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Enhancing Pavement Subgrade and Subbase Performance Using Natural Fibre Reinforcement: A Study on Coir and Jute Fibres

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Soft soils are highly susceptible to significant settlement when moisture is exposed, drastically reducing their load-bearing capacity. This weakness can lead to premature deterioration of pavement structures if not adequately managed before the pavement layers are constructed. Neglecting to address these soil conditions adequately can lead to significant damage, often necessitating expensive repairs and rehabilitation. Additionally, many researchers have observed problems like linear shrinkage and desiccation cracks after constructing pavements over soft soils. These issues weaken the asphalt or concrete layers, increasing their vulnerability to rutting and fatigue-related failures. To overcome this problem, improving the subgrade soil and subbase layer is necessary. Adding discrete fibres to the subgrade layer is an effective method for addressing shrinkage and tension-induced cracking. While randomly distributed fibres do not entirely reduce the progression of soil cracks, they significantly decrease shrinkage cracks' occurrence and depth. So, this study focuses on the performance of natural fibres to increase the strength characteristics of subgrade and subbase materials. Two types of natural fibres, i.e. coir fibre and jute fibre, are used as reinforcement in the subgrade and granular subbase layer. CBR and unconfined compressive strength tests were performed to find the performance of the fibre-reinforced subgrade layer. However, a direct shear test assessed the granular subbase material's performance. The overall improvement of the discrete natural fibres was measured in terms of bearing capacity improvement by conducting a model plate load test using a steel tank of 600mm x 600mm x 600 mm.

1. Introduction

The properties of locally available clayey soils used in subgrade construction for flexible road pavements can be enhanced by incorporating randomly distributed fibres into the soil. The fibre- reinforced soil works well as a ground improvement technique for subgrades, embankments, and other related uses [1. Using randomly distributed fibres has several advantages, including homogeneous strength distribution, simplicity of mixing, and removing any potential weak planes that would develop along the orientated reinforcement's path [3-5]. The experimental investigation by several researchers found that when different types of fibres were mixed with varying types of soil, a significant rise in the CBR value was recorded with increased fibre content [6-9]. Fibers are usually introduced into the soil as mats or grids, which are then integrated into the soil structure. These fibres assist in distributing stresses throughout the soil, enhancing its load-bearing capacity and minimizing deformation. Using natural fibres to stabilize expansive clay provides several advantages over other methods [11-12]. A key benefit is that natural fibres are biodegradable and environmentally safe. Unlike synthetic fibres, they do not contribute to pollution or waste and pose no risk to human health. A laboratory test was conducted on a strip footing placed on a soil bed reinforced with randomly distributed fibre-reinforced pond ash over soft clay. The results showed an improvement in the bearing capacity ratio (BCR) when the fibre thickness was 1.5 times the width of the footing, with the optimal fibre content in the soil system being 1% [13].

1.1 Subgrade and subbase materials

Soil and river sand were used in this study to prepare the subgrade and subbase layers. The grain size distribution curve of the soil and sand is shown in Figure 1. The compaction parameters of the subgrade soil were determined as per IS 2720, part-7, 1980, and given in Table 1. The subgrade soil was classified as inorganic clay with medium plasticity. The relative density of the sand was determined as per IS 2720, Part 14, 1983. The properties of the river sand are given in Table 2. The sand was classified as poorly graded sand.The durability and performance of flexible road pavements largely depend on the strength and stability of the subgrade and subbase layers. Subgrade soils, particularly those with a clayey or silty composition, are prone to significant deformation under load and can lead to premature pavement failures caused by settlement, cracking, and moisture infiltration. Traditional stabilization techniques involving lime, cement, and bitumen have been widely adopted. However, these methods often incur high costs, consume significant energy, and contribute to environmental pollution due to carbon emissions.

As an eco-friendly and sustainable alternative, natural fibres such as jute and coir have shown potential in enhancing soil strength and mitigating pavement issues. These fibres, known for their high tensile strength, biodegradability, and cost-effectiveness, distribute stresses uniformly and improve load-bearing capacities. This study aims to investigate the impact of jute and coir fibre reinforcement on subgrade and subbase layers through laboratory tests, including the California Bearing Ratio (CBR) and model plate load tests.

By exploring the effects of fibre length, content, and type, this research addresses the pressing need for sustainable road construction materials that are cost-effective and environmentally friendly, ultimately extending pavement life while minimizing maintenance costs.

2. Literature Review

1. Subgrade Stabilization

Weak subgrades composed of clayey and silty soils pose challenges due to settlement, cracking, and moisture-induced deterioration. Traditional stabilization methods such as lime or cement treatments are effective but environmentally detrimental. Researchers have shifted toward natural fibres as an eco-friendly solution. Studies have demonstrated the capacity of jute, coir, and sisal fibres to reduce shrinkage cracks, improve load-bearing capacity, and enhance soil flexibility.

For example, Alhassan and Mustapha (2007) highlighted the effectiveness of natural materials in stabilizing lateritic soils. Ghosh and Bhandari (2017) explored coir fibre's performance, concluding it significantly enhances subgrade strength while maintaining flexibility under load.

2. Properties of Natural Fibres

Natural fibres are gaining popularity for their high tensile strength, flexibility, and biodegradability. Coir fibres, with their rough texture and durability, can absorb moisture and provide enhanced soil grip. Jute fibres, characterized by their fine texture and moderate tensile strength, contribute to uniform stress distribution and prevent desiccation cracks.

Studies by Basu et al. (2009) emphasized the importance of fibre characteristics like density, tensile strength, and water absorption in reinforcing weak soils. Ghosh and Bhandari (2017) and Prabakar and Sridhar (2002) documented significant improvements in soil performance when fibres were added in optimal proportions, typically 1–2% of the soil weight.

3. Benefits of Fibre Reinforcement in Pavements

Fibre reinforcement reduces linear shrinkage, desiccation cracks, and settlement, thereby enhancing the durability of pavements. Akinmusuru (1991) reported improved bearing capacities and reduced deformation when steel slags and natural fibres were used in soil reinforcement. More recent studies, including those by Muntohar and Rahman (2016), confirmed the effectiveness of fibre-reinforced clay under cyclic loading, while Ramasamy and Kiran (2019) demonstrated the combined benefits of jute and coir in expansive soils.

4. Test Findings on Fibre-Reinforced Subgrades

Laboratory tests have consistently revealed improvements in the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) with fibre-reinforced subgrades. The inclusion of jute and coir fibres in varying lengths (10–30 mm) and proportions (1–2%) has shown a significant increase in load-bearing capacity and a reduction in pavement deterioration. Babu et al. (2008) and Sinha and Singh (2022) noted that optimal fibre content and arrangement play a critical role in achieving maximum soil stabilization benefits.

Natural fibres such as coir, jute, sisal, and bamboo have been extensively studied for their potential to improve soil properties. These fibres possess high tensile strength, flexibility, and durability, making them suitable for reinforcing weak soils (Ghosh & Bhandari, 2017).

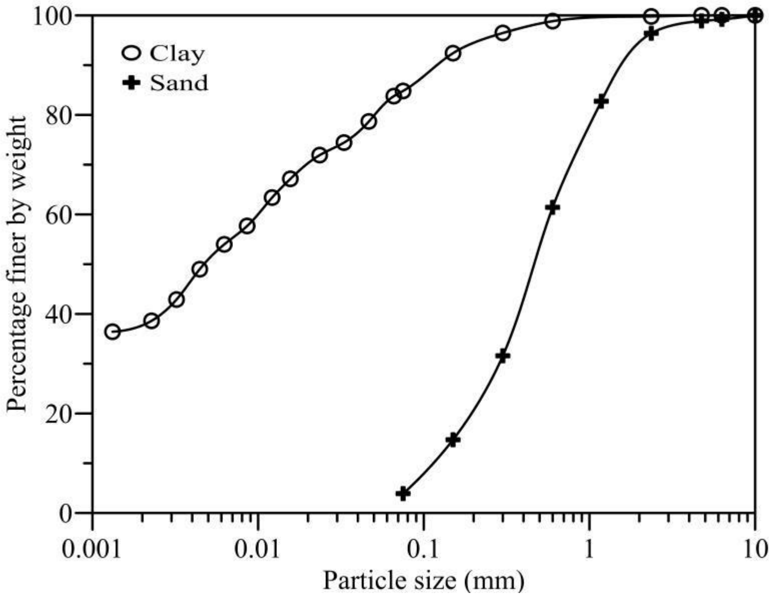


Fig 1. Particle size distribution of subgrade soil and sand

Table1. Properties of the subgrade soil

Properties	**Values**
Specific gravity	2.61
LL (%)	43
PL (%)	25
PI (%)	19
Classification (USCS)	CL
Optimum moisture content(%)	23.8
Maximum dry Density(kN/m^3)	15.79

Table2. Properties of the river sand

Properties	Values
Specific gravity	2.65
D10	0.115
D30	0.286
D60	0.58
Coefficient of uniformity (Cu)	5.40
Coefficient of curvature (Cc)	1.23
Maximum dry density, kN/m^3	17.7
Minimum dry density, kN/m^3	14.8
Internal friction angle (ϕ) [at R_d of 70%]	34.5
Classification (USCS)	SP

Natural fibers

Jute and coir fibre were used to reinforce the subgrade and subbase material. Jute and coirropes were collected from the local market, and fibres were extracted from the rope. The collected fibres were separated according to the length of the fibre. Then, the fibres were dried in a hot air oven at a temperature of 100±5 degrees. The jute and coir fibres were cut in different sizes, i.e. 10mm, 20mm and 30mm for further use. The properties of the jute and coir fibre are given in Table 3.

Table3. Properties of the jute and coir fibre

Properties	Jute	Coir
Density (g/cm^3)	1.39	1.27
Avg. thickness (mm)	0.08	0.28
Tensile strength (N)	3	267
Water absorption (%)	19.3	23.5

3. Methodology

Different tests, i.e. standard proctor test, California bearing ratio test, and Plate load test, were conducted to find the effect of fibre reinforcement in the subgrade and subbase layers. The Standard proctor test was performed to find the optimum moisture content of fibre-reinforced subgrade and subbase material. Maity et al. performed different tests on various types of fibre-reinforced soil and concluded that the optimum percentage of fibre in the subgrade and subbase material is 2%. Therefore, the weight of both jute and coir fibres was considered to be 2% of the weight of the soil and sand used as subgrade and subbase material. The CBR test was conducted at optimum moisture content, considering the optimum fibre content of 2%. However, the fibre length varied from 10mm to 30 mm. Moreover, the CBR test was conducted on a layered subgrade and subbase material. For the layered system, the subgrade soil was considered 75 mm, i.e. 3/5 of the mould, and the subbase was considered 50 mm, i.e. 2/5 of the mould. The test plan of the CBR test is given in Table 4.

A small-scale plate load test was conducted to determine the ultimate bearing capacity of the unreinforced and fibre-reinforced layered system. A steel tank of 600mm×600mm×600mm was used to perform the test using a square footing plate of 100 mm×100 mm×20 mm. The load was applied with a hydraulic jack. The loading rate was 3mm/min until failure or 25 mm, whichever was earlier.

Table 4 Test plan of the CBR test

Test Configuration	Reinforcement types	variables
Unreinforced subgrade soil		
Subgrade soil	Jute fibre (2%)	Fiber length (10,20,30mm)
Subgrade soil	Coir fibre (2%)	Fiber length (10, 20, 30 mm)
Unreinforced sub-base		
sub-base	Jute fibre (2%)	Fiber length (10, 20, 30 mm)
sub-base	Coir fibre (2%)	Fiber length (10, 20, 30 mm)

Unreinforced subgrade+ sub-base		
subgrade+ sub-ase	Jute fibre (2%)	Fiber length (10, 20, 30 mm)
subgrade+ sub-base	Coir fibre (2%)	Fiber length (10, 20, 30 mm)

4. RESULTS AND DISCUSSION

1. Compaction Curve (Standard Proctor Test)

o The compaction curves illustrate that the addition of fibres slightly increases the optimum moisture content (OMC) due to the water absorption capacity of the fibres.

o Maximum dry density (MDD) decreases with the inclusion of fibres, as the fibres create voids within the soil matrix, reducing overall compactability.

2. CBR Test Results

o Effect of Fibre Length:

 The CBR value improves with an increase in fibre length up to 20 mm, after which it plateaus or slightly reduces.

 The optimum fibre length for both jute and coir fibres is 20 mm.

o Comparison Between Jute and Coir Fibres:

 Jute fibres yield higher CBR values than coir fibres for the same fibre content and length, indicating slightly better performance in reinforcing subgrade and subbase materials.

3. Model Plate Load Test

o The load-settlement curves from the plate load tests show a clear improvement in bearing capacity for fibre-reinforced layers compared to unreinforced layers.

o Jute fibres provide higher load-bearing capacities than coir fibres, though both show significant improvement over untreated soils.

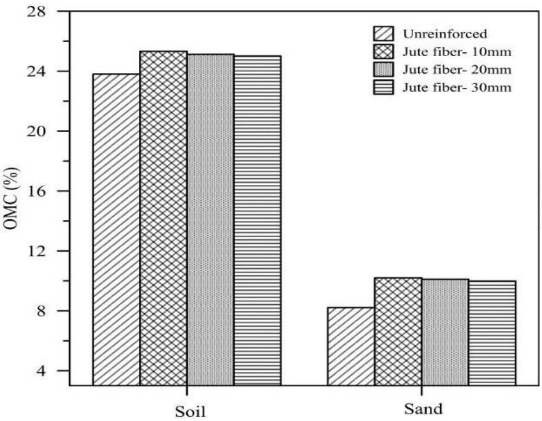
o The reinforced subgrade layers exhibit reduced settlement under similar loads, highlighting their improved stability.

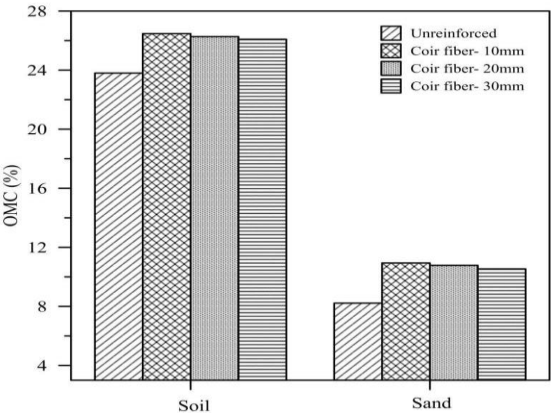
4. Shrinkage Crack Mitigation

o Graphs or visual data demonstrating crack width or depth reduction indicate that fibre reinforcement significantly minimizes shrinkage and desiccation cracks.

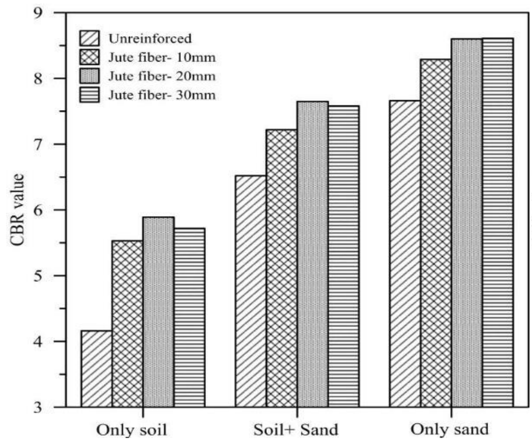
o Coir fibres absorb more water, slightly improving crack resistance in moisture-sensitive conditions compared to jute fibres

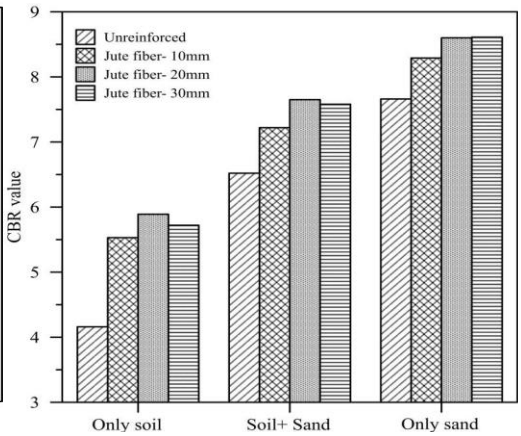
Standard Proctor test



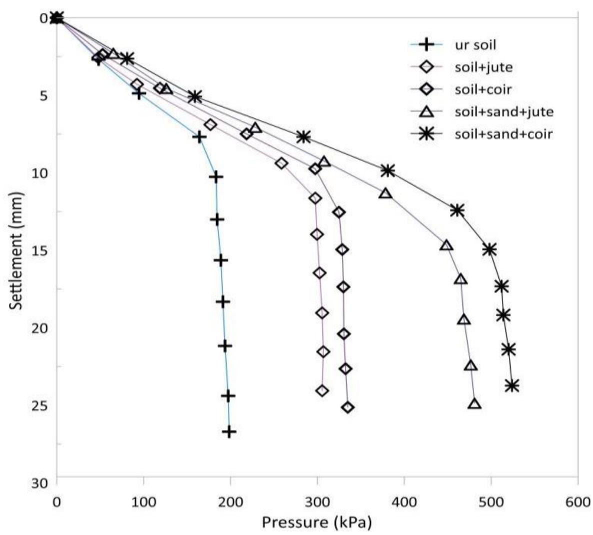


Result of CBR test





4.3. Model plate load test



Key Observations from Graphs

• Fibre content of 2% and fibre length of 20 mm consistently provide optimal results for subgrade and subbase performance.

• Jute fibres slightly outperform coir fibres in terms of strength characteristics, but coir fibres have better water absorption and flexibility.

• Both materials are effective in improving load-bearing capacity and reducing deformation and cracking.

5. CONCLUSIONS

• Improvement in Load-Bearing Capacity: The inclusion of natural fibres, such as coir and jute, in the subgrade and granular subbase layers significantly enhances the bearing capacity of the soil. Model plate load tests demonstrated a marked improvement in the load-bearing characteristics of fibre-reinforced layers compared to untreated soils.

• Reduction in Shrinkage Cracks: Fibre reinforcement effectively reduces the occurrence and depth of shrinkage and desiccation cracks. Coir and jute fibres mitigate the formation of tension-induced cracks, leading to a more stable subgrade and reducing the risk of pavement deterioration due to cracking.

• Increased Strength Characteristics: The California Bearing Ratio (CBR) and unconfined compressive strength (UCS) tests revealed that the addition of discrete natural fibres improves the strength characteristics of subgrade materials. The performance of granular subbase layers also showed improvement, as confirmed by direct shear tests.

• Sustainable and Cost-Effective Solution: Using natural fibres like coir and jute provides a sustainable and eco-friendly method to enhance the durability of pavement layers. These fibres are readily available, biodegradable, and offer a cost-effective alternative to synthetic reinforcements.

• Practical Implications: The study concludes that fibre-reinforced subgrade and subbase layers can minimize maintenance costs and extend the lifespan of pavement structures by reducing the vulnerability to rutting, fatigue, and moisture-induced settlement

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