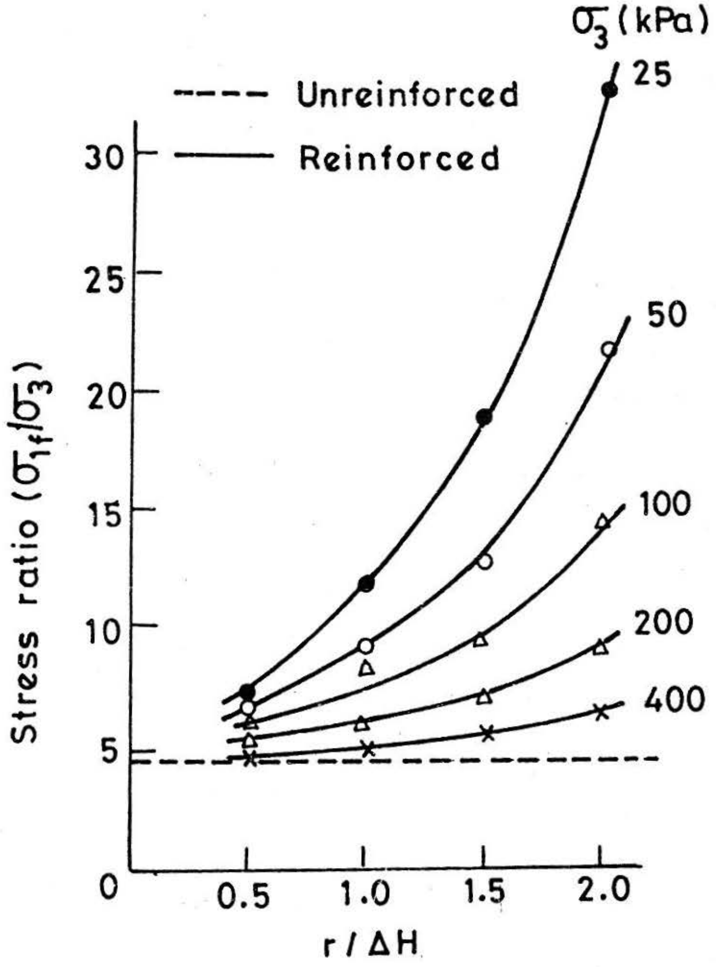


Figure 9 : Variation of Maximum Stress Ratios with r/ΔH for Yamuna Sand Reinforced with Woven Fabric

both reinforced as well as reinforced sands indicating clearly the validity of hyperbolic relationship suggested by Kondner and Zelasko (1963) as expressed by Eqn. 5 given below. Similar trends have been observed for sands reinforced with different number of discs studied.

$$\varepsilon/(\sigma_1 - \sigma_3) = a + \varepsilon\, b \tag{5}$$

where ε = is axial strain,

$(\sigma_1 - \sigma_3)$ = is the deviator stress, and

a and b = constants.

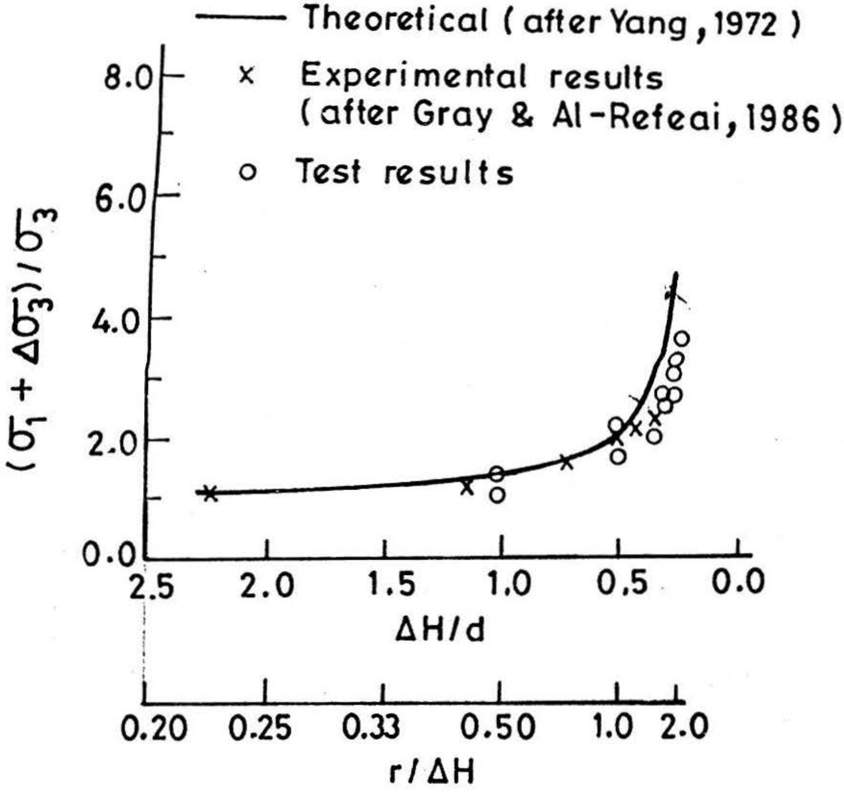


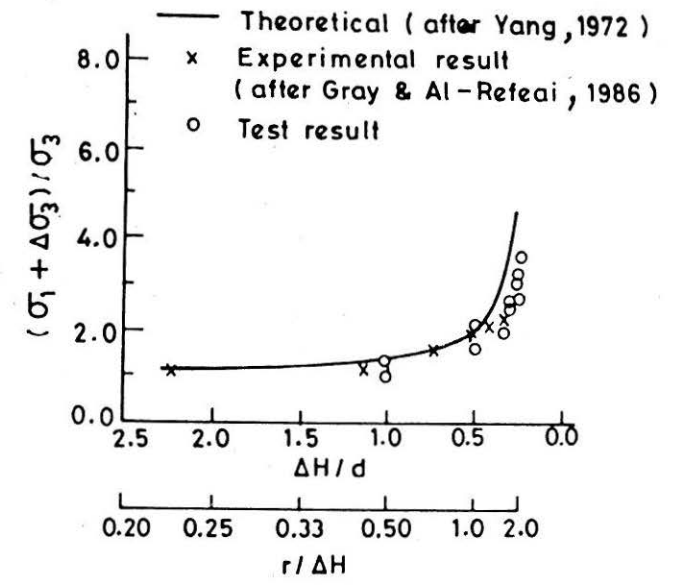
Figure 10 : Variation of Equivalent Strength Ratios with r/ΔH

The ultimate strength $(\sigma_1 - \sigma_3)_{ult}$ evaluated from the above figure has been compared with the maximum deviator stress at failure $(\sigma_1 - \sigma_3)_f$ obtained from the stress-strain plots. For all the cases studied here it has been observed that $(\sigma_1 - \sigma_3)_{ult}$ are higher than $(\sigma_1 - \sigma_3)_f$ and corresponding values of failure ratios R_f have been calculated from Eqn. 6 given below as suggested by Duncan and Chang (1970) for reinforced sand.

$$(\sigma_1 - \sigma_3)_f = R_f(\sigma_1 - \sigma_3)_{ult} \tag{6}$$

The values of R_f for unreinforced sand range between 0.75 and 1.00 and are in agreement with those observed by them. For reinforced sand, R_f ranges between 0.6 to 0.95 which are somewhat lower those for unreinforced sand. This may probably be due to increase in axial strain of reinforcing fabric at failure.

The inverse of constant "a" in Eqn. 5 yield initial tangent modulus (E_i).



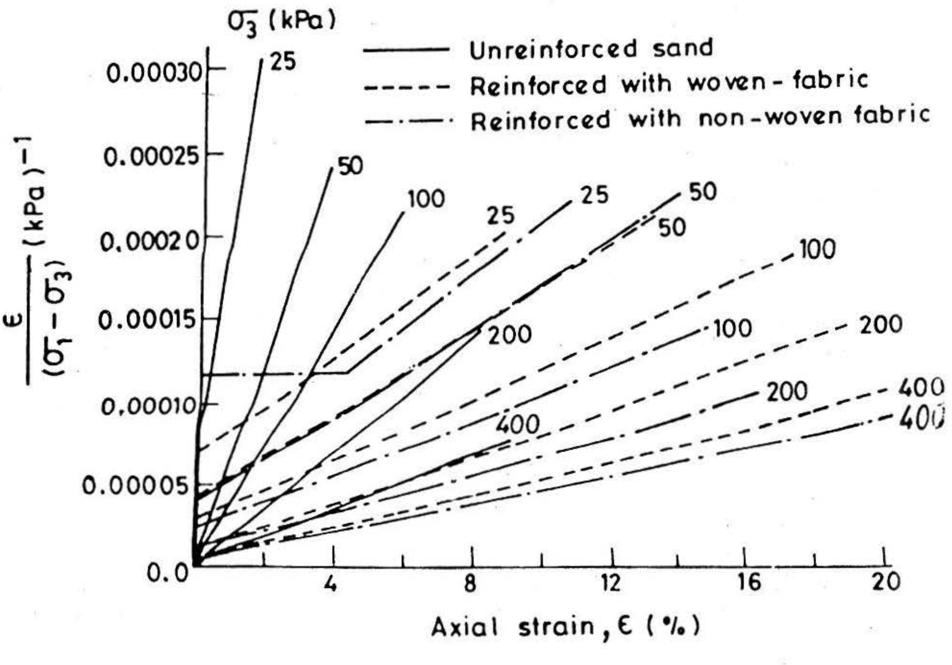


Figure 11 : Hyperbolic Plot for Yamuna Sand

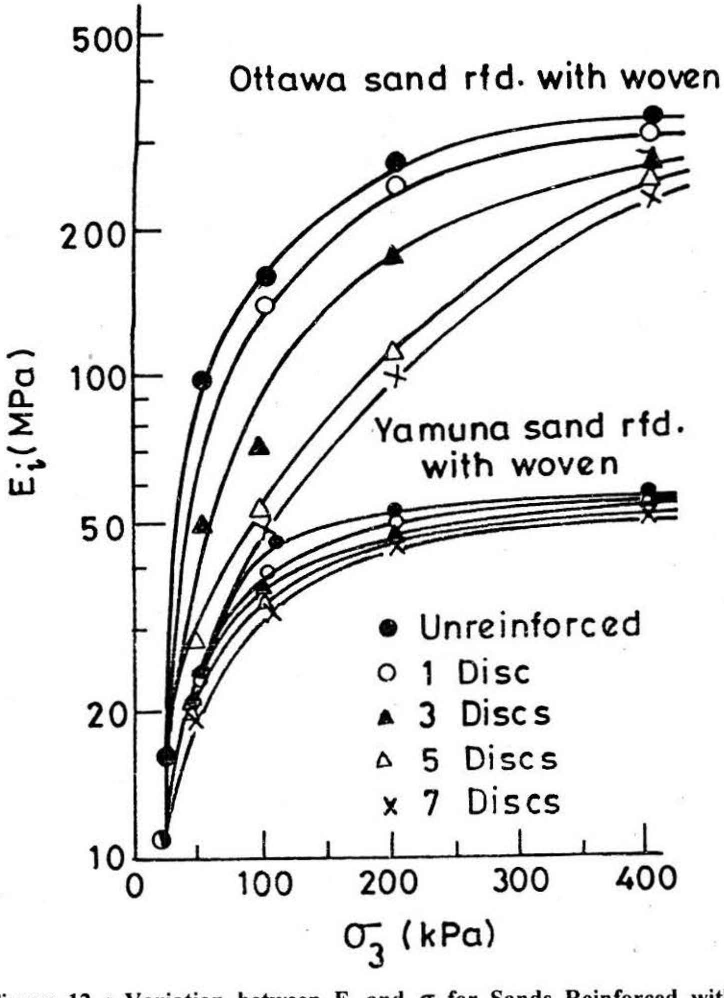


Figure 12 : Variation between E_i and σ_3 for Sands Reinforced with Woven Fabric

The value of E_i thus obtained from Fig. 11 for unreinforced Yamuna sand is 55.5 MPa. The variation of initial tangent modulus with confining pressures is presented in Figs. 12 and 13 for unreinforced and reinforced sand with varying number of discs of woven and nonwoven fabrics respectively. It is interesting to note that for both reinforced and unreinforced sand E_i increases curvilinearly with increase in σ_3 upto certain values of σ_3 beyond which E_i remains almost constant. The values of σ_3 beyond which E_i remains constant are around 150 kPa and 200 kPa for Yamuna sand with woven and nonwoven fabrics respectively, whereas these are 350 kPa and 400 kPa respectively for Ottawa sand. The comparison of initial tangent modulus show that the unreinforced sand has higher modulus than the reinforced one. The

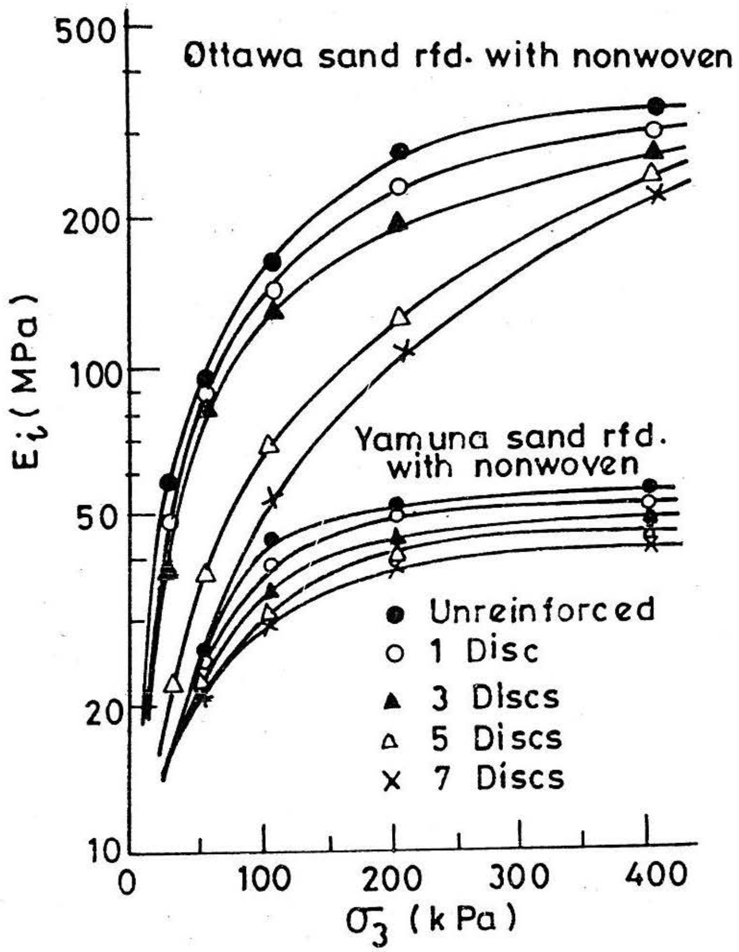


Figure 13 : Variation between E_i and σ_3 for Sands Reinforced with Non-woven Fabric

reinforcement increases the ultimate strength and tends to reduce overall stiffness of the sand as shown in figures. This tendency was more pronounced as the number of reinforcement layers increased. The reinforcements also tend to increase the amount of strain e.g. for unreinforced Yamuna sand the failure strain was between 2% and 8%, for reinforced Yamuna sand with woven fabric between 6% and 16% and with nonwoven fabric it was between 8% and >20%.

To understand the above behaviour, in-isolation tests were conducted on each of these fabrics and sands and the relationship between their secant modulus and strain were obtained as per the procedure suggested by Richards and Scott (1986). Such variations between secant modulus and strain on

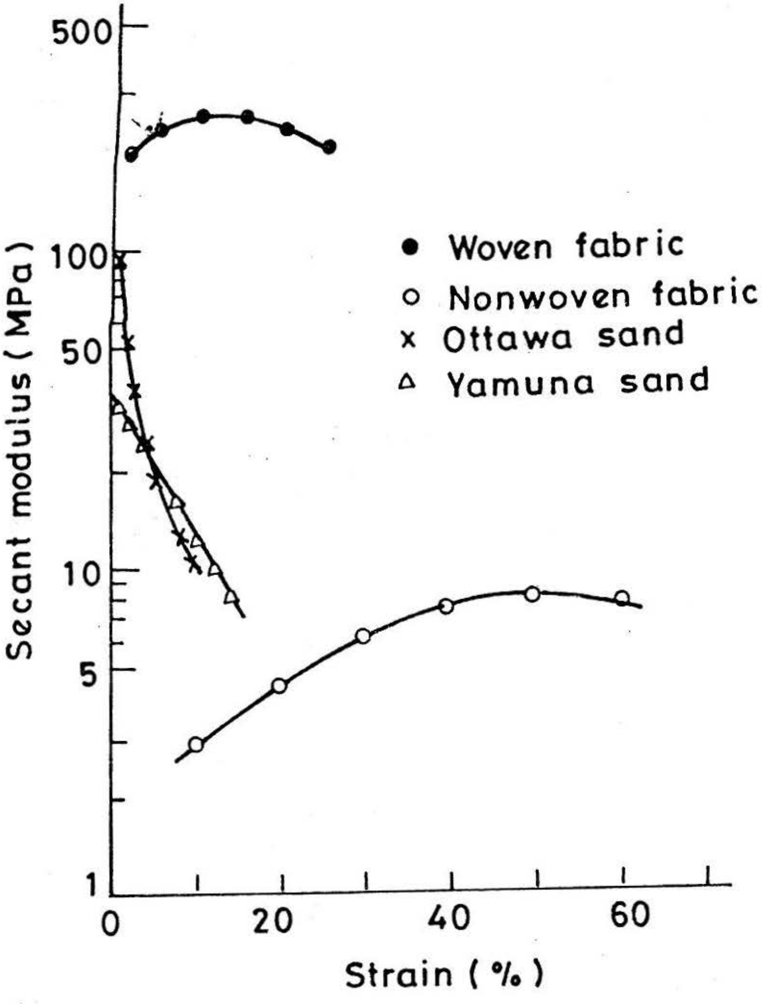


Figure 14 : Secant Moduli for Geotextiles and Sands

semi-log plot are presented in Fig. 14. The figure shows that the woven fabric exhibits higher stresses than nonwoven at low strain. On the other hand, the nonwoven fabric can pickup the stresses and still perform its function without rupture at higher strains. This indicates that, for sand reinforced with woven fabric it is only the interface friction which is mobilized whereas with nonwoven fabric it is the mobilisation of both interface friction and tensile stresses. This may be the probable reason of sand reinforced with latter exhibiting higher strength than the former.

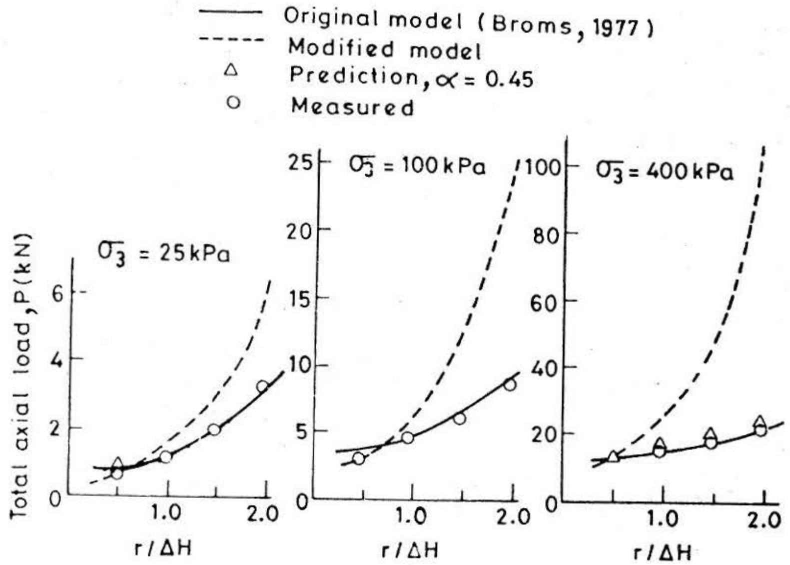


Figure 15 : Comarison between Experimental and Computed Peak Axial Load for Ottawa Sand Reinforced with Non-woven Fabric

Prediction of Ultimate Axial Load at Failure

Herein an attempt has been made to explore the applicability of semi-empirical approach suggested by Broms (1977) and Chandrasekaran et al. (1988) to predict the total axial load at failure of geotextile reinforced sand. The results obtained in the present experimental study were substituted in Eqn. 1 for original model and Eqn. 2 for modified model and the corresponding values of P_{max} were computed. The typical values for Ottawa sand reinforced with woven geotextile are presented in Table 7. Typical results for Ottawa sand reinforced with woven geotextile are presented in Fig. 15 which shows the comparison between measured and computed values of axial load at failure under different confining pressures. The curves in this figure clearly reveal that the computed values for original model (Broms, 1977) are much higher than the measured values. However, the values of ultimate axial load by the modified model (Chandrasekaran et al., 1989) and the measured values show a good match for different values of multiplication factor α as shown in the table. Similar observations for Yamuna sand reinforced with woven and nonwoven geotextiles have been already reported by authors (Shamsher et al., 1991). The corrected values of mobilised effective friction angle (ϕ'_a) has been taken equal to 0.78 ϕ' for non woven (Miyamori et al., 1986) and 0.76 ϕ' for woven (Makiuchi and Miyamori, 1988). The multiplication factors α were therefore back calculated with ϕ'_a and measured value of P_{max}. It was also found that the back calculated α values were much lower for both woven and nonwoven geotextile. The test

Table 7: Observed and Predicted Values of P_{max} for Ottawa Sand Reinforced with Woven Geotextile

No. of Layers	σ_3 (kPa)	ΔH (mm)	$r/\Delta H$	K_a	K_{av}	Axial Load Observed P_{max} (kN)	α	Modified Model P_{max} (kN)	Original Model P_{max} (kN)	Predicted at α = 0.45 P_{max} (kN)
1	25	100	0.5	0.271	0.388	0.7	1	1.0	0.8	0.83
	50					1.7	1	2.0	1.6	1.66
	100					3.5	1	4.1	3.2	3.33
	200					7.0	0.75	7.4	6.4	6.65
	400					13.1	0.50	13.5	12.9	13.30
3	25	50	1.0	0.271	0.388	1.2	1	1.5	1.4	0.95
	50					2.8	1	3.0	2.9	1.90
	100					4.6	0.80	4.9	5.8	3.80
	200					7.6	0.50	7.9	11.6	7.60
	400					14.4	0.40	14.8	23.1	15.4
5	25	33.3	1.5	0.271	0.388	2.1	1	2.2	3.0	1.10
	50					3.7	0.90	3.8	5.9	2.20
	100					6.3	0.80	6.7	11.8	4.30
	200					9.8	0.55	10.0	23.6	8.70
	400					16.6	0.40	17.0	47.2	17.40
7	25	25	2.0	0.271	0.388	3.4	1	3.4	6.2	1.30
	50					5.4	0.90	5.5	12.3	2.60
	100					8.7	0.80	9.0	24.6	5.20
	200					13.0	0.60	13.1	49.3	10.40
	400					20.5	0.45	20.8	98.5	20.80

results show that the values of α along the fabric increased with decreasing spacing of the fabric layers. However, the value of $\alpha = 0.45$ computed in the present work seems to be consistent enough to make easy prediction at higher confining pressures as well as higher values of $r/\Delta H$ as illustrated in Fig. 15. In the present study no rupture of the fabric was observed.

Conclusions

On the basis of the results of present experimental study and their analysis the following conclusions have been drawn:

(i) Both the woven as well as nonwoven geotextiles improve the strength and stress-strain behaviour of sand. In general, the strength ratios increase with increase in number of reinforcement discs whereas they decrease with increasing confining pressure.

(ii) The values of c' and ϕ' both increase with confining pressure upto a critical confining pressure of around 100 kPa. Beyond this confining pressure the values of c' increase whereas ϕ' remains nearly constant.

(iii) The induced confining stress ($\Delta\sigma_3$) due to the reinforcement increases with σ_3 upto a critical confining pressure (σ_c) beyond which there is little change. The ratios of estimated and measured values of $\Delta\sigma_3$ approach unity.

(iv) The maximum stress ratios σ_{1f}/σ_3 increase rapidly with $r/\Delta H$ at lower confining pressures. At higher confining pressures, the influence of $r/\Delta H$ on σ_{1f}/σ_3 is marginal. This indicates that the geotextile reinforcement is much more effective in structures of relatively low height.

(v) The value of multiplication factor (α) of 0.45 computed in the present study seems to be consistent enough to make easy prediction about P_{max} from the modified model equation.

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Notations

a	=	hyperbolic constant
b	=	hyperbolic constant
c'	=	effective cohesion
d	=	diameter of triaxial specimen
E_i	=	initial tangent modulus
ΔH	=	spacing between reinforcement
K_a	=	Rankine's coefficient of active earth pressure
K_{av}	=	average value of K_a and K_b
K_b	=	coefficient of earth pressure, next to the fabric.
P_{max}	=	maximum ultimate axial load at failure.
R	=	r, radius of triaxial specimen
R_f	=	failure ratio
α	=	multiplication factor
ε	=	axial strain
σ_1	=	major principal stress
σ_{1f}	=	major principal stress at failure
σ'_{ho}	=	lateral confining pressure at the perimeter of the specimen
σ_3	=	confining pressure; minor principal stress
$\Delta\sigma_3$	=	*increase in confining pressure or induced confining* stress
σ_c	=	critical confining pressure
ϕ	=	friction angle of sand
ϕ'	=	*effective angle of internal friction*
ϕ'_a	=	effective interface friction angle.