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Strength and Stiffness Response of Itanagar Soil Reinforced with Jute Fiber

H. P. Singh[1], M. Bagra[2]

Associate Professor, Department of Civil Eng., NERIST, Itanagar, A.P., India [1]

Research Scholar, Department of Civil Eng., NERIST, Itanagar, A.P., India [2]

Abstract: Randomly distributed fiber reinforcement technique has successfully been used in a variety of applications such as slope stabilization, road subgrade and sub base etc. This is a relatively simple technique for ground improvement and has tremendous potential as a cost effective solution to many geotechnical problem. Keeping this in view the present study was taken up. In this study a series of triaxial compression tests under different confining pressures were conducted on locally available (Itanagar, Arunachal Pradesh, India) soil without and with Jute Fiber. The percentage of Jute fiber by dry weight of soil was taken as 0.25 %, 0.5 %, 0.75 and 1 % and they were randomly mixed with the soil. The soil samples of unreinforced and reinforced soil for triaxial tests were prepared at maximum dry density corresponding to optimum water content The shear strength parameters (c and ϕ) and stiffness modulus (σ_d/ϵ i.e. ratio of deviator stress to corresponding strain) of soil corresponding to each fiber content was determined in the geotechnical engineering laboratory of NERIST. The effect of change in diameter of fiber was also investigated. Tests results indicate that on inclusion of Jute fiber, the shear strength parameters (c and ϕ) and stiffness modulus (σ_d/ϵ) of soil are increases. It was also observed that on increasing the percentage of Jute fiber, these parameters are further increases and the increase is substantial at fiber contents of 1 %. It was further observed that the change in diameter of fiber affects these strength parameters and they increase with the increase in diameter of fiber.

Thus there is a significant increase in shear strength parameters and stiffness modulus of soil due to Jute fiber and this will considerably increase the load carrying capacity and reduce the value of immediate settlement of soil significantly

Keywords: Soil, Jute Fiber, Shear Strength Parameters, Stiffness Modulus, Fiber content, Fiber Diameter,

I. INTRODUCTION

Reinforced soil is a composite material which is formed by the association of frictional soil and tension resistant elements in the form of sheets, strips, nets or mats of metal, synthetic fabrics or fiber reinforced plastics and arranged in the soil mass in such a way as to reduce or suppress the tensile strain which might developed under gravity and boundary forces. The reinforcement in soil is placed more or less in the same way as steel in concrete and the end product is called reinforced soil. It is very effectively used for retaining structures, embankments, footings, subgrade etc. The incorporation of reinforcement in the earth mass, particularly in case of non-cohesive soils is not only for carrying the tensile stresses but instead meant for anisotropic suppression or reduction of one normal strain rate (Saran 2010). Soil reinforcement technique with randomly distributed fiber is used in a variety of applications like, retaining structures, embankments, footings, pavement subgrade. During last 25 years, much work has been done on strength deformation behaviour of fiber reinforced soil and it has been established beyond doubt that addition of fiber in soil improves the overall engineering performance of soil. Among the notable properties that improved are greater extensibility, small loss of post peak strength, isotropy in strength and absence of planes of weakness etc. Fiber reinforced soil has been used in many countries in the recent past and further research is in progress for many hidden aspects of it. Fiber reinforced soil is effective in all types of soils (i.e. sand, silt and clay). Use of natural material such as Jute, coir, sisal and bamboo, as reinforcing materials in soil is prevalent for a long time and they are abundantly used in many countries like India, Philippines, Bangladesh etc. The main advantages of these materials are they are locally available and are very cheap. They are biodegradable and hence do not create disposal problem in environment.

Studies have also shown that durability of natural fiber can be improved using coating of fiber with Phenol and Bitumen which is easily available in these areas (Sivakumar Babu and Vasudevan 2008). Many studies have been conducted relating to the behaviour of soil reinforced with randomly distributed fiber. Gray and Ohashi (1983)

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conducted a series of direct shear tests on dry sand reinforced with different synthetic, natural and metallic fiber to evaluate the effects of parameters such as fiber orientation, fiber content, fiber area ratios, and fiber stiffness on contribution to shear strength. Based on the test results they concluded that an increase in shear strength is directly proportional to the fiber area ratios and shear strength envelopes for fiber-reinforced sand clearly shows the existence of a threshold confining stress below which the fiber tries to slip or pull out. Various types of randomly distributed elements such as polymeric mesh elements (Andrews et.al, 1986), synthetic fiber (Gray and Al Refeai 1986, Mahar and Gray 1990, Ranjan et. al, 1996, Charan 1995, Consoli et al., 2002, Michalowski and Cermak, 2003, Gosavi et al., 2004, Yetimoglu and Inanir 2005, Rao et al., 2006, Chandra et al. 2008 and Singh 2011) metallic fiber (Fatani et al.1999) and discontinuous multioriented polypropylene elements (Lawton et.al, 1993) have been used to reinforce soil and it has been shown that the addition of randomly distributed elements to soils contributes to the increase in strength and stiffness. Lekha (2004) and Vishnudas et al. (2006) have presented a few case studies of construction and performance monitoring of coir geotextile reinforced bunds and suggested that the use of coir is a cost effective ecohydrological measure compared to stone-pitching and other stabilization measures used in the protection of slopes and bunds in rural areas. Sivakumar Babu and Vasudevan (2008) and Singh et.al (2011) studied the strength and stiffness response of soil reinforced with coir-fiber. Singh and Yachang (2012) used the Jute Geotextile sheets to improve the laboratory CBR value of fly ash. Based on the experimental results they found that stress-strain behaviour of soil is improved by inclusion of coir-fiber in the soil. They also observed that stiffness modulus of reinforced soil increases considerably which can reduce the immediate settlement of soil significantly.

Aggarwal and Sharma (2010) studied the application of Jute fiber in the improvement of subgrade characteristics. From this study it was concluded that Jute fiber reinforcement reduces the maximum dry density and increases the optimum moisture content of the subgrade soil. The CBR value of the subgrade soil increases up to 250% with the inclusion of bitumen coated Jute fiber.

A recent study revealed that greenhouse gas emission by Jute is negative whereas all other synthetic fiber possesses a net GHG emission. GHG emission is a matter of great concern under the Kyoto Protocol and all developed countries are to demonstrate commitment by way of reduction of GHGs.

This paper presents the influence of Jute fiber on the shear strength (c and ϕ) and stiffness modulus (σ_d/ϵ) of Itanagar, Arunachal Pradesh, India soil which is a typical soil and is normally used in the construction of embankments and pavement subgrade in tropical countries such as India. A number of triaxial compression tests have been conducted on soil and soil reinforced with Jute fiber. The effects of fiber contents and fiber diameters on shear strength parameters and stiffness modulus of reinforced soil have been investigated and results were compared with that of unreinforced soil.

II. MATERIALS AND TEST PROCEDURE

A. Soil

The soil used in this study was collected from the site of Doimukh RCC Bridge constructed on Dikrong River near Itanagar, Arunachal Pradesh, India. The various index properties and compaction properties i.e. maximum dry density and optimum moisture content (IS: 2720, Part VII, 1965) of soil were determined in the laboratory which is given in Table 1. The grain size distribution curve of soil is shown in Fig.1.

B. Reinforcement

The reinforcing material used in this study is natural Jute fiber of diameters 1 mm and 2 mm. The length of fiber was taken as 30 mm. A typical view of Jute fiber is shown in Fig. 2.

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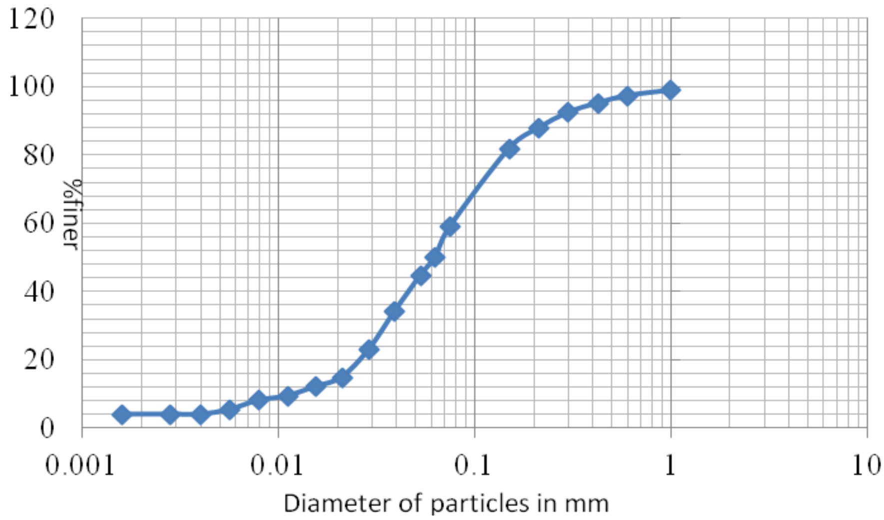

Fig.1: Particle Size Distribution Curve of Soil

Table 1: Index and Compaction Properties of Soil.

1	Specific Gravity (G)		2.60
2	Liquid Limit, LL (%)		26
3	Plastic Limit, PL (%)		NP
4	Particle Size Distribution Curve	Gravel Size (> 4.75 mm)	0
		Sand Size (0.075- 4.75 mm)	44 %
		Silt Size (0.002-0.075 mm)	52 %
		Clay Size (<0.002 mm)	4 %
5	Co-efficient of uniformity (C_u)		8
6	Co-efficient of curvature (C_c)		1.53
7	Maximum Dry Density, γ_d (kN/m^3)		17.30
8	Optimum Moisture Content, OMC (%)		16.45

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Fig.2: View of Jute Fiber (D = 2 mm, L = 30 mm)

C. Test Procedure

Soil from borrow area was air-dried and then sieved through 425 micron sieve. Soil specimens were prepared in a standard cylindrical split mould of 38 mm diameter and 76 mm long from this soil. All specimens were prepared at a dry density of 15.57 kN/m^3 (97% of maximum dry density) and at corresponding water content of 14.80 % to enable a proper comparison of results (Sivakumar Babu and Vasudevan 2008). Dry soil of specified weight was mixed with required quantity of water and kept in desiccators for equilibrium. Subsequently, the wet soil was taken out from the desiccators and the specified weight of fiber (precents by dry weight of soil) was distributed uniformly over the soil and mixed uniformly. Here, the Jute fiber length was taken as 30 mm (less than 38 mm) for proper random mixing with soil. The fiber-soil mixture was then kept in a plastic container for equilibration of moisture content of mix. The entire soil-fiber mixture was filled in the mould and statically compacted and specimens for testing are obtained.

All the specimens were tested in a conventional triaxial apparatus under three different confining pressures (ranging from 50 to 150 kPa) in undrained condition. Load was applied at a controlled strain rate of 1.58% per minute until the specimen failed/strain of 20% whichever was earlier. A total number of 30 tests were carried out for various fiber contents and fiber diameters under different confining pressures.

III. TEST RESULTS AND DISCUSSIONS

A number of stresses versus strains curves were plotted from the tests results of triaxial compression test performed on the soil and soil reinforced with various fiber contents. Because preparation of identical samples of Jute fiber reinforced soil beyond 1 % fiber content was not possible in the laboratory hence the present investigation was restricted up to 1 % of the fiber content only. The values of stiffness modulus (σ_d / ϵ) for Jute fiber reinforced soil (JFRS) having different fiber contents and fiber diameters of 1 mm and 2 mm.were computed from the plots and are shown in Table 2. The values of shear strength parameters (c and ϕ) of soil and reinforced soil for various fiber contents were measured

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from Mohr's Coulomb failure envelopes and are given in Table 3. The typical plots of stress versus strain curves and Mohr's Coulomb failure envelopes for unreinforced soil and reinforced soil with 0.25 % fiber content are presented in Fig. 3 to Fig. 6.

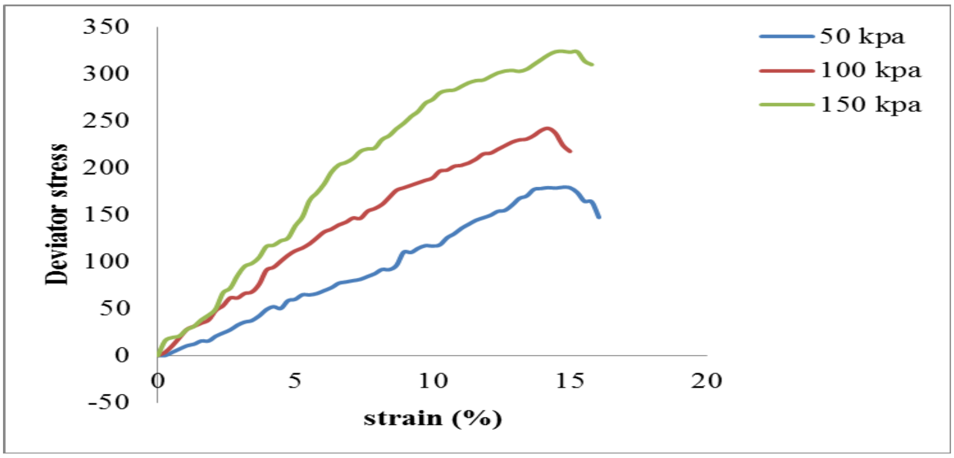

Fig. 3 Stress versus Strain Curves of Unreinforced Soil under Different Confining Pressures

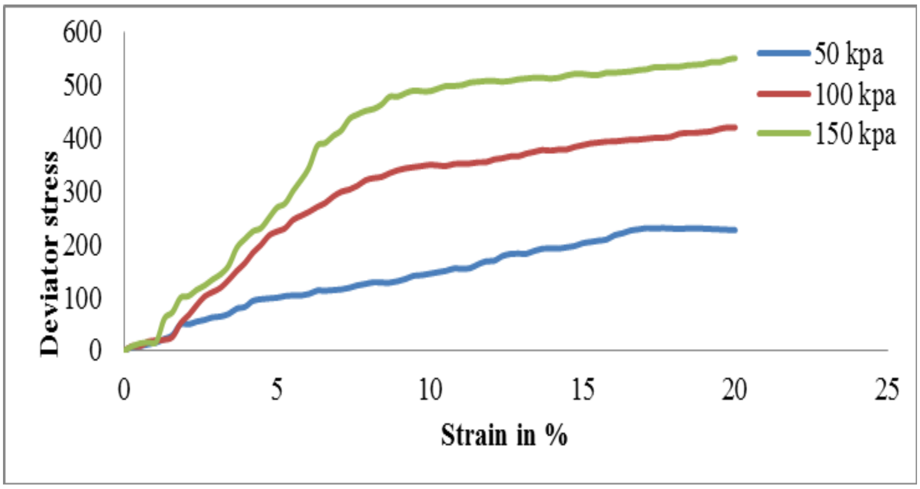

Fig. 4: Stress versus Strain Curve of Reinforced Soil for 0.25 % Fiber Content at Different Confining Pressures

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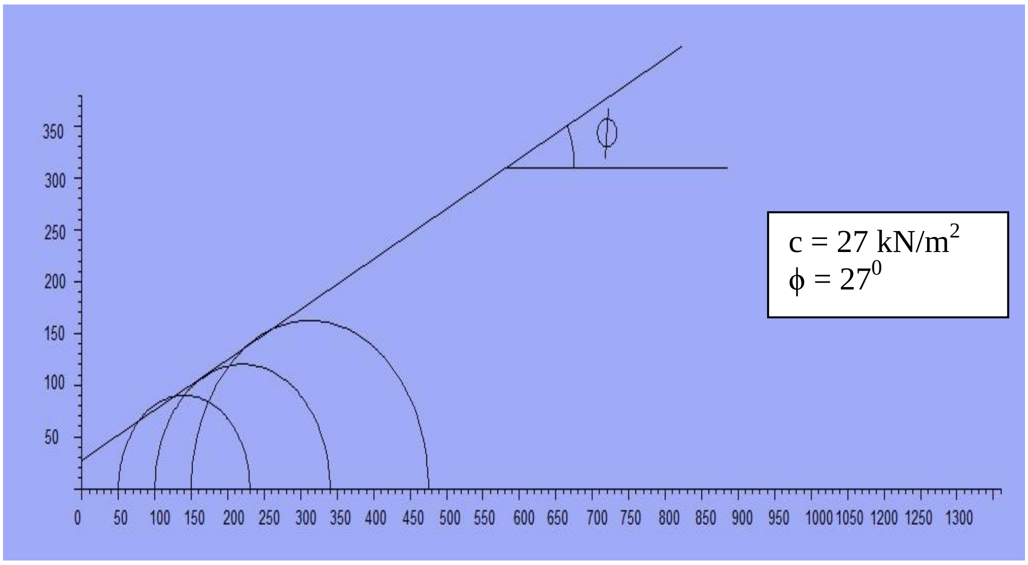

Fig. 5: Mohr's Coulomb Failure Envelope of Unreinforced Soil

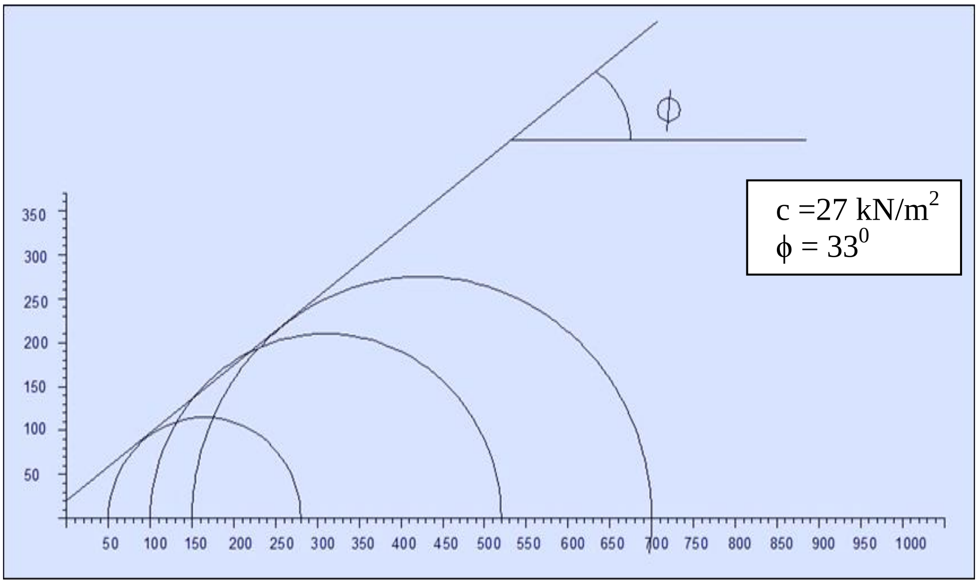

Fig. 6: Mohr's Coulomb Failure Envelope of Soil Reinforced with 0.25 % Fiber (D = 1mm)

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Table 2: Stiffness Modulus of Reinforced Soil for Various Fiber Contents at Different Confining Pressure

Fiber Content (%)	Confining Pressure (kN/m^2)	Diameter of Fiber = 1mm			Diameter of Fiber = 2mm		
		Stiffness Modulus (σ_d / ϵ)	Average Stiffness Modulus	Increase in Average Stiffness Modulus	Stiffness Modulus (σ_d / ϵ)	Average Stiffness Modulus	Increase in Average Stiffness Modulus
0	50 100 150	1216 1703 2230	1716	-	1216 1703 2230	1716	-
0.25	50 100 150	1267 2100 2750	2039	323 (18 %)	1896 2800 3000	2563	847 (49 %)
0.5	50 100 150	1605 2400 2600	2201	485 (28 %)	1850 2700 4000	2850	1134 (66 %)
0.75	50 100 150	1650 2450 3250	2450	734 (42)	2500 3000 4050	3183	1467 (85 %)
1	50 100 150	1376 3000 3250	2542	824 (48 %)	2500 3250 4250	3333	1617 (92 %)

Table 3: Shear Strength Parameters (c and ϕ) of Reinforced Soil for Various Fiber Contents

Fiber Content	Diameter of Fiber = 1mm				Diameter of Fiber = 2mm			
	Shear Strength Parameters (c and ϕ)				Shear Strength Parameters (c and ϕ)			
	c (kN/m^2)	ϕ (Degree)	Percentage Increase in (c)	Percentage Increase in (ϕ)	c (kN/m^2)	ϕ (Degree)	Percentage Increase in (c)	Percentage Increase in (ϕ)
0	27	27	-	-	27	27	-	-
0.25	27	33	0	22	40	30	48	11
0.5	40	36	48	33	90	36	233	25
0.75	80	38	196	41	110	36	311	25
1	85	38	214	41	110	38	311	41

A. Effect of fiber content

Based on the results of triaxial compression tests performed on reinforced soil at different fiber content varying from 0 % to 1 % for fiber diameters of 1mm and 2 mm, the computed values of stiffness modulus and shear strength parameters of reinforced soil are shown in Table 2 and Table 3 respectively. It is observed from Table 2 that the stiffness modulus of reinforced soil increases with the increase in confining pressure, fiber content and fiber diameter. The results of column 3 and column 6 of Table 2 shows the values of stiffness modulus of reinforced soil

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corresponding to different confining pressures for fiber diameters of 1mm and 2 mm respectively. Column 4 and Column 7 of Table 2 show the average value of stiffness modulus for fiber diameters of 1mm and 2 mm respectively. It is clear from the values of stiffness modulus that it increases with the increase in confining pressure and this aspect can be observed for all the fiber contents. This is due to the fact that under higher confining pressures soil samples are more confined and more resistant to deformation which results into higher deviator stress at failure. It is further observed that the average increase in stiffness modulus of reinforced soil increases with the increase in fiber contents and this trend is observed for both the fiber diameters i.e. 1 mm and 2 mm. For instance the average stiffness modulus of unreinforced soil is 1716. When 0.25 % Jute fiber having diameter 1 mm is added to the soil, the stiffness modulus of soil increases to 2039 i.e. improvement in stiffness modulus of soil is 18 % due to 0.25 % inclusion of Jute fiber. Similar trend is observed from the results of Table 2 for fiber contents of 0.5 %, 0.75 % and 1 % also and the maximum improvement in average stiffness modulus of soil is 48 % for fiber content of 1 %. For 2 mm fiber diameter the improvement in average stiffness modulus of soil is substantial i.e. 92 % for fiber content of 1 %. The significant increase in average stiffness modulus of soil due to addition of Jute fiber improves the load-settlement characteristics of soil and the amount of immediate settlement would be reduced significantly. It is observed from Table 3 that the shear strength parameters (c and ϕ) of reinforced soil increases with the increase in fiber content and this aspect can be observed for both the fiber diameters i.e. 1 mm and 2 mm. Column 2 and Column 3 of Table 3 show the values of cohesion (c) and angle of internal friction (ϕ) of reinforced soil for fiber diameter of 1 mm. Column 4 and Column 5 of Table 3 show the amount of percentage increase in (c) and (ϕ) values of soil due to inclusion of Jute fiber of 1 mm diameter. The results of Column 4 and Column 5 clearly show that the percentage increase in (c) value and (ϕ) value are 0, 48, 196, 214 and 22,33,41,41 respectively for fiber contents of 0.25 %, 0.5 %, 0.75 %, and 1 %. Similar trend is observed from the results of column 8 and column 9 of Table 3 for fiber diameter of 2 mm also and here corresponding percentage increase in (c) and (ϕ) values are 48, 233, 311, 311 and 11, 25, 25, 41 respectively. The significant increase in shear strength parameters of soil due to addition of Jute fiber improves the load carrying capacity of soil and Jute fiber reinforced soil can be used as foundation soil for supporting heavier loads of civil engineering structures. Similar trend of results was observed by Sivakumar Babu and Vasudevan (2008), Singh et al. (2011) and Singh (2011) also with the natural and geosynthetic fiber reinforced soil and fly ash. The increase in stiffness modulus and shear strength parameters of soil due to inclusion of Jute fiber is due to the fact that randomly oriented discrete inclusions incorporated into soil mass improves its load deformation behaviour by interacting with the soil particles mechanically through surface friction and also by interlocking. The function of bond or interlock is to transfer the stress from soil to the discrete inclusion by mobilising the tensile strength of discrete inclusion. Thus, fibre reinforcement works as frictional and tension resistance element. Further, addition of Jute fiber makes the soil a composite material whose strength and stiffness is greater than that of unreinforced soil.

B. Effect of fiber diameter

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It is clear from the tests results of Table 2 and Table 3 that the value average stiffness modulus and shear strength of soil increases with the increase in diameter of Jute fiber. The results of column 5 and column 9 of Table 2 show the increase in average stiffness modulus of reinforced soil for fiber diameters of 1 mm and 2 mm respectively. The percentage increase in stiffness modulus of reinforced soil due to 0.25 % fiber content is 18 % for 1 mm diameter of Jute fiber. In case of 2 mm diameter of Jute fiber, the percentage increase in stiffness modulus of reinforced soil due to same fiber content i.e. 0.25 % is 49 % and this aspect can be observed for all the fiber contents i.e. 0.5 %, 0.75 % and 1 %. It is further observed from Table 2 that maximum percentage increase in stiffness modulus of reinforced soil for fiber diameter of 2 mm and at fiber content of 1 % is 92 % which is very much substantial and would reduce the immediate settlement of soil significantly. Similar trend of increase in shear strength parameters (c and ϕ) of soil due to inclusion of Jute fiber is observed from Table 3 also. Although there is no significant increase in (ϕ) value of reinforced soil but there is a significant increase in (c) value of soil due to increase in diameter of Jute fiber and overall shear strength of soil would be increased due to increase in diameter of Jute fiber. Similar trend was observed by Sivakumar Babu and Vasudevan (2008) also in case of coir fiber. This is attributed to the fact that due to increase in diameter of fiber increases the pull out resistance of fiber. In addition, large diameters fibers are capable of sharing more stresses induced in the soil specimens.

IV. CONCLUSIONS

Based on the present investigation it is concluded that preparation of identical samples of Jute fiber reinforced soil beyond 1% of fiber content was not possible and hence optimum fiber content is 1 %. The value of stiffness modulus of reinforced soil increases with the increase in fiber content and the maximum percentage increase is 48 % over the plain soil for fiber diameter of 1 mm and at fiber content of 1 %. The shear strength parameters (c and ϕ) of soil increases with the increase in fiber content. The maximum increase in the values of (c) and (ϕ) are 214 % and 41 % respectively over the plain soil at fiber content of 1 % for fiber diameter of 1 mm. The stiffness modulus of reinforced soil increases with the increase in fiber diameter and its maximum percentage increase is 92 % over the plain soil for fiber diameter of 2 mm and at fiber content of 1 %.

The shear strength parameters (c and ϕ) increases with the increase in fiber diameter. The maximum values of (c) and (ϕ) are 311 % and 41 % respectively for fiber diameter of 2 mm at fiber content of 1 %.

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