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EFFECT OF DISCRETE RANDOMLY ORIENTED INCLUSIONS AS REINFORCEMENT IN COARSE SOILS

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ABSTRACT

This paper presents a study where lab information were acquired from tri-axial tests performed on fine sand with sub-adjusted particles and medium sand with sub-rounded particles built up with glass strands and polypropylene mash and lattice components. Tests were performed on sand examples with considerations in shifting lengths and substance and tried at various keeping stresses. Results showed that short incorporations require an extraordinary restricting pressure to forestall bond disappointment notwithstanding sand type. Soil—incorporation grinding connection relies primarily upon the extensibility of the considerations. Fine sand with sub-rounded particles showed a more good reaction to fiber support than medium sand with sub-angular particles. The cross section components were better than glass filaments in further developing sand strength particularly on account of fine sand.

1 INTRODUCTION

Randomly oriented tensile inclusions incorporated into granular soil improve its load—deformation behavior by interacting with the soil particles mechanically through surface friction (bond) and also by interlocking and not creating any internal forces at molecular levels. The function of the bond or interlock is to transfer the stress from the soil to the tensile inclusions, and to mobilize their tensile strength and impart this

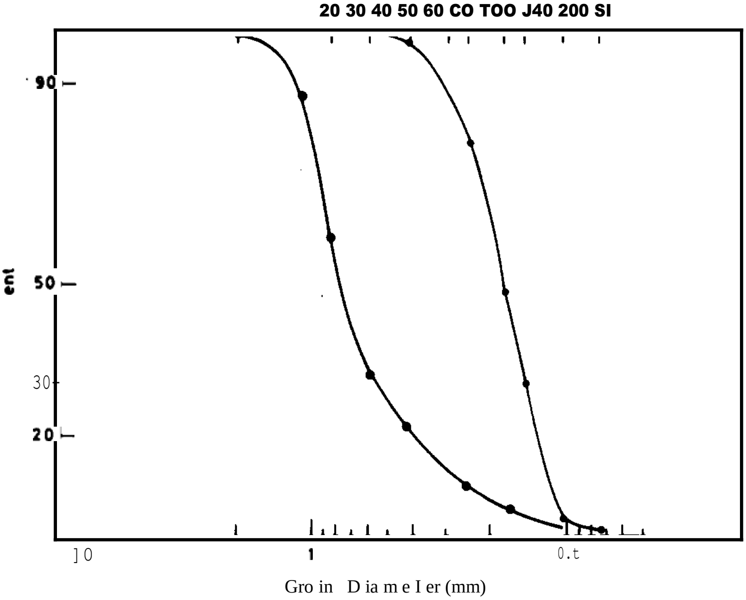

Fig. 1. Grain size distribution curves.

TABLE 1
Sand Properties

	Fine sand	*Medium sand*
D_{10} (mm)	0 12	0-26
D_{50} (mm)	0 IS	0-75
C_u	1 67	0-94
C_c	3 3(I	I -40
G_s	2 67	2-69
ez,g	0 566	0-516
e,,,,	0 755	0-767
— # 200 (to)	0-70	0-30
Friction angle, d› (°)	*(D,* — 60%) 35.00	*(D,* — 509o) 40 5

TABLE 2
Reinforcement Properties

	Polypropylene fiber	*Glass* ***fiber***
Manufacturer	Synthetic industries	Pilkington
Single fiber **tensile** strength (GN/m ^{2})	0-36	3 7
Young’s modulus (GN/m ^{2})	3 5	76
Elongation at break (%)	17 + 5	2 4
Specific gravity	0-9	2-68
Equivalent diameter (mm)	0 4 (mesh) 0 1 (P° P)	0.3

resisting force to the soil, thus reducing the strains induced in reinforced soil which lead to the improvement in load carrying capacity of the soil. Various types of inclusions have been employed, such as discrete and continuous fibers and mesh elements. Previous researches have studied the behavior of granular soil reinforced with discrete randomly oriented fibers.'*" The strength of granular soil reinforced with randomly oriented mesh elements was investigated by McGown *et al.'* The use of continuous yarns to strengthen granular soils has been reported. [7]"

Factors that influence the soil—inclusion interaction mechanism include soil density, grading, particle size, particle shape and inclusion surface properties, strength, stiffness, geometry and orientation.

The principal objective of this study was to investigate the load—deformation behavior of two different sands having different particle shapes and sizes reinforced by randomly oriented inclusions which had different strength, stiffness and geometry. A second objective was to determine if there is an optimal range of fiber lengths for the tested soils.

2 MATERIALS AND EXPERIMENTAL PROCEDURES

Sand: Two types of uniform sands were selected for this study. One was fine dune sand with subrounded particles, while the other was a medium wadi sand consisting of subangular particles. The grain size distribution curves, and other selected properties of the two sands are shown in Fig. 1 and Table 1, respectively.

Reinforcement: Three types of reinforcements-two of polypropylene and one of glass-were used in this testing program. One type of the polypropylene reinforcement was in the form of 25 and 50 mm long mesh elements in a soil colored fiber cut from fibrillated polypropylene fiber. The second type was a pulp fiber which was 2—12 mm white random cut fiber. The type of glass fiber used was chopped strand roving cut in lengths of 10, 25, 50, 75 and 100 mm. The physical properties of the polypropylene and glass fibers are shown in Table 2.

2.1 Sample preparation and testing

In this study, triaxial tests were conducted using Wykeham Farrance triaxial compression apparatus on samples 100 mm in diameter and 220 mm high. To avoid segregation while forming the triaxial test specimen and to distribute the fibers as evenly and randomly as possible throughout the soil it was necessary to moisten the sand slightly. The specific amount of fibers-as a weight percentage of dry sand—was mixed thoroughly with air dry sand, and water was added to raise the water content to 6%. The sand—fiber—water was then mixed by hand until the fibers were evenly distributed and randomly oriented throughout the sand. The reinforced sands with different fiber concentration were compacted in a triaxial test mold by tamping successive layers. With each sand, reinforced and unreinforced samples were compacted to the same density of soil excluding the volume of reinforcement. Relative densities of 60% for fine and 50% for medium sands were selected because they were easily and efficiently achieved for all inclusions used. The vertical load was applied slowly, at a strain rate of about 0-37 mm/min. All strength and stiffness data points were the average of at least two specimens with some data points being the average of as many as four specimens. All results reported in this paper, and used for strength and stiffness comparison, were obtained from specimens tested at a confining stress of 200 KPa.

3 TEST RESULTS

3.1 Soil-inclusion interaction

Figure 2 shows the relationship between the confining stress and the principal stress at failure for fine and medium sands reinforced with 0-5% by weight of different inclusions. For sands reinforced with pulp fiber with a very low aspect ratio, the failure occurred by rupture of sand—inclusion bond (slippage), whereas for sands with longer glass fiber and mesh two different failure modes were observed. At low confining stress the system failure was due to slippage or bond failure, where the sand—inclusion interface friction was fully mobilized. At a high confining stress, failure

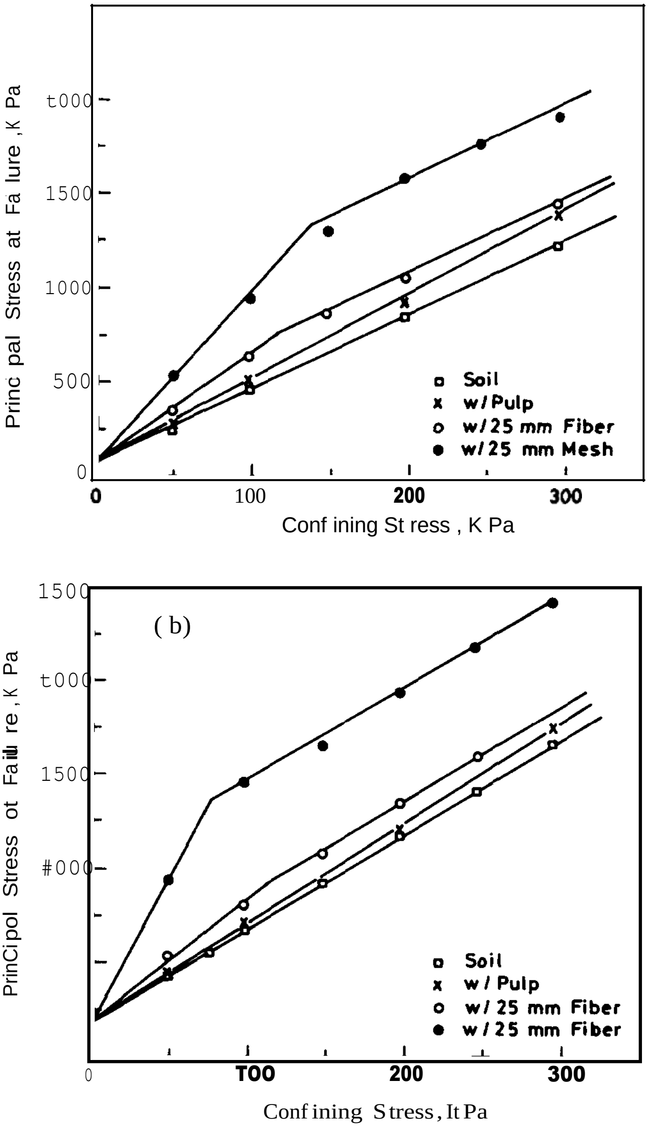

Fig. 2. Principal stress at failure versus confining stress for (a) fine sand and (b) medium sand.

TABLE 3
Triaxial test results

m3 (k Pa)	*49*	*98*	*147*	/9d	*245*	*294*	*d›* (°)	*d›* (°)	*‹f* $\bar{\phi}$
m I f (k Pa)									
Fine sand	252	461	—	543	—	1226	36 5		
Fine sand with pulp	257	512	—	913	—	1390	—	35-7	I -06
Fine sand with 25 mm fiber	341	634	563	1059	—	1448	—	45	1 23
Fine sand with 25 mm mesh	523	946	1304	1554	1764	—	—	53	1 -45
Medium sand	425	688	927	1183	1412	1663	41-6		
Medium sand with pulp	444	709	—	1206	—	1750	—	43 5	1-07
Medium sand with 25 mm fiber	523	804	1082	1355	1604	—	—	4f› 2	1- 11
Medium sand with 25 mm mesh	932	1462	1659	1939	2185	2425	—	58-6	1-41

occurred by inclusion yielding. The critical confining stress (corresponding to break in failure envelopes) was almost equal for both sands with stiff glass fibers. However, for the mesh element, the critical conhning stress was lower for the medium sand compared to that of fine sand.

From the triaxial test results obtained on specimens reinforced with 0 59c of different inclusions, the friction angles were determined using Mohr envelopes. The ratios of reinforced friction angle (d›,) (Ref. 9) to the soil internal friction angle (d›) were calculated and summarized in Table 3. Although when two sands have the same particle sizes, contact efficiency is larger if angularity is higher, the results appeared to indicate that the friction angle ratio was not greatly affected by the sand type. This was probably due to the fact that contact efficiency was larger in the case of fine sand *(D,t,* – 0-18 mm) than that of the medium sand *(D,,* — 0 78 mm). It is also observed that mesh is superior to glass fiber, and that increasing the fiber length (pulp to 25 mm glass fiber) results in increasing the reinforced friction angle (Q,).

Based on the proceeding observations, the shear strength of reinforced sand with bond failure was characterized by an apparent friction angle (Mr) which was larger than that of the soil alone, and both $, and the critical confining stress were mainly influenced by the soil—inclusion interface friction and the inclusion specific area (or aspect ratio).

As shown in Fig. 2, the ultimate strength of reinforced soil failed by inclusion yielding was governed primarily by the number of fibers and the geometry of inclusions. With the more extensible inclusions (mesh elements), the improvement in strength of reinforced sands was significantly larger than that for the same sands reinforced with stiff glass fiber because the large expected number of mesh per unit volume of composite and the interaction of their netting with the soil grains.

Stresmtrain behavior

Typical stress—strain curves of sands reinforced by 0-5% of glass fiber and mesh inclusions in varied length are shown in Fig. 3 at an applied confining stress of 200 KPa. In the case of fine sand the mesh inclusions increased the ultimate strength, stiffness and ductility (failure strain 10%). All glass fibers increased the stiffness. The strength of sand reinforced with 50 mm glass fibers gradually dropped after the shearing deformation advanced to a certain extent and approached that of sand reinforced with 25 mm glass fiber. This is thought to be caused by the inclusion extensibility as postulated by McGown *et al."'* Similar observations apply to stress—strain results of medium reinforced sand. However the stiffness of sand reinforced with some inclusions decreased. This result was most probably due to densification effect on sand with subangular particles since the calculated density of sand did not adjust for volume occupied by inclusions. This behavior was anticipated from the work of Holubec and D’Appolonia [I] ', where they found that deformations of sand with angular particles can be decreased considerably by densification. However, little effect is obtained by densification of sand with rounded particles.

Effect of fiber length

Specimens with glass fiber of various length but the same diameter were used to study the effect of fiber length on the improvement in strength of the two sands at a confining stress of 200 kPa. The ratios of the principal stress at failure for reinforced sands to the principal stress at failure of the sand are illustrated in Fig. 4. It was found that the longer the fiber, the greater the effect of the fiber. This trend appeared to be stronger with specimens having a larger fiber content. This was anticipated because when friction is mobilized fully along the length of the reinforcement, the tensile force in the reinforcement is proportionate to its length. If the fiber is long enough the load is transferred by an average interfacial shear stress, and the longitudinal tensile stress in the fiber varies from zero at the ends of the fiber to the failure stress. For a short fiber there is not enough accumulated strain to mobilize the fiber failure tensile stress. However, as

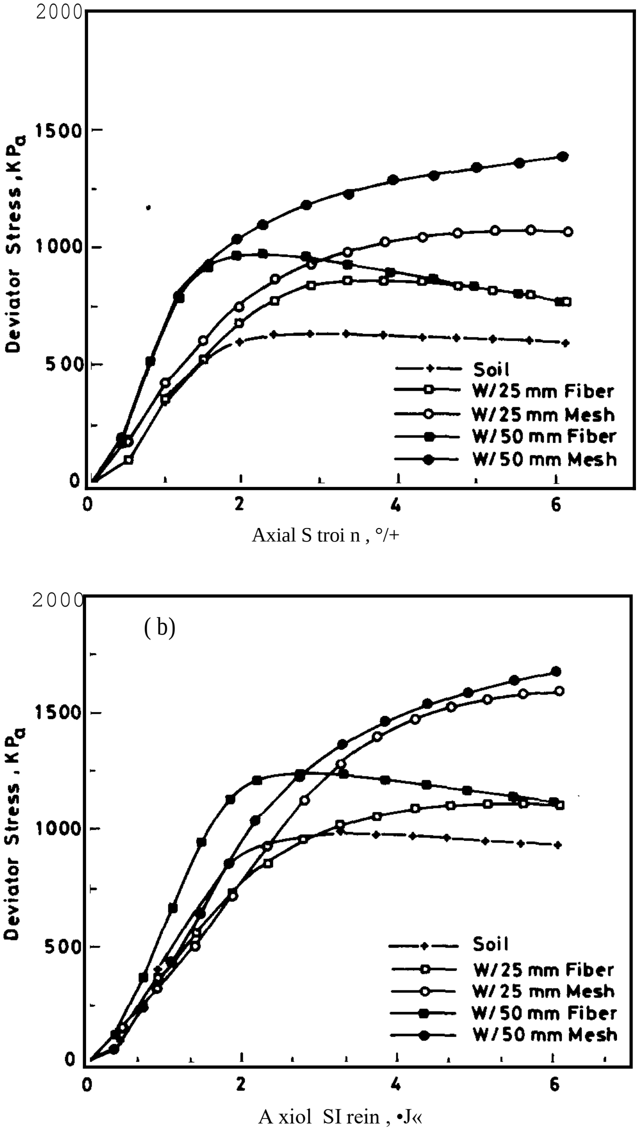

Fig. 3. Stress—strain relationships of reinforced sand for (a) fine sand and (b) medium sand. (o-, = 200 k Pa).

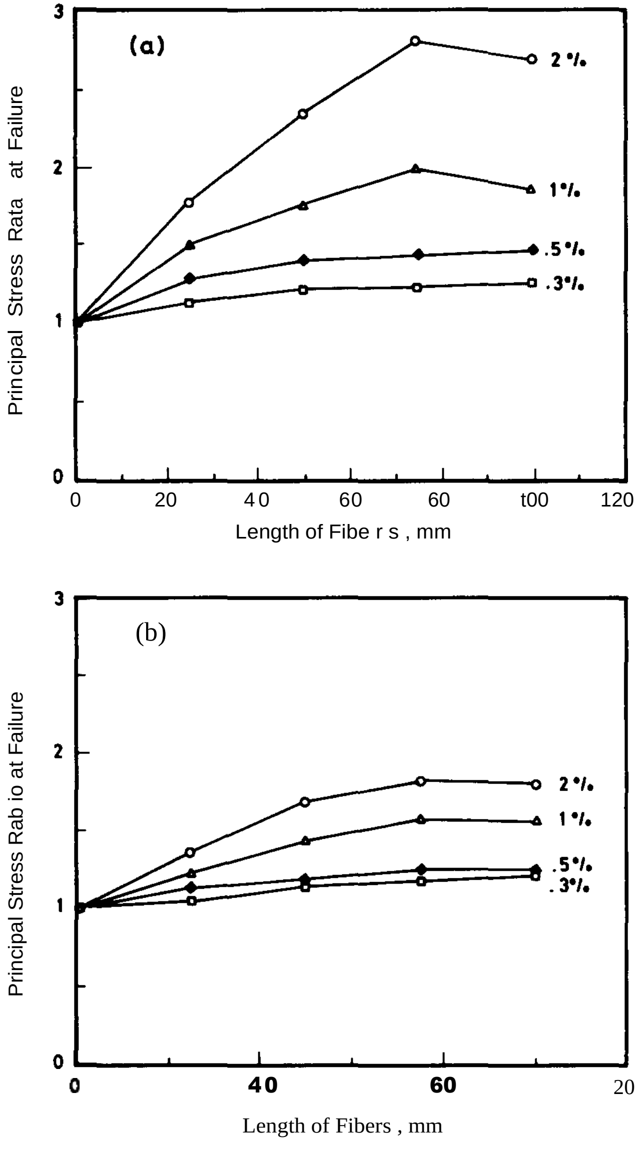

Fig. 4. Principal stress ratio at failure versus length of fibers for (a) fine sand and (b) medium sand.

the embedded length of hber in a dilatant soil increases, the difference in strength should become progressively less as shown in Fig. 4. The test results show that fine sands exhibit the largest increase in principal stress ratio with increasing fiber length. It was interesting to note that the principal stress ratios reached higher values and showed a slightly decreasing trend at the same fiber length for the fine and medium sand. This is believed to be due to the greater difficulty in achieving completely uniform fiber distributions as the fiber content and length are increased.

Figure 5 presents the relationship between the ratio of secant modulus of glass fiber reinforced sand to secant modulus of unreinforced sand at 2% strain and length of fibers. For fine sand specimens, it was found that the fiber reinforced specimens had higher secant moduli in comparison with no fiber specimens but they either remained the same or decreased slightly as the fiber length was increased up to an optimum length. The addition of 1% of 50 mm long fiber has resulted in over a two-fold increase in the secant modulus of sand alone as shown in Fig. 5(a). For medium sand, there was a slight decrease in the modulus with the addition of short fibers, but the decrease is not affected by the weight percent of fiber. Increased fiber length resulted in increased modulus and the rate of modulus increase tends to increase as the weight percent is increased. However, no appreciable advantage is gained by using fiber longer than 50 mm in order to increase the stiffness of the sand as presented in Fig. 5(b).

3.4 Effect of inclusion shape

The effect of inclusion shape on the strength of reinforced sands is shown in Fig. 6 where the relation between principal stress ratio at failure and length of glass fibers and mesh elements is presented. In the fine sand specimens, the principal stress ratio of mesh reinforced specimens increased linearly with the increase of mesh element length. The effect of inclusion shape on the strength of reinforced sand was obvious. For medium sand similar trends can be observed as shown in Fig. 6(b) which shows that increase in strength is essentially proportional to fiber length for a given fiber concentration. The strength of specimens reinforced with 1% mesh elements remained the same with the increase of mesh length beyond 50 mm.

The addition of mesh elements had a much less dramatic effect on stiffness than on the strength of reinforced sand as shown in Fig. 7 where glass fiber reinforcement generally gave higher stiffness than mesh elements with the exception of fine sand specimens reinforced with 25 mm mesh elements. However, the differences in stiffness were small.

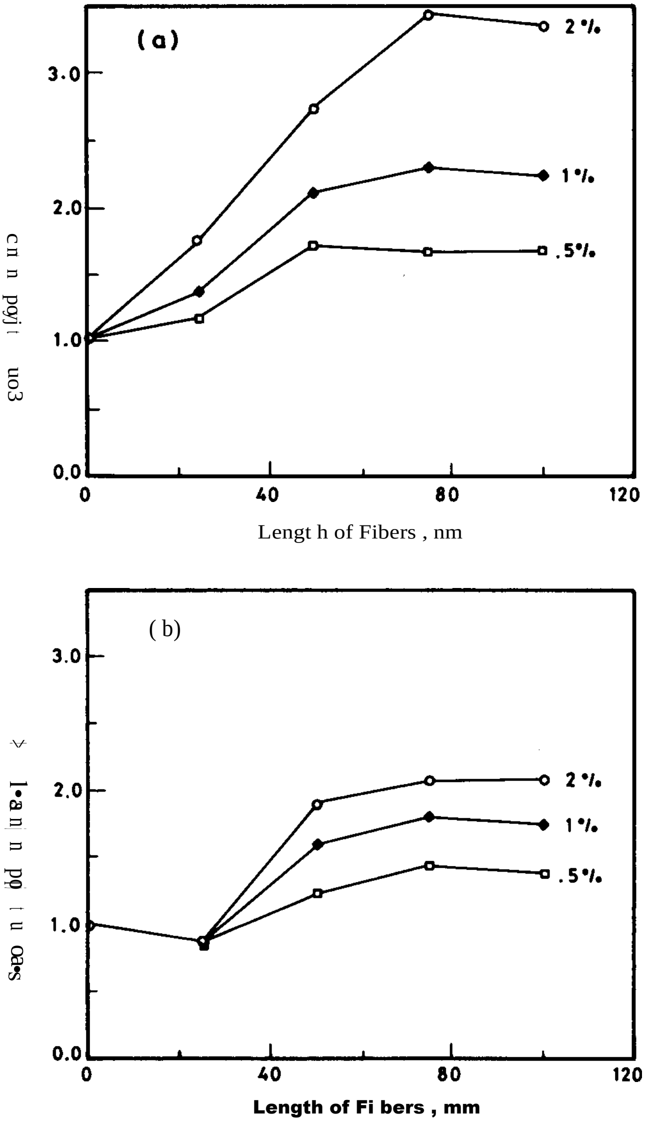

Fig. S. Secant modulus ratio at 2% strain versus length of fiber for (a) fine sand and (b) medium sand.

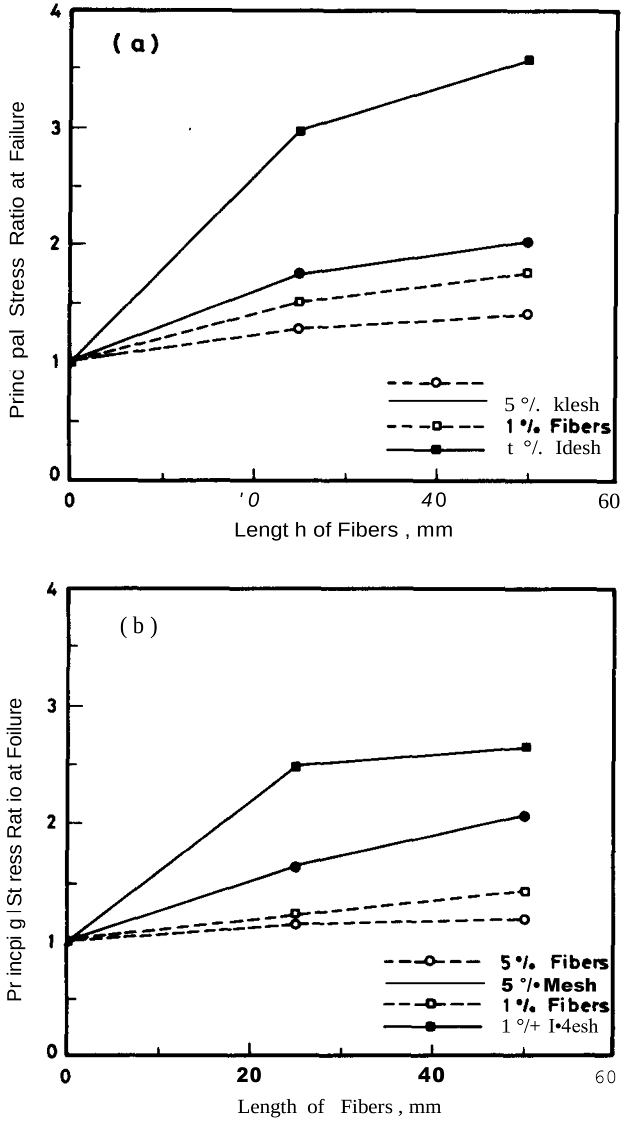

Fig. 6. Principal stress ratio at failure versus length of fibers and mesh for (a) fine sand and (b) medium sand.

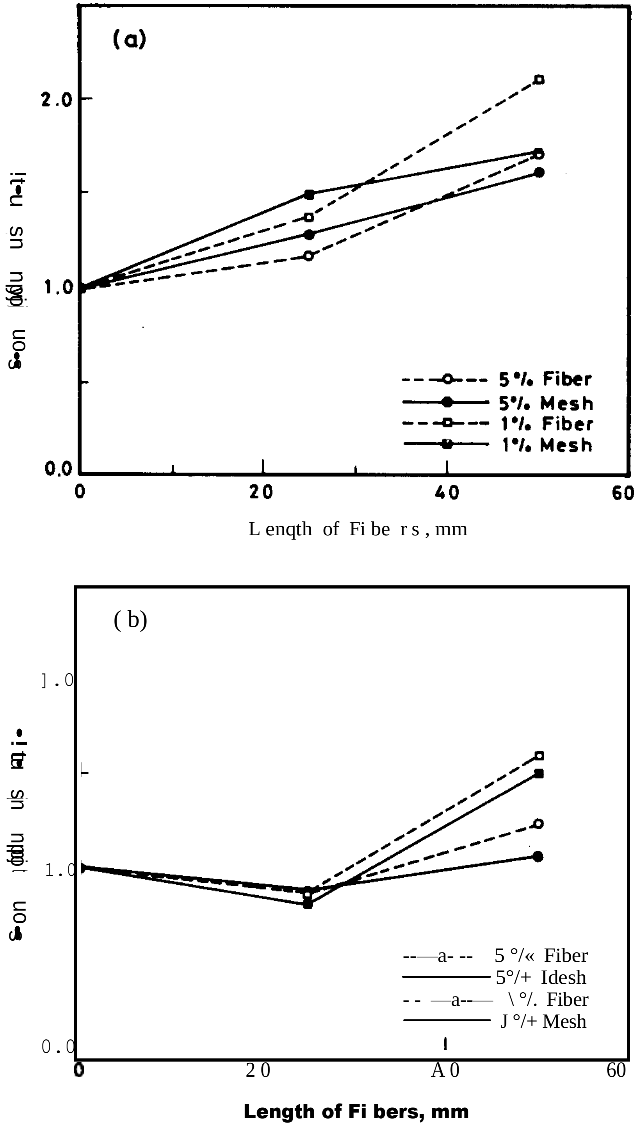

Fig. 7. Secant modulus ratio at 2% strain versus length of fiber and mesh for (a) fine sand and (b) medium sand.

CONCLUSIONS

A series of triaxial tests was undertaken to investigate the load—deformation behavior of fine and medium sands reinforced with glass fiber or mesh elements and to compare this behavior with that of unreinforced sand. The major inclusions from this study are summarized as follows:

1. All reinforced sands showed significant load capacity improvement.
2. Shorter fibers required a great confining stress to prevent bond failure regardless of size or shape of sand particles.
3. Soil—inclusion friction interaction depends mainly on the extensibility of the inclusion rather than the mechanical properties of the sand.
4. Extensible inclusions showed the greatest improvement in strength and ductility with both sands investigated.
5. Fine sand with subrounded particles showed a more favorable response to fiber reinforcement than medium sand with subangular particles.
6. The percentage increases in principal stress and secant modulus from the inclusion of glass fibers are directly proportional to fiber length, for a constant fiber concentration. There is an optimum length (75 mm) of fiber for maximizing the strength and stiffness of fiber reinforced fine and medium sands.
7. The addition of mesh elements to fine and medium sands increased the principal stress at failure significantly. The superiority of the mesh is more pronounced in the case of fine sand and as the weight percent of mesh is increased.
8. Short inclusions decreased the stiffness of medium sand.
9. The improvement in stiffness of mesh reinforced sands is less than that of glass fiber reinforced sands with the exception of fine sand reinforced with short mesh.

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