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Impact of Jute Reinforcement on the Resilience at the Outermost Limits of Cohesive Black-top Geomaterials

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Abstract

In this work, cohesion-less asphalt geo-material supported with multi-facets of geo-support as jute filaments have been contemplated. The current work is completed on the unreinforced soil and jute fiber supported soil to research the strength and firmness limit of asphalt geo-materials utilizing California bearing ratio (CBR) test. The quantity of layers, ideal profundity and arrangement of the geo-support in geo-material are researched. The implant profundity of jute fiber, i.e., D/2, D/3 and D/4 in single, twofold, and significantly increase layers has been upgraded utilizing CBR values. A clever idea of firmness limit alongside entrance factor is acquainted with assess the strength of the unreinforced and jute-supported geo-material. The experimental outcomes exhibit that remembering jute fiber for single, twofold and triple layer builds the solidness limit of the dirt at the ideal profundity of D/4. The liquid limit at shifted input boundary fluctuates from 0.378 to 0.682 at most extreme entrance factor which shown an 80.42 % upgrade of solidarity in asphalt geo-material. The result of the current review gives a savvy answer for the strength improvement in cohesion-less soils for dike, subgrade, and asphalt development advances.

Keywords

Jute fiber, California bearing ratio, Cohesion-less soil, geo-material.

1. Introduction

The use of natural fiber composites in road construction has become popular for their eco-friendliness and cost-effectiveness. Unpaved roads often suffer from ruts and deformations, but geo-synthetic reinforcement has shown promise in addressing this issue in limited lab studies [4]. Low strain Geo-Gauge stiffness tests on compacted silts show the link between stiffness and other variables, including water content, dry unit weight, saturation level, volume change after soaking, shear strength, and soil plasticity [3]. Few researchers have studied geo-material reinforced with jute, geo-grid, geo-synthetic etc. [5,6]. To evaluate the stiffness and strength properties of a compacted subgrade, a cross-hole dynamic cone penetrometer (DCP) was utilized [2]. A study uses stiffness measurements to estimate the compactness of granular geo-materials used in road sub-base and base courses [1]. CASM-n, a unified critical state model for bonded geo-materials that extend an existing model for reconstituted geo-materials (CASM). In order to more accurately characterize bonded geo-material, CASM-n takes into account pre-yield greater strength and stiffness as well as the cohesive-frictional shearing mode in the post-yield zone [8]. The proposed paper suggests optimizing stiffness and damping of structural systems simultaneously by minimizing sum of mean square responses to stationary random excitations and ensuring constraints on total stiffness and damper capacity. The best design for a constant total stiffness and damper capacity is found in the first phase of a two-step optimization approach, and a number of best designs for changing total stiffness and damper capacity are found in the second step [7]. This paper reviews existing literature on the impact of jute reinforcement on the stiffness capacity of geo-materials. Stiffness capacity measures a soil specimen's resistance to deformation when subjected to external forces such as the weight of a building or pavement. It is a fundamental parameter that determines the soil's ability to support applied loads without excessive settlement or deformation. Factors like composition, density, moisture content and reinforcement materials affect soil stiffness capacity. A higher stiffness capacity indicates a stronger and more stable soil that can bear greater loads and stresses without significant deformation. Even many researchers have reported their studies on the stiffness capacity of the soil.

2. Material and Test Procedure

2.1. Soil

In this research, a soil sample was collected from nearby local places and subjected to sieve analysis test to determine the particle size distribution curve as shown in Figure 1 (a). Based on the test results, the soil was categorized as SP-SM (Poorly graded sand with silt) in accordance with the IS: 2720 Part-4 (1985) standard. A soil's liquid limit (LL) refers to the moisture content on which the soil exhibits characteristics similar to that of a liquid yet displays minimal shear strength. This can be determined by using Casagrande's liquid limit device which involves closing a groove in the soil sample by repeatedly striking it with a standard sized cup. To obtain the liquid limit of the soil, a semi-log plot is created where the logarithm of the number of blows is plotted against water content. The liquid limit is then determined as the moisture content corresponding to 25 no. of blows as achieved from the plot as shown in Figure 1 (b). To determine the maximum dry density (MDD) and optimum moisture content (OMC) of the soil, a standard proctor test (light compaction) was performed according to IS: 2720 Part-7 (1980). The soil sample was compacted in three equal layers in a 1000 cc mould by applying 25 numbers of blows to each layer using a 2.6 kg rammer and a free fall height of 31cm. The MDD and OMC achieved from this test were 18.63 KN/m3 and 12.94% respectively as shown in Figure 1 (b). In addition, other geotechnical characteristics of the soil, including Atterberg Limits and specific gravity, were examined in the lab and are shown in Table 1.

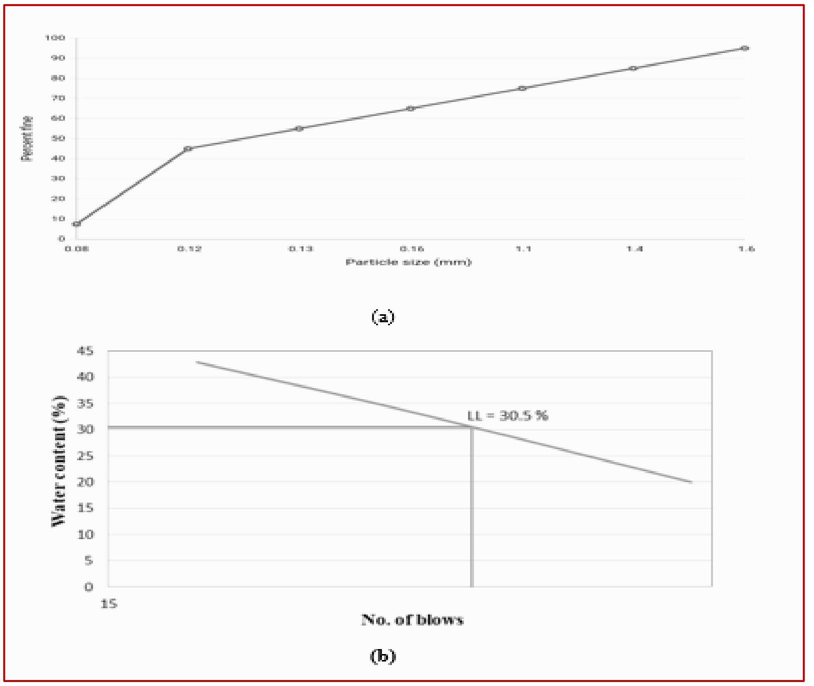

Figure 1. (a) Grain size distribution curve of soil, (b) Atterberg limits graph of soil.

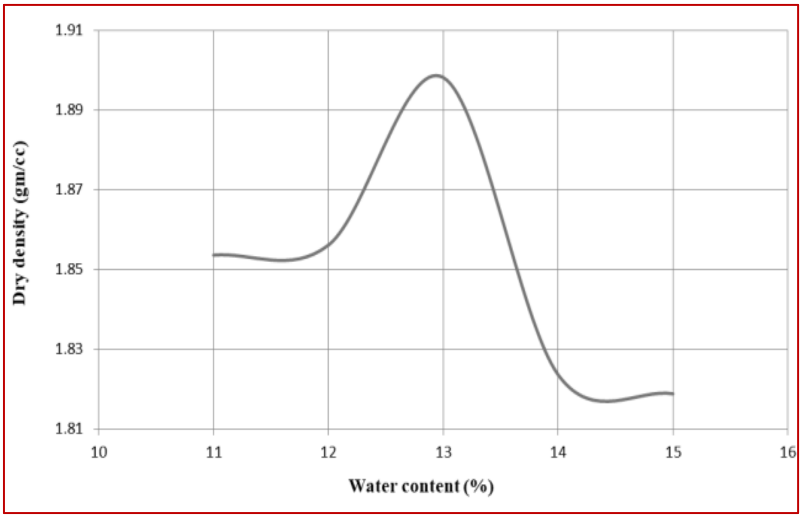

Figure 2. Standard proctor test compaction curve for soil.

Table 1. Soil Properties.

Serial No.	Property	Notations	Values	Units
1	Gravel Fraction	-	9.7	%
2	Sand Fraction	-	81.3	%
3	Silt and Clay Fraction	-	9	%
4	Specific Gravity	G	2.63	-
5	Liquid Limit	LL	30.5	%
6	Plastic Limit	PL	25	%
7	Soil Classification	SP-SM	-	-
8	Maximum Dry Density	$\gamma dmax$	18.63	KN/m^3
9	Optimum Moisture Content	OMC	12.94	%

2.2. Jute Geotextile

Woven jute fiber sheets are used in this research as shown in Figure 3. The jute geotextile is a sustainable and cost-effective solution for a variety of geotechnical and environmental applications offering superior performance and durability compared to other natural fiber-based materials. Jute fiber is a versatile natural fiber with a number of notable physical and chemical properties which is shown in Table 2.

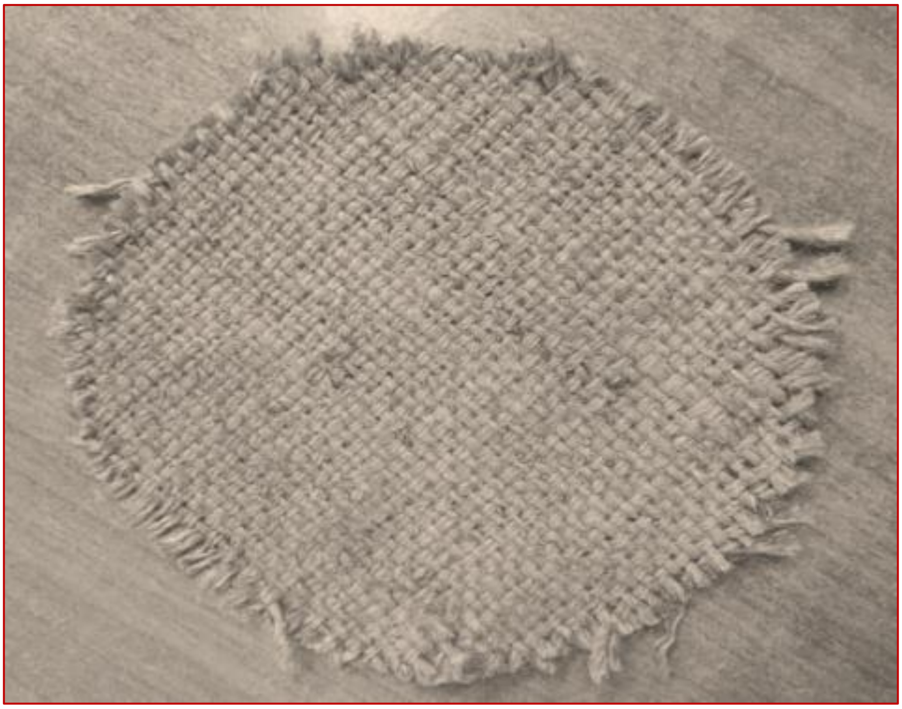

Figure 3. Woven Type Jute Sheet.

Table 2. Properties of Jute Fiber.

Jute Fiber	Values	Units
Physical Properties		
Density	1.3	g/cm^3
Elongation at break	1.5-1.8	%
Tensile Strength	393-773	MPa
Young's Modulus	26.5	GPa
Color	Light Brown to Gray	-
Texture	Coarse, Rough and Stiff	-
Chemical Properties		
Lignin	12-15	%
Cellulose	65-70	%
Hemicellulose	12-14	%
Pectin	0.5-1	-
Reaction with Acids	Decomposes	

2.3. Test Procedure

To assess the California bearing ratio (CBR) on samples of both reinforced and unreinforced soil, standard procedures were followed. The first step was to take the required amount of oven dried soil and mix it thoroughly with water until it reached its optimum moisture content (OMC). This mixture was then placed in a CBR mould that had diameter of 15 cm and depth of 17.5 cm along with a base plate that can be detached and has perforations as per IS: 2720 Part-16 (1987). To achieve the maximum dry density, laboratory standard proctor test (light compaction) was conducted and the soil was compacted accordingly. Filter paper and a perforated metallic disc were placed over the specimen to prepare the soil samples and a space disc was inserted into the mould reducing the effective height to 12.7 cm with a net capacity of 2250 cm3. After the soil samples were prepared, the CBR mould containing the unsoaked soil sample was subjected to testing using a CBR testing machine shown in Figure 3. The CBR values of both the unreinforced and reinforced soil samples were then evaluated based on the plunger penetration of 2.5 mm and 5 mm. The testing was conducted by applying a load on the sample's top surface through the plunger at a constant rate of penetration (1.25 mm/min.). The load and corresponding penetrations were recorded and the CBR values were calculated as the ratio of the load required to penetrate the soil sample by the plunger at a depth of 2.5 mm or 5 mm to the standard loads. This testing process helps to determine the strength and stiffness capacity of the soil which is an important factor in various engineering applications.

3. Results and Discussion

3.1. CBR Testing

The test involves mixing an unreinforced soil sample with single, double and triple layers of jute fiber at various depths to determine the optimal depth of the layers.

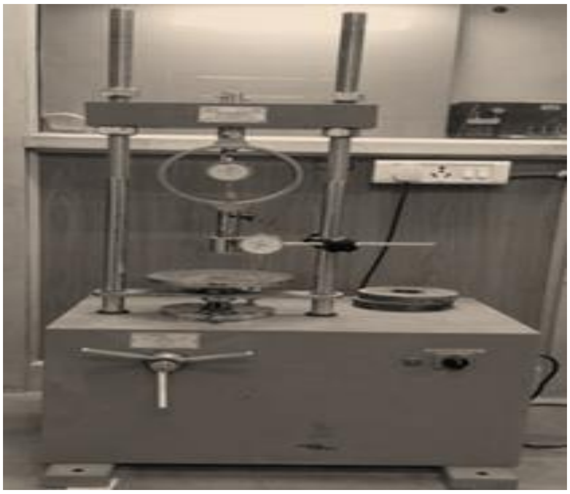

Figure 4. CBR Testing Machine.

From the data of CBR results, evaluate the spring constant (K) values and stiffness capacity (K/Kmax.) of soil which is shown in Table 3 as well as in the equation forms. By reinforcing the single, double and triple layers of jute fiber in unreinforced soil sample which signifies the optimum depth at D/4 (3.175 cm) which represents the higher stiffness capacity and increases the strength of the pavement in comparison to unreinforced soil specimen. Figure 4 illustrates the stiffness capacity versus penetration factor plot curves for single, double and triple layers of jute fiber reinforced soil as well as a comparison between reinforced and unreinforced soil. The plot demonstrates the significant improvement in stiffness capacity of the reinforced soil compared to the unreinforced soil at the same penetration factor.

$$\mathbf{k} = \frac{\mathbf{F}}{\boldsymbol{\delta}} \rightarrow \frac{\mathbf{Q(t, L_f, P_r)}}{\boldsymbol{\delta}\mathbf{(t, dgr)}} \tag{1}$$

The Eq. 1 relates the spring constant (k) of soil to the applied force (F) divided by the amount of deflection (δ) that it experiences under the load.

$$\boldsymbol{Q} = (\boldsymbol{t}, \boldsymbol{L_f}) \tag{2}$$

Eq. 2 represents the applied force (Q) on sample of soil as a function of time (t), load factor (Lf) and proving ring reading (Pr). The equation suggests that the applied force is influenced by several factors including the time over which the load is applied, the size of the soil and the output signals of measuring devices used to measure the load.

$$\boldsymbol{\delta} = (\boldsymbol{t},) \tag{3}$$

The Eq. 3 relates the deflection (δ) of soil to the variables time (t) and dial gauge reading (dgr). The dial gauge reading refers to the displacement or deflection of the material under the applied load. The equation suggests that the amount of deflection of a soil is influenced by several factors incorporating the time over which the load is applied and the displacement of the soil specimen as measured by a dial gauge.

$$\boldsymbol{P_f} = \frac{\boldsymbol{\delta}}{\boldsymbol{\delta_{max.}}} \tag{4}$$

Where P_f is the penetration factor, $\boldsymbol{\delta}$ is the deflection of the specimen and $\boldsymbol{\delta_{max.}}$ is the maximum deflection.

Table 3. Comparison of stiffness capacity values at different penetration factor between unreinforced and reinforced soil (D = 12.7 cm).

PenetrationFactor	Unreinforced soil	JF embeded in 1 layer		JF embeded in 2 layer	
0	1	1	1	1	1
0.3	0.65	0.71	0.7	0.66	0.65
0.4	0.54	0.6	0.6	0.533	0.52
0.5	0.49	0.54	0.56	0.44	0.46
0.8	0.45	0.5	0.54	0.4	0.42
0.9	0.4	0.48	0.49	0.35	0.39
1	0.37	0.48	0.51	0.34	0.38

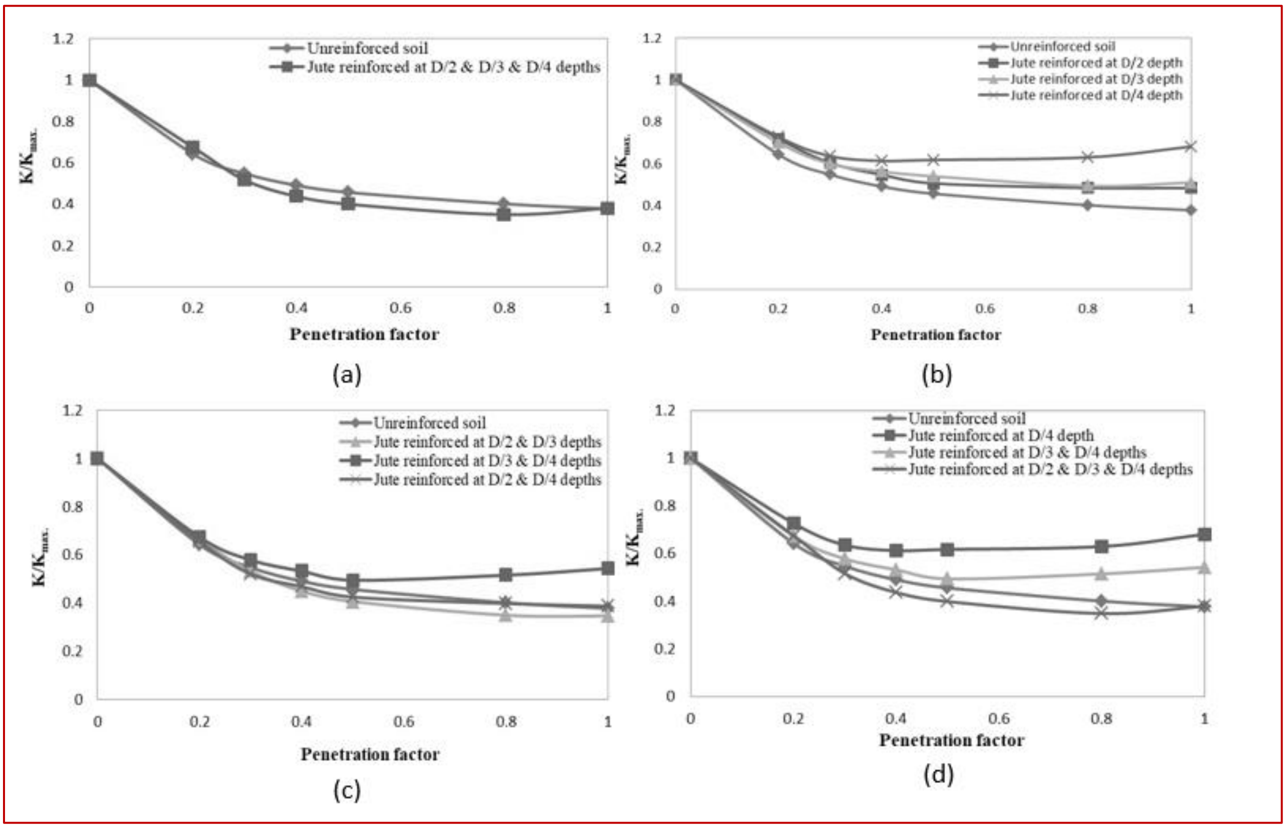

Figure 5. Stiffness Capacity Versus Penetration Factor.

Figure 5 shows the stiffness capacity verses penetration factor plot for (a) soil reinforced with single, (b) double, (c) triple and (d) optimum depths of jute fiber among all layers.

4. Conclusion

Based on the information provided in this research paper, it can be concluded that incorporation of jute fiber in unreinforced soil sample enhances the stiffness capacity of soil specimens at different penetration factor values particularly at the optimal depth of D/4 (3.175 cm) which resulting in improvement in strength of the pavement. The stiffness capacity increased from 0.378 to 0.682 at maximum penetration factor shown in Table 3 which increases 80.42 % of the capacity of stiffness when compared to unreinforced soil. The results obtained from the stiffness capacity versus penetration factor plot curves which are shown in section 3 demonstrate that the stiffness capacity increases with the number of jute fiber layers which indicating that the addition of jute fiber reinforcement can significantly enhance the soil's stiffness. The single layered jute fiber reinforced soil shows the highest stiffness capacity among all the reinforced soil configurations tested. Moreover, the plot curves highlights that the reinforced soil's stiffness capacity is significantly higher than the unreinforced soil at the same penetration factor indicating that jute fiber reinforcement can effectively improve the soil's load carrying capacity thereby increases the strength of the pavement.

Therefore, the findings of this study highlight the potential of jute fiber reinforcement as a viable alternative to conventional reinforcement materials in geotechnical engineering, providing an economical and sustainable solution for enhancing the capacity of stiffness and load-carrying capacity of soil in various geotechnical applications

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