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Shear Strength Performance of Sandy Soil Reinforced with Jute Fiber

Kuldeep Singh Kulhar[1] and M. Raisinghani[2]

[1,2]Department of Civil Engineering, Vivekananda Global University, Jaipur
E-mail: [1]kskulhar23@gmail.com, [2]vicechairperson@vgu.ac.in

Synopsis—*For improving soil properties use of Jute fibre is advantageous because they are cheap, locally available, biodegradable and eco-friendly. Therefore, in the present investigation, Jute fibre has been chosen as the reinforcement material and it was randomly included in to the soil at four different percentages of fibre content, i.e. 0.5, 1.0, 1.5 and 2% by weight of raw soil. Three different lengths of fibre, i.e. 5, 10, and 15 mm are also considered as one of the parameters of this study. The main objective of this investigation had been focused on the strength behaviour of the soil reinforced with randomly included Jute fibre. The reinforced soil samples were subjected to compaction and Direct Shear tests. The results indicate that the ductility and shear strength parameters of the soil-fibre mixture (i.e.* C *and φ) can be improved significantly. A regression analysis of test results has been carried out to develop a mathematical model to bring out the effect of these factors on the shear strength of reinforced soil. It is concluded that the optimum fibre content for both sands is 1.5% of the dry unit weight and optimum fibre length is 5mm. The Jute fibres added as inclusion are expected to provide better compact interlocking system in sand.*

Keywords*: Reinforcement, Jute Fiber, Direct Shear Test, Soil, Cohesion, Peak Friction Angle*

1. INTRODUCTION AND SCOPE

Randomly distributed fibers, if mixed uniformly within the soil mass, can provide isotropic increase in the strength of the soil composite without introducing continuous planes of weakness. Fiber reinforcement is an effective method for improving engineering properties of soil. In the recent past, this technique has been used for various geotechnical applications including retaining wall earth structures, earthen embankments, subgrade stabilisation below pavements and footings (Gray et al. 1983)[1]. The suitable method to measure shear strength of sandy soils used as backfill, in embankments etc. is direct shear test. Coulomb in 1776[2], first used direct shear testing, later on it has been a common practice to use this method to estimate shear parameters.

Ranjan et al., 1996[3], Al-Refeai and Al-Suhaibani, 1998[4], Consoli et al., 2003[5] and Diambra et al., 2010[6] observed that the fibers inclusion increases the soil shear strength. Extensive research on randomly oriented discrete fibers reinforced sandy soil has been well investigated and reported by Nataraj and McManis (1997)[7], Maher and Gray (1990)[8]. (Zornberg, 2002)[9], predicts the 'equivalent' shear strength of the fiber-reinforced soil based on the independent properties of fibers (e.g. fiber content, fiber aspect ratio) and soil (e.g. friction angle and cohesion). Among the notable properties that improved due to fiber inclusion are greater extensibility, small loss of post peak strength, isotropy in strength and absence of planes of weakness.

2. AN OVERVIEW

The first modern form of soil reinforcement was developed by Henry Vidal in 1966. Reinforced soils are classified into two main groups: (i) systematically reinforced soil, and (ii) randomly distributed fiber reinforced soil. The behaviour of all reinforced soils is mainly dependent on the type of reinforcement inclusions. The use of random discrete fibers mimics the behavior of plant roots and contributes to the stability of soil mass.

3. MATERIAL USED FOR INVESTIGATION

The fine sand (Soil 1) and silty sand (Soil 2) were collected locally from village Dantali and Goner, Jaipur. Rajasthan, India respectively. Natural Jute fibers were also collected from local market. The particle size distribution curve for each soil type is shown in Figure 1. The soil properties are:

SOIL 1: I.S. Classification=SP, G=2.65, OMC=12.31%, MDD=1.72 g/cc, φ=34°, Soaked CBR=37.4%, W_L=23.4%, W_P=NP,

SOIL 2: I.S. Classification=SM, G=2.67, OMC=13.20%, MDD=1.74 g/cc, φ=28°, Soaked CBR=28.6%, W_L=24.8%, W_P=NP,

FIBER: γ=1.47 g/cc (in general), D=0.02-0.03 mm, L=5, 10, 15 mm

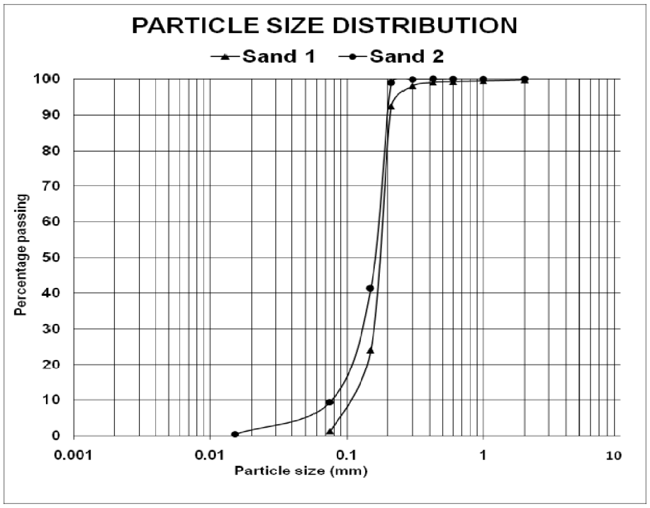


Fig. 1: Particle Size Distribution for the sands

4. TEST PROGRAMME ON SOIL AND SOIL FIBER MIXES

The laboratory investigations carried out include heavy compaction and direct shear tests on both reinforced and unreinforced soil types. The fibre content ranged from 0.5 to 2.0% of the dry unit weight of the soil. With fibre content more than 2%, the balling effect occurred during soil compaction. The fibres were first separated by hand then mixed in the soil. Oven-dried soil was used and required water was added in small increments and mixed by hand until uniform mixing of the fibres was ensured. All tests were performed in accordance with the procedures prescribed in Indian Standards (IS:2720). Three specimens were prepared and used for each type of test. The average result of three specimens were reported and used for the analysis.

5. METHOD OF SAND-FIBER MIXTURE AND SPECIMEN PREPARATION

Jute fibers used in small length of 5 mm, 10 mm and 15 mm are shown in fig. 2. Fiber content considered was 0.5, 1.0, 1.5 and 2.0 % by weight of the dry sand for both sands. The short discrete fibers are added and mixed randomly with soil part manually and care was taken for uniform mixing. Fibers could be mixed more easily in the moist sand than in the dry sand.

Fig. 2: Jute Fibers in pieces of small length

6. ANALYSIS OF TEST RESULTS

Compaction Tests:

IS Heavy Compaction Tests were carried out in accordance with the procedure laid in IS:2720 (Part 8)[10], so as to study their dry unit weight (MDD) and moisture content (OMC) relationship of unreinforced and reinforced soil specimens. It was found that the Light Compaction Test (Standard Test) could not reproduce the densities measured in the field under heavier loading conditions, and this led to the development of the Heavy Compaction Test (Modified Test). The fibers-as-solid principle is followed to define dry density in this study. However, a slight decrease in dry unit weight is observed with an increase of fibre content. Similar results have been observed by Nataraj and McManis (1997)[7], Maher and Ho (1964)[11].

Direct Shear Tests: UU

Specimens were tested in a 60x60 mm square shear box at normal stresses of 0.5, 1.0 and 1.5 Kg/cm^2 and sheared at a rate of 1.25 mm/minute according to IS:2720 (Part 13)[12]. The resulting peak friction angle and cohesion values are given in Table 1. The sheared sand specimen is shown in Fig. 3.

Table 1: Summary of Results of Direct Shear Test C(Kg/cm^2), φ value

Fiber Length	% of Fiber	Soil 1		Soil 2	
		φ	C	φ	C
	0.0	34°	0.07	28°	0.07
5mm	0.5	28°	0.05	32°	0.10
	1.0	42°	0.07	36°	0.07
	1.5	47°	0.06	40°	0.05
	2.0	45°	0.10	38°	0.07
10mm	0.5	37°	0.09	31°	0.06
	1.0	40°	0.07	34°	0.05
	1.5	46°	0.07	38°	0.09
	2.0	45°	0.10	37°	0.07
15mm	0.5	37°	0.09	32°	0.07
	1.0	43°	0.09	35°	0.04
	1.5	46°	0.09	36°	0.03
	2.0	43°	0.09	35°	0.05

Fig. 3: A typical view of reinforced sand specimen after shearing

Calculation of maximum shear stress had been carried out taking into account continual change in the shear area:

Corrected area= $A_0(1-\delta/L)$, A_0=initial area of the specimen, δ=displacement, at any time

7. DIRECT SHEAR TEST RESULTS AND DISCUSSION

Effect of inclusion of Jute fibers with sand on Shear Strength

The specimens for Direct Shear Test were prepared at OMC using dynamic compaction for both the two types of sands mixed with fibers of different sizes and proportions by weight of dry sand for each mix. The effect of various factors like length and proportion of fibers mixed randomly, on resulting shear strength, *C* and φ value are discussed below.

(I) The effect of Fiber Content and Length on the Shear Strength for different types of sand

The shear strength parameters φ and *C* of unreinforced and reinforced soils in terms of total stresses and the extent of strength improvement are summarized in Table 1 and 2. The variation of φ values of two different sands namely Soil 1 and Soil 2 due to addition of jute fibers of various length and fiber contents by the weight of dry sand, are shown in Figs. 4 and 5 respectively. The φ vs Length of Jute fiber curve for different types of sand i.e. Soil 1 and Soil 2 mixed with varying percentage of Jute fiber by the weight of dry sand are shown in Figs. 6 and 7 respectively. The shear stress-horizontal displacement curves obtained from UU tests for unreinforced and reinforced sand with different contents of Jute fibres are given in Fig. 8 and 9.

Table 2: Peak Shear Strength, Ƭ (Kg/cm²) of sands from Direct Shear Test - UU

Fiber Length	% of Fiber	Soil 1			Soil 2		
		σ (Kg/cm²)			σ (Kg/cm²)		
		0.5	1.0	1.5	0.5	1.0	1.5
	0.0	0.41	0.77	1.06	0.38	0.59	0.86
5 mm	0.5	0.48	0.83	1.25	0.43	0.74	1.04
	1.0	0.53	1.02	1.47	0.49	0.85	1.21
	1.5	0.68	1.17	1.78	0.50	0.89	1.34
	2.0	0.63	1.09	1.57	0.47	0.83	1.27
10 mm	0.5	0.45	0.83	1.18	0.39	0.65	0.93
	1.0	0.51	0.93	1.29	0.42	0.75	1.07
	1.5	0.63	1.10	1.64	0.47	0.88	1.23
	2.0	0.65	1.17	1.62	0.43	0.81	1.18
15 mm	0.5	0.47	0.82	1.22	0.36	0.72	0.97
	1.0	0.54	1.07	1.55	0.41	0.70	1.06
	1.5	0.64	1.14	1.65	0.43	0.72	1.06
	2.0	0.57	1.07	1.53	0.43	0.76	1.11

Table 3: Summary of Results of C- φ value at different moisture contents

Optimum Fiber Length & Content	Moiture content	Soil 1		Soil 2	
		φ	C Kg/cm²	φ	C Kg/cm²
5 mm 1.5%	OMC	47°	0.06	40°	0.05
	2% dry of OMC	42°	0.10	36°	0.10
	2% wet of OMC	44°	0.05	38°	0.07

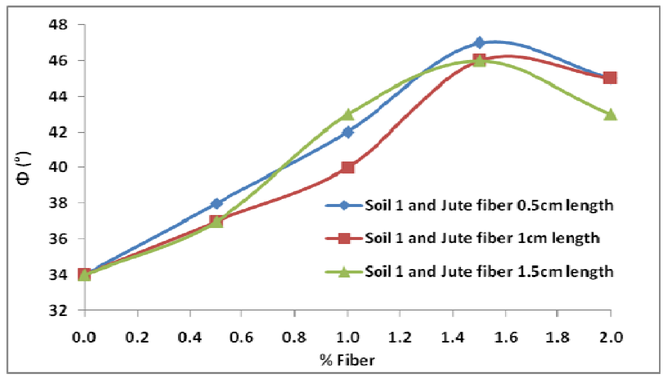


Fig. 4: Effect of fibre content on φ of Soil 1

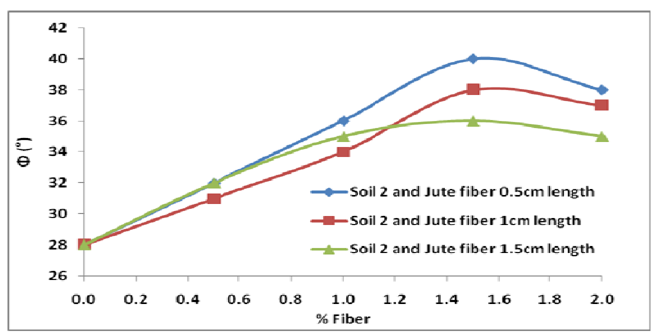


Fig. 5: Effect of fibre content on φ of Soil 2

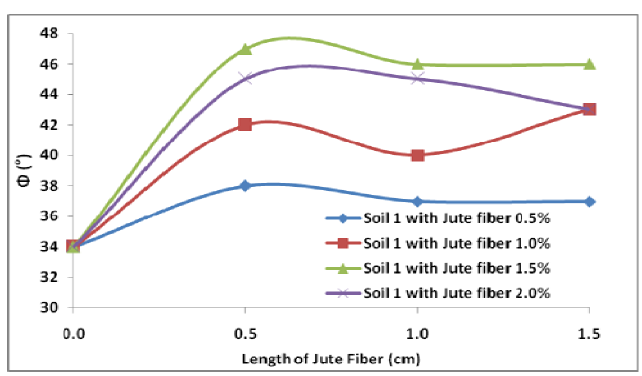


Fig. 6: Effect of fibre length on φ for Soil 1

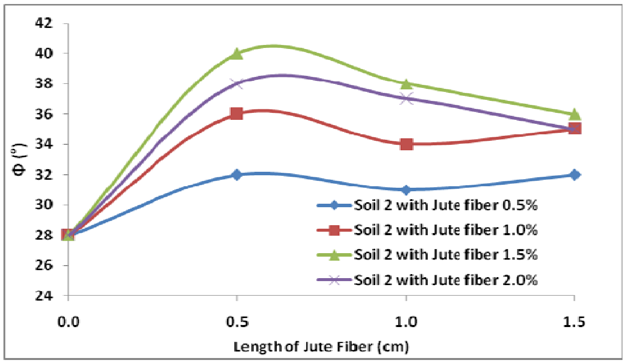
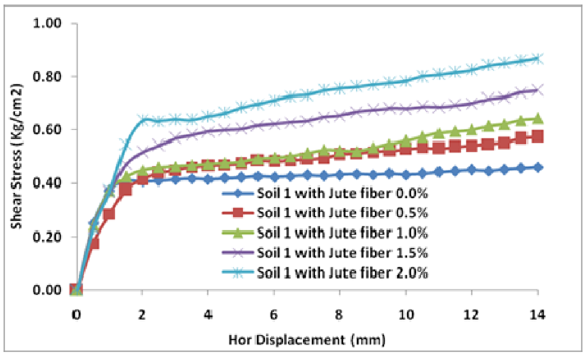
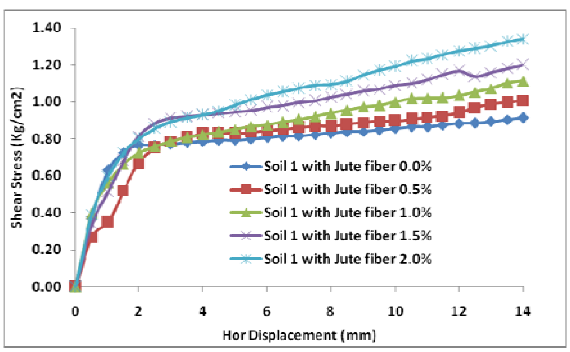


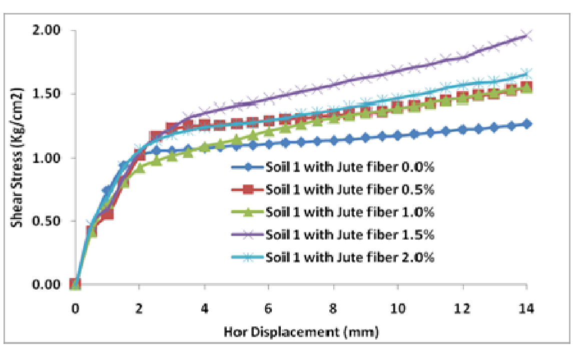
Fig. 7: Effect of fibre length on φ for Soil 2



(a) at σ = 0.5 Kg/cm²

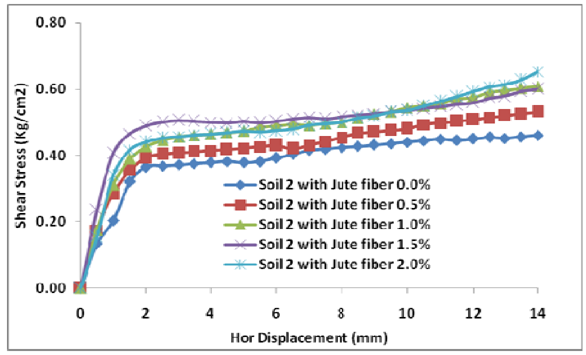


(b) at σ = 1.0 Kg/cm²

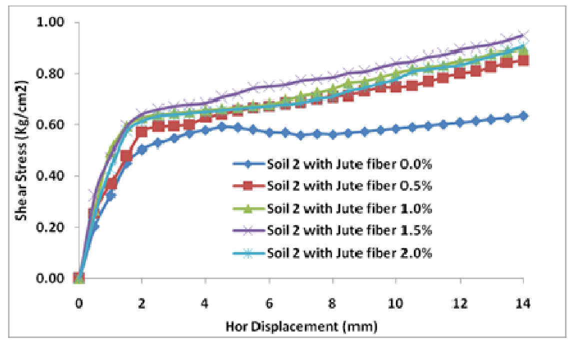


(c) at σ = 1.5 Kg/cm²

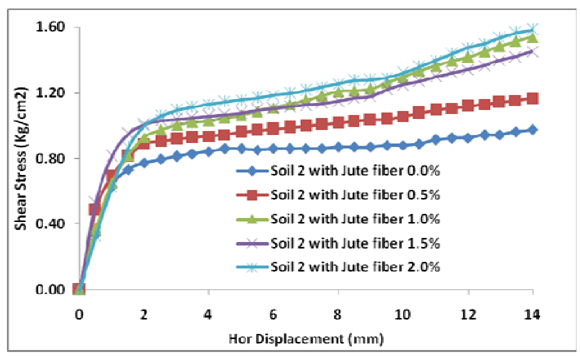
Fig. 8: Shear Stress vs Hor Displacement for Soil 1 and Fiber L=5mm



(a) at σ = 0.5 Kg/cm²



(b) at σ = 1.0 Kg/cm²



(c) at σ = 1.5 Kg/cm²

Fig. 9: Shear Stress vs Hor Displacement for Soil 2 and Fiber L=5mm

It can be seen that fibre inclusion enhanced the peak shear stress and the failure strain of both soils resulted in higher values of φ and c which were found to increase with increasing fibre content up to 1.5% for sands. It can also be observed that the φ values increases to a maximum value with the increase in fiber length of 5 mm, and after that it decreases to a constant value for both Soil 1 and Soil 2 for further increase in length of the fibers. Beyond the optimum dose, the observed shear parameters decreases or nearly remain the same. This is due to the fact that high fibre content resulted in poor mixing with less contact between soil particles reducing the availability of soil matrix for holding the fibre and developing a sufficient bond between fibres and soil.

The experimental results indicate that the percentage of fibre plays an important role in the development of φ for both soils. The results reveal that φ values increase with increasing fibre content. The peak φ value is approximately 47 ° for Soil 1 and 40 ° for Soil 2 with a optimum dose of 1.5% fibre content and 5mm fiber length, which again is approximately 40% higher than that for the unreinforced specimens. On the other hand, cohesion does not change considerably with fibre content.

(II) The effect of moisture contents on φ value (at OMC, 2% dry and 2% wet of OMC).

To investigate the effect of moisture content, direct shear tests were conducted under different moisture contents (at OMC, 2% dry and 2% wet of OMC) for optimum fiber length and fiber content values and results are tabulated in Table 3 for both sands. At OMC the packing of soil and fibre is the maximum with minimum voids resulting in higher strength. As the moisture variation is towards either side of OMC, the strength decreases. Moreover, specimen performance was enhanced in both wet and dry of optimum conditions.

(III) The Compaction Effect on φ value (Heavy Compaction vs Light Compaction)

Direct shear tests were conducted on specimens prepared from light compaction and heavy compaction efforts and test results are given in table 4. From test results it is evident that heavy compaction increases the φ value of fiber reinforced sand substantially than light compaction.

Table 4: Summary of Results of C- φ value at different compaction efforts (Heavy Compaction vs Light Compaction)

Optimum Fiber Length & Content	Parti-cular	Soil 1		Soil 2	
		MPT	SPT	MPT	SPT
Unreinfo-rced	OMC %	12.31	12.89	13.20	15.20
	MDD g/cc	1.72	1.66	1.74	1.64
	Ø	34°	27°	28°	25°
	C Kg/cm^2	0.07	0.10	0.07	0.09
Reinforc-ed 5 mm 1.5%	Ø	47°	39°	40°	35°
	C Kg/cm^2	0.06	0.05	0.05	0.09

8. POTENTIAL OF JUTE UTILIZATION

Jute is abundantly grown in Bangladesh, China, India and Thailand. Jute is mainly environmental-friendly fiber that is used for producing porous textiles which are widely used for filtration, drainage, and soil stabilization. Bitumen was used for coating fibers to protect them from microbial attack and degradation. Natural fibers like Jute are already been used for different engineering solutions in practice like improvement of sub-grade made of fine grained soils for road construction, erosion control for slopes etc. and Indian Standard Code for application of such fibers are also available (IS 14986: 2001)[13]. For low cost embankment/rural road constructions, randomly distributed discrete natural fiber reinforced soils may results in significant cost advantages.

9. REGRESSION ANALYSIS OF UU TESTS DATA

Effect of Fiber Content on φ for Different types of sand

The quadratic regression equation for the trends of the variations of Peak Friction Angle (φ) for each type of mixes have been generated to correlate Peak Friction Angle (φ) value with Jute fiber content are given in general form equations as below:

$$\varphi = a.\ P^2 + b.\ P + c$$

Where, P= Jute fiber content (%), φ = Peak Friction Angle (°).

The value of a , b and c for Soil 1 and Soil 2 with fiber length 15 mm, 10 mm and 5 mm are given in Table 5.

Table 5 Value of a, b and c for Soil 1 and Soil 2 with different Fiber Length

Types of Sand	Soil 1			Soil 2		
Leng-th of Fiber	15 mm	10 mm	5mm	15 mm	10 mm	5mm
a	-4.286	-1.429	-3.143	-3.429	-2.0	-3.429
b	13.97	9.057	12.49	10.46	9.0	12.46
R^2 (%)	91.5	93.0	94.5	99.7	95.4	95.6
c	34			28		

10. SUMMARY

An experimental study was carried out to investigate the influence of randomly oriented fiber inclusions on the geotechnical behaviour of two sands. The following are the conclusions from the study.

Inclusion of fibres in sandy soil has a considerable effect on their shear strength. Optimum fiber content of 1,5% and optimum fiber length of 5mm, significantly increases peak friction angle. The maximum increase in angle of friction is found to be 1.4 times higher than that for unreinforced soil at the optimum fiber content of 1.5%. The shear strength of soil increases with inclusion of fiber up to 1.5%, beyond which it decreases. The shear strength of fiber-reinforced soil occurs at higher strain compared to un- reinforced soil. The rate of increase of peak shear strength increases with increases in fiber content commensurate with increase in normal stress. On the other hand, cohesion does not change considerably with fibre content. The corresponding failure strain is higher than that for un-reinforced soil.

Moreover, fibre reinforcement changes soil's brittle shear failure behaviour to ductile shear failure behaviour. The toughness and ductility of the fiber-reinforced soils are beneficial for antiearthquake geostructures (Makiuchi and Minegishi, 2001[14]). Due to the presence of fibres, a residual shear load was maintained after shear failure. It suggests that the fibre reinforcement is a favourable ground improvement technique, and has the potential to increase soil cracking resistance and the stability of earth structures. The main application of composite soil can be in embankment, sub-grade, sub-base, and slope stability problems.

The results are based only on laboratory investigations and hence it is further recommended that the viability and long-term performance in field, of this material should be determined in actual highway construction projects.

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