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Strength and Stiffness Response of Itanagar Soil Reinforced With Arecanut Fiber

T.Muni[1], Y. Jeram[1], K. Padu[1], Omo Yachang[1], *H.P. Singh[2]

Post Graduate Students, Department of Civil Engineering, NERIST, Itanagar, A.P., India[1]

Associate Professor, Department of Civil Engineering, NERIST, Itanagar, A.P., India[2]

ABSTRACT: Natural fibers like coir, sisal, jute, cotton and others have attracted the attention of various researchers for applications in civil engineering works because they are cheap, locally available, biodegradable, eco-friendly and their inclusion significantly increases the engineering properties of soil. Among all the natural fibers Arecanut fiber appears to be one of the promising fiber because it is inexpensive, available in abundant and it is a very high potential perennial crop. India is in the top position in Arecanut production in world with its share of 55 percent. 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 Arecanut Fiber. The percentage of Arecanut 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. The effect of change in length of fiber was also investigated. Tests results indicate that on inclusion of Arecanut fiber, the shear strength parameters (c and ϕ) and stiffness modulus (σ_d /ϵ) of soil increases. It was also observed that on increasing the percentage of Arecanut fiber, these parameters further increases and this increase is substantial at fiber contents of 1 %. It was further observed that the increase in length of fiber increases the shear strength parameters of reinforced soil. Thus there is a significant increase in shear strength parameters and stiffness modulus of soil due to addition of Arecanut fiber and this will considerably increase the load carrying capacity and reduce the value of immediate settlement of soil significantly.

KEYWORDS: Soil, Arecanut Fiber, Shear Strength Parameters, Stiffness Modulus, Fiber content, Fiber length

I. INTRODUCTION

Randomly distributed fibre-reinforced soils or ply soil – termed as RDFS is among the latest ground improvement techniques and it has recently attracted increasing attention in geotechnical engineering. In comparison with systematically reinforced soils, randomly distributed fibre-reinforced soils exhibit some advantages. Preparation of randomly distributed fibre-reinforced soils mimics soil stabilization by admixtures. Discrete fibres of desired type and quantity are added in the soil, mixed randomly and laid in position after compaction. Thus, the method of preparation of fibre reinforced soil is similar to conventional stabilization techniques. Fibre reinforced soil is different from the other soil reinforcing method in its orientation. 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.

Many studies have been conducted relating to the behaviour of soil reinforced with randomly distributed fiber. Gray and Ohashi (1983) 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.

This paper presents the influence of Arecanut fiber on the shear strength (c and ϕ) parameters 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 Arecanut fiber. The effects of fiber contents and fiber length 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 of soil were determined in the laboratory as per IS: 2720, Part VII, 1965 and are given in Table 1.The grain size distribution curve of soil is shown in Fig.1.

B. Reinforcement

The natural Arecanut fiber used in this study was collected from the garbage dumping ground located at back side of Naharlagun and Nirjuli, Itanagar (Arunachal Pradesh, India) market. The fiber was cleaned and air dried before using in the present investigation. The average lengths of fiber considered in the present study are 20 mm and 30 mm. A typical view of Arecanut fiber having length 20 mm has been shown in Fig. 2.

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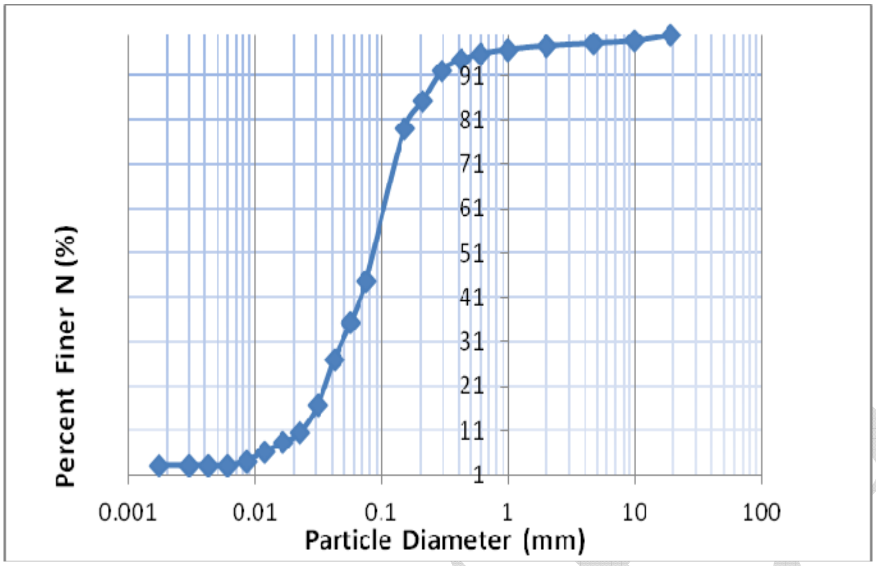

Fig.1: Particle Size Distribution Curve of Soil

Table 1: Index and Compaction Properties of Soil.

1.	Specific Gravity (G)		2.54
2.	Liquid Limit, LL (%)		29.41
3.	Plastic Limit, PL (%)		NP
4.	Particle Size Distribution Curve	Gravel Size (> 4.75 mm)	1.83 %
		Sand Size (0.075- 4.75 mm)	53.47 %
		Silt Size (0.002-0.075 mm)	37.65 %
		Clay Size (<0.002 mm)	7.054 %
5.	Co-efficient of uniformity (C_u)		6.06
6.	Co-efficient of curvature (C_c)		1.26
7.	Maximum Dry Density, γ_d (kN/m^3)		17.6
8.	Optimum Moisture Content, OMC (%)		16

Fig.2: View of Arecanut Fiber (Average Length L = 20 mm)

C. Test Procedure

Soil collected from site 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 length. All specimens were prepared at a dry density of 17 kN/m^3 (97% of maximum dry density) and at corresponding water content to enable a proper comparison of results (Sivakumar Babu and Vasudevan 2008). Dried soil of specific weight was mixed randomly with the Arecanut fiber taken by dry weight of soil. The entire soil- fiber mixture was filled in the mould and statically compacted. In this study two different lengths of fiber were incorporated inorder to find the effect of fiber length (20 mm and 30 mm) . All the specimens were tested in a conventional triaxial apparatus under four different confining pressures (ranging from 50 to 200 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.

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 Arecanut 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 Arecanut fiber reinforced soil (AFRS) having different fiber contents and fiber lengths 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 with various fiber contents were measured 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 only are presented in Figs. 3 to 6.

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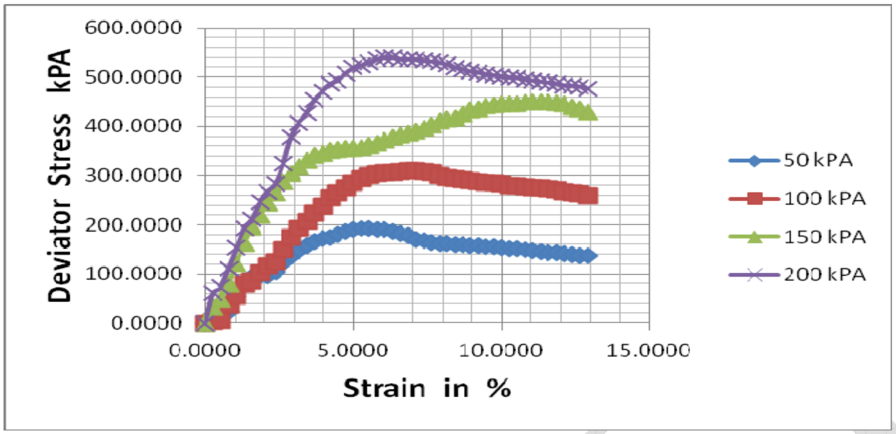

Fig. 3 Stress versus Strain Curves of Unreinforced Soil under Different Confining Pressures

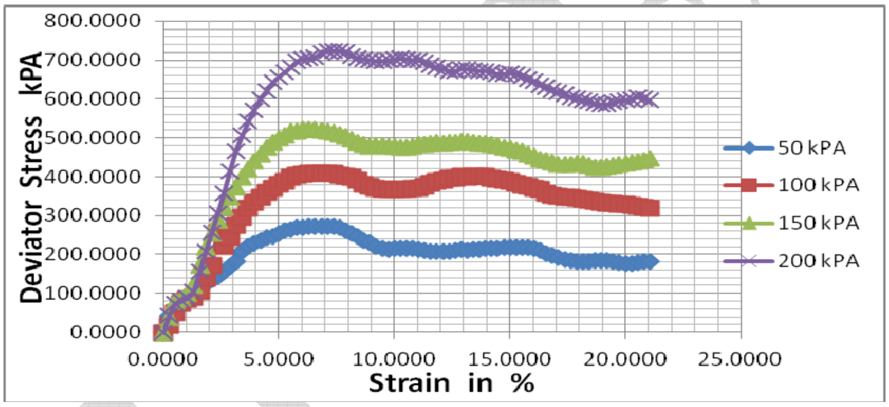

Fig. 4: Stress versus Strain Curve of Reinforced Soil for 0.25 % Fiber Content at Different Confining Pressures

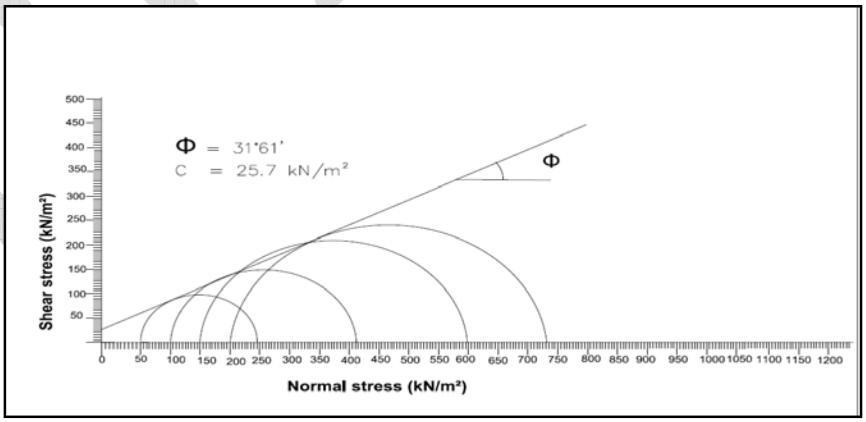

Fig. 5: Mohr's Coulomb Failure Envelope of Unreinforced Soil

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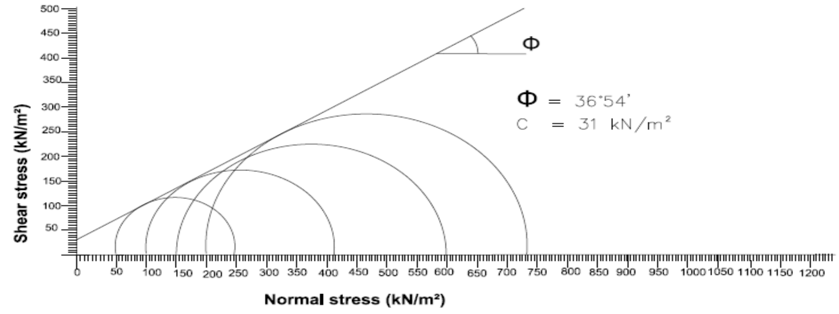

Fig. 6: Mohr's Coulomb Failure Envelope of Soil Reinforced with 0.25 % Fiber Content (L=20 mm)

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

Fiber Content (%)	Confining Pressure (kN/m^2)	Length of Fiber = 20 mm			Length of Fiber = 30 mm		
		Stiffness Modulus (σ_d /ϵ)	Average Stiffness Modulus	Percentage Increase in Average Stiffness Modulus	Stiffness Modulus (σ_d /ϵ)	Average Stiffness Modulus	Percentage Increase in Average Stiffness Modulus
0	50 100 150 200	3156 4373 5009 5787	4581	-	3156 4373 5009 5787	4581	-
0.25	50 100 150 200	3678 5550 5666 6730	5406	825 (18 %)	5050 5924 6767 7856	6399	1818 (40 %)
0.5	50 100 150 200	4652 6078 6087 6971	5947	1366 (29 %)	5986 6708 6951 7358	6750	2169 (47 %)
0.75	50 100 150 200	5266 6203 6382 7058	6227	1646 (36%)	6524 6273 6836 8230	6965	2384 (52 %)
1	50 100 150 200	8232 6551 6639 7145	7141	2560 (56 %)	7424 7711 7433 7529	7524	2943 (64 %)

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

Fiber Content %	Length of Fiber = 20 mm				Length of Fiber = 30 mm			
	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	26	31	-	-	26	31	-	-
0.25	31	36	19	16	32	38	23	23
0.5	38	38	46	23	51	39	96	26
0.75	65	39	150	26	66	40	154	29
1	72	40	177	29	81	42	212	35

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 average lengths of 20mm and 30 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 length. The results of column 3 and column 6 of Table 2 shows the values of stiffness modulus of reinforced soil corresponding to different confining pressures for fiber lengths of 20mm and 30 mm respectively. Column 4 and Column 7 of Table 2 show the average value of stiffness modulus for fiber lengths of 20mm and 30 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 increase in stiffness modulus of reinforced soil increases with the increase in fiber contents and this trend is observed for both the fiber lengths i.e. 20 mm and 30 mm. For instance the average stiffness modulus of unreinforced soil is 4581. When 0.25 % Arecanut fiber having length 20 mm is added to the soil, the stiffness modulus of soil increases to 5406 i.e. improvement in stiffness modulus of soil is 18 % due to 0.25 % inclusion of Arecanut fiber. Similar trend is observed for all the fiber contents of 0.5 %, 0.75 % and 1 %. The maximum improvement in average stiffness modulus of soil is 64 % at fiber content of 1% for fiber length of 30 mm. There is significant increase in average stiffness modulus of soil due to addition of Arecanut fiber and this will apparently improve the load-settlement characteristic of the soil. 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 lengths i.e. 20 mm and 30 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 length of 20 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 Arecanut fiber of 20 mm length. The results of Column 4 and Column 5 clearly show that the percentage increase in (c) value and (ϕ) value increases with increase in fiber content. Similar trend is observed from the results of column 8 and column 9 of Table 3 for fiber length of 30 mm. The significant increase in shear strength parameters of soil due to addition of Arecanut fiber improves the load carrying capacity of soil and Arecanut 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 Arecanut 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, fiber reinforcement works as frictional and tension resistance element. Further, addition of Arecanut fiber makes the soil a

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composite material whose strength and stiffness is greater than that of unreinforced soil.

B. Effect of fiber Length

It is clear from the tests results of Table 2 and Table 3 that the average value of stiffness modulus and shear strength parameters of soil increases with the increase in length of Arecanut fiber. The results of column 5 and column 9 of Table 2 show the increase in average stiffness modulus of reinforced soil for fiber lengths of 20 mm and 30 mm respectively. The percentage increase in stiffness modulus of reinforced soil due to 0.25 % fiber content is 18 % for 20 mm length of fiber. In case of 30 mm length of fiber, the percentage increase in stiffness modulus of reinforced soil due to same fiber content i.e. 0.25 % is 40 % 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 length of 30 mm and at fiber content of 1 % is 64 % 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 Arecanut fiber is observed from Table 3 also. The increase in stiffness modulus and shear strength parameters of reinforced soil having larger fiber length is due to the fact that the pull out resistance of larger length fiber is more than that of shorter length fiber at the same fiber content and hence larger length fiber is more effective in increasing the stiffness modulus and shear strength parameters of reinforced soil.

IV. CONCLUSIONS

Based on the present investigation it is concluded that preparation of identical samples of Arecanut fiber reinforced soil beyond 1% of fiber content was not possible and hence optimum fiber content was found to be 1 %. The value of stiffness modulus of reinforced soil increases with the increase in fiber content and the length of the fiber. It was found that maximum increase in average stiffness modulus of reinforced soil are 56 % and 64 % over the plain soil for fiber lengths of 20 mm and 30 mm respectively at fiber content of 1 %.

The shear strength parameters (c and ϕ) of soil also increase with the increase in fiber content and the length of fiber. For 20 mm fiber length the maximum increase in the values of (c) and (ϕ) of reinforced soil are 117% and 29% and for 30 mm fiber length the maximum increase in these shear strength parameters (c and ϕ) are 212 % and 35% respectively over the plain soil at fiber content of 1 %.

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