A Study on Effect of 12 mm Polypropylene Fiber on Shear Strength Characteristics of Fine Sand

D. Neeraj Varma and T. Vamsi Nagaraju

Abstract Fiber is a non-definite failure plane reinforcing material used for enhancing the engineering properties of various building materials. This paper presents the effect of 12 mm polypropylene fiber on shear strength characteristics of fine sand. Direct shear tests are conducted on fine sand reinforced with varying percentages of randomly distributed fiber, from 0 to 1.50% at an increment of 0.25% (by dry weight of soil). With increase in fiber content, angle of shearing resistance increased. Development of apparent cohesion is witnessed from the test data due to the formation of thin films of fiber. Maximum shear strength of fine sand observed at 1.0% of fiber content. In addition, the fiber effect on permeability characteristics is also ascertained through constant head permeability test, and reduction in coefficient of permeability is observed with fiber inclusion. Thus, increases the seepage resistance of the fine sand.

Keywords Fine sand · Fiber · Shear stress · Angle of shearing resistance · Apparent cohesion · Fiber film

1 Introduction

Infrastructure is a major assert for any country to compete with other challenging countries. The progress of infrastructure mainly depends on the available resources and economy. For a fast developing country like India, it is necessary to utilize all the available resources economically. With a rapid growth in construction industry, the availability of material with good engineering properties is being declined. As a result, the cost of materials increasing drastically. From the geotechnical engineering perspective, foundation materials such as coarse sand and moorum come under the same category due to their superior engineering properties. In the current scenario,

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for effective utilization of low-cost material, it is necessary to use existing materials with less engineering properties through proper stabilization techniques.

Fine sand is an abundant material, available in various places around the globe. Due to the poor gradation and inadequate engineering properties, fine sand is not utilized as foundation material [1, 2]. Conventional stabilization techniques using cementitious products are effectively used for improving the engineering properties of soil [3–5]. However, the usage of cementitious products, commercially available cement, emits greenhouse gases, which is an environmental concern [6]. Hence, researchers are working on new stabilization techniques by considering both environment and economy aspects.

Reinforcement with fiber is one of the new stabilization techniques adopted for strengthening materials. Researchers are working with variety of synthetic and natural fibers for stabilizing various types of soil [7–12]. Fiber reinforcement imparts stability to soil through the development of tensile forces [7]. As granular soils are weak in tension, the engineering properties can be enhanced by reinforcing with randomly distributed fiber. One should not contemplate randomly distributed fiber reinforcement as reinforced earth in which reinforcement in the form of sheets, strips, grids, etc., placed in predetermined positions. Unlike reinforced earth, randomly distributed fiber will not show any definite failure plane [13, 14] and offer strength isotropy [15]. Hence, in the present study, the shear strength characteristics of fine sand was improved by reinforcing with randomly distributed 12 mm polypropylene fiber.

2 Materials and Methods

For the present study, soil collected from Suryalanka, Bapatla, Andhra Pradesh. About 99% of soil passed through 425 micron IS sieve and retained on 75 micron IS sieve. Most of the soil particles were fine in nature and not suitable for foundation material. Therefore, the collected soil was best suited for fiber reinforcement. As per IS Soil Classification System [16], the collected soil sample was classified as poorly graded sand (SP) with a specific gravity of 2.62. Various laboratory tests were conducted to determine properties of fine sand, and the same were presented in Table 1.

Commercially available 12 mm Recron 3S polypropylene fiber was used for reinforcing the fine sand. The properties of fiber were presented in Table 2. Fine sand was mixed with varying percentages of fiber (0.25, 0.50, 0.75, 1.00, 1.25, and 1.50%) by dry weight of soil. Initially, optimum moisture content (OMC) and maximum dry density (MDD) of fiber reinforced fine sand reinforced was determined by performing IS light compaction test as per IS 2720 part 7, 1980 [17]. The compaction test results were presented in Table 3. With increase in fiber content, the maximum dry density decreased and optimum moisture content increased.

Fiber-reinforced soil specimens are compacted at respective OMC and MDD in shear box of 60 mm × 60 mm × 60 mm size, and direct shear test was conducted

Table 1 Engineering properties of collected soil sample

S. No.	Engineering properties	Values
1	Compaction characteristics	
	(a) Optimum moisture content	11.2%
	(b) Maximum dry density	15.6 kN/m^3
2	Shear strength parameters	
	(a) Cohesion	0
	(b) Angle of internal friction	23°
3	Coefficient of permeability	2.67×10^{-3} cm/s

Table 2 Properties of Recron 3S polypropylene fiber

S. No.	Property	Value	Units
1	Diameter	0.04	mm
2	Cut length	12	mm
3	Aspect ratio	0.0033	–
4	Specific gravity	0.91	–
5	Tensile strength	4000–6000	kN/m^2
6	Melting point	>250°	C
7	Elongation	60–90	%
8	Shape of fiber	Triangle shape	–

Table 3 Variation of compaction characteristics with varying fiber content

S. No.	*F*(%)	OMC (%)	MDD (kN/m^3)
1	0	11.2	15.6
2	0.25	12.4	15.52
3	0.50	13.4	15.50
4	0.75	14.8	15.46
5	1.00	16	15.40
6	1.25	17	15.30
7	1.50	18.2	15.24

Note F(%)—Percentage of fiber by dry weight of soil

on soil specimens as per IS 2720 part 13, 1986 [18]. The shear load was applied at a rate of 1.25 mm/min until the specimen failed or 20% of strain was reached, whichever was earlier. Direct shear tests carried out for different fiber contents (% *F* = 0.25, 0.50, 0.75, 1.00, 1.25, and 1.50%) under different normal stresses (0.5, 1.0, and 2.0 kg/cm^2).

For accessing the permeability characteristics of fiber-reinforced soil, constant head permeability test was conducted on soil specimens prepared at OMC and MDD as per IS 2720 part 17, 1986 [19]. For achieving uniform saturation, water was allowed to flow through soil specimen for two hours prior to the test.

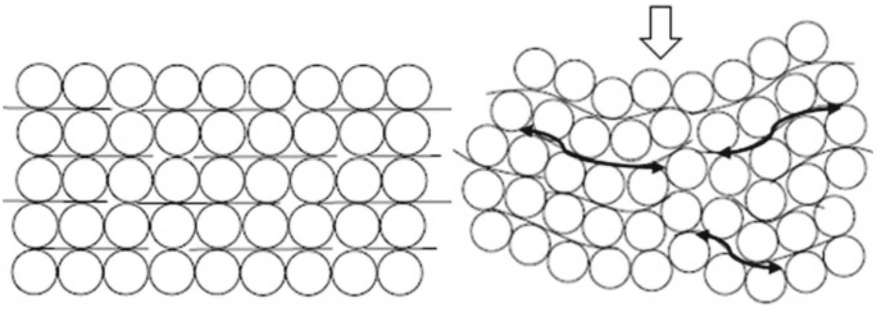
3 Results and Discussions

3.1 Shear Strength Parameters

Typical results of direct shear test conducted on fiber-reinforced fine sand were given in Table 4. The angle of shearing resistance (ϕ) of fine sand increased with increase in fiber content. Many researchers also reported a similar trend in enhancement of shear strength parameters [9, 11, 12, 20]. Marandi et al. [10] reported that the shear zone and surface failure direction of soil was effected by the tensile properties of fiber. With an increase in fiber content, the interaction of fiber with soil grains increased through surface friction. Therefore, under the combined action of surface friction and tensile resistance of the fiber, the angle of shearing resistance of fine sand increased. The tensile force developed in the fiber under the action of normal stress was represented in Fig. 1b. The maximum shearing resistance of fiber-reinforced fine sand was encountered at 1.0% fiber content. Thereafter, with increase in fiber content, the portion of soil grains were replaced by the fiber. The behavior of reinforced soil is categorically governed by the fiber, resulting in the reduction of angle of shearing resistance. Further, in the presence of moisture content, thin films of fiber

Table 4 Variation of shear parameters with varying fiber content

S. No.	$F(\%)$	Angle of shearing resistance (ϕ) (°)	Apparent cohesion (kN/m^2)
1	0	23	0
2	0.25	37	0
3	0.50	40	9
4	0.75	40	29
5	1.00	45	32
6	1.25	42	28.5
7	1.50	41	35.5



a) Without normal stress. b) With normal stress.

Fig. 1 Effect of normal stress on tensile resistance of fiber

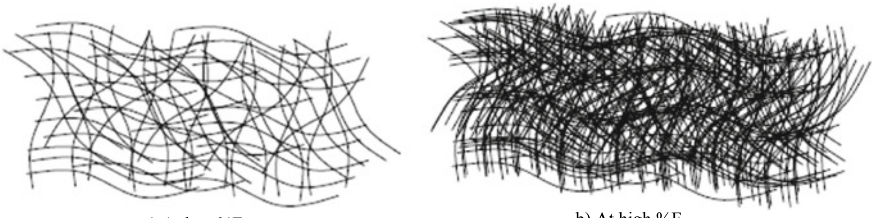


Fig. 2 Thin film of fiber

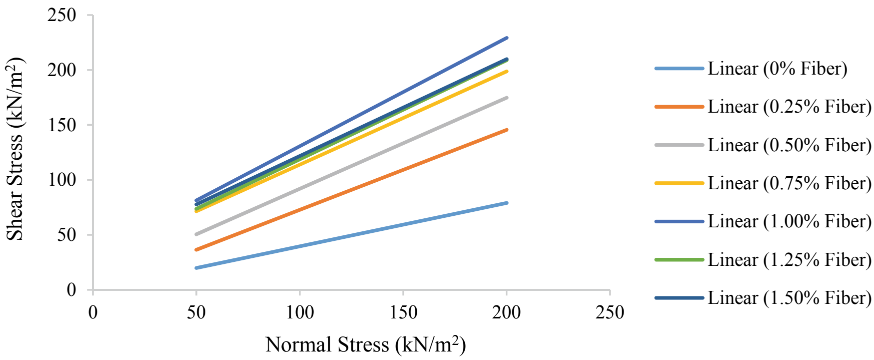


Fig. 3 Failure envelope of fiber-reinforced fine sand

(shown in Fig. 2) were developed between soil grains causing superficial force of attraction between soil grains. The resultant force of attraction was represented as apparent cohesion. At low fiber content (i.e., 0.25 and 0.5%), apparent cohesion is not predominant due to the insufficiency in fiber content for producing superficial force (Fig. 2a). With increase in fiber content, apparent cohesion increased with increase in fiber content and maximum of 35.5 kN/m^2 observed at a fiber content of 1.5%. In contrast, Darvishi and Erken [12] reported a decrease in the apparent cohesion beyond 1.0% of fiber addition. As fiber and fine sand are inert in nature, the development of apparent cohesion is constrained to certain limit only. For most of the fiber contents, apparent cohesion was in the range of 28–35.5 kN/m^2. The typical failure envelopes for varying percentages of fiber were presented in Fig. 3.

3.2 Shear Stress and Ductile Behavior of Fine Sand

The variation in shear stress for various proportions of fiber at each normal stresses (i.e., 50, 100, and 200 kN/m^2) presented in Figs. 4, 5, and 6. With increase in fiber content, the peak stress of fine sand increased under the action of tensile forces in

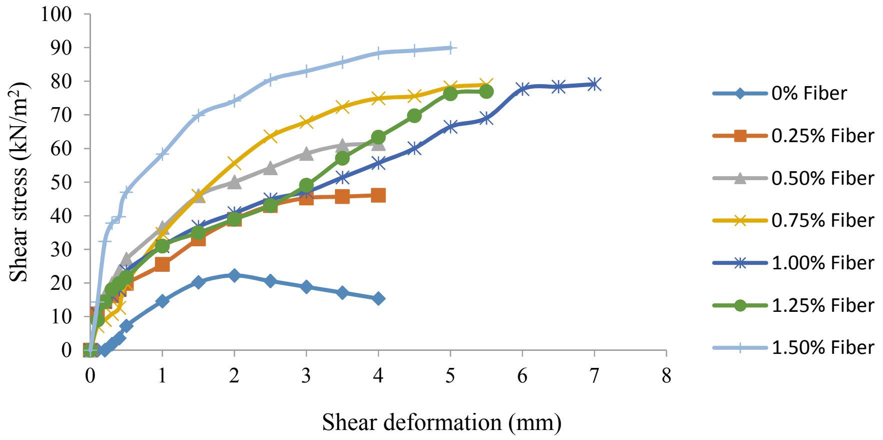


Fig. 4 Shear deformation vs. shear stress plot at 50 kN/m^2 normal stress

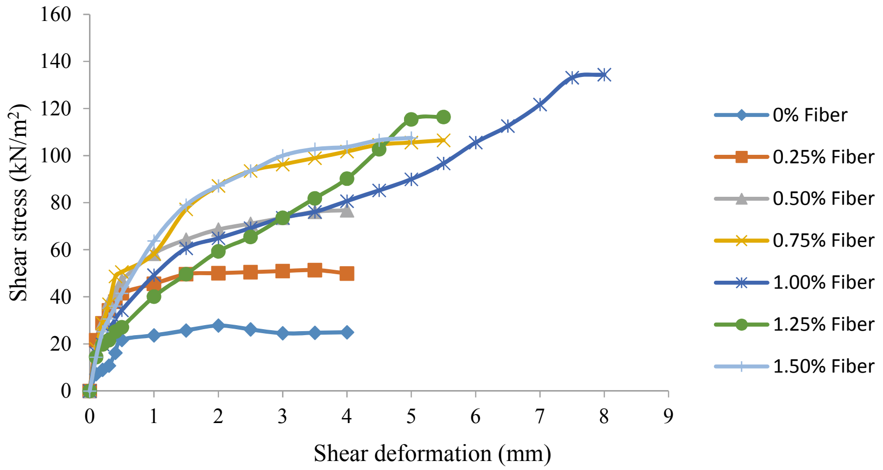


Fig. 5 Shear deformation vs. shear stress plot at 100 kN/m^2 normal stress

the soil–fiber matrix (as shown in Fig. 1b) and surface friction. For most of the fiber-reinforced specimens subjected to varying normal loads, strain-hardening behavior was noticed. Consoli et al. [21] reported that the longer fiber exhibits strain-hardening behavior and shorter fiber exhibits strain-softening behavior. Heineck et al. [22] reported that the strain-hardening behavior was not only controlled by fiber length but also with aspect ratio. However, the variation in aspect ratio is not in the scope of this study. Further, the addition of fiber increased the failure strain in fine sand, resulting in induction of ductile behavior in fine sand [10].

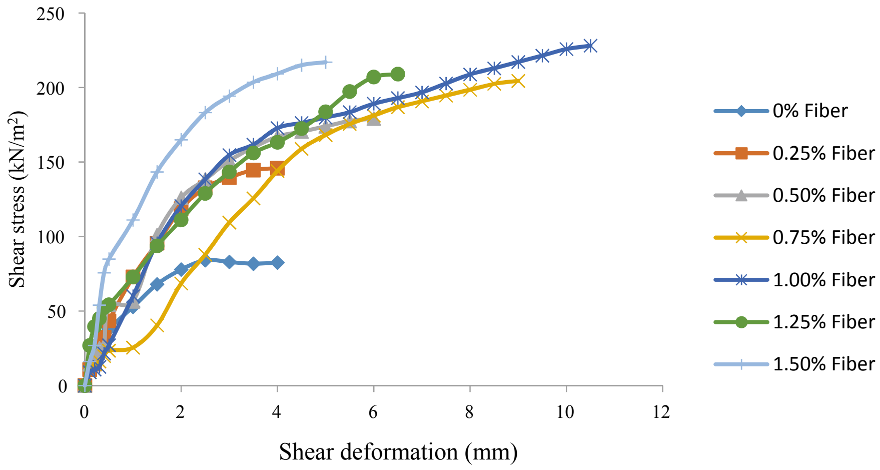


Fig. 6 Shear deformation vs. shear stress plot at 200 kN/m^2 normal stress

3.3 Permeability Characteristics

The coefficient of permeability (k) of fine sand reinforced with varying percentages of fiber is shown in Fig. 7. A significant decrease in k value was observed up to 0.5% of fiber content. With increase in fiber content from 0.5 to 0.75%, the decrease became insignificant. With further increase in fiber content form 0.75 to 1.5%, a slight increase in permeability was noticed. Irrespective of fiber percentage, the coefficient of permeability of fiber-reinforced fine sand was less than that of unreinforced soil.

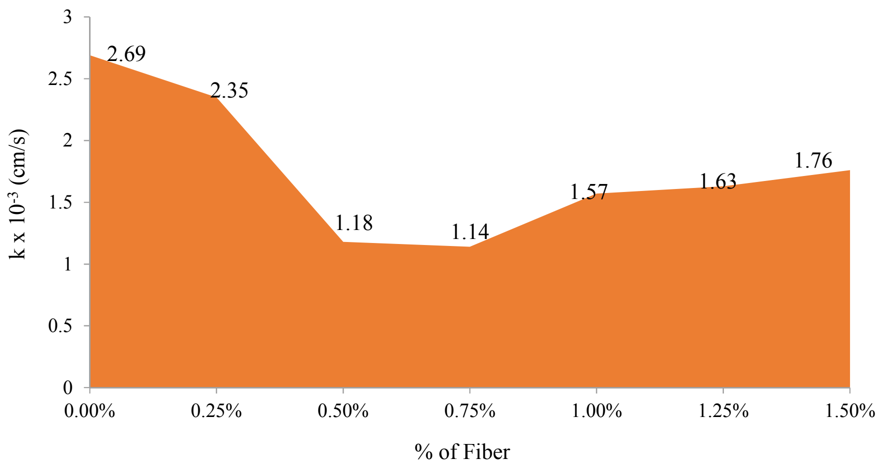


Fig. 7 Variation in k (cm/s) with fiber content

Yang et al. [23] also reported that the decline in k value of sand with fiber inclusion is higher under dense state. As the specimens were compacted at OMC and MDD, the pores in the sand are partially filled with fibers and develop fiber films around the soil grains. Thus, the ability of water to flow through the reinforced fine sand was hindered. However, at 0.25% of fiber addition, the development of fiber film was not predominant. Therefore, the coefficient of permeability (k) at initial fiber content was higher. For other percentages of fiber (0.5–1.5%), the coefficient of permeability of fine sand was within a range of 1.18 × 10–3 to 1.76 × 10–3 cm/s. However, the fiber-reinforced fine sand was constrained to be a low permeable material. Thus, the fiber inclusion might improve the resistance against the seepage flow and piping failure of fine sand.

4 Conclusions

From the results and discussion cited above, the following conclusions were adopted:

- With increase in 12 mm polypropylene fiber content, the maximum dry density decreased and optimum moisture content increased. These results are likely attributed to the resistance offered by the fiber under compaction energy which prevents denser packing and increases the void ratio in the sand-fiber mix.
- The addition of high tensile strength fiber in fine sand increased the interaction between grains through friction. Under the mutual action of tensile force and friction, the angle of shearing resistance (ϕ) of soil increased. The peak value of ϕ is observed at 1.0% of fiber. In the similar manner, the improvement in shear stress and ductile behavior of fine sand are observed with fiber inclusion.
- Under the action of moisture content, apparent cohesion was developed in reinforced fine sand. The development of superficial forces attributed to the formation of thin films of fiber in between the planes of soil grains. The maximum apparent cohesion of 35.5 kN/m^2 observed at 1.50% of fiber content. Therefore, it was stated that the 12 mm polypropylene fiber can be effectively utilized for increasing the shear strength characteristics of fine sand.
- The fiber in the compacted fine sand partially blocks the seepage pores and reduces the water flow through the sand-fiber matrix. Thus, the fiber-reinforced fine sand might have potential resistance against seepage flow. However, further investigation is to be carried out to analyze the piping failure effect under varying soil characterizes such as void ratio, initial moisture content, etc., to use the best of fiber-reinforced sand.

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