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Compaction and strength behavior of lime-coir fiber treated Black Cotton soil

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Abstract. This paper describes the compaction and strength behavior of black cotton soil (BC soil) reinforced with coir fibers. Coir used in this study is processed fiber from the husk of coconuts. BC soil reinforced with coir fiber shows only marginal increase in the strength of soil, inhibiting its use for ground improvement. In order to further increase the strength of the soil-coir fiber combination, optimum percentage of 4% of lime is added. The effect of aspect ratio, percentage fiber on the behavior of the composite soil specimen with curing is isolated and studied. It is found that strength properties of optimum combination of BC soil-lime specimens reinforced with coir fibers is appreciably better than untreated BC soil or BC soil alone with coir fiber. Lime treatment in BC soil improves strength but it imparts brittleness in soil specimen. BC soil treated with 4% lime and reinforced with coir fiber shows ductility behavior before and after failure. An optimum fiber content of 1% (by weight) with aspect ratio of 20 for fiber was recommended for strengthening BC soil.

Keywords: lime; coir fibers; maximum dry density; aspect ratio; unconfined compressive strength.

1. Introduction

The expansive soils occur all over the world. India has large tracks of expansive soil known as Black Cotton soil (BC soil), covering an area of 0.8 million square kilometer, which is about 20% of total area. The major areas of their occurrence are states of Maharashtra, Gujarat, southern parts of Uttar Pradesh, eastern parts of Madhya Pradesh, parts of Andhra Pradesh and Karnataka. This type of soil is available up to a depth of 3.7 meters on an average in the above parts of India. Expansive soils occurring above water table under go volumetric changes with change in moisture content. Increase in water content causes the swelling of the soils and loss of strength and decrease in moisture content brings about soil shrinkage. Swelling and shrinkage of expansive soil cause differential settlements resulting in severe damage to the foundations, building, roads, retaining structures, canal lining, etc. The construction of foundation for structure on black cotton soils poses a challenge to civil engineers. Chemical stabilization is one of the oldest methods of stabilization of problematic soil. In recent days it has been investigated that addition of fibers will improve the

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ductility behaviour of the soil there by reducing the development of crack during shrinkage. Use of artificial fibers poses the environmental problems. Natural fibers like coir, jute, and wood pulp can be used as a reinforcing material to soil. In order to increase the effectiveness of the ground improvement method, an attempt is made to study the influence of coir fiber reinforcement on compaction and strength properties of lime treated BC soil and compared with the results obtained for BC soil alone and BC soil reinforced with coir fiber.

Several researches have been carried out to investigate and assess the behaviour of treated ground with chemical or fibers alone, (Setty and Rao 1987, Bell 1988a, Ramesh *et al.* 1999, Gosavi *et al.* 2004, Ramesh *et al.* 2005, Ramana Murthy and Hari Krishna 2006, Samadhiya *et al.* 2008). The use and application of chemicals and fibers together in soil is increasing in recent times. Kaniraj and Vasant (2001) reported on behavior of cement-stabilized fiber-reinforced fly ash soil mixtures. Kaniraj and Gayathri (2003) reported on geotechnical behavior of fly ash mixed with randomly oriented fiber inclusions. Nagu *et al.* (2008) have investigated on improvements to lime stabilized clayey soil synthetic fiber reinforcement. Pradip and Nagarnaik (2008) have reported on influence of polypropylene fiber and cement addition on behaviour of soil-fly ash mixture. Nisha and Ilamparuthi (2008) have reported on the performance of soil stabilization using various fibers and cementatious materials. In this paper, the effect of coir fiber along with lime addition on compaction and strength behaviour of BC soil has been presented.

2. Experimental work

Black Cotton soil (BC soil) was collected from Davanagere, Karnataka state, India by an open excavation from a depth of 2 meters below natural ground level. The BC soil was air dried and pulverized in a ball mill after separating the pebbles. The pulverized soil which is passing through 425 micron IS sieve was used in the present investigation. The physical properties of the soil are presented in Table 1.

Lime obtained form **Sd Fine-Chemicals Limited**, Mumbai, India is used in present investigation. The chemical Composition of lime is presented in Table 2.

Coir fibers cut into various lengths were used as a natural reinforcing material. Coir fibers,

Table 1 Basic properties of Black Cotton soil

Type of test	Values
Natural moisture content w (%)	8.7
Grain specific gravity (Gs)	2.72
Liquid limit (%)	83
Plastic limit (%)	32.5
Plasticity index (%)	50.5
Shrinkage limit (%)	8.3
Compaction test	
Proctors	
M.D.D kN/m^3	14.4
O.M.C (%)	28.5
Unconfined compressive strength (kN/m^2)	313

Table 2 Chemical composition of lime

Chemical configuration	$Ca(OH)_2$
Minimum assay (%)	90
Maximum limits of impurities:	
Chloride (Cl) (%)	0.01
Sulphate (SO_4) (%)	0.2
Arsenic (As) (%)	0.0004
Lead (Pb) (%)	0.001
Hydrochloric acid insoluble matter (%)	1.0

brownish in color, were collected from the local small scale factory in Trichy, Tamilnadu, India.

Parameters considered in the present experimental work were aspect ratio and percentage of coir fiber. Fiber-reinforced soil samples were prepared at maximum dry density (MDD) and optimum moisture content (OMC). Samples were prepared by adding coir fibers 0.5%, 1%, 1.5%, 2%, 2.5% and 3% (by weight of soil) with aspect ratio (A_r) of 20, 40, 60, 80, 100 and 120. Optimum lime content was determined by mixing BC soil with 2% to 8% lime (by weight of soil). Fibers were randomly mixed in soil to form homogenous mixture. Moist soil fiber mix was transferred to the mould and compacted. Compaction test was conducted using Mini compaction test apparatus (Sridharan and Sivapullaiah, 2005) and Light compaction test as per BIS 2720 part VII (1980) and unconfined compressive strength tests were conducted for various combinations of soil sample compacted to their OMC-MDD as per BIS 2720 part X (1973).

3. Results and discussions

The compaction and unconfined compressive strength tests were carried out for various percentages of lime and 4% lime was found to be optimum. The above tests were also carried out with the coir fibers reinforced with BC soil treated with optimum percentage of lime and the results are discussed.

3.1 Dry density-water content of BC soil reinforced with coir fibers

It has been observed in general, that addition of randomly distributed coir fiber to BC soil with different percentages and aspect ratios reduces MDD and increases OMC. The reduction in MDD and increase in OMC in the case of BC soil specimen reinforced with coir fiber in most of the aspect ratios is due to the fact that lighter material replaces heavy soil mass and also due to rearrangement of particles with reinforcement reduces MDD. Similar conclusions were drawn by Gosavi *et al.* (2004). However a decrease in OMC and increase in MDD was observed with aspect ratio of 20 with 1% of coir fiber and with aspect ratios of 80 with 0.5% of coir fiber -in accordance with the observations of Kaniraj and Vasant (2001), Nataraj and Manis (1997), Kaniraj and Gayathri (2003) on clay soil/fly ash with synthetic reinforcement.

The present study reveals that coir fiber in BC soil is more effective than the results obtained by the use of synthetic or glass fibers reported by other investigators in improving the compaction behavior. This may be due to the fact that the coir fiber gets mixed randomly with soil and has improved frictional bond when compared with the use of synthetic fibers. It was observed that the

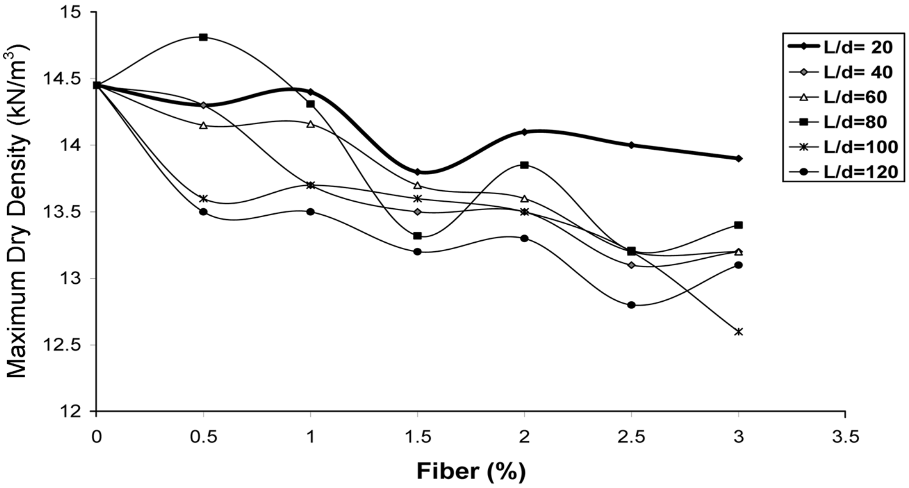

Fig. 1 Influence of fiber content on maximum dry density of reinforced Black Cotton Soil (BCS)

ratio of MDD of composite specimen mixed with coir fiber to that of untreated BC soil specimen is in the range of 0.93 to 1.03, for fiber content of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% and for aspect ratio of 20. For the case of synthetic fiber/glass fibers used in BC soil, Gosavi *et al.* (2004) have reported that the above ratio was in the range of 0.92 to 0.95 for all these fiber content, for aspect ratios of 25, 50, 250 and 500. This indicates that the coir fiber increases the MDD when compared to synthetic fibers.

The variation of MDD with fiber content is shown in Fig. 1 and variation of OMC with fiber content is shown in Fig. 2. These variations reveal that the optimum value of fiber content is found to be 1% (by weight) with aspect ratio of 20. Gosavi *et al.* (2004) have reported from their results of compaction test on BC soil with synthetic/glass fiber, an optimum value of 2% (by weight) fiber content. However, in the present study with fiber content and aspect ratio higher than 1% and 20 respectively, the relative volume occupied by coir fibers increases, indicating that the fiber-to-fiber

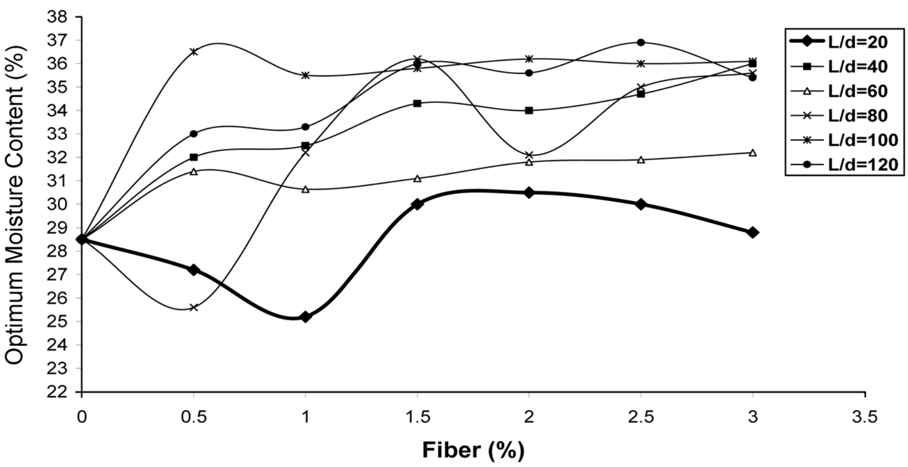

Fig. 2 Influence of fiber content on optimum moisture content of reinforced Black Cotton Soil (BCS)

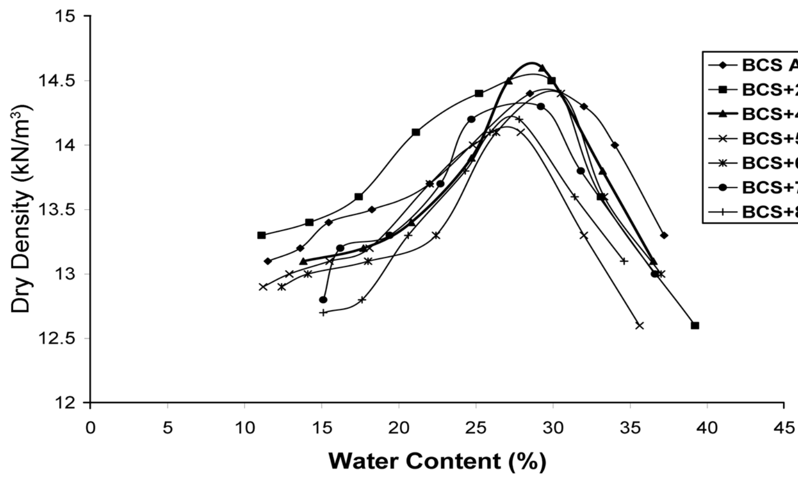

Fig. 3 Dry density-water content of Black Cotton Soil (BCS) and BCS with 2 to 8% lime

interaction dominates rather than soil to fiber interaction. Hence the degree of interlocking and friction mobilized in the sample reduced. The decrease in OMC for increasing fiber content from 0 to 1% is as much as 11.6% with marginal reduction in MDD for aspect ratio of 20. However, for 2% fiber content OMC increases by about 13% and MDD increases by 2% for aspect ratio of 80. With the further addition of coir fiber, the OMC increases and MDD reduces as shown in Fig. 1 and Fig. 2.

3.2 Dry density-water content of BC soil with various percentage of lime

It can be observed from Fig. 3 that MDD of BC soil increases with the addition of lime with corresponding marginal increase in OMC. The increase of MDD is more with the addition of lime up to 4%. The adhesion between the water and soil particles increases with the increase in lime content up to 4%. With the further addition of lime beyond 4% MDD reduces and OMC increases due to the disintegration of soil particles.

3.3 Dry density-moisture content of BC soil with lime and coir fibers

Dry density-moisture content of lime treated BC soil at various percentage of coir fibers are shown in Fig. 4. The OMC and MDD have been reduced for lime treated BC soil reinforced with coir fiber with different aspect ratios. This is due to the disintegration of soil particles with the addition coir fibers

3.4 Unconfined compressive strength of BC soil with coir fibers

A typical variation of unconfined compressive strength with curing period is presented in Fig. 5. It has been observed that addition of coir fiber with aspect ratio 20 and 80 have shown significant increase in the unconfined compressive strength with curing period compared with other aspect ratios.

Fig. 6 shows stress-strain behavior of all the composite specimens. It can be seen that the BC soil reinforced with coir fiber will increase its strain carrying capacity after post peak strength in all

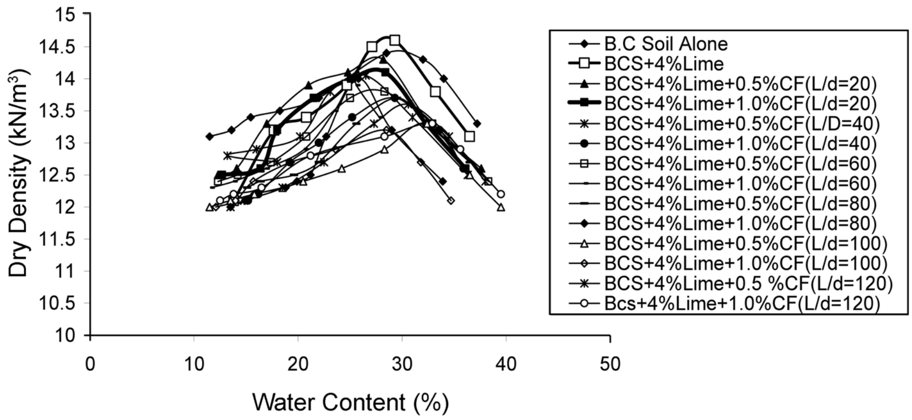

Fig. 4 Dry density-water content for various percentage and aspect ratio of coir fibers in optimum Black Cotton Soil (BCS)-lime mixture

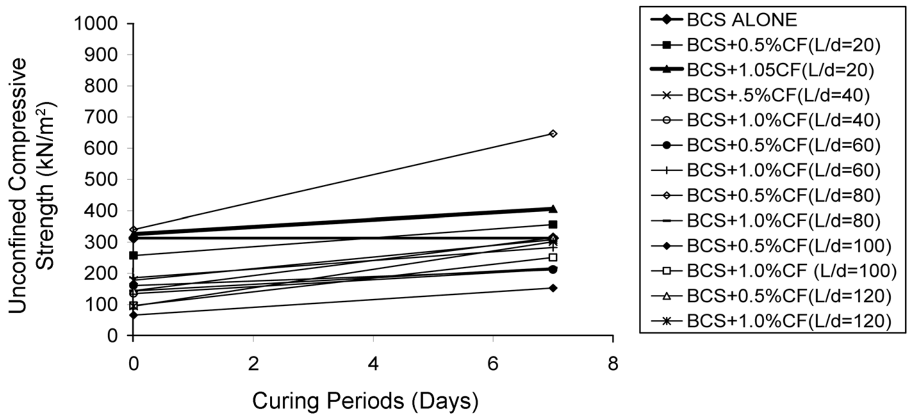

Fig. 5 Unconfined compressive strength of unreinforced and reinforced Black Cotton Soil with 0.5 to 3.0% coir fiber

percentage of fiber reinforcement and aspect ratios. Similarly, marginal improvement of stress carrying capacity for BC soil specimens reinforced with 1% and 0.5% coir fibers (with aspect ratio of 20 and 80 respectively) have been observed. The increase in strength of BC soil reinforced with fiber is quite predictable since the technique primarily involves the introduction of a stiffer material in a weak soil and it is in accordance with the observation of Porbaha *et al.* (2001) and Vinod *et al.* (2007). In the present study, BC soil alone attains a peak stress at about 5.5% axial strain and remains almost constant up to 6.5%. BC soil reinforced with 1% coir fiber with aspect ratio of 20 increases the axial strain from 6 to 9% exhibiting a ductile behavior of composite soil. Same trend has been observed in higher aspect ratio, in accordance with the observations of Ranjan *et al.* (1999).

3.5 Unconfined compressive strength of, BC soil with optimum percentage of lime and various combinations of coir fibers

Unconfined compressive strength of lime treated BC soil with various percentage of coir fiber

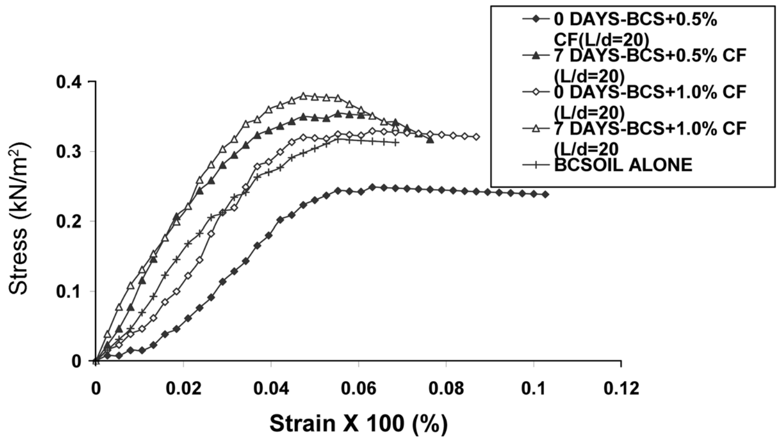

Fig. 6 Stress-strain behavior of Black Cotton Soil and optimum combination of BCS with 0.5 to 1.0% coir fiber at aspect ratio of 20

with curing is as shown in Fig. 7. It has been observed that unconfined compressive strength of BC soil increases for all the composite specimens. The increase in strength for optimum combination of BC soil-lime is well established. This is in accordance with the technique that primarily involves the maintenance of the pH of 12.4 in soil which can be obtained by adding optimum percentage of lime as reported by Balasubramaniam *et al.* (1989). This is substantiated by Broms (1984) who reports that large amount of heat is released upon the hydration of quick lime which causes a rise in temperature with the increase in pH and is favorable to long term chemical reactions in the soil-lime mixture. The present study reveals that there is strength gain for BC soil reinforced with randomly distributed coir fiber of 1% with aspect ratio 20 and 0.5% with aspect ratio of 80. However, for lime treated BC soil reinforced with 1% coir fiber for aspect ratio 20- the strength gain is more compared to other percentages and aspect ratios.

The Relative Strength Gain Number (RSGN) as suggested by Kaniraj and Vasant, (2001) has been used in the present study. Relative Strength Gain number, G_f is given by Eq. (1) (Kaniraj and Vasant, 2001) as below:

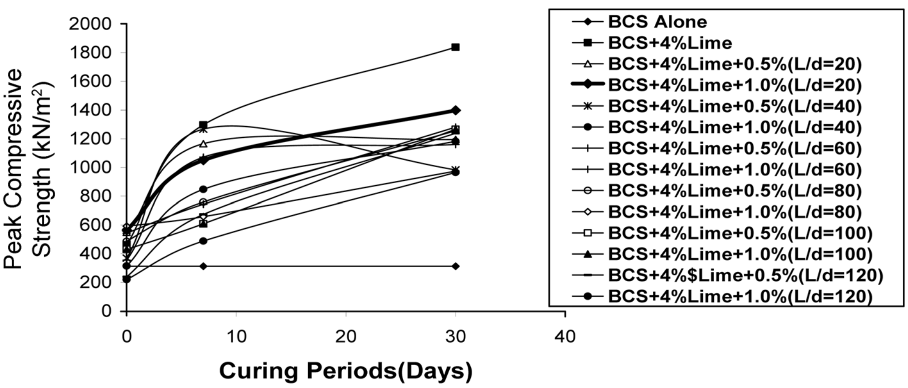

Fig. 7 Unconfined compressive strength of optimum combination of Black Cotton Soil-lime with various percentage and aspect ratios of Coir Fiber (CF)

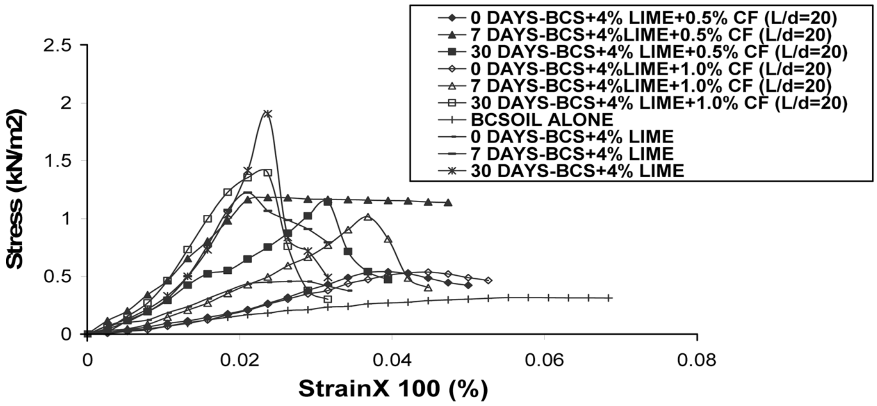

Fig. 8 Stress-strain behavior of Black Cotton Soil and optimum combination of BCS-lime reinforced with 0.5 and 1.0% coir fiber at aspect ratio of 20

$$G_f = \frac{Q_{f_o} - Q_o}{Q_o} \tag{1}$$

where, Q_{fo} = UCS of fiber-reinforced specimen, and
Q_o = UCS of un reinforced specimen.

Nagu *et al.* (2008) reported that when optimum percentage of synthetic-nylon fibers were used in stabilization of lime treated clay soil with an aspect ratio 200 at 28 days curing, the highest RSGN is 1.25 where as when polyester fiber were mixed with Delhi silt-fiber with 3% cement and 1% fiber (Kaniraj and Vasant 2001), the RSGN obtained was 2.46.

The RSGN of the composite specimen obtained in the present investigation using coir fibers to that of untreated BC soil specimen is 2.81 and 3.45 respectively for fiber content 0.5 and 1.0% for aspect ratio of 20 at optimum lime soil combination of sample tested at 30 days curing. Thus, the coir fiber is more effective than synthetic-nylon/polyester fiber in improving RSGN. This indicates that the friction mobilized by the inclusion of coir fiber is more than the synthetic-nylon fibers or polyester fibers, resulting in better mobilization of tensile stress in fibers.

Stress-strain behavior of lime treated BC soil with various percentage of coir fibers up to 30 days curing are shown in Fig. 8. It has been observed from the figure that addition of lime increases the peak stress with curing. The post peak strain reduces significantly due to the brittle nature of the specimen. The brittle behavior of optimum lime treated BC soil reduces with the addition of randomly distributed coir fibers with various aspect ratios which increases the post peak strain as shown in Fig. 8.

4. Conclusions

Based on the results presented in this paper, the following conclusions are drawn:

1. Addition of lime to BC soil increases the strength. It has been observed that 4% lime by weight is found to be optimum.
2. Addition of randomly distributed coir fiber to BC soil increases strain after reaching peak

strength. Thus it shows the ductile behavior of soil sample.

3. Addition of optimum lime to BC soil increases the strength and the sample become brittle with curing.

4. Addition of 1.0% coir fiber with aspect ratio of 20 and 0.5% coir fiber with aspect ratio 80 increases the strength of BC soil compared with other coir fiber combinations. The strength of BC soil reinforced with 0.5% coir fiber with aspect ratio 80 is higher than 1.0% coir fiber with aspect ratio of 20.

5. Lime treated BC soil reinforced with 1.0% coir fiber with aspect ratio of 20 increases the strength and reduces the brittle behavior of soil specimen, where as with 0.5% coir fiber and aspect ratio of 80 strength increase is marginal.

6. Addition of 4% lime to soil with 1% coir fiber increases strength and improves ductility. Beneficial effect is more with aspect ratio of 20.

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Notations

A_r	: Aspect Ratio
BIS	: Bureau of Indian Standards
BCS	: Black Cotton Soil
BC soil	: Black Cotton soil
IS sieve	: Indian Standard sieve
μ	: Micron
UCS	: Unconfined Compressive Strength
RSGN	: Relative Strength Gain Number
MDD	: Maximum Dry Density
OMC	: Optimum Moisture Content
%	: Percentage
G_f	: Strength Gain Number
Q_o	: UCS of Black Cotton soil alone
Q_{fo}	: UCS of Various percentage and aspect ratio of coir fiber and optimum percentage of lime mixed with black cotton soil specimen