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Performance of Black Cotton Soil Reinforced with Randomly Distributed Banana Fibers

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Abstract. The most significant part of India and a portion of South India are covered with black cotton soil. These soils have high swelling and shrinkage characteristics and low shear strength. Hence, there is always need of improvement in various engineering properties using suitable reinforcement material. Many researchers used various materials to stabilize or reinforced the black cotton soil. For sustainable construction, it is essential to use natural material or material with low pollution capacity satisfying, all parameters of good soil. The use of different natural fibers as soil reinforcement changed various properties of soil. Here, an attempt had been made to reinforced black cotton soil with randomly distributed banana fires. The unconfined undrained triaxial tests and direct shear tests were conducted on black cotton soil (BC Soil) mixed with banana fibers. The fiber content in reinforced specimens varied from 0.5% to 2.0% with an increment of 0.5% by dry weight of soil. The samples were prepared by adding banana fibers at different percentage and with different aspect ratio of, 10, 20 mm and 30 mm. The MDD and OMC of reinforced soil were determined and the test samples were prepared for respective MDD & OMC of reinforced soil. The results of the experimental investigation of triaxial test and direct shear shows that use of banana fiber as reinforcement to BC soil results in significant increase in shear strength. The increase in length of banana fiber shows increase in cohesion by 110% to 600% and angle of internal friction of 116 % to 227% .

Keywords: Banana fiber, Black cotton soil, Shear strength, angle of internal friction , Cohesion

1 Introduction

"Black cotton soil" covers more than 200,000 square miles, accounting for almost 20% of the whole area. Since soils are expansive in nature, construction issues increases due to low shear strength, high compressibility and swelling potential. Soil reinforcement with natural fibers is frequently used with attention to increasing the compressive strength, shear strength sustainable way. Banana fiber is a natural and easily available material in Jalgaon District of Maharashtra state. Hence using waste banana trunk in terms of fibers is need for sustainable development.

2. Literature Review

The various researchers studied the reinforcement of soil using natural and artificial fibres. The study reveals the utility of fibres for soil improvement. To understand the concept and methodology few literatures discussed below.

Gray and Ohashi (1983) conducted research on sandy soil reinforced with two types of polypropylene fibres, one with a flat profile that is highly flexible and the other with a crimpled profile that is moderately stiff and has four different aspect ratios (L/D) for each type. The study's test results demonstrated that adding more flexible flat profile fibres boosted the sand's shear strength. Additionally, it was observed that the angle of internal friction and the shear strength rose with an increase in the flexible flat profile's aspect ratio. The crimpled profile fibre boosted the sand's shear strength when subjected to a high normal load, but it had little to no impact when the load was moderate and the aspect ratio was low.

Patel and Vanza (2016) studied the shear strength characteristics of Black cotton soil from Bharuch region of Gujarat were performing the direct shear test and triaxial compression test on compacted specimens based on different range of relative compaction. Shear strength parameters were determined for different relative compaction of 90%, 92.5%, 95%,97.5% and 100%. From experimental investigation Black cotton soil for different relative compaction increases the cohesion and decreases the friction angle.

Kumar and Jairaj (2018) studied the shear strength parameters of black cotton soil admixed with coir fibers with varying % quantity and length such as 0.0%, 0.5%, 1.0%, 1.5% ,2.0%,2.5% and 3.0% and length varies from 10, 20, and 30 mm. The peak shear stress increases with increase in percentage of fiber content for BC soil .The strength of expansive BC soil was improved by the inclusion of coir fibers. Fiber content beyond 2% poses mixing difficulty as soil lumps are formed during mixing. This has led to decrease in peak shear strength with addition of fiber content beyond 2%. Hence, there exists a specific fiber content to get optimum strength benefits. Increase in length of fiber increase peak deviator stress for a given percentage of fiber content. However when the length of fiber exceeds 20mm, there is marginal reduction in peak deviator stress. Marginal reduction in cohesion occurs when the length of fiber becomes larger than 20mm for BC soil.

Widianti *et al.* (2020) studied the impact of random inclusion of coir fiber on the shear strength of clay with excessive plasticity.The carried test in this study is a direct shear strength test.The fiber content variations used are 0%, 0.25%, 0.50%, 0.75%, and 1% of the dry weight of the mixture with a fiber length of between 30 mm to 50 mm. The results show that the reinforcement of coir fiber can increase the cohesion and friction angle. The maximum increase in cohesion value was obtained at fiber content of 0.75%, which was 39.66%. The increase in the value of the friction angle was obtained at 1% fiber content, which was 46.67%. The optimum coir fiber content was achieved at the fiber content of 0.75%. With this content, the value of the shear

strength reaches its maximum with an increase of 39.4% at a normal stress of 8.071 kPa.

3. Methodology

The soil was collected and identified as black cotton soil through various tests. The collected banana fibers mixed in the soil in different proportions. The percentage of banana fiber was 0.0%, 0.50%, 1.00%, 1.5 % and 2.00%. The lengths of banana fibers were 10 mm, 20 mm and 30 mm. The different laboratory tests were performed on soil mixed with banana fiber.

4. Materials and Methods

The black cotton soil and banana fiber were used in this study. The test results by conducting various test also discussed below.

4.1 Black Cotton Soil

The soil used in this study was collected from Dhamangaon village , Jalgaon district, Maharashtra, India. The various index properties and compaction properties i.e. maximum dry density (MDD) and optimum moisture content (OMC) of soil was determined in the laboratory. Table 1 shows the consistency limit, free swell index, MDD and OMC of the soil used in the study.

Table 1. Index and compaction properties of soil

SN	Description	Result
1	Liquid Limit, LL (%)	85.33
2	Plastic Limit, PL (%)	62.72
3	Plasticity Index, I_P (%)	22.61
4	Free Swell Index, FSI (%)	69.53
5	Maximum Dry Density, MDD (kN/m^3)	14.9
6	Optimum Moisture Content, OMC (%)	29.6

4.2 Banana Fiber

The banana fiber extruded from banana pseudo stem. It acts as a strong fiber after proper drying and has good stiffness and mechanical properties. The fiber was collected from a factory in Varangaon village Tal. Bhusawal Dist. Jalgaon , Maharashtra, India. The soil to banana fiber proportion in terms of weight used in this study were 0.0%, 0.50%, 1.00 %,1.5% and 2.00%. The banana fiber of 0.15mm diameter with 10 mm, 20 mm and 30 mm long were used for the present study. The aspect rations of fibres were 66, 133 and 200 respectively.

4.3 Test Methods

A preliminary study was conducted to analyze the geotechnical properties of black cotton soil such as liquid limit, plastic limit and free swell index of soil alone. A standard Proctor test was performed to determine the optimum moisture content (OMC) and maximum dry density (MDD) of soil. The soil sample were prepared with different % of banana fibre for different percentage and with different length viz, 10 mm, 20 mm and 30 mm and compacted to OMC. The Unconfined Undrained triaxial tests were conducted in a standard tri- axial apparatus, with and without banana fibers, to study the improvement in the shear strength parameters of black cotton soil. Also Direct shear test was conducted with normal stresses of 50 KN/m^2, 100 KN/m^2 and 150 KN/m^2 at constant rate of strain and measure failure of soil and reinforced soil.

5. Results and Discussion

The soil was mixed with different percentage of banana fibers for varying lengths. The Unconfined Undrained triaxial tests and direct shear test were conducted for original soil and reinforced soil to determine its shear strength.

5.1 Unconfined Undrained Triaxial Test:

Different percentage of banana fibers were added to black cotton soil and tested in triaxial compression testing machine. Parameters such as percentage of reinforcement and length of banana fibers were considered for investigation. Samples were prepared for 38 mm diameter and 76 mm high. The specimens were subjected to four levels of confining pressures (σ3) i.e. of 50 kN/m^2, 100 kN/m^2, 150 kN/m^2 and 200 kN/m^2. The tests were repeated by mixing BC soil with fiber lengths 10 mm, 20 mm and 30 mm. The deviator stress was applied up to the failure of specimen and then shear strength parameters were determined.

5.1.1 Shear strength parameters from unconfined undrained triaxial shear test. The shear parameters were determined using modified failure envelop. The modified failure envelops obtained for BC soil and soil mixed with banana fiber of different % of fibres envelop is shown in Figure 1. It can be seen that modified failure envelops of soil with different fiber content are parallel to each other.

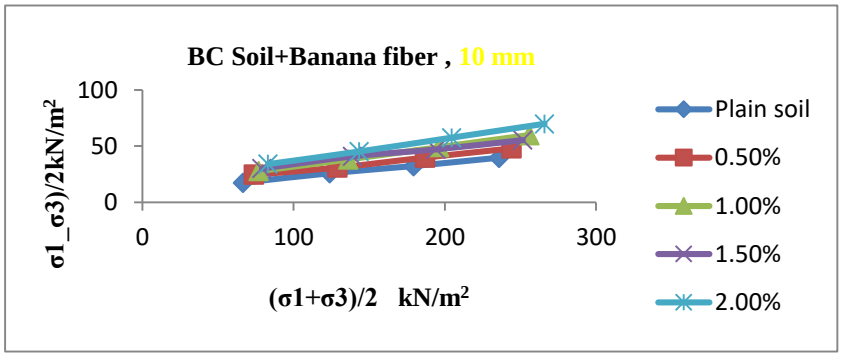

Figure 1: Modified failure envelop for BC soil admixed with banana fiber for 1 cm

The shear strength parameters determined from unconfined undrained triaxial shear strength tests are tabulated in Table 1 for different % of banana fibres and different length of fibres.

Table 1: Shear Strength Parameters by Unconfined Undrained Triaxial Shear Test

Black cotton soil + Banana fiber						
Length	10 mm		20 mm		30 mm	
Banana fiber %	Cohesion C kN/m²	Angle of internal friction Φ˚	Cohesion C kN/m²	Angle of internal friction Φ˚	Cohesion C kN/m²	Angle of internal friction Φ˚
0	9.069	6.84	9.069	6.84	9.069	6.84
0.5	13.84	7.91	56	6.84	10.04	10.2
1.0	13.86	10.15	52.63	9.42	11.29	11.58
1.5	19.42	8.19	34.35	9.31	18.14	14.2
2.0	17.45	11.09	35.87	12	18.86	15.54

5.2 Direct Shear Test

In direct shear tests, both unreinforced and reinforced specimen were tested in a 60 mm square shear box at normal stresses of 50 KN/m^2, 100 KN/m^2 and 150 KN/m^2 and sheared at a rate of 1.25 mm/minute according to IS:2720(Part 13) for UU condition. The fiber content in reinforced specimens varied from 0.5% to 2.0% with an increment of 0.5% by dry weight of soil for banana fibers. The samples were prepared by adding banana fibers at different percentage and varying length viz, 10 mm, 20 mm and 30 mm. The measurement of shear strength is carried out by measuring load on proving ring and evaluating the shear parameter. Table 2 shows C – Ø parameters obtained by direct shear test for different % of banana fibres. The increase in fiber content increases cohesion and angle of friction for BC soil. However, increase in angle of friction is not significant.

Table 2: C – Ø parameters for Direct shear test

Black cotton soil + Banana fiber						
Length	10 mm		20 mm		30 mm	
Banana fiber %	Cohesion C kN/m²	Angle of internal friction Φ˚	Cohesion C kN/m²	Angle of internal friction Φ˚	Cohesion C kN/m²	Angle of internal friction Φ˚
0	13	34.34	13	34.34	13	34.34
0.5	18	38.66	21	37.68	15	34.60
1.0	19	45.56	29	38.31	17	36.50
1.5	25	39.00	15	38.31	20	38.31
2.0	33	36.50	27	36.50	27	38.00

5.3 Effect of Fibers on Shear Strength Parameters

Table 3 & 4 shows the % increase in cohesion and angle of friction with fiber content for different length of banana fiber mixed with BC soil. It can be seen that, increase in length of the fiber increases cohesion and angle of friction. However, when length of the fiber becomes large than 20 mm, there is decrease in cohesion. This is attributed to the fact that, increase in length beyond 20 mm of banana fiber induces difficulty in uniform mixing with the formation of soil lump and leading to decrease in strength of soil. The % increase in cohesion is varying between 110% to 600% while for angle of friction the increase is 116% to 227%.

Table 3: % increase for C and Phi for Unconfined Undrained Triaxial Shear Test

Length	10 mm		20 mm		30 mm	
Banana fiber %	**% Increase in C**	**% Increase in Phi**	**% Increase in C**	**% Increase in Phi**	**% Increase in C**	**% Increase in Phi**
0	-	-	-	-	-	-
0.5	**153**	**116**	**617**	**0**	**111**	**149**
1.0	**153**	**148**	**580**	**138**	**124**	**169**
1.5	**214**	**197**	**378**	**136**	**200**	**207**
2.0	**192**	**162**	**395**	**175**	**208**	**227**

Table 4: % increase for C and Phi for Direct Shear Test

Length	10 mm		20 mm		30 mm	
Banana fiber %	**% Increase in C**	**% Increase in Phi**	**% Increase in C**	**% Increase in Phi**	**% Increase in C**	**% Increase in Phi**
0	-	-	-	-	-	-
0.5	**138**	**112**	**162**	**109**	**115**	**101**
1.0	**146**	**133**	**223**	**112**	**131**	**106**
1.5	**192**	**113**	**115**	**112**	**154**	**112**
2.0	**253**	**106**	**207**	**106**	**207**	**107**

6 Conclusions

On the basis of present experimental investigation the following conclusions were drawn

i. The addition of banana fibres in black cotton soil indicates the increase in shear strength of soil.

ii. The maximum cohesion of soil depends upon the % content of banana fibres and length of banana fibres. The maximum cohesion is observed for fiber with aspect ratio of 133. % increase in cohesion is observed between 110% to 600%.

iii. The increase in the angle of friction of reinforced soil is not significant compared to increase in the cohesion. However, % increase in angle of friction is in the tune of 116% to 227%.

iv. The increase in shear strength parameter leads to increase the bearing capacity of black cotton soil which may proves to be sustainable way of development.

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