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FIBER-REINFORCED COHESIVE SOIL SUBJECTED TO PLATE LOAD TEST

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ABSTRACT

This paper talks about the heap settlement reaction from three plate load tests (0.3 m × 0.3 m square, 25 mm thick) completed on a thick homogeneous layer of compacted durable soil, supported with arbitrarily circulated polypropylene fibers and coir strands, just as on a similar soil without the support. Notwithstanding the field test program, research facility unconfined pressure tests were performed to decide the pressure strain reaction of the compacted strong soil built up with arbitrarily appropriated polypropylene and coir fibers. The research facility test results showed that the consideration of strands in the dirt builds the unconfined compressive strength and the comparing endure disappointment up to ideal fiber content and fiber length and diminishes from there on. The ideal fiber content is found as 0.5% and 0.8% for polypropylene and coir filaments separately. The ideal length of fiber is 20 mm in the scope of fiber lengths researched. Three plate load tests, one without fiber incorporation and the other two with polypropylene and coir fiber considerations at ideal fiber content and ideal fiber length, gotten from unconfined pressure tests, were directed. The plate load test on the dirt fiber layer was performed to moderately high tensions, and gave a perceptible stiffer reaction than that did on the unreinforced layer.

KEYWORDS: Aspect ratio, polypropylene fibers, coir fibers, unconfined compressive strength, plate load test, settlement

INTRODUCTION

Applications of soil strengthening or stabilization range from the mitigation of complex slope hazards to increasing the subgrade stability. Over the years, number of methods has been developed for soil stabilization in particular and ground improvement in general. These methods can be broadly divided into three types, such as mechanical methods, chemical methods, and physical methods. Reinforced soil technique is one of the physical methods of ground improvement, the concept of which was first given by Vidal of France in 1966. Since then significant advances have been made in the design and construction of geotechnical structures such as retaining walls, foundations, embankments, pavements, etc. The function of the reinforcements in the soil matrix is to increase the strength (shearing resistance) and reduce the deformation. Reinforcements may vary either in form (strips, sheets, grids, bars or fibers), textures (rough or smooth) or relative stiffness (high such as steel or low such as fabrics and fibers). Mc Gown et al. (1978) pointed out the distinction between high modulus and low modulus reinforcements and classified the reinforcements in two major categories: (a) ideally inextensible inclusions (metal strips and bars) and (b) ideally extensible inclusions (natural and synthetic fibers, plant roots and polymeric fabrics). The fundamental concepts of reinforced soil are summarized in Shukla et al. (2009). Heimdahl and Drescher (1999) reported that the orientation of reinforcement in a particular direction might result in anisotropy of the soil mass that could result in a decrease of directional strength. On the contrary, the primary advantages of randomly distributed fibers are the absence of potential planes of weakness that can develop parallel to oriented reinforcement (Maher and Gray, 1990).

Past research has demonstrated that inclusion of fibers significantly improves the engineering response of soils. Gray and Ohashi (1983) studied the mechanics of fiber reinforcement in cohesionless soils and showed that inclusion of fibers increased peak shear strength and ductility of soils under static loads. A number of factors such as fiber content, orientation of fibers with respect to the shear surface, and the elastic modulus of the fiber were found to influence the contribution of the reinforcement to the shear strength. Later work (e.g., Gray and Al Refeai, 1986; Maher and Gray, 1990; Al Refeai, 1991; Maher and Ho, 1993, 1994; Ranjan et al., 1994; Cavey et al., 1995; Michalowski and Zhao, 1996; Morel and Gourc, 1997; Consoli et al., 1998; Montardo, 1999; Feuerharmel, 2000; Casagrande, 2001; Michalowski and Cerma´k, 2002) has improved understanding of the mechanisms involved and the parameters affecting the behavior of fiber-reinforced soils under static loading conditions.

Kumar et al. (1999) studied the engineering behaviour of randomly distributed fiber-reinforced pond ash and silty sand based on laboratory investigation and arrived at optimum fiber content of 0.3 to 0.4% of dry weight. Consoli et al. (2003) studied the load–settlement response by conducting plate load tests in the field on a thick homogeneous stratum of compacted sandy soil, reinforced with randomly distributed polypropylene fibers. In addition, he conducted laboratory triaxial compression tests and found that the strength increased continuously at a constant rate, regardless of the confining pressure applied, not reaching an asymptotic upper limit, even at axial strains as large as 25%. Theoretical models have also been developed to study the mechanics of fiber-reinforced soil, which show adequate accuracy when compared with experimental results (Gregory, 1999; Zornberg, 2002). Marandi et al. (2008) studied the strength and ductility of fiber reinforced silty sand with palm fibers and concluded that palm fibers could be used as a reinforcing material in improving the strength and ductility characteristics of soil. Jadhao and Nagarnaik (2008) studied the influence of polypropylene fibers on the engineering behavior of soil fly ash mixtures by using different fiber lengths (6 mm, 12 mm and 24 mm) in the range of 0-1.5% by dry wet of soil and observed that maximum improvement in strength was achieved at a fiber length of 12 mm with fiber content of 1%.

Construction of buildings, roads and other civil engineering structures on weak or soft soil is highly risky because such soil is susceptible to differential settlements due to its poor shear strength and high compressibility. Hence, there is a need to improve certain desired properties like bearing capacity, shear strength (c and φ) and CBR of subgrade soil. In tropical countries like India, the locally available soil (cohesive material) is too plentiful to be ignored. Furthermore, in terms of cost, the use of locally available materials will result in reducing the cost of construction. Thus, the authors are motivated to study the load settlement characteristics of randomly distributed fiber-reinforced cohesive soil through plate load tests using polypropylene (synthetic) and coir (natural) fibers as reinforcement, at different aspect ratio.

EXPERIMENTAL PROGRAMME

Materials Used

The soil sample was locally collected from near Sambalpur city of India. The soil lumps were broken into small pieces and screened through 4.75 mm size sieve to make it free from roots, pebbles, gravel etc. The soil was screened to have a homogeneous mass containing sand to clay. Both polypropylene (synthetic) and coir (natural) fibers were obtained from the local market and used as reinforcement.

The fibers used in the experimental testing programme are commercially available polypropylene and coir fibers. They are commercialized under the name “Geofibers”. Fig. 1 shows the fibers used in the study. The properties of fibers used in this investigation are summarized in Table 1.

(*a*) Polypropylene (*b*) Coir

Figure 1: Fibers cut into 20 mm length.

The soil used is classified as CL according to Unified Soil Classification System. The liquid limit and plastic limit of the soil are found to be 48% and 21%, respectively. The grain size distribution curve shown in Fig. 2 indicates that the soil is composed of 33% fine sand 28% silt and 39% clay with specific gravity of 2.68. The soil has a maximum dry density (MDD) of 1.8 Mg/m^3 with optimum moisture content (OMC) of 11%. The free swell index is 36%.

Sample Preparation

The fibers were cut into average lengths of 15 mm, 20 mm and 25 mm and thus, three different aspect ratios for both the fibers were considered in the investigation. Oven-dried soil was ground and sieved through 2 mm sieve. The fibers were added to this soil at different percentages varying from 0 to 0.6 at an increment of 0.1% for polypropylene and 0 to 1.0% at an increment of 0.2% for coir. The fibers to be added to the soil were considered as a part of the solids fraction in the void-solid matrix of the soil. The content of fiber reinforcement (ρ) is defined herein as $\rho = W_f / W$, where W_f is the weight of the fibers, and W is the weight of the oven-dried soil.

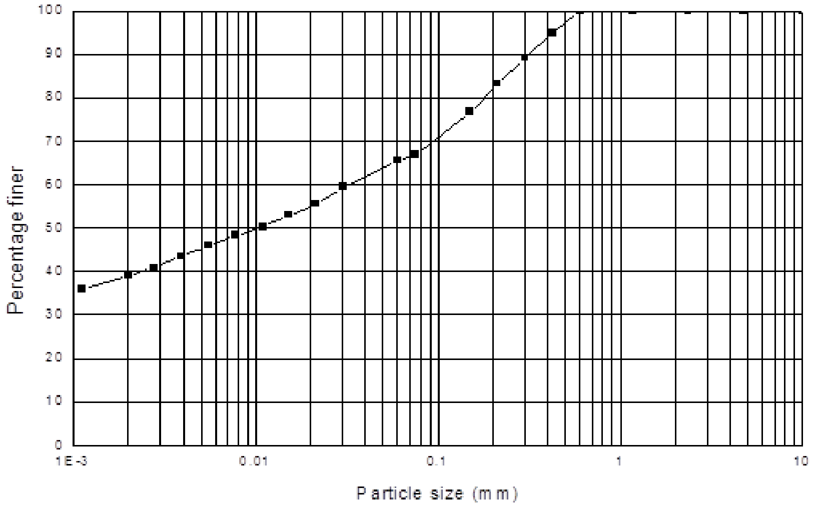

Figure 2: Grain size distribution curve for the soil used

The soil samples were prepared by initial dry mixing of oven-dried soil and corresponding quantity of fiber content (according to percentage by weight of oven-dried soil) as described above. Then optimum water obtained from standard Proctor compaction test was added gradually and mixed in phases until the water spread all over the soil. The dry and wet mixing of soil–fiber–water was carried out in a non-porous metal tray in order to avoid loss of water. The soil, fiber and water were mixed manually spending sufficient time with proper care to get homogeneous mix. The soil mixed with fibers and water was kept in closed polyethylene bags for 24 hours in the laboratory at room temperature (27 ± 2 °C) for uniform mixing of soil with water. The mix thus obtained was used for preparation of unconfined compression test specimens. The above test was also conducted on unreinforced soil specimens to make comparison between the results of unreinforced soil with that of fiber-reinforced soil with variation in the fiber content and fiber length (aspect ratio).

Table 1: Properties of fibers

Properties	Values	
	Polypropylene	Coir
Diameter (mm)	0.20	0.20
Specific gravity	0.91	1.4
Linear density (denier)	260	395
Young’s modulus (GPa)	3	2.1
Tensile strength (MPa)	120	128

Figure 3: Experimental setup for plate load test.

Tests Conducted

In the present investigation an attempt was made to study the effects of random inclusion of polypropylene and coir fibers (with aspect ratio, *l/d* =75, 100 and 125) on the strength of locally available cohesive soil compacted to standard Proctor's maximum density. The effects of fiber inclusion were studied by conducting a series of unconfined compression tests with un-reinforced as well as fiber-reinforced soil. The fiber content was varied from 0 to 0.6% at an increment of 0.1% for polypropylene and 0 to 1.0% at an increment of 0.2% for coir. Thus, a total of 34 unconfined compression tests were conducted. Improvement in the strength was also studied through three plate load tests, one without fiber inclusion and the other two with polypropylene and coir fiber inclusions at optimum fiber content and optimum fiber length, obtained from unconfined compression tests.

Unconfined Compression Test

The soil-fiber-water mix as prepared under sub-heading 2.2.1 was filled in approximately three equal layers in a standard cylindrical mould of 50 mm diameter and 100 mm high and compacted in three equal layers to standard Proctor's maximum density by tamping in several trials. Then, the specimen was extracted for unconfined compression test. Specimens were prepared at ρ = 0.1%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% with polypropylene fibers and 0.2%, 0.4%, 0.6%, 0.8% and 1.0% with coir fibers for all the three aspect ratios. Three specimens were prepared and tested for each combination of variables including the specimens without fiber inclusions.

The initial length, diameter and weight of the specimen were measured and the specimen placed on the bottom plate of the loading device. The upper plate was adjusted to make contact with the specimen. The deformation dial gauge was adjusted to a suitable reading and force was applied so as to produce axial strain at a rate of 0.125 mm per minute. The force reading was taken at suitable intervals of the deformation dial reading. The specimen was compressed until failure surfaces had definitely developed or until an axial strain of 20 percent was reached. The unconfined compression tests were conducted on both unreinforced and reinforced specimens as per Indian Standards Specifications IS 2720 (Part-10), 1991.

Plate Load Test

Plate load test in the field is a cumbersome task and therefore it was decided in the present investigation to conduct three tests, one without fiber inclusion and the other two with polypropylene and coir fiber inclusions at optimum fiber content and optimum fiber length, obtained from unconfined compression tests. The optimum fiber content obtained from unconfined compression tests was 0.5% for polypropylene fibers and 0.8% for coir fibers at fiber aspect ratio of 100 (20 mm long fiber).

Plate load tests were conducted in excavated test pits of size 2000 mm × 2000 mm × 1200 mm in VSSUT campus by using 300 mm × 300 mm smooth square steel plates of 25 mm thick. The test pits were excavated to a depth of $4B$ (4 × 300 mm = 1200 mm) where B was the width of test plate and the excavated materials were thrown away. This depth was chosen based on Boussinesq stress distribution theory. Using this theory, the stress below a footing dissipates to effectively zero at a depth of about $3B$ below the footing. Therefore, using an excavation depth of $4B$ ensured that the test results were not affected by previous tests. The size of the pit was 2000 mm × 2000 mm in plan i.e. not less than $5B$ (5 × 300 mm = 1500 mm) to allow free development of failure surface as per Indian Standards Specifications (Bureau of Indian Standards, IS 1888, 1982). In the process, the effect of the wall of the pit on settlement was overcome. Three such pits were excavated; one for soil without reinforcement and the other two for soil reinforced with polypropylene and coir fibers. After excavation of each pit, the bottom of the pit was perfectly rammed and leveled. Soil in Pit-1 and soil–coir fiber mix in Pit-2 and soil-polypropylene fiber mix in Pit-3 were compacted in 12 equal layers of 100 mm thick each by ramming uniformly over the entire area. Dry soil was added with optimum water determined from standard Proctor compaction test and mixed thoroughly in a rotating drum mixer to be compacted in Pit-1. Dry soil and coir fibers (0.8% fibers by weight of dry soil) were added with optimum water and mixed in the mixer as described above to be compacted in Pit-2. Similarly, soil mixed with polypropylene fibers (0.5% fibers by weight of dry soil) were added with optimum water and mixed to be compacted in Pit-3. To maintain a consistent in-place density throughout the test pits, the same compacting effort was used on each layer. In-place density was measured by a nuclear moisture density gauge.

The field load testing program was carried out at the experimental site as described above. The load was applied through a system comprising a hydraulic jack, a reaction beam, and a load platform, and measured using a calibrated load cell. Four dial gauges with divisions of 0.01 mm and 50 mm travel were used for settlement measurement. The gages were fixed to a reference beam and supported on external rods. The load was applied in equal increments. The experimental setup is shown in Fig.3.

A minimum seating load of 0.70 kN was applied and removed before starting the load test. The load was applied to soil in equal increments of 5 kN through hydraulic jack and was measured by load gauge, attached to the pumping unit kept over the pit**,** away from the testing plate through extending pressure pipes.

Settlements were observed for each increment of load after an interval of 1, 2.25, 4, 6.25, 9, 16 and 25 min and thereafter at hourly intervals to the nearest 0.02 mm. Load increment was applied when the rate of settlement was reduced to a value of 0.02 mm/min or 24 hours whichever was earlier. The next increment of load was then applied and the observations repeated. The test was continued till, a settlement of 25 mm was obtained or till failure occurred, whichever was earlier. Thus, the tests were conducted on the soil alone and then the soil reinforced with coir and polypropylene fibers in accordance with Indian Standards Specifications IS 1888, 1982.

The load settlement curves were then plotted and ultimate loads were calculated from the tangent intersection of the two straight portions of the curve, at the initial straight portion of the load-settlement curve and the steeper straight portion at the end of the curve.

TEST RESULTS AND DISCUSSIONS

Observations from unconfined compression tests and plate load tests have been analyzed to study the effect of randomly distributed polypropylene and coir fibers on the strength of the soil.

Unconfined Compression Tests

The test results of unconfined compression tests are presented in the form of stress-strain relationships in Fig. 4 and Fig. 5. The strain at failure and the corresponding unconfined compressive strength at different fiber content and fiber length have been presented in Table 2 and Table 3. The variations of failure strain at different fiber content and fiber length have been presented in Fig. 6. It is observed from Fig. 4 and Table 2 that with the inclusion of polypropylene fibers in the soil the unconfined compressive strength (q_u) and the strain at failure increases with increase in fiber content up to certain fiber content and decreases thereafter. It is also observed that the maximum increase in failure strain is 217% compared to unreinforced soil occurring at a fiber content of 0.5% for 15 mm fiber length. The corresponding increase in q_u of the reinforced soil is observed to be 131%.

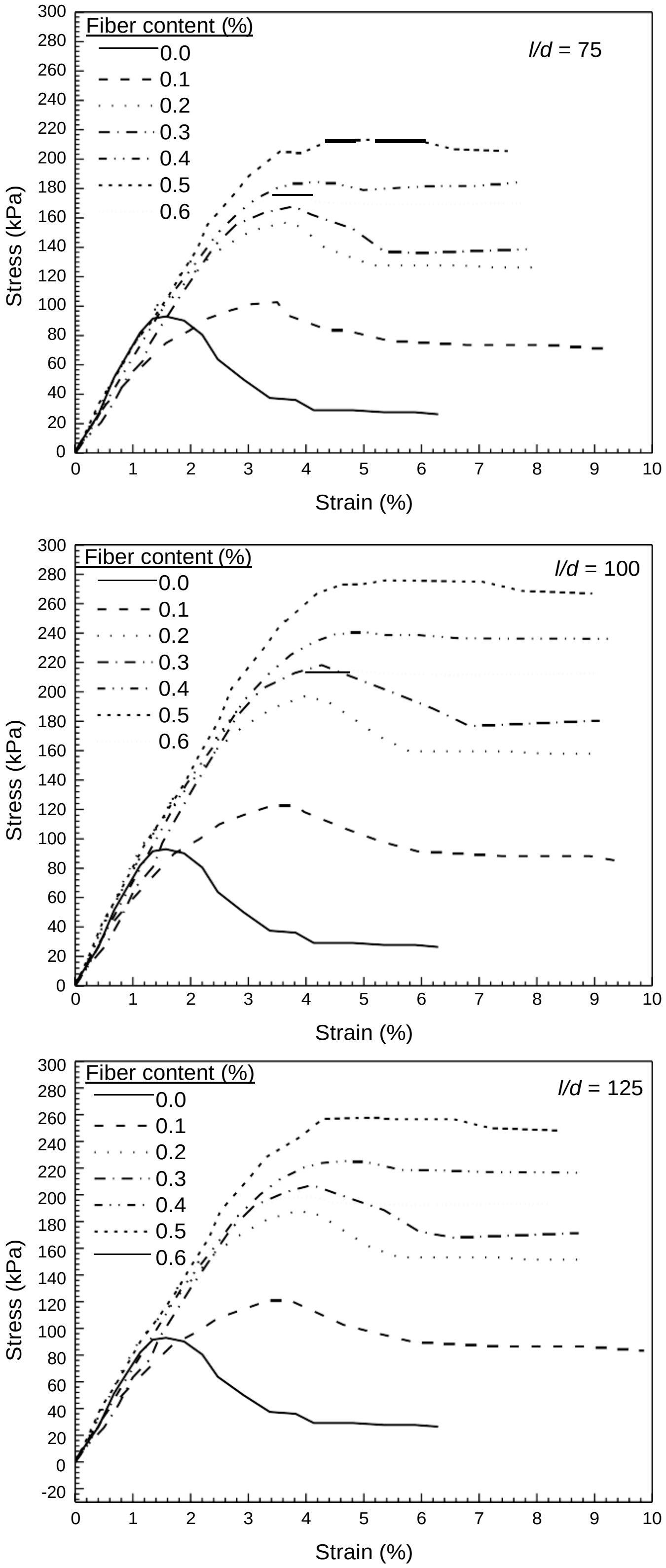

Figure 4: Stress-strain response of soil reinforced with polypropylene fibers.

Table 2: Unconfined compressive strength (UCS) of soil reinforced with polypropylene fibers

Fiber content (%)	*l/d* = 75		*l/d* = 100		*l/d* = 125	
	Failure strain (%)	UCS (kPa)	Failure strain (%)	UCS (kPa)	Failure strain (%)	UCS (kPa)
0.0	1.57	92.95	1.57	92.95	1.57	92.95
0.1	3.51	102.66	3.82	123.20	3.68	121.72
0.2	3.62	156.76	3.99	196.95	3.85	188.12
0.3	3.79	167.86	4.27	218.22	4.10	207.31
0.4	4.18	184.50	4.97	240.86	4.73	225.47
0.5	4.99	213.25	5.38	275.93	5.18	257.82
0.6	3.98	175.00	4.53	218.30	4.18	198.40

Similarly, for fiber lengths of 20 mm and 25 mm, the maximum increase in failure strains are 243% and 230% and the corresponding increase in q_u are 199% and 179% respectively compared to unreinforced soil occurring at a fiber content of 0.5%. Thus, the unconfined compressive strength and the corresponding strain at failure increase up to 20 mm fiber length (*l/d* =100) and decrease thereafter. Increase in the length of fiber beyond 20 mm reduces the soil–fiber interlocking, which may be the reason for the reduction in failure strain and the corresponding q_u. Hence, the optimum fiber content is observed to be 0.5% in the range of fiber lengths considered in the study. Further, it is observed from Fig. 6 (a) that with the inclusion of polypropylene fibers, the strain at failure and hence the ductility of the reinforced soil increases when compared with the unreinforced soil up to optimum content and length of fiber. Thus, the maximum ductility expressed in terms of strain at failure for polypropylene fiber-reinforced soil is observed to be 3.43 times the unreinforced soil occurring at a fiber content of 0.5% and fiber length of 20 mm.

Table 3: Unconfined compressive strength (UCS) of soil reinforced with coir fibers

Fiber content (%)	*l/d* = 75		*l/d* = 100		*l/d* = 125	
	Failure strain (%)	UCS (kPa)	Failure strain (%)	UCS (kPa)	Failure strain (%)	UCS (kPa)
0.0	1.57	92.95	1.57	92.95	1.57	92.95
0.2	2.61	115.38	2.87	140.76	2.82	136.54
0.4	3.15	135.44	3.35	165.24	3.29	160.28
0.6	3.69	159.42	4.20	200.86	4.03	190.82
0.8	3.98	169.56	4.39	214.79	4.19	202.20
1.0	3.37	143.76	3.91	179.70	3.24	169.28

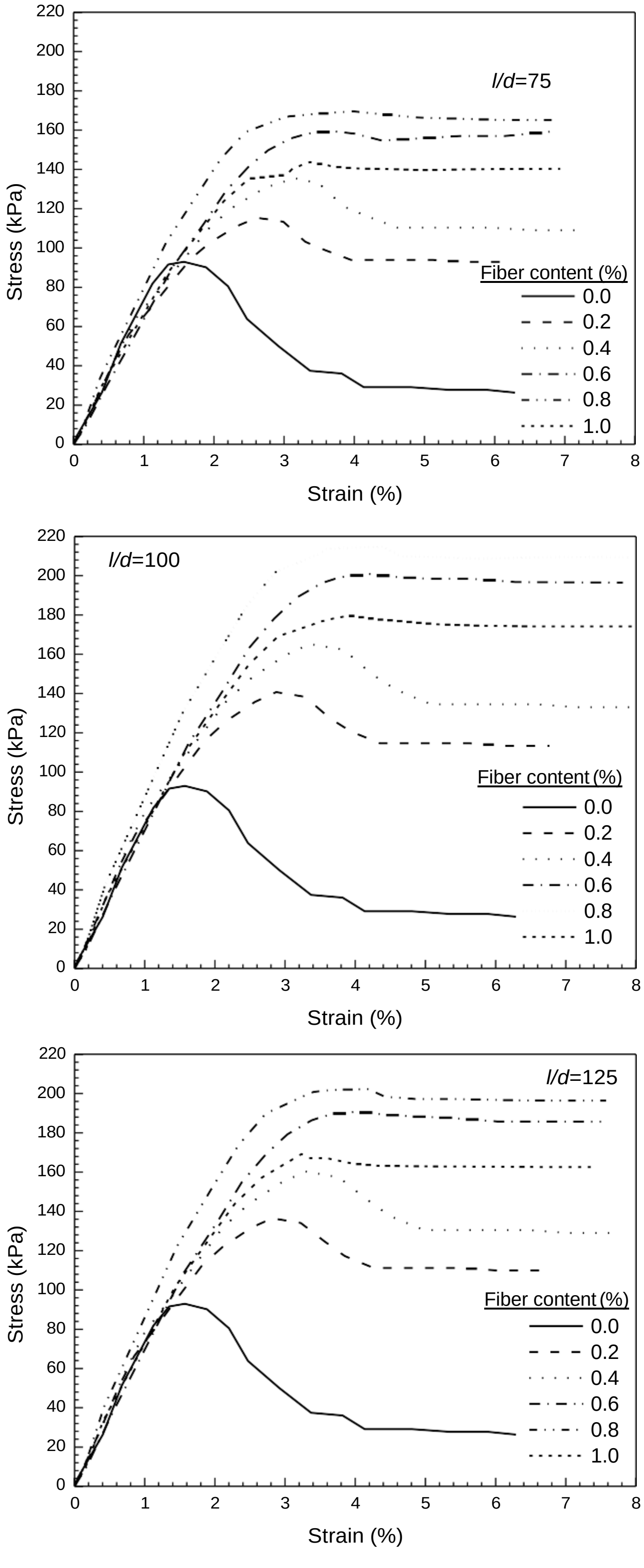

Figure 5: Stress-strain response of soil reinforced with coir fibers.

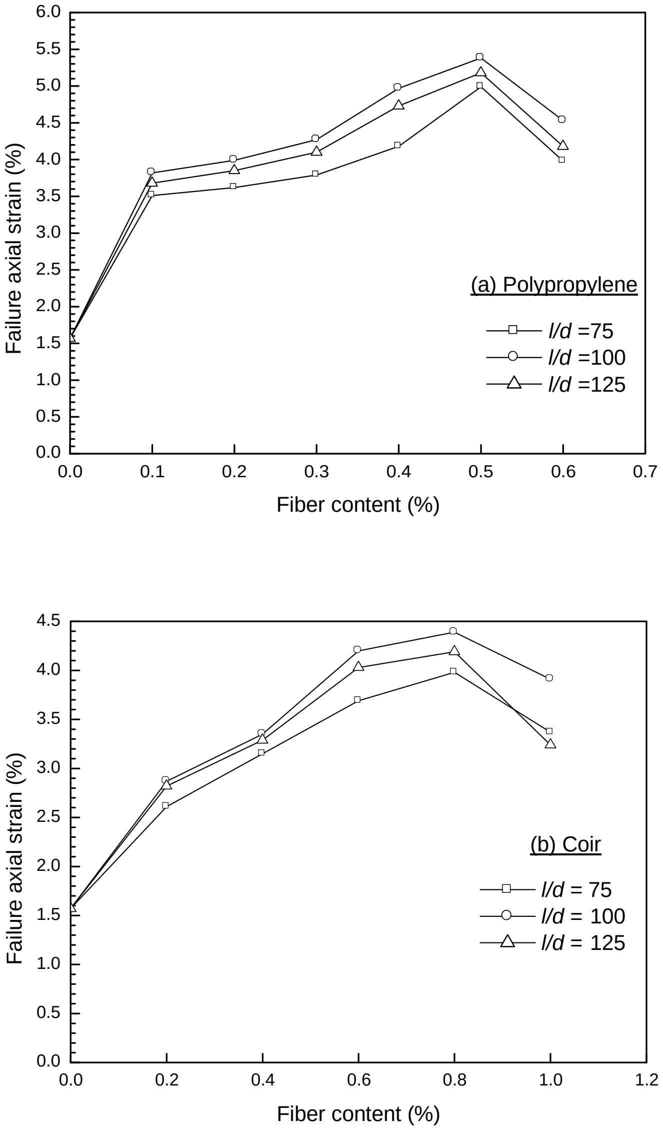

Figure 6: Failure strain for fiber-reinforced soil at different fiber.

Similarly, it is observed from Fig. 5 and Table 3 that the inclusion of coir fibers in the soil increases the unconfined compressive strength (q_u) and the strain at failure with increase in fiber content up to a given fiber content and decreases thereafter. It is also observed that the maximum increase in failure strain is 153% compared to unreinforced soil occurring at a fiber content of 0.8% for 15 mm fiber length. The corresponding increase in q_u of the reinforced soil is observed to be 84%. Similarly, for fiber lengths of 20 mm (*l/d* =100) and 25 mm (*l/d* =125), the maximum increase in failure strains, are 180% and 167% and the corresponding increase in q_u are 133% and 119% respectively compared to unreinforced soil occurring at a fiber content of 0.8%. Thus, the unconfined compressive strength and the corresponding strain at failure increase up to 20 mm fiber length (*l/d* =100) and decrease thereafter. Increase in the length of fiber beyond 20 mm reduces the soil–fiber interlocking, which may be the reason for the reduction in failure strain and the corresponding q_u. Hence, the optimum fiber content is observed to be 0.8% in the range of fiber lengths considered in the study and maximum increase in q_u occurs at fiber length of 20 mm (*l/d* =100). Further, it is observed from Fig. 6 (b) that with the inclusion of coir fibers, the strain at failure and hence the ductility of the reinforced soil increases when compared with the unreinforced soil up to optimum content and length of fiber. Thus, the maximum ductility expressed in terms of strain at failure for coir fiber-reinforced soil is observed to be 2.8 times the unreinforced soil occurring at a fiber content of 0.8% and fiber length of 20 mm.

At fiber content higher than the optimum, q_u decreases compared to its maximum value for both the fibers. This may be due to the fact that with higher fiber content, the quantity of soil matrix available for holding the fiber is insufficient to develop an effective bond between fibers and soil, causing balling of fibers and poor mixing.

Kumar et al. (1999) reported increase in both peak and residual strength along with the strain at failure of silty sand with inclusion of 30 mm polyster fiber up to an optimum fiber content of 4%. Jadhao and Nagarnaik (2008) reported increase in both peak and residual strength along with the strain at failure of soil-fly-ash mixture with increase in fiber content and length of polypropylene fiber inclusion and the optimum fiber content was 1% for 12 mm fiber length. Marandi et al. (2008) reported similar results on ductility of silty sand reinforced with palm fibers.

Also, Jiang et al. (2010) reported that the unconfined compressive strength (UCS) of soil reinforced with polypropylene fibers was greater than those of the parent soil; the UCS, of fiber-reinforced soil exhibited an initial increase followed by a rapid decrease with increasing fiber content and fiber length, and hence the optimal fiber content and fiber length were found as 0.3% by weight of the parent soil and 15 mm, respectively. Similar trend is observed in the present investigation with optimal fiber content of 0.5% and 0.8% by weight of dry soil for polypropylene and coir fibers respectively. The optimal length for both the fibers is 20 mm.

Plate Load Tests

Load-settlement curves are plotted with the data obtained from the plate load tests and presented in Fig. 7. Study of load-settlement behavior from Fig. 7 shows that at each load increment, the settlement in unreinforced soil is much more compared to the reinforced soil, minimum settlement being observed for the soil reinforced with polypropylene fibers. Thus, it is revealed that the inclusion of fiber reinforcement increases the stiffness of the soil. The ultimate load for the unreinforced and reinforced soil are found from the tangent intersection of the two straight portions of the load-settlement curve at the initial straight portion and the steeper straight portion at the end (Adams and Collin, 1997) as shown in Fig 8. The ultimate load for the unreinforced soil is found to be 42 kN and the values for soil reinforced with coir fibers and polypropylene fibers are 70 kN and 80 kN respectively. Thus, the ultimate load of the soil reinforced with 0.8% coir fibers and 0.5% polypropylene fibers increases by 67% and 90% respectively as compared to unreinforced soil.

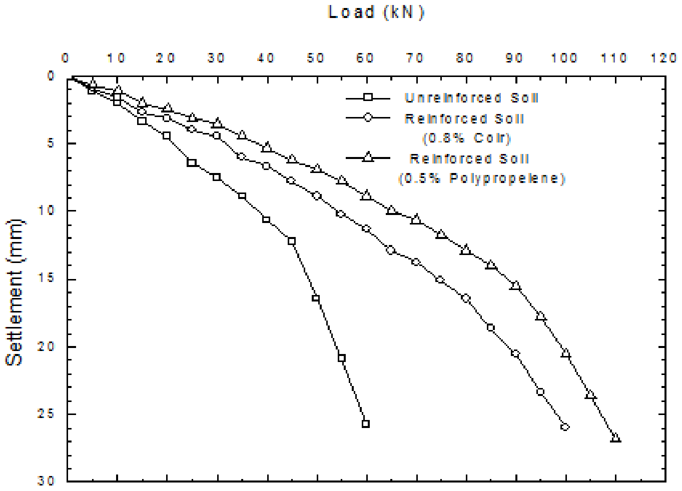

Figure 7: Load settlement response for plate load test.

Also, an attempt has been made to express the load-settlement behavior in a non-dimensional form. Settlement (*S*) is expressed as a fraction of the width of the test plate (*B*) and called settlement ratio (*S/B*) and load (*Q*) is expressed as a fraction of the ultimate load of unreinforced soil (Q_{uu}) called load ratio (Q/Q_{uu}). *S/B* versus Q/Q_{uu} plotting thus obtained is presented in Fig. 9. The rate of settlement decreases with inclusion of fibers either coir or polypropylene, maximum decrease being observed with the inclusion of polypropylene fibers. It is also observed that *S/B* for unreinforced soil increases linearly up to Q/Q_{uu} 1.0, beyond which it changes abruptly to a steeper slope. Similarly, almost linear variation in *S/B* is observed up to Q/Q_{uu} value 2.0 for fiber-reinforced soil with a slope flatter compared to unreinforced soil. For Q/Q_{uu} value beyond 2.0, a gradual increase in slope is observed, less being observed for soil reinforced with polypropylene fibers. This indicates that the fiber-reinforced soil is capable of absorbing more strain energy prior to failure. Thus, soil-fiber matrix may be used as an improved material in the field of geotechnical engineering.

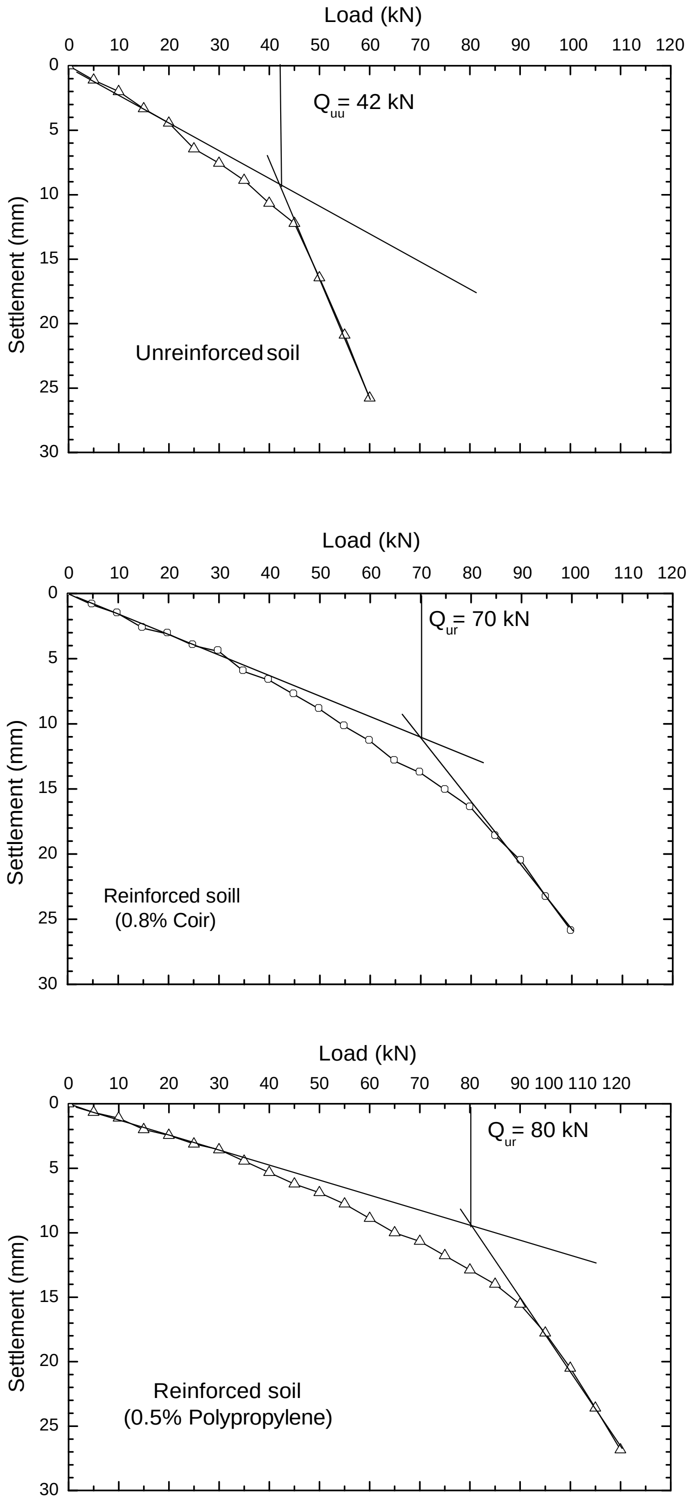

Figure 8: Ultimate loads for unreinforced and fiber-reinforced soil.

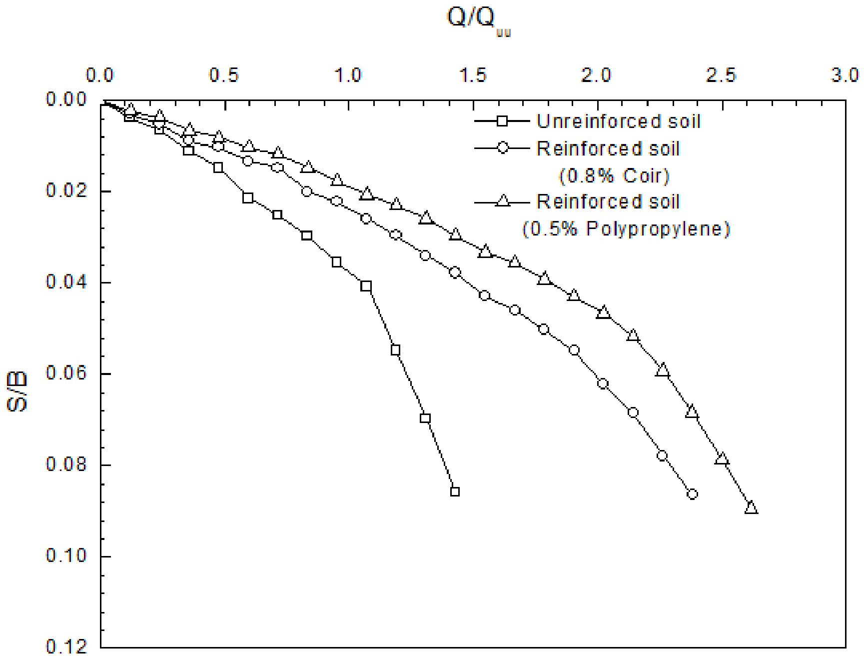

Figure 9: S/B versus Q/ Q_{uu}.

CONCLUSIONS

Based on the results and discussions the following conclusions are drawn.

With inclusion of fibers in the soil, the unconfined compressive strength and the corresponding strain at failure increase up to an optimum fiber content and fiber length and decrease thereafter. The optimum fiber content is observed to be 0.5% and 0.8% for polypropylene and coir fibers respectively in the range of fiber lengths investigated.

The maximum increase in q_u and failure strain for soil reinforced with polypropylene fibers is 199% and 243% respectively compared to unreinforced soil, which occur at fiber length of 20 mm (*l/d* =100). Similarly, the maximum increase in q_u and failure strain for soil reinforced with coir fibers is 133% and 180% respectively at fiber length of 20 mm (*l/d* =100).

Inclusion of fibers in soil increases the strain at failure and therefore makes the reinforced soil matrix more ductile.

It is concluded from plate load tests that the settlement under a particular load in unreinforced soil is much more compared to the reinforced soil, minimum settlement being observed for the soil reinforced with polypropylene fibers.

The ultimate load for the unreinforced soil is found to be 42 kN and the values for soil reinforced with coir fibers and polypropylene fibers are 70 kN and 80 kN respectively. Thus, the ultimate load of the soil reinforced with 0.8% coir fibers and 0.5% polypropylene fibers increases by 67% and 90% respectively as compared to unreinforced soil.

Fiber-reinforced soil is capable of absorbing more strain energy prior to failure. Thus, soil-fiber matrix may be used as an improved material in the field of geotechnical engineering.

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