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Strength Evaluation of Fiber Reinforced Sands

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Abstract—*Fiber reinforcement is an effective method for improving engineering properties of soil because of its cost effectiveness, easy adaptability, biodegradability and reproducibility. This paper presents a laboratory study on the strength behaviour of randomly distributed jute fibre-reinforced sandy soil by conducting a series of California Bearing Ratio tests. Jute fibres of three different lengths (5 mm, 10 mm and 15 mm) were used as reinforcement in this study. The effect of fibre content (0.5, 1, 1.5 and 2%) by weight of dry soil and fibre length on the CBR of fibre reinforced soil is investigated. To represent varying soil conditions for field applications, both unsoaked and soaked specimens were investigated. The CBR tests have been conducted under different moisture contents (at OMC, 2% dry and 2% wet of OMC). Soil is compacted with Modified Proctor Test's maximum dry density to reproduce the densities measured in the field under heavier loading conditions, i.e. more relevant compaction standard with greater stability. The test results reveal that the inclusion of fibers in soil increases the CBR value significantly.*

Keywords: *Modified Proctor Test, CBR value, Jute Fiber, Rreinforcement, Sand*

1. INTRODUCTION

Reinforced soil with randomly distributed fibres (natural and synthetic) is a viable soil improvement technique to improve strength and stability of soils for various geotechnical applications. To develop high CBR value and to improve the compactness of sand different fiber materials like Glass fiber (Pazare *et al*, 2002)[1], Nylon fiber (Jain *et al*, 2003)[2], synthetic fiber (Consoli *et al*, 1998[3], Kaniraj *et al*, 2001[4]) etc. are reported.

Natural fibers like jute, coir, sisal, bhabhar, hemp, sabai grass fiber etc. are mostly available in third world countries at a low cost and their supply is ensured from agriculture products. Geotextiles made from natural fibres like jute or coir are being employed as economic and eco-friendly solution (Chattopadhyay et.al, 1998[5], 2004[6], 2009[7]). Jute has highest tensile strength among the natural fibers and withstand rotting and heat (Sen and Reddy, 2011)[8]. Durability of natural fiber can be improved using coating of fiber with Phenol and Bitumen (Sivakumar Babu and Vasudevan 2008[9]). Coating of fibres increases interface friction between fibre and soil particles by increasing the surface area.

Sand is gradually being projected as alternate material for construction of sub base (Singh and Prasad, 2004)[10]. In this regard preliminary research of using fibre reinforced sand shows possibility to improve the compactibility of the sand, to develop high CBR value and to sustain the compactness (Gray and Ohashi, 1983[11]; Santoni and Webstar, 2001[12]; Kumar and Singh, 2008[13]). Aggarwal and Sharma (2010)[14] studied the application of Jute fiber in the improvement of subgrade characteristics. Use of randomly distributed fibre reinforced soils can be advantageously utilized as a ground improvement technique in the case of embankments, subgrades and in similar other problems (Pazare *et al*, 2002[1], Jain *et al*, 2003[2], Consoli *et al*, 1998[3], Kaniraj *et al*, 2001[4],Matty *et al*, 2014[15], Singh *et al*, 2013[16]).

California Bearing Ratio test is used to evaluate the potential strength of subgrade, subbase, and base course materials. The increase in CBR value will substantially reduce the thickness of pavement subgrade. Steep slopes of road embankments can be made stable using reinforced soil reducing spread width.

2. MATERIAL SELECTION

A. Soil Selection (Sands):

Locally available fine sand, one from village Dantali and other from village Goner were used in the present investigation. The particle size distribution curves of these sands used in the experiments are shown in Fig. 1. The physical properties of these two types of sands used in the experiments are tabulated in Table 1, 2 and 3.

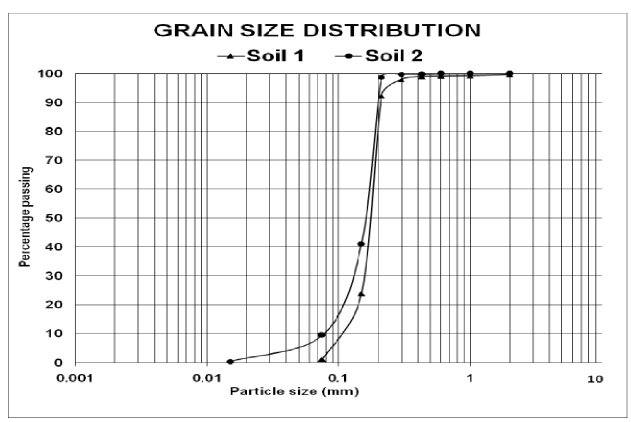

Fig. 1: Grain Size Distribution Curve for different types of sand

Table 1: IS Classification of Soil.

Soil	IS Classification	Gravel (%)	Sand (%	Silt (%)	Clay (%)
1	SP	0.0	98.8	1.2	0.0
2	SM	0.0	88.6	11.4	0.0

Table 2: Sand size distribution.

Sand Size	Soil 1	Soil 2
Coarse Sand (4.75-2.0 mm) %	0.3	0.0
Medium Sand (2.0-0.425 mm) %	0.7	0.1
Fine Sand (0.425-0.075 mm) %	97.8	88.5
Silt (0.075-0.0022mm) %	1.2	11.4

Table 3: Summary of Physical & Compaction Properties of Sands

Properties	Soil 1	Soil 2
Colour	Brown	Whitish gray
Classification (IS)	SP	SM
Specific Gravity	2.65	2.67
Coefficient of uniformity, Cu	1.72	2.60
Coefficient of curvature, Cc	1.36	1.43
Maximum dry density, γd, (g/cc)- Heavy compaction	1.72	1.74
Optimum moisture content, OMC, (%) -MPT	12.31	13.20
Angle of internal friction (φ)	340	280
Unsoaked California bearing ratio (%) at OMC	39.8	38.6
Soaked California bearing ratio (%) at OMC	37.4	28.6
Plastic Limit, PL (%)	NP	NP
Liquid Limit, LL (%)	23.4	24.8
Effective size D10 (mm)	0.108	0.070
Effective size D30 (mm)	0.165	0.135
Effective size D60 (mm)	0.185	0.182

B. Selection of fibre and experimental design parameters

Natural Jute fibers:

Natural Jute fibers were collected from local market for use in this experimental study. The summary of the physical properties of fibers in general are given in Table 4.

Table 4 Summary of Physical Properties of Fibers

Tests	Jute Fiber
Density (g/cc)	1.47
Diameter (mm)	0.02 – 0.03
Length (mm)	5, 10, 15

3. EXPERIMENTAL PROGRAMME

To investigate the effect of inclusion of the natural jute fibers of various lengths and proportion, in different types of sands i.e. Soil 1 and Soil 2 taken, a series of Modified Proctor tests and CBR tests have been conducted using Proctor mould and CBR mould as per I.S. codal provision. 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). Different parameters considered in the experiments are given in the Table 5. Fig. 2 and 3 shows the compaction curve based on the modified proctor test results. The fibers-as-solid principle is followed to define dry density in this study.

Table 5 Different parameters considered in the experiments

Type of fibres	Type of Soil	% fiber by weight of the dry sand	Fiber length (mm)
Jute fibre	Fine sand: 1 & 2	0.5, 1.0, 1.5, 2	5, 10, 15

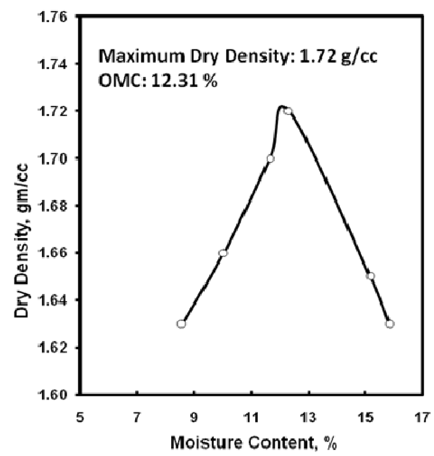

Fig. 2: Modified Proctor Test Result for Soil 1.

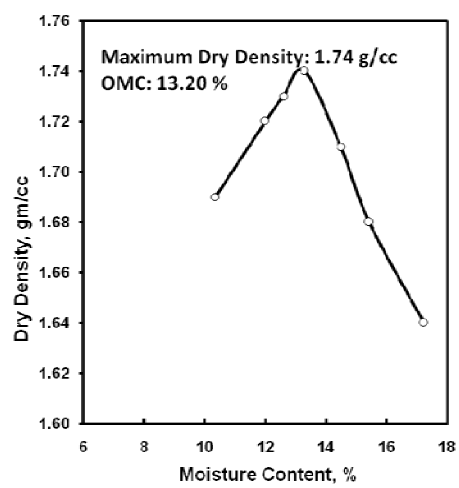

Fig. 3: Modified Proctor Test Result for Soil 2.

4. METHODOLOGY

Jute fibers are cut into small pieces of length 5 mm, 10 mm and 15 mm for use as fiber material and are shown in fig. 4. The Jute fibers were randomly mixed in sand by percentage of weight of the dry sand. Details of Sand-Jute fiber combinations of mixtures are given in Table 6. It was found that the fibers could be mixed with sand more effectively in the moist state than in the dry state.

5 mm 10 mm 15 mm

Fig. 4: View of Jute Fibers cut into pieces of definite length

Table 6: Details of Different Sand-Jute Fiber Combinations of Mixtures

Type of Sand used	Length of jute Fiber (mm)	Fiber Content (%) by weight of the dry sand
Soil 1	15, 10 and 5	0.5, 1.0, 1.5, 2
Soil 2	15, 10 and 5	0.5, 1.0, 1.5, 2

5. RESULTS AND DISCUSSIONS

The optimum moisture content (OMC) and corresponding maximum dry density (MDD) for both sands was determined by conducting Modified Proctor tests.

Effect of inclusion of Jute fibers with sand on California bearing ratio

Unsoaked and Soaked CBR tests were conducted at OMC on both the two types of sands mixed with fibers of different sizes and proportions by weight of dry sand for each mix. The CBR value both Unsoaked and Soaked obtained in these tests are tabulated in Table 7. Since the CBR values in soaked conditions are used in practice for design consideration, the effect of various factors like length and proportion of fibers mixed randomly, on resulting CBR value in soaked condition are discussed below.

Table 7 Summary of Results of Unsoaked CBR tests and Soaked CBR tests

Fiber leng-th	% of Fiber	Soil 1		Soil 2	
		Un-soaked CBR	Soaked CBR	Un-soaked CBR	Soaked CBR
	0.0 %	39.8	37.4	38.6	28.6
5 mm	0.5 %	50.4	45.4	50.8	45.7
	1.0 %	71.0	68.1	68.5	66.7
	1.5 %	79.1	74.3	79.6	75.2
	2.0 %	72.4	59.5	76.2	65.2
10 mm	0.5 %	67.6	56.2	65.4	52.8
	1.0 %	76.9	72.1	79.5	67.1
	1.5 %	69.0	67.6	73.7	70.0
	2.0 %	66.7	61.4	75.5	73.8
15 mm	0.5 %	64.8	58.1	61.5	57.1
	1.0 %	76.6	69.0	78.5	65.6
	1.5 %	67.6	63.8	72.3	64.4
	2.0 %	69.5	66.2	74.4	68.6

(I) Effect of Fiber Content on soaked CBR for Different types of sand

For visual comparison of the variation of soaked CBR 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. 5 and 6 respectively From these figures, it can be observed that the soaked CBR values increases with the increase in fiber inclusion (%) up to a maximum limit, after that it decreases for Soil 1 and Soil 2. The soaked CBR value is maximum for 1.5% of fiber inclusion of the dry weight of sand for both types of sand. The decrease of soaked CBR value above optimum content may be due to the fact that, at that fiber content, fiber quantities are higher enough to effect more fiber-fiber interaction than fiber-sand interaction.

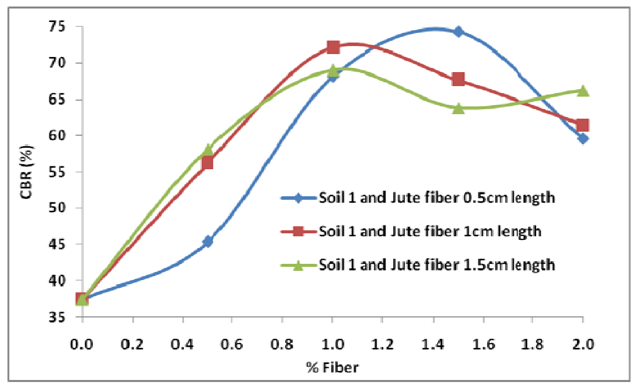

Fig. 5. Effect of fibre content on soaked CBR of Soil 1

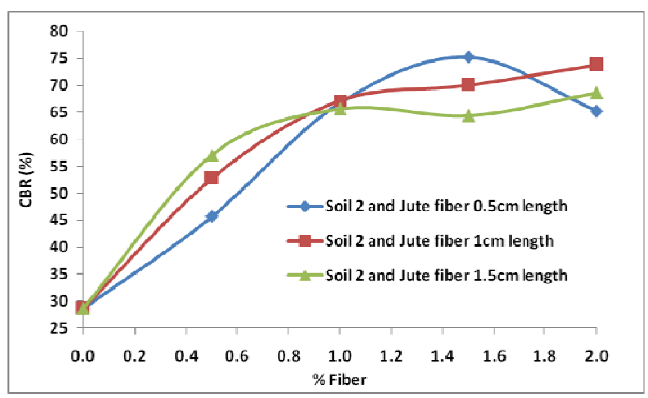

Fig. 6: Effect of fibre content on soaked CBR of Soil 2

(II) Effect of Fiber Length on soaked CBR for Different types of sand

The CBR 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. 7 and 8 respectively.

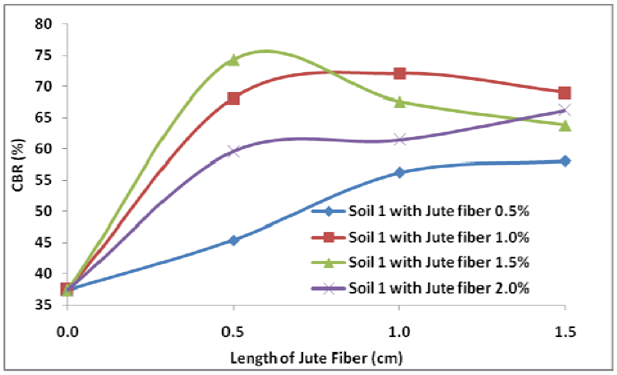

Fig. 7: Effect of fibre length on soaked CBR for Soil 1

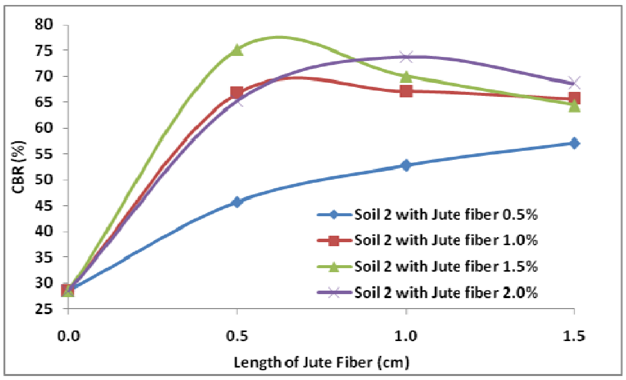

Fig. 8: Effect of fibre length on soaked CBR for Soil 2

From the figures, it can be observed that the soaked CBR 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.

(III) Effect of Submergence duration on CBR value for different types of sand

To determine the soaking effect for long period duration the compacted soil in CBR mould were immersed in water tank with seating load. The CBR tests were then carried out at 4 days to 30 days time interval. The results of Soaked CBR tests at different durations for different sand-jute fiber mix combinations are given in Table 8.

Table 8 Summary of Results of Soaked CBR tests at different durations

Details of sand-fibre composite	4 days	1 month
Soil 1 with 1.5% Jute fiber 0.5 cm	74.3	73.3
Soil 2 with 1.5% Jute fiber 0.5 cm	75.2	72.4

From this it is observed that the value of soaked CBR of sand-jute fiber composite decreases slowly with time to a constant value. However these values are still higher than the soaked CBR value of this sands without mixing any jute fibers. This decrease in soaked CBR value with the duration was observed under extreme condition of keeping of the sand-jute composite remaining under total submergence over this long durations.

(IV) Effect of moisture contents on CBR value (at OMC, 2% dry and 2% wet of OMC).

To investigate the effect of moisture content, CBR 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 9 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.

Table 9 Summary of Results of CBR tests at different moisture contents

Optimum Fiber Length & Content	Moisture content	Soil 1		Soil 2	
		Un-soak-ed CBR	Soak-ed CBR	Un-soak-ed CBR	Soak-ed CBR
5 mm 1.5%	OMC	79.1	74.3	79.6	75.2
	2% dry of OMC	63.8	60.0	73.3	65.7
	2% wet of OMC	75.7	69.0	71.8	69.0

(V) Compaction Effect on CBR value (Heavy Compaction vs Light Compaction)

CBR tests were conducted using light compaction and heavy compaction efforts and test results are given in table 10. From test results it is evident that heavy compaction increases the CBR value of fiber reinforced sand manifold than light compaction. Modified proctor testing typically requires a lower moisture content for achieving maximum dry density. 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).

Table 10 Summary of Results of CBR tests 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
	Unsoake d CBR	39.8	29.7	38.6	31.6

	Soaked CBR	37.4	22.3	28.6	23.7
Reinforc-ed 5 mm 1.5%	Unsoaked CBR	79.1	43.0	79.6	41.4
	Soaked CBR	74.3	38.5	75.2	36.1

(VI) Expansion in Fiber Reinforced Sand due to Soaking effect

Expansion of 4 days soaked fiber reinforced sands was also measured. Expansion due to 4 days soaking is not substantial and varies from 0.01% to 0.08%, even after 30 days soaking it does not exceed 0.08%, which is insignificant. After submergence expansion in both the sands takes place within 24 hours only and there after no expansion has been noticed.

Table11 Value of α, β and c for Soil 1 and Soil 2 with different Fiber Length

Types of Sand	Soil 1			Soil 2		
Length of Fiber	15 mm	10 mm	5mm	15mm	10mm	5mm
α	-15.06	-20.11	-17.74	-16.66	-14.91	-19.06
β	42.77	52.11	50.11	50.77	51.35	58.65
R^2 (%)	93.3	97.4	85.5	93.9	98.9	96.4
c	37.4			28.6		

6. REGRESSION ANALYSIS

Effect of Fiber Content on CBR for Different types of sand.

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

$$CBR = \alpha . P^2 + \beta . P + c$$

Where, P= Jute fiber content (%), CBR = California bearing ratio (%).

The value of α, β and c for Soil 1 and Soil 2 with fiber length 15 mm, 10 mm and 5 mm are given in Table 11.

7. CONCLUSIONS

The test results report that the inclusion of fibers in soil increases the CBR value significantly. It is cocluded that the optimum fiber content for achieving maximum strength is 1.5% of the dry weight of the soil with fibre length 5mm. California Bearing Ratio test is used to evaluate the potential strength of subgrade, subbase, and base course materials. The increase in CBR value is of the order of 160% that of raw soil and this will substantially reduce the thickness of pavement subgrade. These sands in such combination with natural jute fibers having highest CBR value may suit best as sub base material. The value of soaked CBR of sand-jute fiber composite decreases slowly with time to a constant value. However these values are still higher than the soaked CBR value of this sands without mixing any jute fibers. The fibers inclusion increases the compaction energy required to bring the specimen to a certain dry density. Expansion due to soaking effect, even after long period of submergence in jute reinforced sand does not exceed 0.08%, which is insignificant. Modified proctor testing typically requires a lower moisture content for achieving maximum dry density. Heavy compaction increases the CBR value of jute fiber reinforced sand manifold than light compaction, hence heavy compaction should be used for fiber reinforced sand. The increase in strength is a function of fiber weight fraction, aspect ratio and soil grain size.

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