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A study on shear strength of sand reinforced with glass fibres

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Abstract— Scarcity of suitable land and unavailability of good quality construction soil lead to the implementation of various ground reinforcement techniques. Among the various reinforcement techniques, fibre reinforcement is achieving more attention in geotechnical engineering. This is beneficial due to the absence of predefined planes of weakness and strength isotropy over conventional reinforcement. In the present study, a series of direct shear tests have been carried out to investigate the shear strength behaviour of a fine sand reinforced with glass fibres. The influence of various parameters such as fibre contentand relative density on the strength behaviour of the sand-fibre mixes has been studied. The test results indicate that the initial stiffness, peak shear strength and dilatancycharactersticsof the sandare affected by the fibre reinforcement.

Index Terms— Direct shear test, Glass fibres, Reinforced sand, Shear strength, Apparent cohesion, Dilation.

1 Introduction

THE primary purpose of reinforcing soil is to increase its shear strength thereby increasing its bearing capacityand reducing its settlement and lateral deformation. Soils can be reinforced either by incorporating continuous reinforcementinclusions within the soil mass in a defined pattern or by mixing discrete fibres randomly with the soil. The influence of various types of fibres on the shear strength of soils has beeninvestigated by several researchers through triaxial tests and direct shear tests.

From triaxial tests, Gray and Al-Refeai [1]observed an approximate linear increase in shear strength of an uniform, medium-grained sandwith increasing amounts of fibres (up to 2% by weight), beyond which the increase in strength approached an asymptotic upper limit, governed mainly by confining stress and fibre aspect ratio. Various other studies from triaxial tests indicate that stress–strain–strength properties of randomly distributed fibre-reinforced soils are a function of fibrecontent and aspect ratio, and also of the relative size of the soil grains and fibre length [2], [3], [4].

From direct shear tests, Gray and Ohashi [5] observed that the inclusion of discrete fibres as reinforcement in cohesionless soils reduces the loss of post-peak stress. In other words, the inclusion of fibres makes the strain-softening less pronounced, and any failure less dramatic. Thus, the ultimate strength of the fibre-reinforced soil is greater than that of unreinforced soil.Ola [6] reported from direct shear tests that fibre reinforcement increases the peak strength of laterite sand and modifies the stressdeformation behaviour in a significant manner by limiting the amount of post-peak reduction in shear resistance. Similarly, thedirect shear test results of [7] suggested that the fibre inclusions to a sandy soil in the dry state introduces an apparent cohesion intercept, which remains almost unchanged by an increase in water content.The peak friction angle was found to be a function of the relative density of sand for both reinforced and unreinforced cases.

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Thedirect shear test results of [8] indicated that adding linen fibre in silty-sandsoil results in an increase in unconfined compressive strength, California bearing ratio values, peak friction angle and cohesion values. Furthermore, adding linen fibres have the dual benefit of increasing the stiffness (modulus of elasticity) and the ductility ofthe reinforced soil.

Only limited information has been reportedin the literature on soils reinforced with randomly distributed glass fibres. This paper presents the results of a direct shear testing program to investigate the shear strength behaviour of a fine sand reinforced with glass fibres.

2 Experimental Program

2.1 Materials

The sand was collected from the nearby bank of Brahmaputra River. The physical properties of the Brahmaputra sand are tabulated in Table 1, and the grain size distribution is shown in Figure 1. According to Indian Soil Classification System, the sand is classified as poorly graded sand (SP). Synthetic glass fibres of 20 mm length(Fig. 2.)were obtained from a local supplier.

TABLE 1

PHYSICAL PROPERTIES OF BRAHMAPUTRA SAND (BS)

Property / Size range	Value
Specific gravity, G_s	2.67
Gravel (> 4.750 mm) (%)	0
Sand (0.75 – 4.750 mm) (%)	98.5
Coarse sand (2 – 4.75 mm) (%)	1.18
Medium sand sand (0.425-2 mm) (%)	16.1
Fine sand (0.075 –0.425 mm) (%)	81.2
Uniformity coefficient, C_u	1.68
Coefficient of curvature, C_c	0.024
Soil classification	SP

2.2 Methods

For preparing test specimens, first the required amounts of sand and fibres were mixed together in a dry state. To prevent the segregation

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of fibres during mixing, a minimum amount of water (6% by dry weight of sand) was then added. All mixing was done by hand and proper care was taken to prepare a homogeneous mix. The compacted specimens were of 35 mm in height and 60 mm in plan area. Three fibre contents (0.5%, 0.75%, and 1%) by dry weight of sand were used along with three different relative densities (50%, 65% and 82%) of the sand.

The designations used for the specimens are: BS for Brahmaputra sand, F for glass fibres, and BS+F for sand-fibre mixes, respectively. In the mix designation, the fibre content by weight is indicated by the numeral prefixed before the symbol F. For example, 1%F indicates that 1% by weight is fibre content and the remaining is soil.

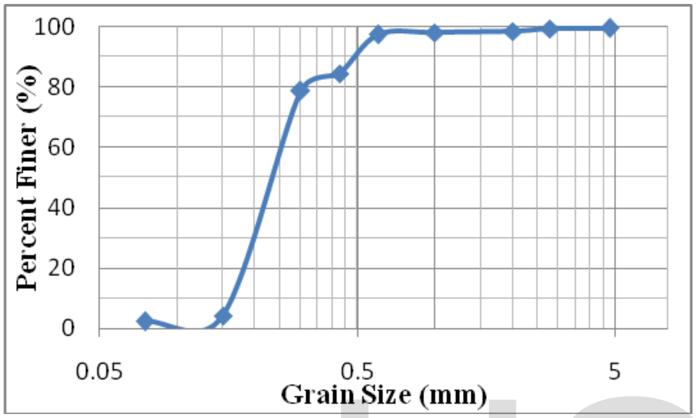

Fig.1. Grain size distribution ofBrahamputra sand

Fig.2. Glass Fibres

The direct shear tests were carried out in accordance with Indian standard procedure[9].The type of test was unconsolidated and undrained (UU). A shear box of 60 mm × 60 mm in plan and 40 mm in depth was used in the tests. The tests were performed at vertical normal stresses of 50, 100 and 150kPa in order to completely define the shear strength parameters. The tests were carried out at a constant displacement rate of 1.20mm/min. Both the shearing load and the vertical displacement were recorded as functions of the horizontal displacement. The testswere continued up to 20% strain. Each test was repeated at least twice to ensure reproducibility.

3 Results And Discussion

Test results include shear stress vs. horizontal displacement and vertical displacement vs. horizontal displacement plots for sand-fibre specimens tested at normal stress levels of 50, 100, and 150 kPa. These plots have been analyzed to investigate the effect of fibres on stress-strain behaviour, volume change behaviour, and shear strength parameters.

3.1 Stress-Strain Behaviour

The shear stress–horizontal displacement curves obtained from the tests for the reinforced sand with 50%, 65% and 82%relative densities and at a normal stress of 100kPa are shown in Figs. 3-5 together with those for unreinforced sand.The general form of the stress-displacement curves of fibre reinforced specimens is similar to that of unreinforced specimens except for an increase in the slope of the stress-displacement curve at small displacements.

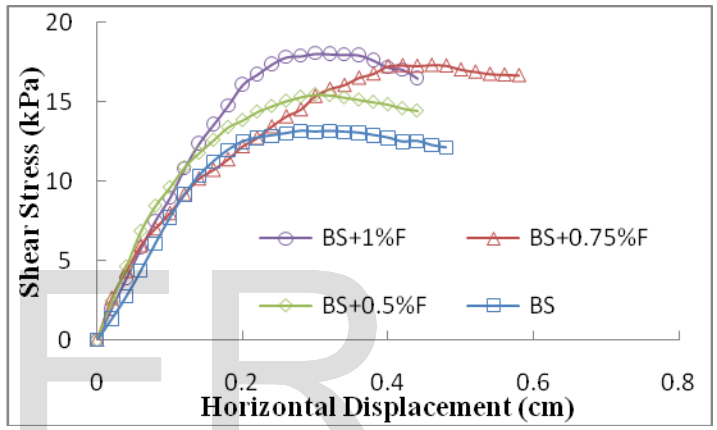

Fig.3. Variation of shear stress with horizontal strain for various BS+F mixes at 50% relative density (100 kPa normal stress)

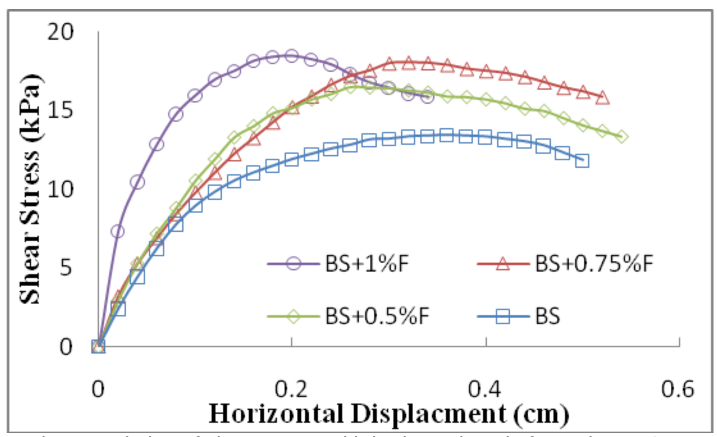

Fig. 4. Variation of shear stress with horizontal strain for various BS+F mixes at 65% relative density (100 kPa normal stress)

The results indicate that for the same normal stress, the shear stress at failure increases with fibre content. The improved behaviour of reinforced sand is on account of sand-fibre interfacial friction and apparent cohesion induced due to moistening of the sand-fibre mix. As the fibre content increases, the contribution of the interfacial friction becomes larger.

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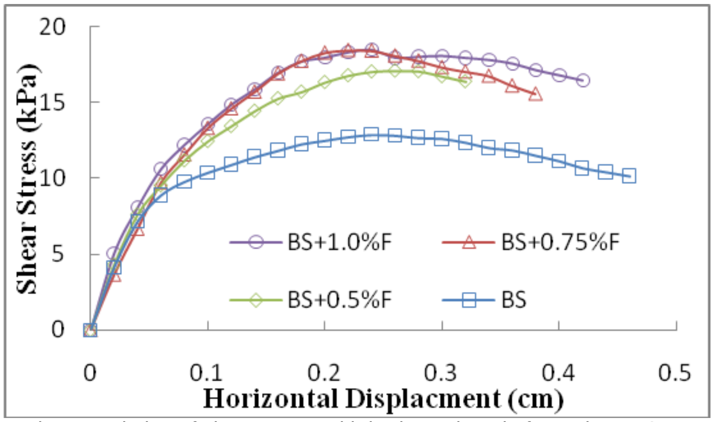

Fig. 5. Variation of shear stress with horizontal strain for various BS+F mixes at 82% relative density (100 kPanormal stress)

The tests results also show that with increase in relative density, both the shear strength and stiffness of the reinforced sand have increased which is attributed to more dense packing and higher sand-fibre interfacial friction.

3.2 VolumeChange Behaviour

Figure 6-8 show the horizontal displacement vs. vertical displacement response of the reinforced sand with different relative densitiesat a normal stress of 150 kPa.

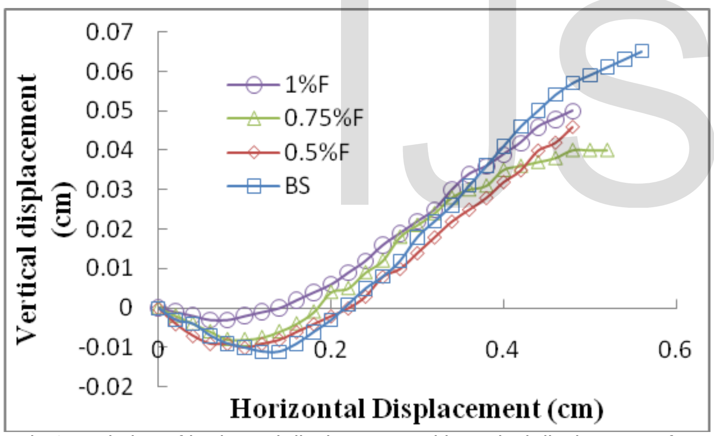

Fig.6. Variation of horizontal displacement with vertical displacement for BS+F mixes at 50% relative density(150 kPanormal stress)

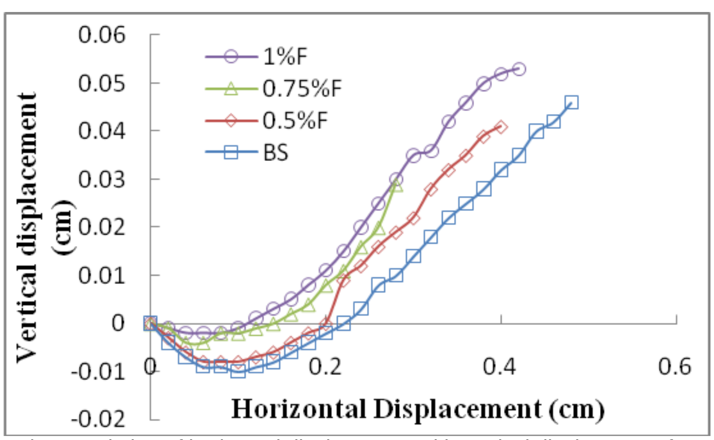

Fig.7. Variation of horizontal displacement with vertical displacement for BS+F mixes at 65% relative density (150kPanormal stress)

The tests indicate that the presence of fibres consistently inhibits the tendency for dilation in fibre-reinforced sand at all normal stresses. The decrease in the dilatancy is more for specimens reinforced with a higher percentage of fibres. This result is similar to the results of direct shear tests [5].With increase in relative density, the trend of horizontal displacement to vertical displacement remains the same but dilatancy is observed to be increasing in the case of both unreinforced sand and reinforced sand.This observed characterstic of increase in dilatancy is due to the ductile nature of the sand-fibremix.

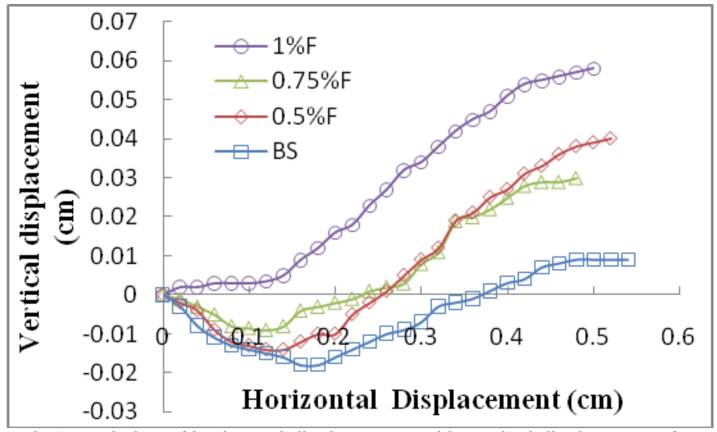

Fig.8. Variation of horizontal displacement with vertical displacement for BS+F mixes at 82% relative density (150 kPanormal stress)

3.3 ShearStrength Parameters

Figures 9-11show the shear stress to normal stress plots of the reinforced sand with different relative densities. The results have shown the variation of shear strength parameters with fibre content and relative density.The values of cohesion and angle of internal friction are tabulated in Table 2. It is observed that for any mix, both the strength parameters increase with relative density. At any relative density, these parameters also increase with fibre content. This is attributedto greater contributions from sand-fibre interfacial friction, mobilisation of tensile resistance, and apparent cohesion induceddue to moistening of sand fibre mix.

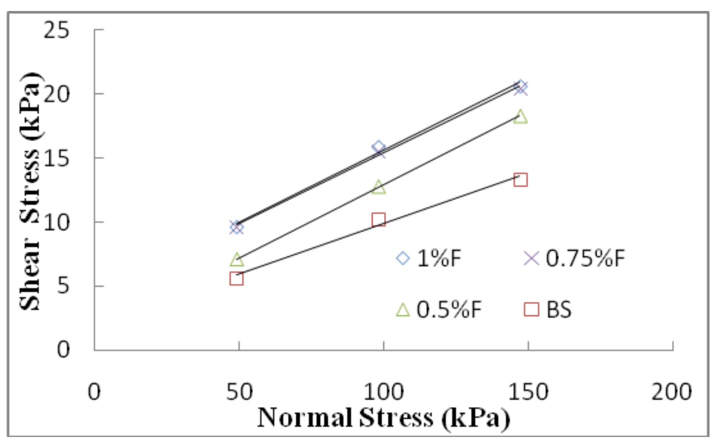

Fig.9. Shear stress vs. normal stress plots for various BS+F mixes at 50% relative density

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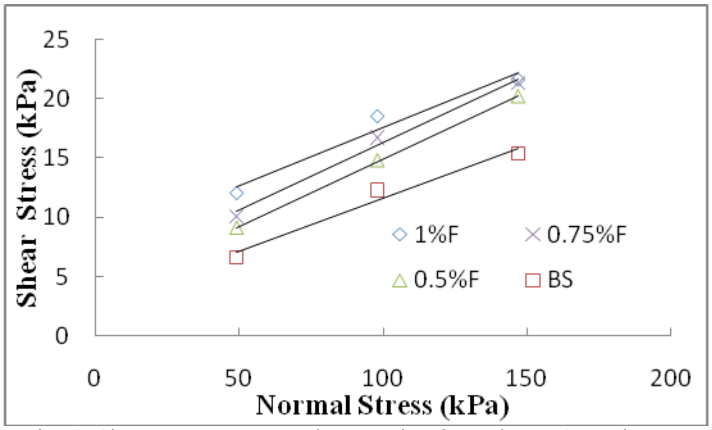

Fig.10. Shear stress vs. normal stress plots for various BS+F mixes at 65% relative density

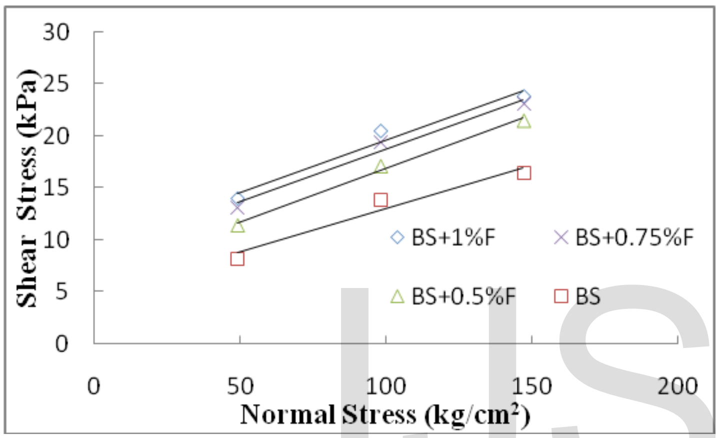

Fig.11. Shear stress vs. normal stress plots for various BS+F mixes at 82% relative density

TABLE 2

SHEAR STRENGTH PARAMETERS FOR DIFFERENT MIXES IN DIRECT SHEAR TEST(UU)

RD	Mixes	C (kPa)	φ (degree)
50%	BS	1.66	23.6
	BS+0.5%F	1.86	26.6
	BS+0.75%F	2.05	27.5
	BS+1%F	2.35	28.2
65%	BS	2.54	26.1
	BS+0.5%F	2.64	28.8
	BS+0.75%F	2.65	29.6
	BS+1%F	2.65	30.1
82%	BS	2.72	28.9
	BS+0.5%F	2.71	31.4
	BS+0.75%F	2.72	32
	BS+1%F	2.75	33.1

4 CONCLUSIONS

The shear stress to horizontal strain response of the fine sand modified bythe addition of glass fibres has been studied. The increase in fibre contentreduces the tendency for dilation in reinforced sand at any relative density. The addition of fibres to the sand specimens results in substantial increases in the measured values of the cohesion and friction angle. The findings of this study have practical significance as a ground improvement technique, with respect to the use in subgrade, embankment and other applications.

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