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Behaviour of Fibre Reinforced Sand in Different Test Conditions

Praveen Kumar Gupta*, Swami Saran and Ravi Kant Mittal*****

Introduction

Past research has demonstrated that random inclusion of discrete fibres significantly improves the engineering properties of soils. Randomly distributed fibre reinforced soil (RDFS) may be used as soil improvement technique, in variety of applications such as slope, embankment, sub-grade/sub-base, retaining structures and shallow foundations. From the literature it is evident that there has been no general consensus among researcher on what type of reinforcing material is suitable for any particular type of soil, what would be the optimum length of reinforcement ,or how exactly the properties of the reinforcement influence the behavior of reinforced soil. Several studies have been conducted to investigate the influence of randomly oriented discrete inclusions (fibres, mesh elements, waste material e.g. plastic strips, tire chips, etc.) on the geotechnical behavior of coarse grained and fine grained soils. Most of these studies were conducted on small size samples in triaxial, C.B.R., unconfined compression and direct shear tests (Andersland and Khattak, 1979; Hoare, 1979; Gray and Ohashi, 1983; Maher and Gray, 1990; Charan, 1995; Michalowski and Zhao, 1996; Michalowski and Cermák, 2003; Kaniraj and Havangi, 2001; Kaniraj and Gayatri, 2003; Gosavi et al., 2004; Yetimoglu et al., 2005).

The improvement of the engineering properties due to the random inclusion of discrete fibres is determined to be a function of a variety of parameters, such as fibre content, aspect ratio, fibre length, fibre type, confining pressure, and soil type. However effect of fibre inclusion on different relative densities of same soil is not reported. Based on direct shear tests on sand, Gray and Ohashi (1983) reported that fibre reinforcement increased the peak shear strength. But oppose to it, Yetimoglu and Salbas (2003) based on direct shear tests on sand, indicated that peak shear strength and initial stiffness of sand were not affected significantly by the inclusion of fibres. Very few studies have been carried out related to its field application such as in slopes (Lindh and Eriksson, 1990; Gregory and Chill, 1998; Sambasivarao and Mandal, 2004), embankments, highway sub-grade (Santoni et al., 2001; Tingle et al., 2002) and

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* Former M. Tech. student, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee-247667, India.

** Emeritus Fellow, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee-247667, India.

*** Research Scholar, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee-247667, India.

shallow foundation (McGown et al., 1985; Wasti and Butun, 1996). Model footing tests (McGown et al., 1985; Wasti and Butun, 1996) have been conducted on sandy soil improved by mixing mesh elements to it. No study is reported on soil reinforced with discrete fibres under model footing. In the present investigation, an experimental study using direct shear and triaxial test on small samples and model footing test on large samples of RDFS has been undertaken to study its behaviour under different test conditions.

Experimental Programme

Test Material

Various preliminary tests i.e. particle size analysis, specific gravity and maximum and minimum void ratio tests have been carried out in accordance with the relevant Indian Standard codes of practices to identify and classify the soil. The soil used in the study was sand. Fig.1 shows the particle size distribution curve of sand and its various properties; specific gravity of solids (G_s), average grain size (D_{50}), coefficient of uniformity (C_u), maximum void ratio (e_{max}) and minimum void ratio (e_{min}) are given in Table 1. As per the Indian Standard (IS- 1498-1970), the soil is classified as poorly graded sand (SP).

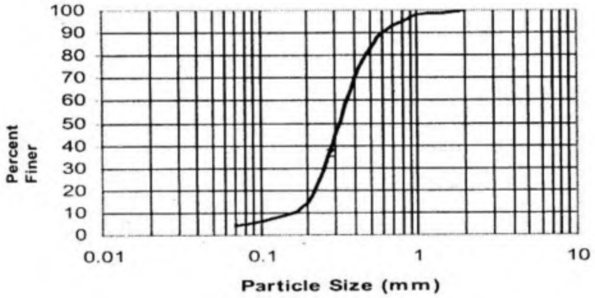


Fig. 1 Particle Size Distribution Curve of Sand

TABLE 1: Properties of Soil Used in the Investigation

Soil Classification	G_s	D_{50} (mm)	C_u	e_{max}	e_{min}
SP	2.64	0.31	2	0.673	0.519

The polypropylene fibres (specific gravity 0.92, tensile strength 1.5×10^5 kPa, and tensile modulus 3×10^6 kPa) were used in the present investigation. It is totally resistant to sea water, acids, alkalies and chemicals (Setty and Rao, 1987). It has high breaking strength and high abrasion resistance as it is less prone to wear and tear.

Direct Shear Test Programme

Direct shear tests were conducted on dry sand specimen size 60mm × 60mm × 25mm depth in a direct shear box. A total of 42 direct shear tests were conducted to study the influence of fibre content (FC) by weight and normal stress on the strength of RDFS. Among the tests, 10 were conducted on dry sand at 50%, and 70% relative densities (D_r) at 5 different normal stresses of 50 kN/m^2, 100 kN/m^2, 150 kN/m^2, 200 kN/m^2 and 250 kN/m^2, and remaining 32 tests were conducted on randomly distributed fibres reinforced sand of relative densities of 50% and 70% with fibre length of 24 mm and fibre content of 0.05%, 0.1%, 0.2% and 0.3% at 4 different normal stresses of 50 kN/m^2, 100 kN/m^2, 150 kN/m^2 and 200 kN/m^2. In preparation of RDFS sample fibre added to sand was considered as a part of the solid fraction. The fibres were mixed by hand and transferred to the direct shear box in three equal layers. Adequate compaction was achieved by light tamping.

Triaxial Test Programme

A Series of drained triaxial compression tests (sample size = 38 mm diameter × 76 mm height) on the RDFS were conducted with a strain rate of 1.22 mm/min. The fibres were mixed by hand and transferred to the triaxial split mould in three equal layers. Each layer of the mix was compacted to achieve the required relative density throughout the depth of the sample using the procedure given by Ladd (1978). A total of 136 triaxial tests were conducted to study the influence of fibre content, fibre length, confining pressure and relative density on the strength of fibre reinforced sand. Eight tests were conducted on dry sand at 50% and 70% relative densities at four confining pressure (CP) of 50 kN/m^2, 100 kN/m^2, 150 kN/m^2, 200 kN/m^2 and remaining, 128 tests were conducted on randomly distributed fibres reinforced sand at relative densities of 50% and 70% with fibre length of 24 mm, 30 mm, 36 mm, 48 mm and fibre content (FC) of 0.05%, 0.1%, 0.2% and 0.3% at 4 confining stresses of 50 kN/m^2, 100 kN/m^2, 150 kN/m^2, 200 kN/m^2.

Model Footing Test Programme

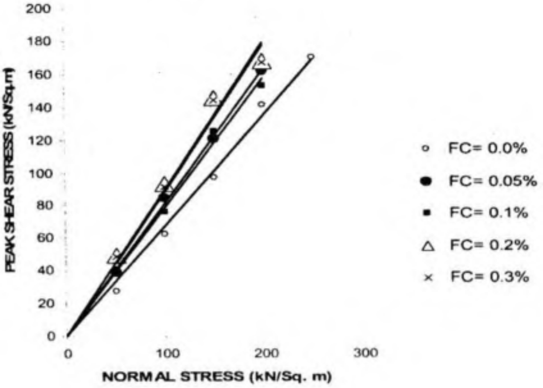
Model footing tests on the fibre reinforced sand were also conducted to investigate the pressure settlement behaviour of RDFS and effect of fibre content on the bearing capacity of the RDFS. All tests were conducted on the square footing of size 150 mm in a square tank of size 1000 mm × 1000 mm × 450 mm (deep). The base of the footing was made rough, to simulate the roughness of actual footings. The fibre reinforced sand was placed in the tank in the three layers and each layer was compacted using hand rammer of weight 12.5 kg to achieve the relative density of 50%. The footing was placed in the middle of the tank. The level of the footing was checked by sprit level.

A total of four model footing tests were performed under vertical load to study the pressure settlement curves of the RDFS and effect of fibre content on the bearing capacity of the RDFS. One test was performed on the unreinforced sand at relative density of 50%. Three tests were performed on randomly distributed fibre reinforced sand at 50% relative density with fibre length of 30 mm and fibre content of 0.05%, 0.1% and 0.2% by weight of sand.

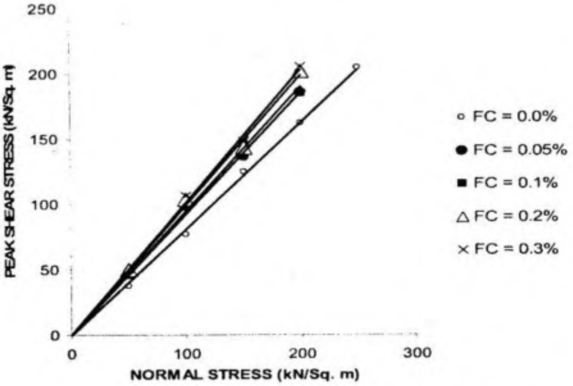
The complete details of direct shear, triaxial and model footing tests are given in Gupta (2004).

Test Results and Discussion

Direct Shear Test: Peak shear stresses are plotted with normal stresses for different fibre contents in Figs. 2 (a) and (b). These figures indicate that the strength of RDFS is more than unreinforced sand.



(a) D_r = 50%



(b) D_r = 70%

Fig. 2 Normal Stress versus Shear Stress Curve

Table 2 shows the percentage increase in peak shear stress of RDFS at different fibre content in comparison to the unreinforced sand. The effect of fibre content at low normal stress is more at relative density 50%. As the fibre content increases the percentage increase in the peak shear stress increases up-to 0.2% FC. At 0.3% FC the increase in the shear stress decreases. As the normal stress increases the percentage increase in the peak shear stress decreases. At 50% relative density, for the RDFS with 0.05% fibre content, the increase in shear stress is 41.4% more at 50 kN/m^2 normal stress than unreinforced sand (D_r = 50%) whereas at 200 kN/m^2 normal stress the increase in shear stress is 14.6%.

At 70% relative density the percentage increase in the peak shear stress of RDFS is low as compared to at 50% relative density. It can be seen from Table 2 that the increase in the peak shear stress at 50% relative density is 41.4% with 0.05% FC whereas at 70% relative density the increase is 22.4% at 50 kN/m^2 normal stress. Also, as the fibre content increases strength increases marginally.

TABLE 2: Percentage Increase in Peak Shear Stress of RDFS in Comparison to the Unreinforced Sand

FC (%)	*Percentage increase in shear strength of RDFS at failure*							
	D_r (50%)				D_r (70%)			
	Normal Stress (kN/m^2)				Normal Stress (kN/m^2)			
	50	100	150	200	50	100	150	200
0.05	41.4	36.3	24.2	14.6	22.4	26.8	9.8	14.5
0.1	48.3	42.7	29.1	17.9	24.9	29.2	17.4	13.9
0.2	79.3	50.0	49.4	18.6	32.5	34.1	15.1	24.4
0.3	77.5	46.9	48.6	18.0	19.9	37.8	18.9	26.7

***Strength of Composite Soil*:** In the present investigation of RDFS in direct shear tests, the strength of fibre reinforced sand has been defined in terms of shear strength parameter (ϕ).

Table 3 clearly indicates that the ϕ-value of the RDFS with 0.05% FC is 39^0 whereas the ϕ-value of unreinforced sand at 50% relative density is 34^0. The ϕ-value increases with increase in the fibre content upto 0.2% and decreases at 0.3% FC. At 70% relative density percentage increase in the ϕ- value is low compared to 50% relative density. As the fibre content increases the ϕ-value increases upto 0.3% FC but the increase is not proportional to the increase in FC. Rate of increase of shear strength parameter (ϕ) of RDFS shows a nonlinear (decreasing) trend, with increase in fibre content, when tested in direct shear test.

TABLE 3: Effect of Fibre Content on the Shear Strength Parameter (ϕ) of RDFS in Direct Shear Test

D_r (%)	ϕ (degrees)				
	Fibre Content (%)				
	0.0	0.05	0.1	0.2	0.3
50	34^0	39^0	39.5^0	42^0	41.5^0
70	39^0	43^0	43.5^0	45^0	45.5^0

Triaxial Test

A series of triaxial tests were conducted on randomly distributed fibre reinforced sand. Typical deviator stresses versus strain curves for some cases, obtained from triaxial tests are shown in the Figs.3 to 6. The increase in fibre content and length of the fibre do not affect the shear strength parameters significantly of the RDFS but increases the ultimate strength of the RDFS.

***Stress Strain Behaviour*:** Figures 3 and 4 show the effect of variation of fibre content on the stress strain curves of the RDFS at 50% relative density. Fig. 3 shows that the peak stress increases with increase in the fibre content with fibre length of 24 mm upto 0.2% fibre content and decreases at 0.3% FC at 50 kN/m^2 cell pressure (CP). Fig. 5 shows that peak stress increases with increase in fibre length up to 36 mm. At higher relative density (70%) the increase in fibre content does not have much effect on the ultimate strength of RDFS as shown by Fig. 6.

Table 4 shows the effect of the fibre content on the major principle stress at failure (σ_{1f}) of the RDFS with 24 mm, 30 mm, 36 mm and 48 mm length of the fibre under different relative density. This table indicates that major principal stress at failure of RDFS is more than that of the unreinforced sand but increase in fibre content does not seem to have a significant effect on the principal stresses at failure of RDFS. The effect of fibre inclusion is more at 50% relative density than that at 70% relative density. At 50% relative density the increase in principal stress at failure is 18.48% whereas at 70% relative density the increase is 12.11% at 0.05% FC with 24 mm fibre length and 100 kN/m^2 cell pressure.

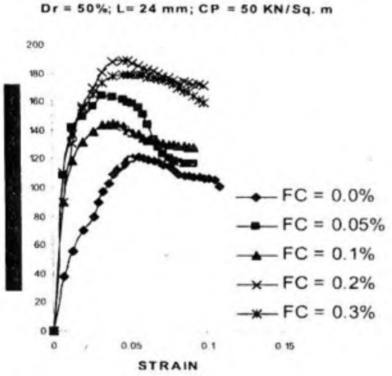


Fig. 3 Variation of Stress Strain with Fibre Content in Triaxial Test (Dr= 50%; L= 24 mm; CP = 50 kN/m^2)

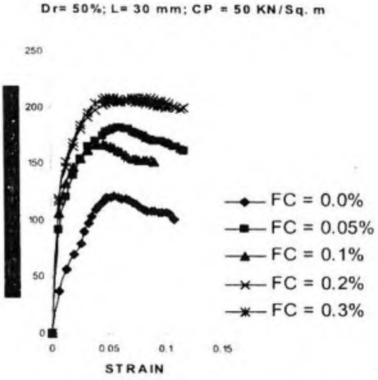


Fig. 4 Variation of Stress Strain with Fibre Content in Triaxial Test (Dr= 50%; L= 30 mm; CP = 50 kN/m^2)

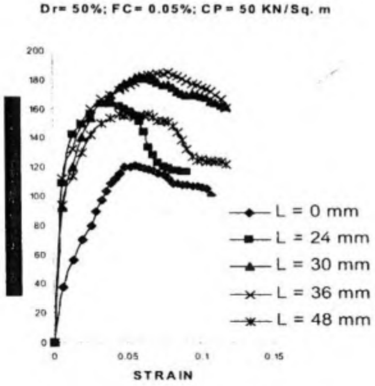


Fig. 5 Variation of Stress Strain with Length of Fibre in Triaxial Test (Dr= 50%; FC= 0.05%; CP= 50 kN/m^2)

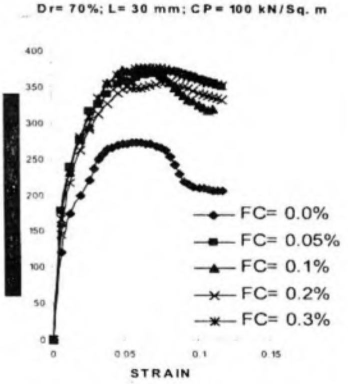


Fig. 6 Variation of Stress Strain with Fibre Content in Triaxial Test (Dr= 70%; L= 30 mm; CP= 100 kN/m^2)

TABLE 4: Effect of Fibre Content on the Failure Principle Stress (σ_{1f}) for Different Fibre Length and Relative Density

FC (%)	σ_3 (kN/m^2)	σ_{1f} (kN/m^2)							
		Fibre Length (mm)							
		24		30		36		48	
		D_r (50%)	D_r (70%)	D_r (50%)	D_r (70%)	D_r (50%)	D_r (70%)	D_r (50%)	D_r (70%)
0.0	50	170.9	198.17	170.9	198.17	170.9	198.17	170.9	198.17
	100	348.1	372.59	348.1	372.59	348.1	372.59	348.1	372.59
	150	533.83	627.57	533.83	627.57	533.83	627.57	533.83	627.57
	200	725.89	817.21	725.89	817.21	725.89	817.21	725.89	817.21
0.05	50	213.44	204.06	231.171	228.01	234.66	244.24	206.21	248.64
	100	412.42	417.73	421.32	471.86	454.21	500.16	424.74	427.31
	150	632.2	599.49	680.61	644.46	650.82	668.13	648.55	639.99
	200	841.97	820.75	847.18	861.73	878.6	880.14	837.14	853.97
0.1	50	194.18	197.14	217.23	252.72	220.16	235.99	213.09	228.01
	100	388.31	434.45	454.78	474.94	440.06	470.35	431.3	454.27
	150	627.83	641.48	658.77	702.04	642.71	685.59	632.47	661.55
	200	850.4	900.67	881.2	900.13	862.8	897.63	861.87	867.61
0.2	50	239.26	235.01	258.51	225.62	215.91	232.62	223.41	226.24
	100	452.59	446.65	483.8	457.73	456.24	449.27	414.04	461.16
	150	630.29	687.31	694.32	674.92	661.34	692.38	640.67	667.16
	200	876.09	918.35	890.31	940.59	929.05	918.01	838.62	865.61
0.3	50	228.62	209.95	258.11	254.28	230.15	239.55	226.63	244.55
	100	499.8	452.3	505.74	476.91	461.44	454.78	435.46	475.92
	150	641.15	691.39	710.9	698.2	693.36	690.46	660.09	686.33
	200	845.23	854.35	966.28	861.93	877.18	912.18	859.09	912.89

Strength of Composite Soil:

The ϕ values obtained from the Mohr circle diagrams of the RDFS are presented in the Table 5. This table indicates that the ϕ-values of reinforced sand is more than that of the unreinforced sand at 50% relative density but the increase in the fibre content does not have significant effect on the ϕ-values. The ϕ-value of the unreinforced sand is 33^0 whereas with 24 mm length of the fibre and 0.05% FC, the ϕ-value is 37.5^0 at 50% relative density. The increase in the length of the fibre also does not affect the ϕ-value significantly. At fibre length of 24 mm, 30 mm, 36 mm and 48 mm the ϕ-values are 37.5^0, 38^0, 38.5^0 and 38.5^0 with 0.05% FC at 50% relative density. The similar trend can be seen at the higher fibre content of 0.1%, 0.2% and 0.3%.

TABLE 5: Effect of Fibre Content and Length of the Fibre on the ϕ Values of the RDFS in Triaxial Tests

FC (%)	ϕ (degrees)							
	Length of Fibre							
	24 mm		30 mm		36 mm		48 mm	
	D_r (50%)	D_r (70%)	D_r (50%)	D_r (70%)	D_r (50%)	D_r (70%)	D_r (50%)	D_r (70%)
0.0	33^0	37^0	33^0	37^0	33^0	37^0	33^0	37^0
0.05	37.5^0	37.5^0	38^0	38.5^0	38.5^0	38^0	38.5^0	37^0
0.1	39^0	39.5^0	39^0	39^0	39^0	39^0	38.5^0	38.5^0
0.2	38^0	40^0	38.5^0	41^0	41^0	39.5^0	38^0	38^0
0.3	37^0	38^0	40^0	39.5^0	38.5^0	39^0	38^0	39^0

At 70% relative density, the ϕ-values of unreinforced and reinforced sand is comparable. The ϕ-value of unreinforced sand is 37^0 whereas the ϕ-value of the reinforced sand at 0.05%, 0.1%, 0.2%, 0.3% FC is 37.5^0, 39.5^0, 40^0, 38^0 respectively with 24 mm length of the fibre. The effect of increasing the length of the fibre also does not seem to have much effect on the ϕ-value of the RDFS at 70% relative density. The ϕ-value at 24 mm, 30 mm, 36 mm and 48 mm length is 37.5^0, 38.5^0, 38^0 and 37^0 with 0.05% FC. Similar to direct shear test in triaxial test also, rate of increase of shear strength parameter (ϕ) of RDFS showed a nonlinear (decreasing) trend, with increase in fibre content.

Model Footing Test

***Pressure Settlement Behaviour*:** Figure 7 shows the pressure settlement curves of the fibre reinforced sand and unreinforced sand. This figure indicates that for a given pressure intensity, the settlement of unreinforced sand is more than that of the reinforced sand and the settlement reduces with the increase in the fibre content.

***Bearing Capacity of Composite Soil*:** The bearing capacity of the unreinforced sand and RDFS determined by plotting the pressure versus settlement curve on a Log- Log graph is shown in the Table 6.

This table indicates that the bearing capacity of the RDFS increases with increase in fibre content. Percentage increase in the bearing capacity of the RDFS in comparison to unreinforced sand is 17.6% at 0.05% FC, 35.3% at 0.1% FC and 64.7% at 0.2% FC. The percentage increase in the bearing capacity with the increase in the fibre content is almost linear as shown in the Fig.8. However, direct shear and triaxial tests do not show linear trend in increase of strength with increase in fibre content. This suggests that small sample results may not be true indicator for prediction of improved strength of RDFS.

TABLE 6: Effect on Bearing Capacity with Increase in Fibre Content

Parameter	Value			
Fibre Content (%)	0.0	0.05	0.1	0.2
Bearing Capacity (kN/m^2)	85	100	115	140
% increase in Bearing Capacity	-	17.6	35.3	64.7

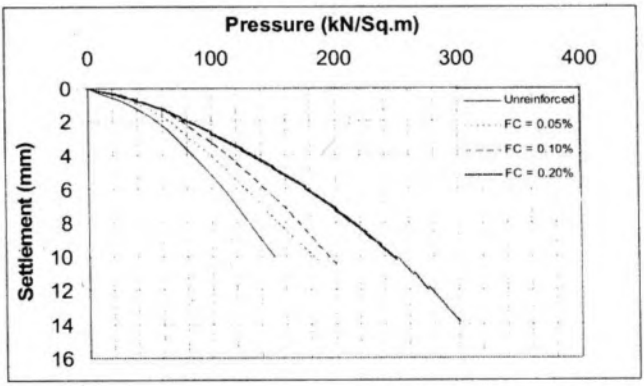


Fig. 7 Pressure Settlement Curve of RDFS at Different Fibre Content

Fig. 8 Variation of Percentage Increase in the Bearing Capacity of the RDFS with Fibre Content

Conclusions

1. In direct shear test, peak shear stress of RDFS is more than that of the unreinforced sand. The effect of fibre content at low normal stress is more at relative density 50%. As the fibre content increases the percentage increase in the peak shear stress increases upto 0.2% FC. Beyond 0.2% FC rate of percentage increase in the peak shear stress starts decreasing. As the normal stress increases the increase in the peak shear stress of RDFS decreases.

2. The ϕ-value of the RDFS is more than that of the unreinforced sand but increase in the fibre content does not have significant effect on the ϕ-value. The increase in the length of the fibre also does not affect the ϕ-value significantly. At 70% relative density, the ϕ-value of unreinforced and RDFS is comparable.

3. The percentage increase in the strength of RDFS is more at 50% relative density compared to 70% relative density. At higher relative density (70%) the increase in fibre content does not have much effect on the strength of RDFS.

4. For a given pressure intensity, the settlement of unreinforced sand is more than that of the reinforced sand and the settlement reduces with the increase in the fibre content.

5. The bearing capacity of the RDFS increases with increase in Fibre Content. The percentage increase in the bearing capacity with the increase in the fibre content shows almost a linear trend.

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