Effect of bamboo fibres and lime on engineering properties of expansive soil

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Abstract. Shear strength, differential settlements and lofty compressibility, extensive soil usually create a problem for civil engineers and geotechnical engineers. Stabilization is one of the oldest ways to augment the soil quality of problematic soil. In current time, it has been experienced to the totalling of fibres improves the ductility performance of the soil close by tumbling the maturity of fractures throughout the contraction. This paper illustrates the outcome of lime plus bamboo fibres on strength performance black cotton soil blending with different percentages by conducting California Bearing Ratio, Modified Proctor Compaction as well as Unconfined Compressive Strength at various curative periods. The test result indicates that strength characteristics of the most viable combination of black cotton soil-lime sample combined with bamboo fibres are considerably better than un-treated black cotton soil and also the strength of soil increased due to increase in the curing period.

Keywords: Black Cotton Soil, Lime, Bamboo Fibers, Compaction, CBR, Unconfined Compressive Strength.

1. Introduction
In most of the cases, expansive soil is called as problematical soils because of their alteration in nature by fluctuations in moisture content. In the globe, the range of studies (Holtz and Gibbs, 1956; Ganapathy, 1977; Evans and Mc Manus, 1999) reported that many structures constructed on expansive soils are failed. If it is essential to build the structure on such soils, the properties must be improved to bare the loads for any type of structure. In addition to this, the highway position is inhibited to appropriate convenience and connectivity criteria, which perpetually might come across swelling soils on the way and thus it turned into the offing to develop their ability, due to traffic operations, through appropriate practice to the in-situ clay in broad and expansive soils in scrupulous. Several researchers (Dembichi and Jermolowietz, 1988; Rao, 1996) believed that reinforcing the earth could solve the bulk number of civil engineering problems in coming future. Lindh and Eriksson (1991) reported that fibre-reinforced sand in road construction improved the strength and deformation properties of pavements. Due to the expansive soils, there have been continuous efforts around the world to create ways and means to solve the problems. However, this and many other methods are only partially successful and therefore efforts to improve better methods are still ongoing. The use of waste materials and natural fibre helps to improve soil property because they are cheap, locally available and environmentally friendly. The use of natural materials such as jute, coir, sisal and bamboo as a strengthening material
in the soil began in the early nineties. At present, it is examined to the accumulation of fibres improves the durability performance of the soil thereby falling the development of fractures during contraction. Navami Chandran B, Veena Vijayan L (2017) are tested the result of rice husk ash (RHA), banana fibre and bamboo fibre on clayey soil by conducting unconfined-compressive-strength, CBR and Compaction tests and from the results, maximum-dry-density decreases and the optimum moisture-content raises with the addition of RHA, Bamboo fibre and Banana fibre and found that the optimum percentage of RHA is 6%. The optimum percentage obtained by adding soil to different percentages of bamboo and banana fibre is 1% and 0.5% respectively. Dipika Devi and Boken Jempen (2016) Properties of a local soil with and without bamboo fibre reinforcement 1%, 2%, 3%, 4% and 5% are studied and compared. The length of the fibres considered are 20 mm and 30 mm and shear tests are performed with a slow strain rate to simulate drained condition. Fibre-reinforced soils increasing till 4%, shear strength increases. John Paul and Antony Rachel Sneha (2016), Black cotton soil treated with fly ash plus reinforced with dissimilar percentages of bamboo fibres with a mean diameter 0.45 mm and 25 mm pieces be assorted randomly and from results, strength properties of best possible amalgamation of black cotton soil-fly ash reinforced through bamboo fibres be palpably improved than untreated soil and 1% fibre and 20% fly ash is found to be optimum. Fly ash blended with 1% of bamboo fibre raises the strength of the BC soil and reduces the brittle behaviour of the soil sample, while other proportions used fibres show a slight enlarge. The outcome of the studies conducted is that the bamboo fibre fly ash treated BC soil can be used as a strengthening material. Dhanya and Ramya, (2016), Geotechnical characteristics of quarry dust treated soil with bamboo fibres indicated the CBR value goes on rising as a proportion of quarry dust increases up to 25%, and then decreases on additional adding, enhance in optimum-moisture-content with raise in the proportion of bamboo fibre to the quarry dust treated soil and reduce in maximum dry density with raise in the percentage of the bamboo fibre to quarry dust treated soil and found that 1% of bamboo fibre was taken as an optimum percentage. Twinkle and Sayida, (2011), experiments were conducted on BC soil blended through the further extent of the lime and of polypropylene fibre, and found that optimum moisture content raises and the maximum-dry-density fallen, adding lime to the soil liquid limit lowered but plastic limit raised. At 6% lime and 0.75% polypropylene fibre unconfined compressive strength gained of about 3.8 times and CBR gained of about 3.19 times compared to untreated soil. In the current research work, a trial has been made to calculate the geotechnical properties of BC soil mixing with unlike proportions of lime and bamboo fibres. From the outcome, it is noticed that there is a development in engineering property as a result.

2. Study Design
The present study has been planned in a three-stage process. In the first stage, it is proposed to carry out various tests to be performed in the laboratory for detecting the important characteristics of the materials used during the study. In the second stage, the stabilization technique tried in the laboratory carried out blending with different proportions of lime as shown in figure 1.
It is proposed to obtain the strength and other important properties, through laboratory tests. In the third stage, it is proposed to carry out the effect of bamboo reinforcement materials on the soil – lime stabilized mix as shown in figure 2. Based on the observations and assessment results, optimum percentages of lime and bamboo fibres from the laboratory experimentation and relative comparison will be made to know the improvement in geotechnical properties.

![Various Mix Proportions of BC Soil with Lime and % of Bamboo Fibres](image)

**Figure 2.** Various Mix Proportions of BC Soil with Lime and % of Bamboo Fibres

### 3. Materials and Properties

A collection of materials used in the course of the lab tests is described in the subsequent section.

#### 3.1 Black Cotton Soil (ES)

Soil is from Shady grey to black in colour, obtained at Amalapuram, Andhra Pradesh, India. The soil has been taken from a depth of 1.0 to 1.5 m beneath the ground surface. The soil was crushed physically to pass throughout 4.75 mm IS sieve shown in the figure. 3. Soil is graded as inorganic land of high compressibility (CH) as stated by IS classification. Characteristics of BC soil Code terms are presented in Table 1.

| Laboratory Test                     | Symbol | Results | Relevant IS Code    |
|-------------------------------------|--------|---------|---------------------|
| Differential Free Swell (%)         | PDF    | 115     | IS 2720 Part XI     |
| Atterberg's limits                  |        |         |                     |
| Liquid Limit                        | \(W_L\) | 82%     | IS 2720 Part V      |
| Plastic Limit                       | \(W_P\) | 40%     | IS 2720 Part V      |
| Plasticity Index                    | PI     | 42%     | IS 2720 Part V      |
| Specific Gravity                    | G      | 2.41    | IS 2720 Part III    |
| Grain Size Analysis                 |        |         |                     |
| Coefficient of Uniformity           | Cu     | 7.1     | IS 2720 Part IV     |
| Coefficient of Curvature            | Cc     | 1.1     | IS 2720 Part IV     |
| Compaction Parameters (Modified Proctor) | |         |                     |
| Optimum Moisture Content (%)        | OMC    | 22.12   | IS 2720 Part VIII   |
| Maximum Dry Density(kN/m³)          | MDD    | 14.99   | IS 2720 Part VIII   |
| California Bearing Ratio (CBR)      |        |         |                     |
| Soaked CBR                          | CBR    | 1.79    | IS 2720 Part XVI    |
| Unsoaked CBR                        | CBR    | 2.6     | IS 2720 Part XVI    |
| Unconfined Strength Compressive     | UCS    | 350 kN/m² | IS 2720 Part X     |
3.2 Lime
Hydrous lime was utilized as a stabilizing agent in this investigation was taken from the local market. 0 % to 8 % amount of lime was mixed by dried weight of soil. The lime’s specific gravity is 2.37. Limestone comes in the structure CaCO$_3$, be sieved throughoutby150μ sieve and preserved in strongbox for successive invitations, as revealed in the figure. 4.

Table 2. Properties of Lime

| Chemical Formula | Ca(OH)$_2$ |
|------------------|------------|
| Molar Mass       | 74.093 g/mol |
| Appearance       | White powder |
| Odour            | Odourless |
| Density          | 21.58 kN/m$^3$, solid |
| Melting Point    | 580$^\circ$C (loses water, decomposes) |
| Solubility in Water | 1.89 g/L (0$^\circ$C), 0.66 g/L (100$^\circ$C) |
| Specific Gravity | 0.9 |
| Acid Resistance  | Very Good |
| Alkali Resistance| Good |
| Dispersion       | Good |
| Young’s Modulus  | 3450 MPa |

3.3 Bamboo Fibers
Sai Laxman Group from Guntur is the provider of the bamboo shown in figure 5 and physical and chemical characteristics are shown in tables 3 & 4. These fibres are green & biodegradable, strong, UV shielding, flexible, soft and are strong in tension with low modulus of flexibility and also this material available nearby with little cost.

Table 3. Physical Properties of Bamboo Fiber
(Courtesy from Sai Laxman Industrial Group)

| Properties              | Units | Values |
|-------------------------|-------|--------|
| Length                  | mm    | 25     |
| Diameter                | microns | 20     |
| Specific Gravity        | -     | 0.82   |
| Water Absorption        | %     | 60-85% |
| Density                 | kN/m$^3$ | 14.45  |
| Tensile Strength        | MPa   | 220    |

Table 4. Chemical Properties of Bamboo Fibers
(Courtesy from Sai Laxman Industrial Group)

| Chemical Name            | Percentage (%) |
|--------------------------|----------------|
| Cellulose                | 49.1           |
| Lignin                   | 27.7           |
| Hemi-Cellulose           | 26.1           |
| Starch                   | 2-6            |
| Fat                      | 2-4            |
| Deoxidized Saccharide    | 2              |
| Protein                  | 0.8 - 6        |
4. Laboratory Experimentation

Various experiments are conducted in the lab by a combination of different proportions of lime and bamboo fibres to black cotton soil to know the optimum value and its result on strength characteristics.

4.1 Index Properties

According to Practice Codes [IS 2720 (Part 5) 1985; IS 2720 (Part 6) 1972], the research has been adopted for the discovery of the plastic and liquid limit for the samples attempted.

4.2 Compaction Properties

Compaction parameter of black cotton soil varied with various proportions of lime and bamboo fibres were determined by using IS Heavy compaction test IS 2720 (Part VIII).

4.3 California Bearing Ratio (CBR) Tests

According to the IS Code (IS 2720 (Part 16) 1979), samples have been prepared for CBR testing using a black cotton soil mixture of different percentage of lime and bamboo fibres to influence optimal percentages and geotechnical properties as shown in figure 6.

4.4 Unconfined Compressive Strength (UCS)

These trials are approved out in the laboratory under IS 2720, Part X (1991). These tests are conducted at maximum dry density and optimum moisture content with a strain rate of 1.2 mm/min. Proving Ring used 2 kN capacity for testing models as revealed in the figure. 7.

5. Discussion on Test Results

According to the IS Code Rules, various trials were conducted in the lab and the test results are listed below.
5.1 Index Properties
Standard methods recommended by relevant IS codes [IS 2720 (Part 5) 1985; IS 2720 (Part 6) 1972], in the research has followed the findings of the liquid limits and plastic limit values of the samples attempted. The outcome of the liquid limit trail on black cotton soil treated with dissimilar proportions of lime is showing that with raise in the proportion of lime, the liquid limit goes reducing from 82 % to 68 % whereas the plastic limit raises beginning 40 % to 52 % while lime proportion increasing from 0 to 8 % respectively as shown in figure 8.

![Figure 8](image)

**Figure 8.** Liquid and Plastic Limit Values of the Expansive soil mixed with various % of Lime

5.2 Compaction Test Results
IS Modified Proctor compaction trails are conducted as per IS: 2720 (Part VIII) in the laboratory mixing with various Proportions of Lime and Bamboo fibres in the pulverized black cotton soil. The graph is drafted between moisture-content & dry-density for each proportion increment of lime and bamboo fibres to Expansive soil and from the results, OMC and MDD values are derived. The results and graph from these tests are presented below. The MDD and OMC values are analysed from the trail results and are shown below. From the outcome the maximum-dry-density values are fallen beginning 14.99 kN/m$^3$, 14.63 kN/m$^3$, 14.11 kN/m$^3$, 13.81 kN/m$^3$and 13.67 kN/m$^3$; optimum- moisture-content values are raise from 22.12 %, 23.41 %, 24.69 %, 25.93 % and 28.07 % correspondingly when the soil is mixed with 0 %, 2 %, 4 %, 6% and 8 % of lime respectively as shown in figure.9.

![Figure 9](image)

**Figure 9.** Compaction Parameter of Expansive soil blend with various % of Lime
From compaction test, the MDD values are fallen from 14.99 kN/m³ to 13.67 kN/m³ and OMC values are raising from 22.12 % to 28.07 % respectively and when the soil–lime mix increases from 0 % to 8 %, the fall in dried unit weight was endorsed to prove that lime responds vastly with black cotton soil ensuing Base-Exchange aggregation and flocculation tends towards amplifying void-ratio of the combination taking to fall in the dry unit weight of the black cotton soil and lime mixture. Optimum 4 % of lime blending with black cotton soil and diverse proportions of bamboo fibres 0 %, 0.5 %, 1.0 %, 1.5 % and 2.0 %, the maximum dry density values decreasing from 14.11 kN/m³, 14.03 kN/m³, 13.71 kN/m³, and 13.42 kN/m³ and 13.23 kN/m³ whereas optimum moisture content is increasing from 24.69 %, 26.9 %, 28.14 %, 29.33 % and 31.52 % as shown in the figure 10. This increase in OMC can result from flocculation because of the lime reaction of the auxiliary water inside the flux and the OMC because of the greater osmosis of the bamboo fibres.

![Figure 10. Compaction parameter of BC Soil Blend with 4 % Lime and Various % of Bamboo Fibres](image)

5.3 California Bearing Ratio (CBR) Test

The outcome of soaked and unsoaked CBR trails are performed on black cotton soil blended using assorted proportions of Lime and Bamboo Fibres be presented below. It was found from that black cotton soil added by dissimilar proportions of lime the un-soaked and soaked CBR results are 2.6, 1.79; 4.87, 2.35; 6.87, 3.93; 6.19, 3.37 and 5.37, 3.1 for 0 %, 2 %, 4 %, 6 % and 8 % of lime respectively presented in the figure 11.

![Figure 11. CBR Values of Black Cotton Soil Blend by Various % of Lime](image)
From the above results at 4% lime-soil mix obtained maximum CBR value as contrasted to other samples tested in this work. The unsoaked and soaked CBR values are raised from 6.87, 3.93; 8.29, 4.25; 9.85, 5.78; 8.34, 4.92 and 6.17, 3.9 respectively when the addition of bamboo fibres 0 %, 0.5 %, 1.0 %, 1.5 % and 2 % with the optimum 4% lime – black-cotton soil mix as revealed in figure 12 and the best proportion of lime and bamboo fibres are 4 % and 1 % correspondingly.

![Figure 12. CBR Values of BC Soil Blend by 4% Lime plus Various % of Bamboo Fibres](image)

5.4 Unconfined Compressive Strength (UCS)

UCS testing machine is used for conducting the trails in the laboratory by IS 2720 - Part X at 0, 7, 14- & 28-days curing. Blending lime to the black cotton soil, Unconfined Compressive Strength values raised to 4 % of lime irrespective of curing and beyond it decreases as shown in figure 13.

![Figure 13. Unconfined Compressive Strength of Black Cotton Soil Blend by Various % of Lime](image)

Similarly, black cotton soil added among 4 % lime plus different percentages of bamboo fibres Unconfined Compressive Strength values are raised to 1 % adding bamboo fibres and further adding fallen the strength as shown in figure 14.
6. Conclusions

The following outcomes were made based on the experimentations carried out.

Adding lime showing falling in liquid limit from 82 % to 68 % and improvement in plastic limit start 40 % to 52 %, as the lime % varies starting 0 % to 8 % with an increment of 2 % added in expansive soil as an output of cation ions from lime reduces in volumetric changes. Addition of lime to the black cotton soil results the decreases the MDD value from 14.99 kN/m$^3$ to 13.67 kN/m$^3$ whereas OMC increases from 22.12 % to 28.07 % at 8% of Lime. Compaction characteristics of treated black cotton soil - lime mix at best 4 % of lime, OMC increasing from 24.69 % to 31.52 % and MDD lessening from14.11 kN/m$^3$ to 13.23 kN/m$^3$ with the adding up of different proportions of fibres ranges from 0.5 to 2 with an increment of 0.5 % of bamboo fibre. Addition of lime to expansive soil, unsoaked CBR values increases from 2.6 % to 6.87 % and soaked CBR values are increasing from 1.79 % to 3.93 % up to 4 % of lime and beyond the value fallen. Un-soaked and soaked CBR value goes increasing from 6.87 % to 9.85 % and 3.93 % to 5.78 % up to addition of 1% bamboo fibres and beyond it falls with further addition. Unconfined compressive strength increased from 350 kN/m$^2$ to 780 kN/m$^2$ up to 4 % adding lime and beyond it decreases and also from 780 kN/m$^2$ to 1110 kN/m$^2$ up to 1 % bamboo fibres correspondingly.

Under examination, utilize of lime and bamboo fibres in strengthen soil be able to develop significantly. CBR values raise due to lime significantly bonded with soil particles that resist the entrance of water and adding fibres enhance the strength. Test results proved that the effect of lime and fibres in soil stabilization can develop the strength distinctiveness significantly. Overall, lime and fibre stabilized soil can be used in engineering projects on weak soils with cost-effective concern for land improvement technology. From the trails, the optimum proportion of lime and Bamboo fibres are 4 % and 1 % correspondingly.

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