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STRENGTH BEHAVIOR OF SOIL REINFORCED WITH POLYPROPYLENE AND COIR FIBER

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Abstract: The strength and compressibility characteristics of local available soil reinforced with randomly distributed discrete fibers are investigated. Polypropylene (synthetic) and coir (natural) fibers, available locally at very low cost are used as reinforcement. The lengths of fibers considered in the investigation are 15 mm, 20 mm and 25 mm which give aspect ratios of 75, 100 and 125. The investigation is made through a series of compaction tests, unconfined compression tests, direct shear tests, triaxial compression tests, CBR tests, field plate load tests and consolidation tests on unreinforced and fiber-reinforced soil, with variation in fiber content and fiber length. The optimum moisture content (OMC) and maximum dry density (MDD) of the soil reinforced with fibers (0 to 1% with an increment of 0.1% and 0.2% to 1.6% with increment of 0.2% by weight of oven-dried soil for polypropylene and coir fibers respectively) are determined in the range of fiber lengths mentioned above by standard Proctor compaction tests. It is observed that the unconfined compressive strength (UCS), the strain at failure, the shear parameters (cohesion and angle of internal friction) of fiber-reinforced soil is greater than those of the parent soil. The UCS, cohesion, and angle of internal friction of fiber-reinforced soil exhibit an initial increase followed by decrease with increase in fiber content and fiber length. Similar trend is also observed in the failure deviator stress and soaked CBR values with increase in fiber content and length. From the above investigation the optimum fiber content is found to be 0.4% and 0.8%, by weight of dry soil for polypropylene and coir fibers respectively. However, the optimum fiber length is observed to be 20 mm for both the fibers investigated. Inclusion of fibers in soil increases the strain at failure thereby making the reinforced soil matrix more ductile.

Keywords: MDD, OMC, Soil, Fiber, CBR, Optimum Fiber

1.0 General:

Reinforced earth is a construction material obtained by associating earth and reinforcements; its cost is fairly low, for the mechanical properties of the earth can be improved in an anisotropic way i.e. only where it is more specifically needed, depending upon the stress pattern to which the material is subjected. The word “earth” refers theoretically to any kind of soil, natural as well as soils treated either by mechanical or by chemical means, granular as well as cohesive soils.

2.0 Types of Reinforcing Materials:

Reinforcement may vary, either in form (strip, sheets, grids, bars or fibers); texture (rough or smooth); or relative stiffness (high such as steel or low such as fabric and fibers). McGown, et al. (1978) pointed out the distinction between high modulus and low modulus reinforcement and classified the reinforcement into two major categories, (a) ideally inextensible inclusions (i.e. metal strips and bar) and (b) ideally extensible inclusions (i.e. natural and synthetic fibers, plant roots and polymeric fabrics).

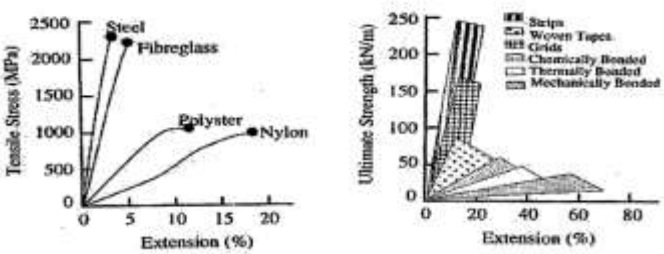
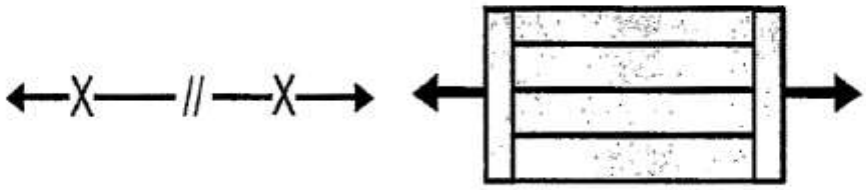


Figure 2.1 Stress- strain characteristics of typical reinforcing materials

a) Bonaparte and Schmertmann (1987) considered steel reinforcement as an inextensible reinforcement and geosynthetic reinforcing materials as extensible reinforcements, for almost all practical applications. Thus, an inextensible metallic reinforcement makes the structure brittle and the extensible geosynthetic increases the ductility of the reinforced soil structure (Fig. 2.2).



(a) inextensible reinforcements (b) extensible reinforcements

Figure 2.2 Analogy of reinforced soil failure mechanisms (after Jones, 1992)

2.3.2 Extensible Reinforcements

Geosynthetics is the collective term applied to thin, flexible, sheets of material incorporated in or about soil to enhance its engineering performance. Geotextile, a generic member of geosynthetic family, is a planner, permeable, polymeric or natural fiber textile material, used in contact with soil or rock and/or any other geotechnical material in civil engineering applications.

(a) Uniaxial geogrid (b) Biaxial geogrid

Figure 2.3 Typical geogrids used as soil reinforcements (after John, 1987)

3.0 EXPERIMENTAL PROGRAMME

The experimental programme conducted in this study is comprised primarily of compaction tests, unconfined compression tests, direct shear tests, triaxial compression tests, CBR tests, plate load tests and consolidation tests on un-reinforced as well as randomly distributed fiber-reinforced soils to evaluate their strength and compressibility characteristics. The material properties, instrumentation, testing procedures, and the scope of the experimental programme are presented in the following sections.

Reinforcement Used

Both synthetic and natural fibers are used as reinforcement in the present investigation. The fibers used in the experimental testing program are commercially available polypropylene and coir fibers. They are commercialized under the name "Geofibers". Fig. 3.1 shows the fibers used in the study. The properties of fibers used in this investigation are summarized in Table 3.1.

Soil Used

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 particle size distribution curve (Fig. 3.2) 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 with optimum moisture content (OMC) of 11%. The free swell index is 36%.

(a) Polypropylene (b) Coir

Figure 3.1 Fibers cut into 20 mm length

Materials

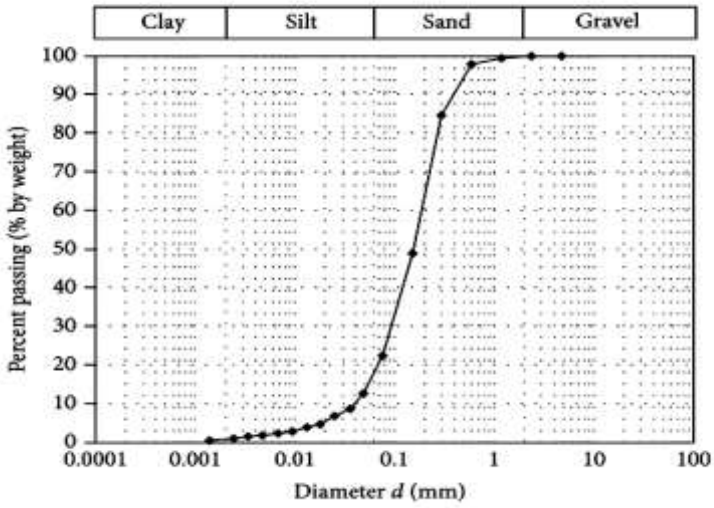


Figure 3.2 Particle size distribution curve

Table 3.1 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

Experimental Programme

The experimental programme conducted in this study includes compaction test, unconfmed compression test, direct shear test, triaxial compression test, CBR test, plate load test and consolidation tests of un-reinforced as well as randomly distributed fiber-reinforced soil. The experimental program is summarized in Table 3.2 and briefly discussed next.

3.4 Test Methods

Compaction Test

The fibers are cut into average lengths of 15 mm, 20 mm and 25 mm and thus, three different aspect ratios for both the fibers are considered in the investigation. Oven-dried soil is ground and sieved through 2 mm sieve. The fibers are added to this soil at different percentages varying from 0 to 1 at an increment of 0.1% for polypropylene and 0 to 1.6% at an increment of 0.2% for coir.

Table 3.2. Summary of Test Programme

Series No.	Soil used	Reinforcement materials	Variables	No. of tests
1. Compaction Test				
1	Locally Available Clayey Soil	Polypropylene fibers Coir fibers	1 .Without fibers 2.With fibers (0.1 to 1 % for polypropylene and 0.2 to 1.6% for coir by dry weight of soil) 3. Aspect Ratio (*l/d* =75, 100 and 125)	55
2. Unconfined Compression Test				
2	Locally Available Clayey Soil	Polypropylene fibers Coir fibers	1 .Without fibers 2,With fibers (0.1 to 0.6% for	34

			polypropylene and 0.2 to 1.0% for coir by dry weight of soil) 3. Aspect Ratio *(l/d* =75, 100 and 125)	
3. Direct Shear Test				
3	Locally Available Clayey Soil	Polypropylene fibers Coir fibers	1 .Without fibers 2.With fibers (0.1 to 0.5% for polypropylene and 0.2 to 1.0% for coir by dry weight of soil) 3. Normal Stress of 100,200 and 300KN	93
4. Triaxial Compression Test				
4	Locally Available Clayey Soil	Polypropylene fibers Coir fibers	1 .Without fibers 2.With fibers (0.1 to 0.5% for polypropylene and 0.2 to 1.0% for coir by dry weight of soil) 3. Confining pressure of 70, 140 and 210 kPa	93
5. CBRTest				
4	Locally Available Clayey Soil	Polypropylene fibers Coir fibers	1 .Without fibers 2,With fibers (0.1 to 0.6% for polypropylene and 0.2 to 1.0% for coir by dry weight of soil) 3. Aspect Ratio *(l/d* =75, 100 and 125)	55

Sample Preparation

The fibers are cut into different lengths and the soil samples are 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 under 3.4.1. Then optimum water obtained from standard Proctor compaction test is added gradually and mixed in phases until the water spreads all over the soil. The dry and wet mixing of soil-fiber-water is carried out in a non-porous metal tray in order to avoid loss of water. The soil, fiber and water are mixed manually spending sufficient time with proper care to get homogeneous mix. The soil mixed with fibers and water is kept in closed polythene bags for 24 hours in the laboratory at room temperature (27 ± 2 °C) for uniform mixing of soil with water. The mix thus obtained is used for preparation of unconfined compression, direct shear, triaxial compression, CBR and consolidation test specimens as described under different sub-headings below. The above tests are also conducted on unreinforced soil specimens to make comparison between the results of unreinforced soil with that of reinforced soil with variation in the fiber content and fiber length (aspect ratio).

Unconfined Compression Test

The soil-fiber mix as prepared under 3.3.2 is 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 is extracted for unconfined compression test. Specimens are prepared at p = 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 are prepared and tested for each combination of variables.

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

Direct Shear Test

The experimental study involves a series of unconsolidated undrained direct shear tests on the soil without and with randomly distributed fibers. Soil-fiber mix, as prepared under 3.2.2 is compacted directly in the shear box of 60 mm × 60 mm in plan and 25 mm in depth, by compacting in two layers by fixing the two-halves of the shear box together with the fixing screws and tamping in several trials to standard Proctor's maximum density to obtain the specimens for direct shear tests. The specimens are prepared at *p* = 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% 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 are prepared for each fiber contents. The shear box with the specimen, plain grid plate over the base plate at the bottom of the specimen, and plain grid plate at the top of the specimen are fitted into position in the load frame. The loading pad is placed on the top grid plate. The water jacket is provided so that the sample does not get dried during the test.

igure 3.4 Experimental setup for unconfined compression test Figure

F 43.5 Experimental setup for direct shear test

Triaxial Compression Test

The soil-fiber mix as prepared under 3.2.2 is 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 by tamping in several trials to standard Proctor's maximum density. Thereafter, the specimen is extracted for triaxial compression test. Specimens are prepared at *p* = 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% 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 are prepared and tested for each combination of variables. The conventional unconsolidated undrained triaxial compression test is performed at a strain rate of 1.27 mm/min under the confining pressures (σ3) of 70, 140 and 210 kPa on reinforced and unreinforced specimens as per Indian Standards Specifications IS 2720 (Part-11), 1993. The specimen prepared, as described above are placed centrally on the pedestal of the triaxial cell. The cell is assembled with the loading ram initially clear of the top cap of the specimen and the cell containing the specimen is placed in the loading machine.

Fig. 3.6 Experimental setup for triaxial compression test

3.4.6 CBR Test

California Bearing Ratio (CBR) tests are carried out to examine the effects of polypropylene and coir fibers on the soaked CBR value of fiber-reinforced soil. CBR test specimens are prepared in a cylindrical mould of 150 mm diameter and 175 mm height by filling the soil-fiber mix prepared under 3.2.2. The spacer disc is placed at the bottom of the mould over the base plate and a coarse filter paper is placed over the spacer disc. The soil-fiber mix is divided into three equal parts; the soil is compacted in three equal layers in the mould, by applying 56 evenly distributed blows in each layer of the 2.6 kg rammer. After compacting the last layer, the collar is removed and the excess soil mix above the top of the mould is evenly trimmed off by means of the straight edge. Specimens are prepared at p = 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9% and 1.0% with polypropylene and 0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 1.2%, 1.4%, and 1.6% with coir fibers for all the three aspect ratios. Similarly, specimen without reinforcement is prepared. Three specimens are prepared for each combination of variables. For each specimen the clamps are removed and the mould with the compacted soil is lifted leaving below the perforated base plate and the spacer disc which is removed. A filter paper is placed on the perforated base plate, the mould with compacted soil is inverted and placed in position over the base plate and the clamps of the base plate are tightened. Another filter paper is placed on the top of surface of the sample and the perforated plate with adjustable stem is placed over it. Surcharge weights of 2.5 kg weight are placed over the perforated plate and the whole mould with the weights is placed in a water tank with drinking water for soaking of the soil specimen for 96 hours. Then, the mould is taken out of the water tank and the sample is allowed to drain in a vertical position for 15 minutes. Thereafter, the plunger of the loading frame is seated at the centre of the specimen and is brought in contact with the top surface of the soil sample by applying a seating load of 4.0 kg. The dial gauge for measuring the penetration values of the plunger is fitted in position. The dial gauge of the proving ring and the penetration dial gauge are set to zero. The load is applied through the penetration plunger at a uniform rate of 1.25 mm per minute. The load readings are recorded at penetration readings of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, and 10.0 and 12.5 mm or to a penetration value at which the sample fails prior to 12.5 mm penetration. After the final reading, the load is released and the mould is removed from the loading machine. The proving ring calibration factor is noted to convert the load dial values into load in kg. The load-penetration curves are plotted for all the specimens and the loads corresponding to 2.5 and 5.0 mm penetration are noted. The CBR is calculated as given below.

CBR = (Unit load carried by soil sample at 2.5 or 5.0 mm penetration / Unit load carried by standard crushed stones at respective penetration level) x 100

Unit loads on standard crushed stones are 1370 kg and 2055 kg at 2.5 mm and 5.0mm penetration respectively. For each specimen, the higher of the values calculated above is taken and the average of three such specimens is reported to the first decimal as CBR for one set. Thus CBR values of the soil with and without reinforcement are found out. Soaked CBR tests are conducted with unreinforced and reinforced soil specimens in accordance with Indian Standards Specifications IS 2720 (Part-16), 1987. The experimental setup is presented in Fig. 3.7.

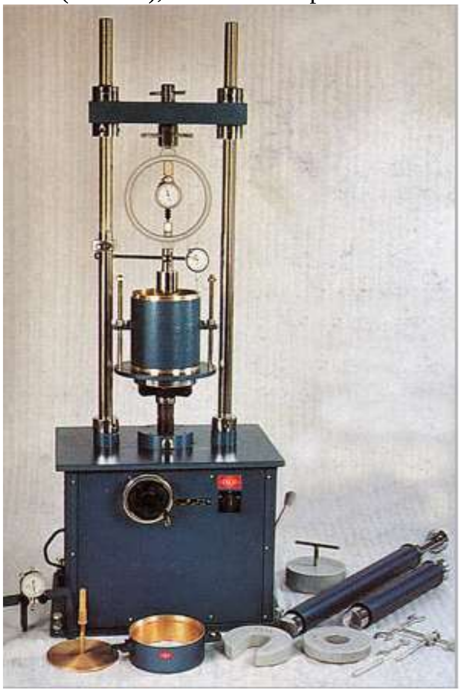
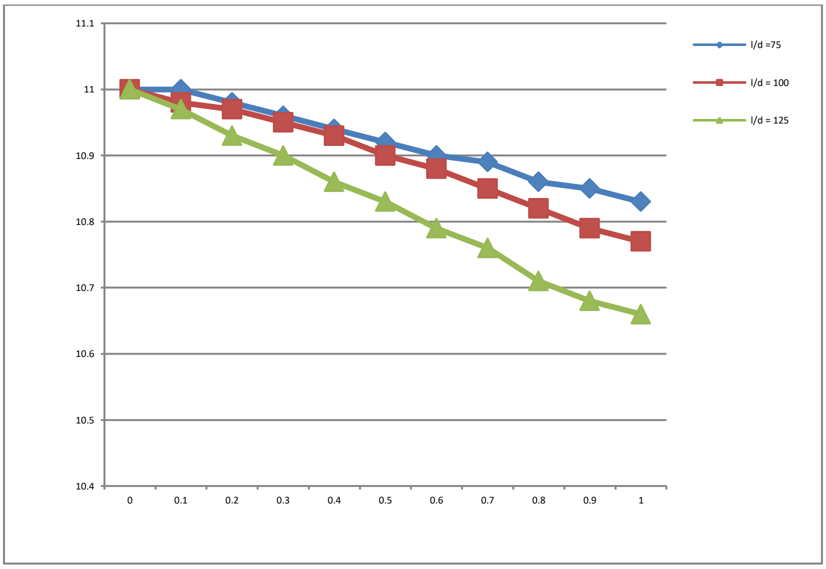


Fig. 3.7 Experimental setup for CBR test

Table 4.2 Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of coir fiber-reinforced soil

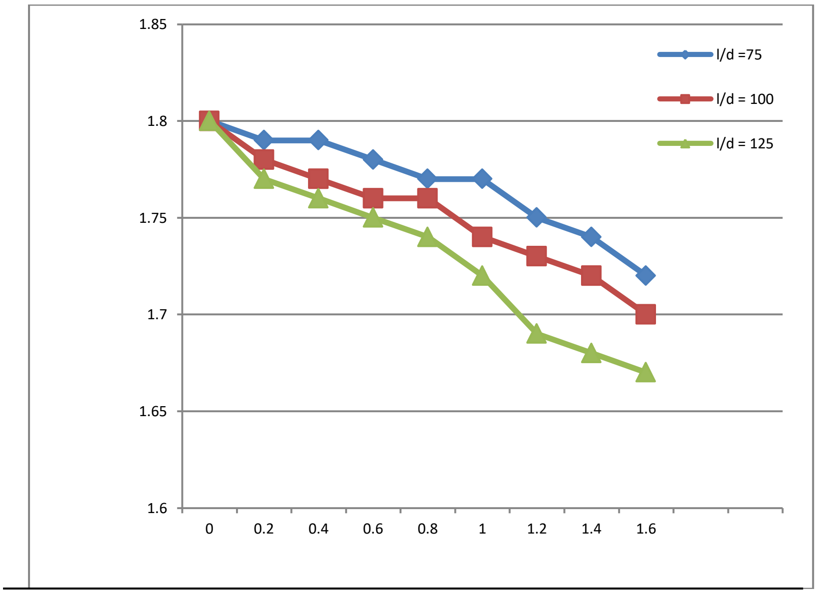
Fiber content (%)	l/d= 75		l/d= 100		l/d= 125	
	OMC (%)	MDD (Mg/m^3)	OMC (%)	MDD (Mg/m^3)	OMC (%)	MDD (Mg/m^3)
0.0	11.00	1.80	11.00	1.80	11.00	1.80
0.2	11.05	1.79	11.08	1.78	11.10	1.77
0.4	11.12	1.79	11.16	1.77	11.20	1.76
0.6	11.19	1.78	11.25	1.76	11.29	1.75
0.8	11.24	1.77	11.30	1.76	11.37	1.74
1.0	11.30	1.77	11.34	1.74	11.42	1.72
1.2	11.34	1.75	11.37	1.73	11.49	1.69
1.4	11.37	1.74	11.41	1.72	11.54	1.68
1.6	11.42	1.72	11.47	1.70	11.61	1.67

MDD (mg/m^3)))((mg/m3



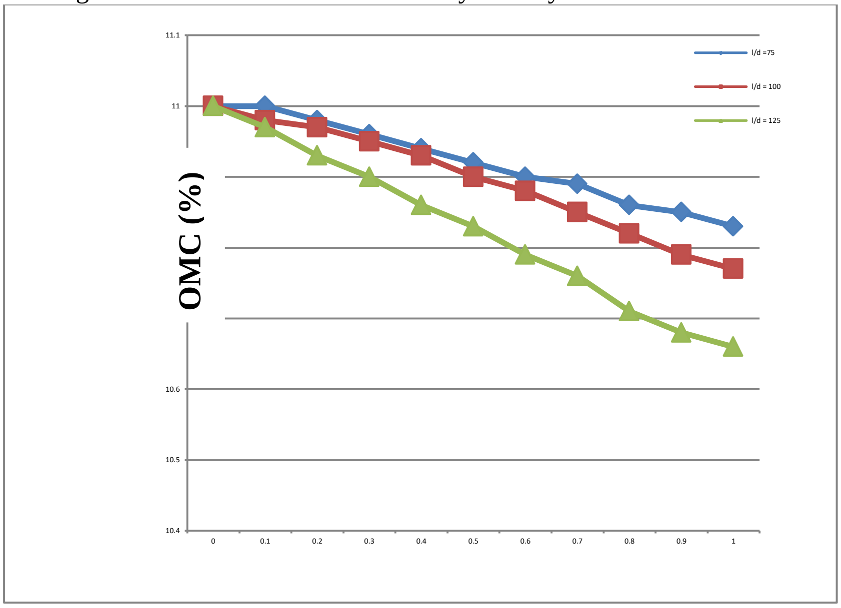
Fiber Contents (%)
(a) Polypropylene

MDD (mg/m^3)))((mg/m3

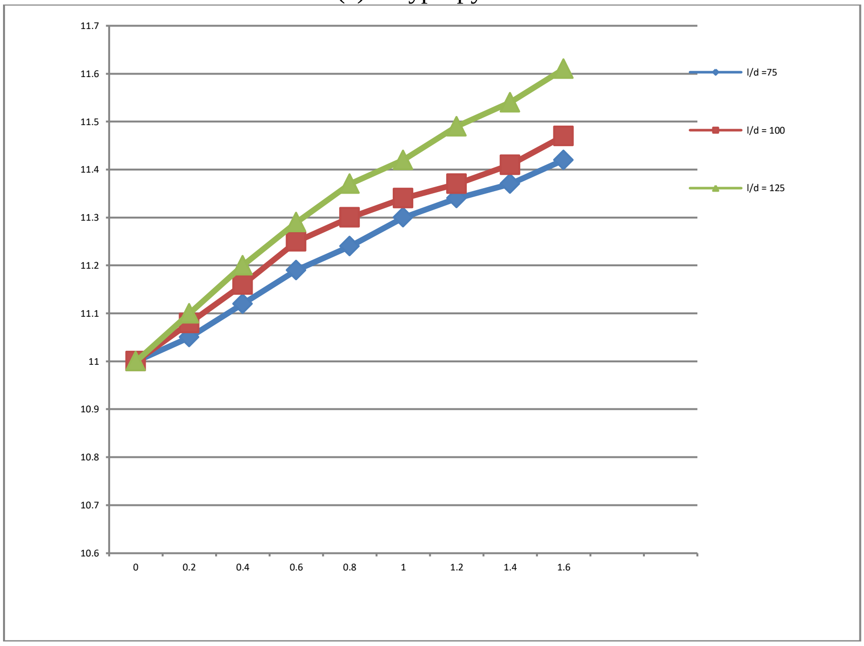


Fiber Contents(%)

Figure 4.1. Variation of Maximum Dry Density With Fiber Contents



Fiber Contents(%)
(a) Polypropylene



Fiber Contents(%)
Figure 4.2. Variation of Optimum Moisture Contents With Fiber Contents

.5 CBR Tests

The results of soaked CBR tests are presented in Table 4.7 and Table 4.8. From the above observations, the variation of CBR with fiber content is presented in Fig. 4.7 and Fig. 4.8 for all the three fiber lengths. It is observed from Fig. 4.7 that with inclusion of polypropylene fibers, the soaked CBR values increase up to fiber content of 0.8% for all the three aspect ratios investigated. The increase in CBR value is 158%, 204% and 177% for fiber lengths 15, 20 and 25 mm respectively, when compared with that of unreinforced soil. It is also observed that the CBR values increase with increase in fiber length up to 20 mm and thereafter decrease. Thus, the optimum content of fiber is 0.8% for the fiber length of 20 mm *(l/d=*100).It is observed from Fig. 4.23 that with inclusion of coir fibers, the soaked CBR values increase up to fiber content of 1.4% for all the three aspect ratios considered in the investigation. The increase in CBR value is 135%, 180% and 169% for fiber lengths 15, 20 and 25 mm respectively, when compared with that of unreinforced soil. It is also observed that the CBR values increase with increase in fiber length up to 20 mm and thereafter decrease. Thus, the optimum content of

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fiber is 1.4% for the fiber length of 20 mm (*f/d*=100).

Table 4.7 CBR Values of soil reinforced with polypropylene fibers

S. No.	Fiber content (%)	Soaked CBR (%)		
		l/d — 75	*l/d* — 100	*l/d* — 125
1	0	2.6	2.6	2.6
2	0.1	3.0	3.5	3.2
3	0.2	3.3	3.9	3.8
4	0.3	4.1	4.6	4.3
5	0.4	4.8	5.3	5.0
6	0.5	5.4	6.0	5.6
7	0.6	5.9	6.9	6.2
8	0.7	6.4	7.5	6.8
9	0.8	6.7	7.9	7.2
10	0.9	6.9	7.9	7.1
11	1.0	6.9	7.7	7.0

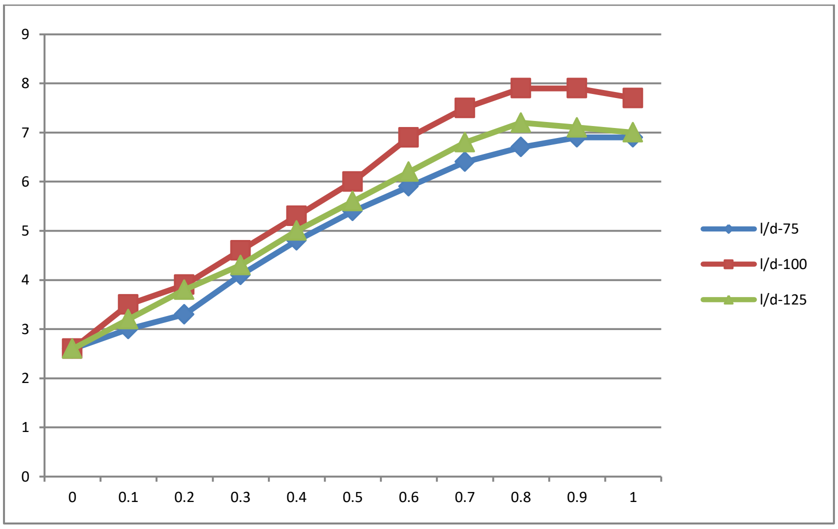

Fig. 4.7 CBR values for polypropylene fiber-reinforced soil at different fiber contents

The decrease in CBR value at fiber content beyond 0.8% for polypropylene fibers and 1.4% for coir fibers and fiber length beyond 20 mm may be due to the fact that with higher fiber content and fiber length, 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.

Jadhao and Nagamaik (2008) reported that the soaked CBR values increase with increase in fiber content and fiber length of polypropylene fiber inclusion in silty soil, the optimum being at fiber content of 1% for 12 mm fiber. Marandi et al. (2008), reported that the soaked CBR values increase with increase in fiber content and fiber length of palm fiber inclusion in silty sand, the increase being more for 40 mm fiber length than 20 mm and up to a fiber content of 1.5%. Similar trend in the results is observed in the present investigation for the soil reinforced with polypropylene or coir fibers.

Study of the results obtained from unconfined compression test, direct shear test, triaxial compression tests reveal the same optimum content of fiber for getting maximum strength for a given fiber. However, optimum fiber content obtained from CBR tests is much higher compared to other strength tests (0.80Z« against 0.4 - 0.5% for polypropylene fibers and 1.4% against 0.8% for coir fibers). This difference in optimum fiber content may be due to the following reasons.

1. CBR test is essentially an arbitrary test as compared to other strength tests.
2. This is a penetration test, the results of which are used only for a specific purpose since its inception by California Division of Highways till date i.e. designs of flexible pavement.
3. However, the results cannot be used to evaluate the fundamental properties of soil. In the present research, improvement in CBR values of soil is studied with inclusion of polypropylene/coir fibers to

find its application in design of flexible pavements only.

Table 4.8 CBR values of soil reinforced with coir fibers

S. No.	Fiber content (%)	Soaked CBR (%) l/d — 75	l/d — 100	l/d — 125
1	0	2.6	2.6	2.6
2	0.2	3.1	3.5	3.3
3	0.4	3.8	4.4	4.0
4	0.6	4.4	5.1	4.9
5	0.8	4.9	6.0	5.7
6	1.0	5.6	6.7	6.2
7	1.2	5.9	7.1	6.8
8	1.4	6.1	7.3	7.0
9	1.6	6.0	7.3	6.8

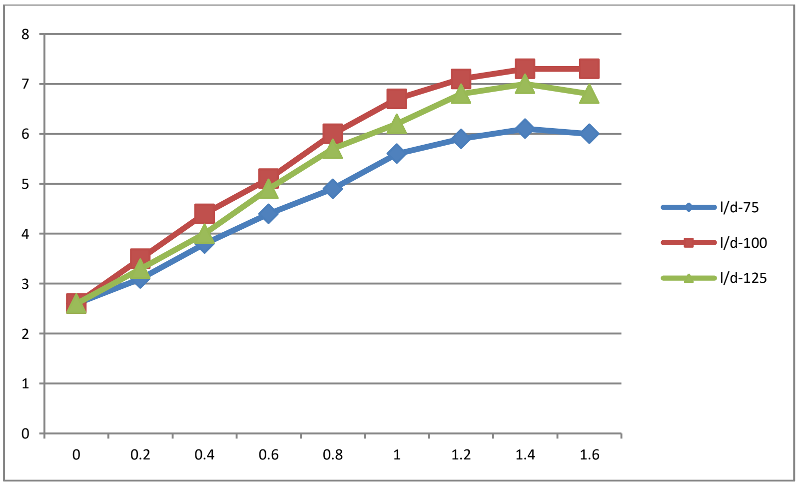

Fig. 4.8 CBR values for coir fiber-reinforced soil at different fiber contents

4.0 CONCLUSIONS

In the present research an attempt has been made to study the strength and compressibility characteristics of randomly distributed fiber-reinforced clayey soil using polypropylene (synthetic) and coir (natural) fibers as reinforcement. As a prelude to the actual investigation the related analytical and experimental investigations including the effect of various types of reinforcement (geotextiles, geogrids, geonets, geocells etc.) fulfilling various functions carried out by past researchers have been critically reviewed in chapter II. This review has given an insight to the existing knowledge and its limitations/inadequacies, thus enabling to draw the scope of the present study. It has been observed from the literature review that limited research has been made on fiber-reinforced clayey soil with polypropylene and coir fibers as reinforcement.

Hence attempt has been made to use these materials as reinforcement in locally available clayey soil to study their effect on the strength and compressibility characteristics. A rigorous experimental investigation has been carried out following the guidelines prescribed by the Bureau of Indian Standards which is presented in chapter III. The results of the above investigation have been studied thoroughly and discussed elaborately in chapter IV.

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

1. Random inclusion of fibers reduces MDD of the soil irrespective of type of fiber, fiber content and length.
2. The OMC of soil reinforced with polypropylene fibers decreases irrespective of fiber content and fiber length. However, the soil reinforced with coir fibers exhibits a reverse trend.
3. 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.

4. 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 *qu* and failure strain for soil reinforced with coir fibers is 133% and 180% respectively at fiber length of 20 mm *(l/d*=100).
5. Inclusion of fibers in soil increases the strain at failure and therefore makes the reinforced soil matrix more ductile.
6. It is concluded from direct shear tests that the shear strength of soil increases with inclusion of fibers up to 0.4% and 0.8% for polypropylene and coir fibers respectively for the fiber lengths considered in the investigation, beyond which it decreases. The increase in shear strength is maximum at fiber length of 20 mm *(l/d*=100) for both the cases.
7. Both angle of internal friction and cohesion increase for polypropylene as well as coir fiber inclusion in soil with increase in fiber content up to the optimum content for all the three fiber lengths and decrease thereafter or remain nearly the same.
8. For most of the cases, the maximum increase in both peak and residual angle of internal friction of the soil is observed at fiber content of 0.4% and 0.8% with inclusion of polypropylene and coir fibers respectively and the increase being 76% and 71% for polypropylene and 50% for coir respectively which occur at fiber length of 20 mm *(l/d* =100).
9. Similarly, the maximum increase in both peak and residual cohesion of the soil is observed at fiber content of 0.4% and 0.8% for polypropylene and coir fibers respectively and the increase is 222 and 140% for polypropylene and167% and 200% for coir fibers respectively which occur at fiber length of mm *(l/d*= 100).
10. The increase in peak and residual shear stress of soil reinforced with polypropylene fibers is 108, 172, 151% and 93, 135, 118% respectively for the fiber aspect ratios 75, 100 and 125. Thus, the maximum increase in both peak and residual strengths occurs for fiber length of 20 mm (*l/d* =100) at 0.4% fiber content. Similarly, the increase in peak and residual shear stress of soil reinforced with coir fibers is 94, 126, 104% and 76, 128, 106% respectively for the fiber aspect ratios 75, 100 and 125. Thus, the maximum increase in both peak and residual strengths occurs for fiber length of 20 mm (7/i7=100) at 0.8% fiber content.
11. It is concluded from unconsolidated undrained triaxial compression tests that the shear strength of fiber-reinforced soil is improved due to the addition of fibers. The shear strength is increased non-linearly with increase in length of fiber up to 20 mm and thereafter an increase in length reduces the shear strength.
12. The shear strength of fiber-reinforced soil is also increased with increase in confining pressure. The fiber content also influences the shear strength as the same improves non-linearly with increase in fiber content. But beyond 0.4% and 0.8% fiber content, the shear stress reduces with increase in fiber content for polypropylene and coir fibers respectively.
13. The value of cohesion is also increased due to the inclusion of fibers in soil. The maximum value of cohesion for fiber-reinforced soil is obtained as 68 kPa for polypropylene fibers at fiber content of 0.4% and fiber length of 20 mm against 20 kPa of unreinforced soil. With coir fiber inclusion, the maximum cohesion is 67 kPa at fiber content of 0.8% and fiber length of 20 mm.
14. There is no much variation in angle of internal friction as it ranges from 9 to degrees for soil reinforced with polypropylene fibers and 6.5 to 10.5 degrees with coir fibers against 8.5 degrees of unreinforced soil. The maximum value of friction angle is obtained at 0.4% and 0.8% fiber content with polypropylene and coir fibers respectively at fiber length of 20 mm.
15. Inclusion of 20 mm polypropylene fibers at 0.4% fiber content, records the maximum failure deviator stress 288 kPa under a confining pressure of 210 kPa and maximum strength ratio as 2.97, under confining pressure of 70 kPa. Similarly, 20 mm coir fiber at 0.8%, records the maximum failure deviator stress 252 kPa under confining pressure of 210 kPa and maximum strength ratio as 2.73, under confining pressure of 70 kPa.
16. It is concluded from CBR tests that the CBR value of the soil increases with inclusion of fibers. The maximum increase in soaked CBR value of soil reinforced with polypropylene fibers is observed to be 204% compared to unreinforced soil for 20 mm fiber length *(l/d* =100) at optimum fiber content of 0.8%. Similarly, the maximum increase in soaked CBR value of soil reinforced with coir fibers is 180% for 20 mm fiber length *(l/d* =100) at optimum fiber content of 1.4%.
17. 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.
18. 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 0.4% polypropylene fibers increases by 67% and 90% respectively as compared to unreinforced soil.
19. 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.

20. The compression index (*Cc*) decreases with inclusion of polypropylene/coir fibers in the soil up to certain fiber content and increases thereafter. Thus, minimum *Cc* value is observed at fiber contents of 0.6% and 0.8% for soil reinforced with polypropylene and coir fibers respectively. The coefficient of volume change *(mv)* also decreases with increase in fiber content up to 0.4% for polypropylene fibers and 0.6% for coir fibers and increases thereafter.
21. The coefficient of consolidation (C_v) increases with increase in fiber content and fiber length in the range of fibers considered in the investigation. But, the rate of increment is more for polypropylene fibers. Thus, the time required to achieve primary consolidation decreases for fiber-reinforced soil for a given degree of consolidation and a given drainage path.

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