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ORIGINAL CONTRIBUTION

Improvement of Characteristics of Clayey Soil Mixed with Randomly Distributed Natural Fibers

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Abstract In subgrade construction for flexible road pavement, properties of clayey soils available locally can be improved by providing randomly distributed fibers in the soil. The fibers added in subgrade constructions are expected to provide better compact interlocking system between the fiber and the soil grain, greater resistance to deformation and quicker dissipation of pore water pressure, thus helping consolidation and strengthening. Many natural fibers like jute, coir, sabai grass etc. which are economical and eco-friendly, are grown in abundance in India. If suitable they can be used as additive material in the subgrade soil to result in increase in strength and decrease in deformability. Such application will also reduce the cost of construction of roads, by providing lesser thickness of pavement layer. In this paper, the efficacy of using natural jute, coir or sabai grass fibers with locally available clayey soil has been studied. A series of Standard Proctor test, Soaked and Unsoaked California Bearing Ratio (CBR) test, and Unconfined Compressive Strength test were done on locally available clayey soil mixed with different types of natural fiber for various length and proportion to study the improvement of strength properties of fiber–soil composites placed at optimum moisture content. From the test results, it was observed that there was a substantial increase in CBR value for the clayey soil when mixed with increasing percentage of all three types of randomly distributed natural fibers up to 2% of the dry weight of soil. The CBR attains maximum value when the length for all types of fibers mixed with the clay taken in this study, attains a value of 10 mm.

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Keywords Subgrade · Natural fiber · Eco-friendly · Fiber–soil composites · Randomly distributed fibers

Abbreviations

C_u	Coefficient of uniformity
CBR	California bearing ratio
MDD	Maximum dry density
OMC	Optimum moisture content
UCS	Unconfined compressive strength

Introduction

Quick development of roads and other Civil Engineering structures in cost effective manner and maintaining such constructed works at a minimal cost for long service life, are becoming essential for economical growth of a country. As a result huge amount of constructions of roads are being made for transportation development in India through different Government schemes. For such constructions, requirement of fill material for sub-grade is enormous but available soils near construction sites sometimes are found to be unsuitable for low strength and high compressibility, even after the necessary compaction. Such soils need addition of some strengthening elements to decrease the compressibility and to enhance the strength of the subgrade so that cost effective construction of works is possible. Reinforced earth construction is an effective technique for increasing the strength of soil and is being widely used in formation of subgrade for roads, railway tracks, airfields and in retaining walls or abutments.

Randomly distributed fiber in soil is one of the latest techniques in which fibers of desired quality and type are mixed with the soil. This type of fiber mixed soil can be advantageously utilized as a ground improvement technique in the case of embankments, subgrades and in other similar cases. The main advantages of randomly distributed discrete fibres are the simplicity in mixing, maintenance of strength isotropy and absence of potential planes of weakness which may develop parallel to the oriented reinforcement. The fibers added in constructions are expected to provide better compact interlocking system between the fiber and the soil system. Gray and Ohashi [1], Maher and Gray [2], Michalowaski and Zaho [3], Santoni and Webster [4] have studied the effect of fiber reinforcement of soils using discrete fibers. Majority of the studies were made with coarse grained soils with synthetic fibers. The studies revealed the common benefits of the reinforcement, like increase of peak strength and change of failure mode of the soil. For the improvement in soil, different materials have been used like Nylon fiber [5], synthetic fiber like polypropylene fibers [6], Polyester fiber [7], etc. But the use of synthetic fibers affects cost effectiveness of the construction in India. Hence application of locally available natural fibers as reinforcing material with locally available clayey soils for low traffic unpaved roads may be cost effective and eco-friendly methodology. Such application will also reduce the cost by providing lesser thickness of pavement structure needing lesser quantity of costly material used for such structure. Shetty and Rao [8] indicated positive influence of natural coir fibers on the CBR value. From their study it was reported that silty sand (SM) reinforced with coir fibers (10% by volume) resulted in increase in CBR value. Nisha and Ilampurthi [9] carried out an experimental program to study the performance of soil mixed with discrete fibers and cementitious materials individually as well as in combination coir and polypropylene fibers of different aspect ratios and in different proportions. Samadhiya et al. [10] and Sreedhar et al. [11] reported that there is a significant increase of the CBR value with the increase in fiber content on the basis of the experimental study of mixing of randomly distributed different types of fibers to different types of soil.

Possibility of reducing unit cost of road making assumes prime importance in allocating fund for increased road length in rural areas where first time connectivity is being aimed to connect villages in rural sector with existing road systems. In such cases, traffic density being low initially, constructing good road at lower cost, utilizing natural fibers may be a great advantage. As traffic density increases with time, initially constructed roads may be further improved upon as a part of routine maintenance programme.

Scope of the Study

The major aim of the study was to determine the amount of improvement which could occur, in locally available clayey soil due to randomly mixing natural fibers of jute, coir, or sabai grass of various length and proportion. Optimum size and proportion of each type of the fibers used were found out from experimental investigation. Laboratory Standard Proctor test, UCS test and CBR (both Soaked and Unsoaked) tests at OMC determined were performed on specimens of the clayey soil chosen for investigation.

Materials and Methods

Description of Materials

Cohesive Soil

Locally available clayey soil collected from near surface level at Nazirabad near Kolkata in the state of West Bengal, was used in this experimental study. As per I.S. Classification [15], the soil is classified as “CI” i.e. Clay with medium plasticity. The physical properties of clayey soil as determined for routine laboratory tests are given in Table 1.

Natural Fibers

Three types of locally available natural fibers i.e. Jute fiber, Coir fiber and Sabai grass were chosen for this investigation. For coconut fibers, ripe coconut was purchased from local market and fibers were separated from the coconut shell. The coir fibers are then dried in sun for several days after which they were properly processed for use of mixing in the soil randomly. Coir fiber after cutting into small pieces of definite length is shown in Fig. 1. Jute fiber is also agricultural product and collected from the local market. Jute fiber after cutting into pieces of definite

Table 1 Summary of physical properties of clayey soil

Properties	Clay
Classification (IS)	CI
Coefficient of uniformity (C_u)	2.10
Liquid limit	41%
Plastic limit	23%
Plasticity index	18%
Proctor’s maximum dry density, gm/cc	1.58
Optimum moisture content, %	19.0
CBR (soaked) (%) at OMC	2.1

Fig. 1 Coir fiber cut into pieces of definite length

Fig. 2 Jute fiber cut into pieces of definite length

Fig. 3 Sabai grass cut into pieces of definite length

length is shown in Fig. 2. Sabai grass was processed by cutting into small pieces of definite length in the laboratory in dry condition and is shown in Fig. 3. The physical properties of Jute, Coir and Sabai grass fibers are given in Table 2.

Table 2 Summary of physical properties of fibers

Tests	Jute spoil	Coir	Sabai grass
Density, g/cc	1.47	1.40	0.639
Diameter, mm	0.03–0.14	0.1–0.45	0.955 (av.)

Parameters Used in this Study

The designations of different mix for soil–fiber composites are given in Table 3.

For each series of testing Standard Proctor tests, CBR tests (both unsoaked and soaked) at predetermined OMC from compaction test and UCS Tests on samples at OMC were conducted. However following parameters were varied for different series of tests.

1. *Types of natural fibers* The natural fibers used in this experimental program are jute fibers, coir fibers and sabai grass.
2. *Length of natural fibers* The fiber of each material is processed by cutting into small pieces of length 0.5, 1.0 and 2 cm
3. *Percentages of natural fibers* Each and every length of jute and coir fibers is used in varying percentages of 1, 1.5, 2.0 and 2.5.

Preparation of Test Specimens

Collected jute fiber, coir fiber and sabai grass were uniformly dried and then cleaned from dust. After that they were segregated to cut into uniform sizes of length 5, 10 and 20 mm. The fibers are randomly mixed with chosen clayey soil with various percentages of 1, 1.5, 2 and 2.5 of the dry weight of soil for preparing samples of various series. The mixing of fibers and soil was done manually with proper care at each stage of mixing for achieving uniform distribution of the natural fibers into the clayey soil. For effective mixing of fiber–clay composite, the fiber was first wetted with some quantity of water, then mixed with clay with remaining amount of required water, uniformly.

Different Types of Tests Done for Soil–Fiber Mix Composite

To investigate the effect of inclusion of the natural fibers of various lengths and proportion, in the clayey soil, a systematic experimental program was undertaken, for soil–fiber composites by conducting Standard Proctor tests, Unsoaked and soaked CBR tests at OMC and UCS Test at OMC. These tests were conducted as per relevant codal provision.

Table 3 Different mix designation for clay-fiber mix composite

Mix designation	Fiber type	Fiber content	Fiber length, mm
CJ2010, CJ2015, CJ2020, CJ2050	Jute fiber	1, 1.5, 2.0 and 2.5%	20
CJ1010, CJ1015, CJ1020, CJ1025			10
CJ0510, CJ0515, CJ0520, CJ0525			5
CC2010, CC2015, CC2020, CC2025	Coir fiber		20
CC1010, CC1015, CC1020, CC1025			10
CC0510, CC0515, CC0520, CC0525			5
CSG2010, CSG2015, CSG2020, CSG2025	Sabai grass		20
CSG1010, CSG1015, CSG1020, CSG1025			10
CSG0510, CSG0515, CSG0520, CSG0525			5

Table 4 Results of standard proctor tests, CBR tests and UCS tests for Clay- Jute fiber mix

Fiber length	% of Fiber	Test result for clayey soil				
		MDD, gm/cm^3	OMC, %	UCS, N/cm^2	CBR, %	
					Unsoaked	Soaked
Clayey soil	0.0	1.58	19.2	1.88	3.8	2.1
Jute fiber 0.5 cm	1.0	1.53	21	2.33	4.8	2.8
	1.5	1.51	21.4	2.61	5.1	3.1
	2.0	1.5	21.9	3.18	5.5	3.4
	2.5	1.49	22.4	3.07	5	3.2
Jute fiber 1.0 cm	1.0	1.52	21.5	2.41	4.8	2.9
	1.5	1.49	22.1	2.74	5.2	3.2
	2.0	1.48	22.8	3.34	5.7	3.5
	2.5	1.47	23	3.18	5.4	3.3
Jute fiber 2.0 cm	1.0	1.51	22	2.37	4.5	2.7
	1.5	1.48	22.4	2.68	4.8	3.1
	2.0	1.46	23.2	3.27	5.3	3.3
	2.5	1.45	23.7	3.13	4.8	3.2

Table 5 Results of standard proctor tests, CBR tests and UCS tests for Clay- Coir fiber mix

Fiber length	% of Fiber	Test result for clayey soil				
		MDD, gm/cm^3	OMC, %	UCS, N/cm^2	CBR, %	
					Unsoaked	Soaked
Clayey soil	0.0	1.58	19.2	1.88	3.8	2.1
Coir fiber 0.5 cm	1.0	1.56	19.7	2.54	5	3
	1.5	1.54	20.1	2.86	5.3	3.2
	2.0	1.53	20.5	3.41	5.8	3.6
	2.5	1.51	20.8	3.33	5.4	3.5
Coir fiber 1.0 cm	1.0	1.52	19.9	2.66	5.2	3.1
	1.5	1.51	20.3	2.99	5.5	3.4
	2.0	1.5	20.6	3.72	6	3.8
	2.5	1.49	20.7	3.52	5.6	3.6
Coir fiber 2.0 cm	1.0	1.51	20	2.62	4.8	3
	1.5	1.5	20.5	2.89	5.3	3.3
	2.0	1.49	21.2	3.58	5.7	3.7
	2.5	1.48	21.2	3.42	5.3	3.5

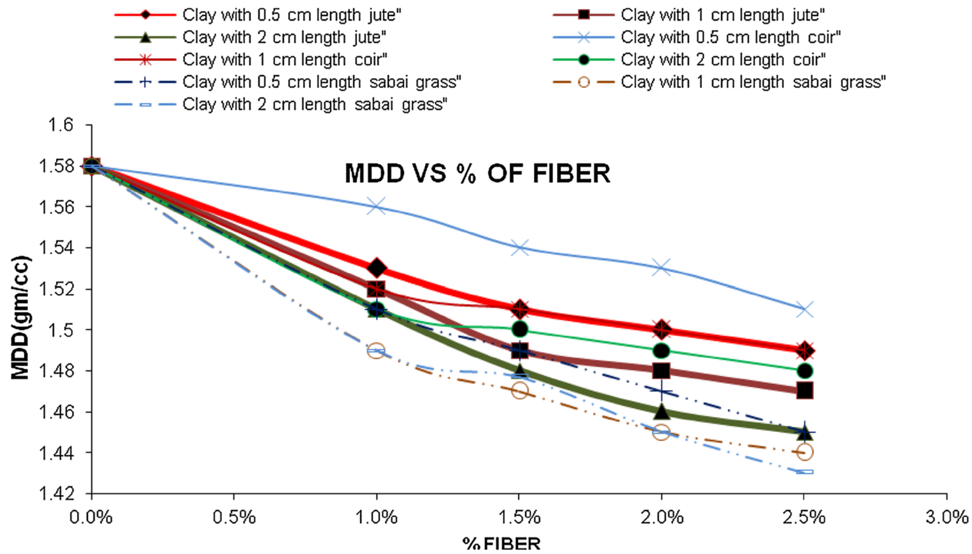


Fig. 4 Effect of fiber content on MDD for clayey soil

Results and Discussion

Standard Proctor tests were conducted for each mix to determine the OMC and corresponding MDD. For each case of clay–fiber mix, CBR tests (both unsoaked and soaked) and UCS tests were conducted at OMC with maximum dry density. The summary of results of Standard Proctor tests, unsoaked and soaked CBR tests and UCS tests for clayey soil with jute fiber, coir fiber and sabai grass are given in Tables 4, 5 and 6 respectively.

Effect of Fibers Inclusion on Standard Proctor Tests

Standard Proctor tests were carried out on cylindrical specimens as per IS 2720 Part 7 [12] to determine the OMC and MDD of the clay–fiber composite prepared by static compaction. For each combination of variables a minimum of three specimens were tested and average value is reported. The values of MDD and OMC obtained from the Standard Proctor tests for clayey soil with jute fiber, coir fiber and sabai grass are given in Tables 4, 5 and 6 respectively.

Table 6 Results of standard proctor tests, CBR tests and UCS tests for Clay- Sabai grass fiber mix

Fiber length	% of Fiber	Test result for clayey soil				
		MDD, gm/cm^3	OMC, %	UCS, N/cm^2	CBR, %	
					Unsoaked	Soaked
Clayey soil	0.0	1.58	19.2	1.88	3.8	2.1
Sabai grass 0.5 cm	1.0	1.51	20.2	2.21	4.2	2.6
	1.5	1.49	20.7	2.42	4.4	3
	2.0	1.47	21.5	2.74	4.7	3.2
	2.5	1.45	22.6	2.51	4.5	3
Sabai grass 1.0 cm	1.0	1.49	21	2.30	4.4	2.8
	1.5	1.47	22.1	2.52	4.6	3.1
	2.0	1.45	22.7	2.88	4.9	3.4
	2.5	1.44	23.1	2.72	4.6	3.3
Sabai grass 2.0 cm	1.0	1.49	22.2	2.26	4.2	2.7
	1.5	1.477	22.8	2.46	4.3	3
	2.0	1.45	23.4	2.82	4.5	3.2
	2.5	1.43	23.9	2.67	4.3	3.1

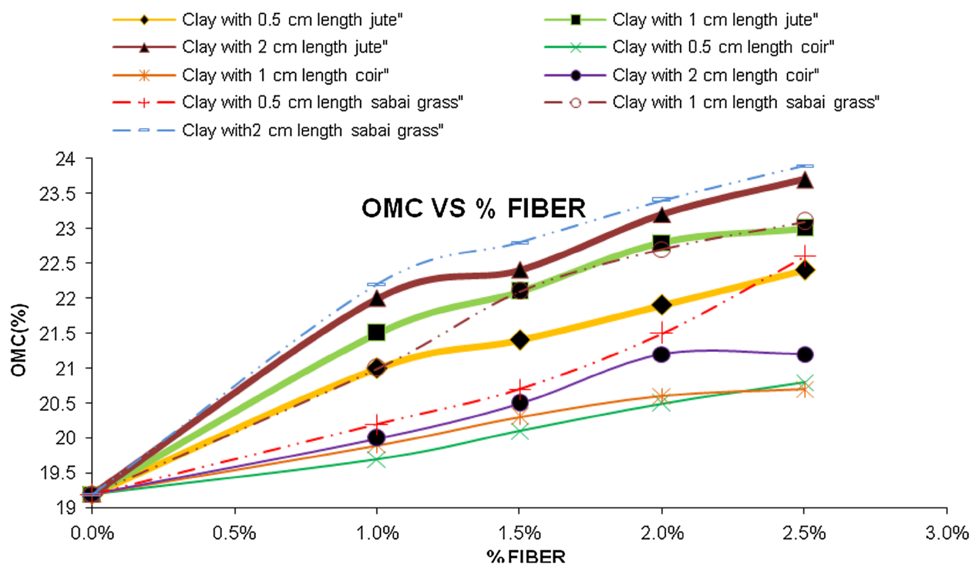


Fig. 5 Effect of fiber content on OMC for clayey soil

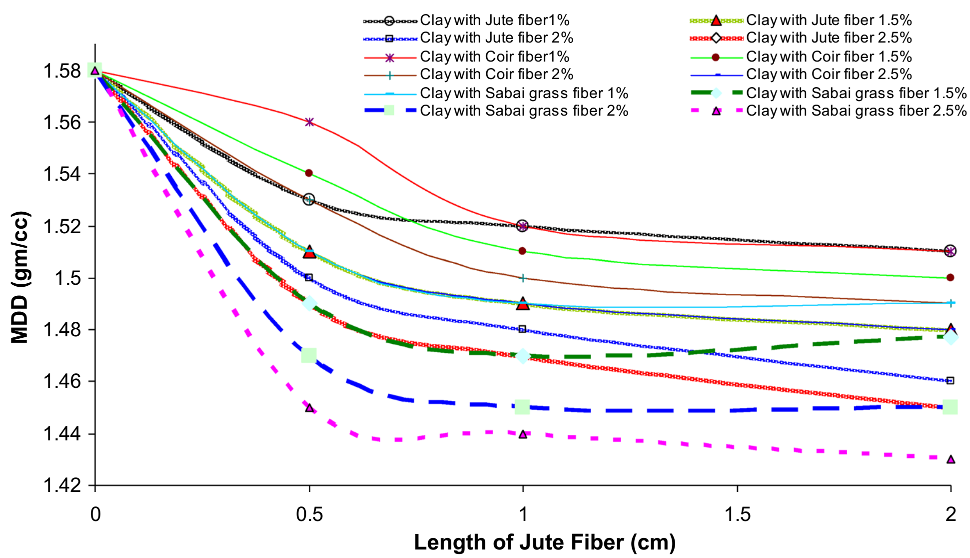


Fig. 6 Effect of fiber length on MDD for clayey soil

MDD Versus Fiber Content and OMC Versus Fiber Content Curves

The MDD versus Fiber content (%) and OMC versus Fiber content (%) curve for clayey soil mixed with various types of different natural fiber of varying length is shown in Figs. 4 and 5 respectively.

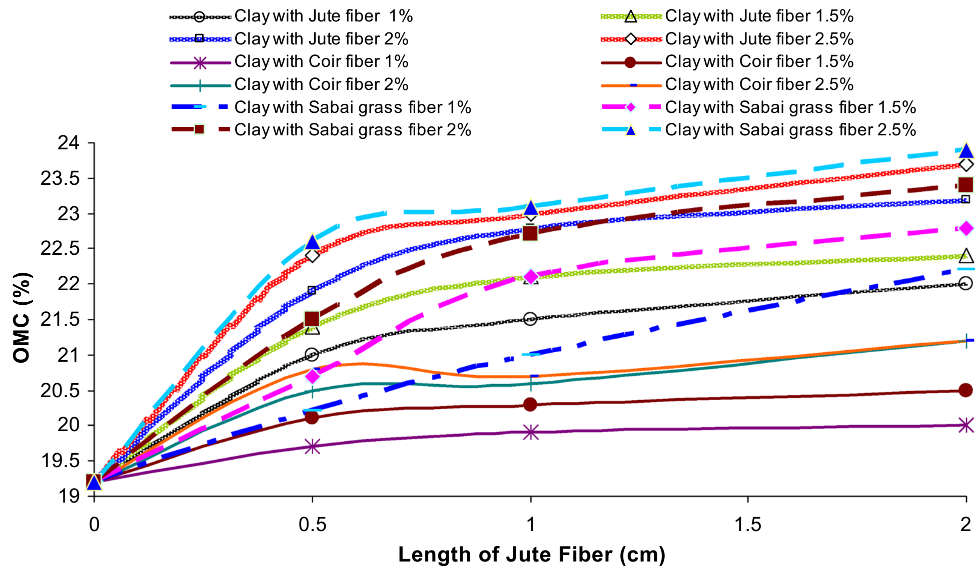
From Figs. 4 and 5, it is seen that the value of MDD decreases as the percentage of fiber content by dry weight of clayey soil increases, but the OMC value increases as the percentage of fiber content by dry weight of clay increases. This observation is true irrespective of type of natural fiber. The decrease in dry density with the increase of fiber content is due to less specific weight of the fiber in comparison with that of the soil solids. The increase in OMC value with increase in fiber content is due to the fact that the natural fibers have greater water absorption capacity than the surrounding soil solids.

MDD Versus Fiber Length and OMC Versus Fiber Length Curves

The variations of MDD and OMC against length of fiber of various types having varying fiber content are shown in Fig. 6 and 7 respectively.

From these figures, it is observed that as the length of fiber increases, the MDD value decreases while the OMC value increases as the length of fiber used in randomly mixing increases. Gradual decrease in value of MDD and increase in value of OMC, with increase in length in fiber

Fig. 7 Effect of fiber length on OMC for clayey soil

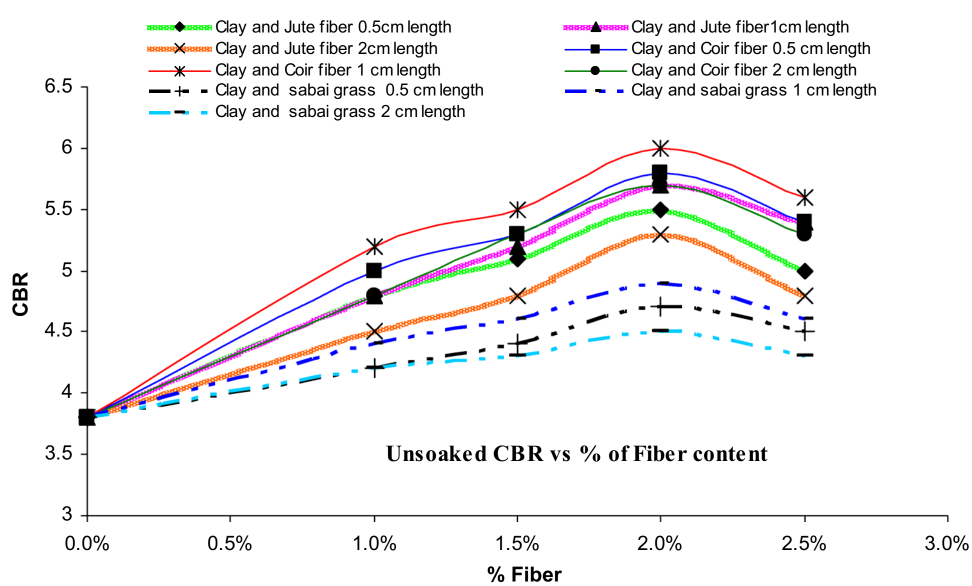


used in random mixing seems to result for lower value of density of fiber compared to that of the soil solids and greater ability of water absorption of fibrers compared to that of the surrounding soil. However, out of the three types of natural fibers used, sabai grass fiber seems to result maximum decrease in MDD and corresponding increase in OMC, for comparable fiber length consideration.

Effect of Fibers on California Bearing Ratio (CBR) Test

To examine the effects of natural fiber on the ultimate strength of clay–fiber composite system, CBR tests (both unsoaked and soaked) were carried out as per IS 2720 Part 16 [13]. The CBR tests (both unsoaked and soaked) were carried out, on the clay–fiber specimens at OMC with fiber inclusion of 1, 1.5, 2, and 2.5%, for fiber lengths of 5, 10 and 20 mm. For unsoaked CBR tests the prepared samples were tested immediately after the compaction phase. However for soaked CBR tests the prepared samples were submerged in water for 4 days and then tested within 10 min of removal from the soaking tank. The unsoaked and soaked CBR values obtained from laboratory tests for clay with jute fiber, coir fiber and sabai grass are given in Tables 4, 5 and 6 respectively.

Fig. 8 Effect of fiber content on unsoaked CBR



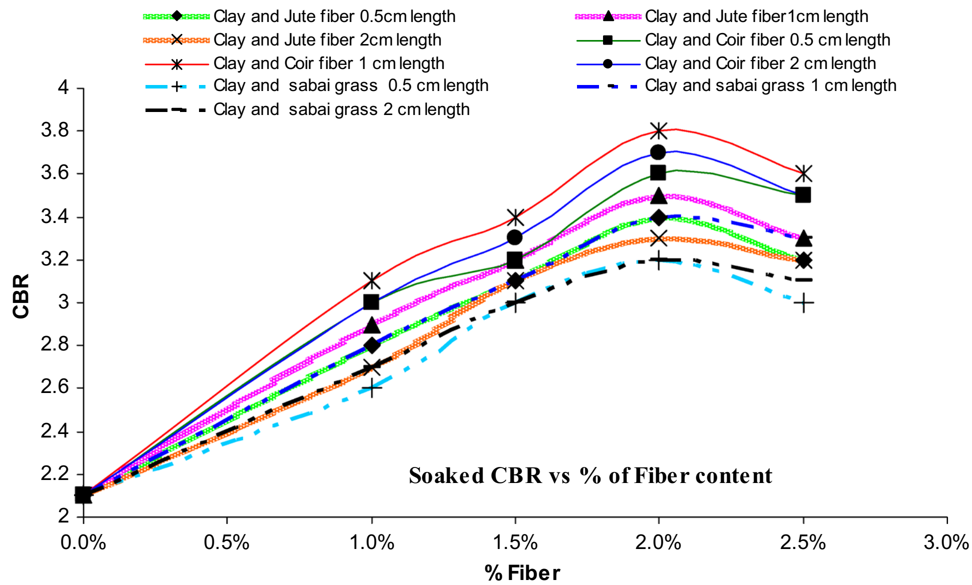


Fig. 9 Effect of fiber content on soaked CBR

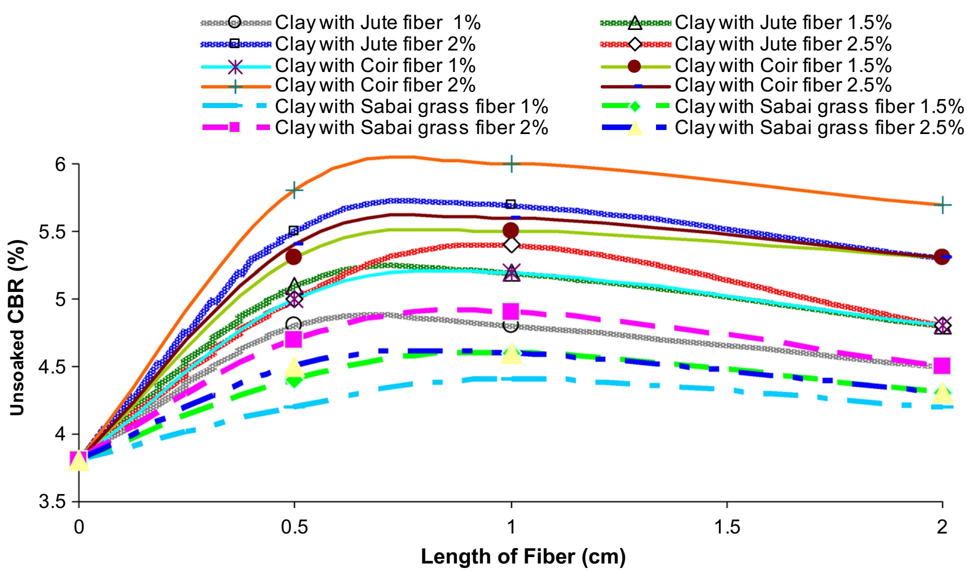


Fig. 10 Effect of fiber length on unsoaked CBR

CBR Versus Percentage of Fiber Content Curves

The unsoaked CBR versus fiber content curves and soaked CBR versus fiber content curves for different clay–fiber mixes are shown in Figs. 8 and 9 respectively.

From these figures, it is observed that both the unsoaked and soaked CBR values for clay–fiber mixes increases with the increase of percentage of fiber of any type used in the experimentation up to a maximum limit and after that the CBR values decrease. The possible reason of reduction of CBR is due to less contact between fiber and soil solid when the fiber content increased beyond the optimum vale. The CBR value (both unsoaked and soaked) of all different types of clay–fiber mixes is maximum for 2% of fiber inclusion of the dry weight of the soil. The improvement of CBR value (both unsoaked and soaked) is more for coir fiber mixed clayey soil compared to the other types of fibers used. For coir fiber of 10 mm length used in randomly mixing at 2% by weight of dry soil, it is observed that CBR value in unsoaked and soaked condition becomes 6 and 3.8% while the corresponding values of the soil are 3.8 and 2.1% respectively.

CBR Versus Length of Fiber Curves

The unsoaked CBR versus length of fiber curves and soaked CBR versus length of fiber curves for clay mixed with chosen three types of natural fibers of varying fiber content are shown in Figs. 10 and 11 respectively.

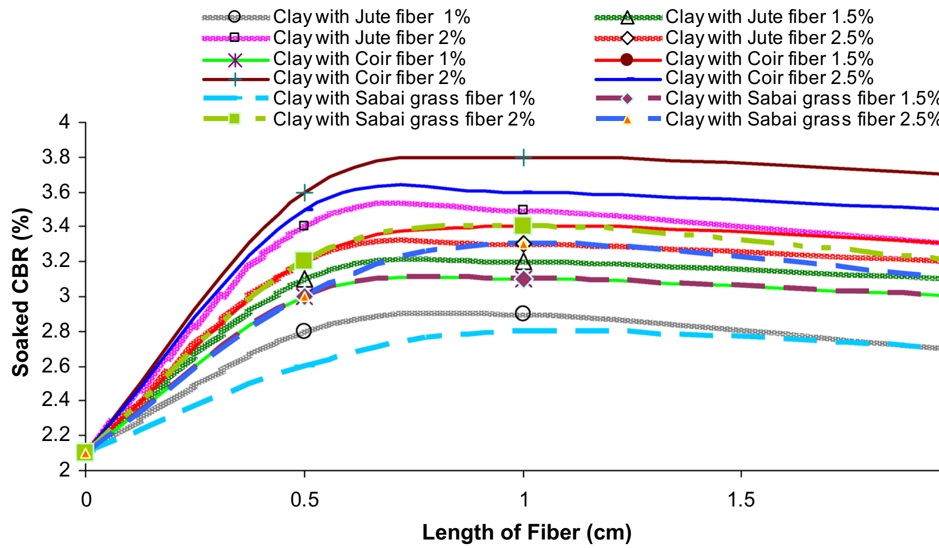


Fig. 11 Effect of fiber length on soaked CBR

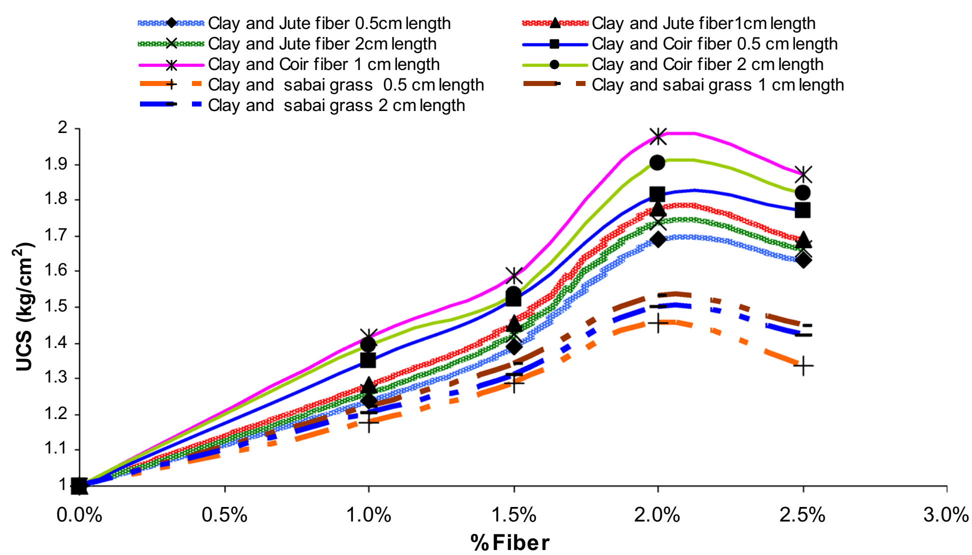


Fig. 12 Effect of fiber content on UCS for clayey soil

From these figures, it is observed that the both the unsoaked and soaked CBR values of clay–fiber mixes increases with the increase of fiber length up to a maximum limit and after that it tends to reach constant value. Hence fiber length beyond the optimum length has little significance in CBR value. Both unsoaked and soaked CBR values are maximum for fiber length of 10 mm for all types of natural fiber used. However out of the three natural fibers tested in this experimental study, coir fibers exhibited highest increase in CBR value both in soaked and unsoaked condition whose length of fibers was 10 mm.

Effect of Fibers on Unconfined Compressive Strength (UCS) Test

The UCS tests were carried out on cylindrical specimens, of size 38 mm diameter and 76 mm length at OMC with maximum dry density prepared by static compaction. The UCS tests were conducted for fiber mixed soil samples as per IS 2720 (Part X) [14]. A minimum of three specimens was tested for each combination of variables and average value was reported. The UCS values obtained from laboratory tests for clay with jute fiber, coir fiber and sabai grass are presented in Tables 4, 5 and 6 respectively.

UCS Versus Percentage of Fiber Content Curves

The UCS versus percentage of fiber content curves for clayey soil with different types of fibers for different fiber length is shown in Fig. 12. From the curve, it is observed that the UCS value increases with the increase in fiber percentage with constant fiber length up to a maximum limit and after that it decreases for all combinations of clay fiber mix. This is due to less fiber–soil solid interaction

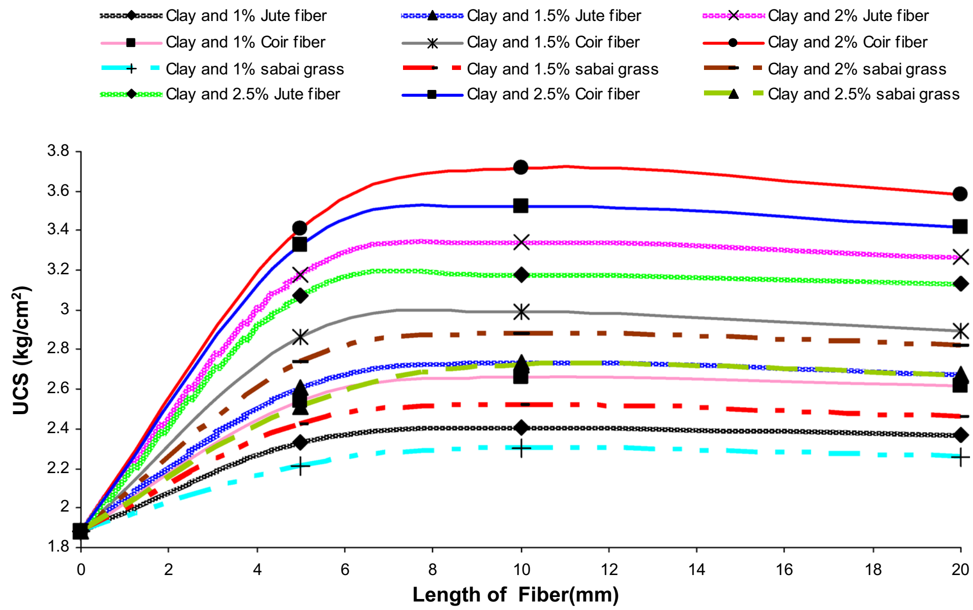


Fig. 13 Effect of fiber length on UCS for clayey soil

when the fiber content increased beyond the optimum. The enhancement of UCS value is more for clayey soil mixed with coir fiber compared to jute fiber and sabai grass. For all combinations of clay fiber mix, the maximum UCS value is for 2% of fiber inclusion of the dry weight of clay.

UCS Versus Length of Fiber Curves

The UCS versus fiber length curves for clayey soil with different types of fibers for different fiber length is shown in Fig. 13. From this curve, it is observed that the UCS value of fiber mixed soils increases gradually with the increase in fiber length up to a maximum value and after that it remains constant. Therefore fiber length beyond the optimum length has little significance in UCS value. But UCS value is maximum for fiber length of 10 mm for all types of fibers used in randomly mixing. UCS value of the soil used in the study at OMC was 1.88 N/cm^2, while maximum value of 3.72 N/cm^2 was observed when natural fiber of coir was used with 10 mm length at 2%. This observation is similar for all three types of natural fiber.

Conclusions

Generally value of California bearing ratio of subgrade material in alluvial plain is low and subsequently construction of roads in such soils becomes costly due to required large thickness of subbase and base courses. To effect decrease of unit cost of such roads, CBR value of subgrade need to be improved. With this aim at end, a systematic experimental investigation was undertaken to study the efficacy of mixing available natural fiber like jute, coir and sabai grass, available in plenty in these area, to elevate the CBR with available local soil. On the basis of this experimental study, following conclusions are drawn:

1. The MDD value decreases with the increase of the percentage of fibers as well as length of fibers in clayey soil for all types of fibers used. The decrease in dry density with the increase of fiber content is due to less specific weight of the fiber in comparison with the soil solids. However the OMC value of clayey soil increases with the increase of the percentage of all types of fibers used in this study within the range tested. This is due to the result of the natural fibers having a greater water absorption capacity than the surrounding soil.
2. There is a significant increase in both unsoaked and soaked CBR value for clayey soil when mixing with the increasing percentage of all three types of randomly distributed natural fibers up to 2% of the dry weight of soil, where after the value decreases. The possible reason of reduction of CBR is due to less contact between fiber and soil solid when the fiber content increased beyond the optimum. Both unsoaked and soaked CBR values are maximum for fiber length of 10 mm for all types of fibers mixed with the soil taken in this study. The improvement of CBR value is more prominent for Coir fiber mixed clayey soil with respect to other fibers.
3. UCS test has been done for the confirmation of optimum percentage and length of fibers which are obtained from CBR test results. There is a considerable increase in the UCS value for the clayey soil when mixing with the increasing percentage of all three

types of natural fibers of 10 mm length up to 2% of the dry weight of soil, where after the value decreases. The enhancement of UCS value is more for Coir fiber mixed with clayey soil.

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