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Improvement Of Soil Using Bamboo Fibre

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Abstract: Soil stabilization is a fundamental aspect of geotechnical engineering, especially when addressing the behavior of non-clayey soils. Although these soils generally present fewer challenges compared to clayey soils, issues related to strength, compressibility, and shear performance under loading still necessitate effective stabilization techniques. While traditional stabilizers such as cement, lime, and synthetic fibres have been widely used, the use of natural fibres has recently gained attention as a more sustainable and environmentally friendly alternative. Among the available natural fibres, bamboo stands out due to its abundance, renewability, and favorable mechanical properties. This study investigates the feasibility of using bamboo fibres to enhance the geotechnical properties of non-clayey soils, specifically silty sand by analyzing their effects on strength, compressibility, and shear behavior. Bamboo fibres, locally sourced and processed, were incorporated into soil samples at varying percentages (0.25%, 0.5%, 0.75%, and 1% by dry weight). Standard laboratory tests, including Atterberg limits, Proctor compaction, direct shear tests and California Bearing Ratio tests were conducted to evaluate the impact of fibre reinforcement on the physical and mechanical characteristics of the soil. The results demonstrated that bamboo fibre reinforcement led to noticeable improvements in strength and ductility compared to unreinforced samples. Additionally, compaction characteristics were enhanced, with an increase in maximum dry density (MDD) and a reduction in optimum moisture content (OMC). Specifically, OMC decreased from 12.16% in untreated soil to 8.48% at 1% fibre content, indicating improved compaction efficiency and a denser soil structure. Although the MDD improvement values were not explicitly stated, the trend indicated increased density with higher fibre content. Shear strength also improved significantly with the inclusion of bamboo fibres. At a normal stress of 50 kPa, shear strength increased from 29.5 kPa (0% fibre) to 35.33 kPa (0.75% fibre). At 100 kPa, it rose from 57.01 kPa to 66.33 kPa, and at 150 kPa, from 84.53 kPa to 97.33 kPa for the same fibre content. These results confirm that bamboo fibre reinforcement enhances the mechanical performance of non-clayey soils, making it a promising and sustainable alternative for ground improvement applications. The California Bearing Ratio (CBR) values increased from 0% fibre (5.02%) to 0.75% fibre (8.32%), indicating an increase in bearing capacity, which shows that bamboo fibre reinforcement can significantly improve the load-bearing capacity of silty sand soils.

Index Terms - Soil, Bamboo fibre, Soil-improvement, Strength**.**

I. Introduction

Soil stabilization plays a critical role in geotechnical engineering by improving the properties of weak or substandard soils to meet construction requirements. Conventional stabilization techniques typically involve the use of materials such as cement, lime, and synthetic fibres. While these methods are proven to be effective, they often raise concerns related to environmental impact, resource consumption, and cost.

In response to these challenges, natural fibre have emerged as a promising alternative due to their biodegradability, local availability, and cost-effectiveness. Among the various types of natural fibres explored, bamboo fibre has attracted considerable interest owing to its superior mechanical properties, notably high tensile strength, and its widespread availability in many developing regions.

Bamboo fibres enhance soil behavior by increasing strength, stiffness, and ductility. Functioning as a reinforcing element, it provides tensile resistance within the soil matrix, which helps control deformations and prevents crack propagation. Numerous studies have explored the potential of bamboo fibres in soil improvement. For example, Singh et al. (2021) observed improvements in the California Bearing Ratio (CBR) and a reduction in the plasticity index of clayey soils upon bamboo fibre addition. Likewise, Sharma and Kumar (2019) reported a decrease in optimum moisture content (OMC) and an increase in maximum dry density (MDD) with increased bamboo fibres content in silty soils. Further studies, such as those by Patel et al. (2020), demonstrated enhanced shear strength and ductility in sandy soils reinforced with bamboo fibre, making them more suitable for use in pavement and embankment construction. Singh and Bagra (2013) found that incorporating bamboo fibre in silty sand at contents ranging from 0.25% to 0.5% by weight significantly improved both cohesion and the internal friction angle, thereby enhancing overall shear strength. Additionally, Rai and Walia (2016) reported slight reductions in OMC and improvements in MDD with optimal bamboo fibre content. Basak et al. (2018) also noted higher CBR values in bamboo fibre-reinforced soils, indicating their potential for subgrade applications.

Despite these promising outcomes, the effectiveness of bamboo fibre reinforcement depends on several variables, including fibre content, fibre length, and soil type. Thus, further experimental research is needed to determine optimal fibre proportions for different soil classifications and to understand the broader implications for geotechnical performance.

In light of this, the present study aims to evaluate the influence of bamboo fibre addition on the strength and compaction characteristics of non-clayey soils. The primary objective is to identify the optimal fibre content that yields maximum improvement in soil performance for engineering applications.

II. Silty Sand

The soil sample was collected from the bank of the Brahmaputra River (Nimati ghat), Jorhat. Silty sand soil is a type of soil that contains both silt and sand particles. Silty sand soil is often found in silt loam and sandy silt loam textures. Silty sand soil feels soft and silky and can sometimes feel gritty.

Table 1: Physical Properties of Soil

Properties	Typical values
IS Classification	SM
Liquid Limit	21.64%
Plasticity Index	Non-Plastic
Uniformity coefficient, C_u	2.93
Gradation coefficient, C_c	0.73
Optimum Moisture Content	12.16%
Maximum Dry Density	1.87/cc

III. Bamboo Fibre

Bamboo fibres are being used as a geo-synthetic material for soil stabilisation in this project. The addition of bamboo fibres to the soil may improve CBR values while simultaneously reducing the thickness of the pavement layer. It may also help to lessen the severity of stress on the subgrade.

Table 2: Properties of Bamboo fibre (Singh et.al. (2021)

Sl No	Property	Value
1	Cellulose (%)	60.8
2	Lignin (%)	32.2
3	Others (%)	7
4	Tensile Strength (MPa)	615 to 862
5	Young's Modulus (GPa)	35.45
6	Hemicellulose (%)	20-25
7	Type	Pulp
8	Colour	Light brown
9	Length of fibre	2-4 cm

Extraction of Bamboo Fibre

1. Bambusa tulda, locally known as jati Bah in Assamese was selected for the project due to its availability, strength and suitable fibre properties.


Figure 1: Cut bamboo culms prepared for fibre extraction

2. The bamboo stem was cut into small strips of 30 cm in length and was dipped in sodium hydroxide solution of different concentrations for 3 days. (i.e., 5% NaOH and 10% NaOH).

Figure 2: 30 cm length of bamboo stem

Figure 3: Bamboo strips soaked in NaOH solution for alkali treatment

3. The lignin present in the bamboo was removed by the alkali treatment, leaving behind the fibres of bamboo.
4. The fibres were washed with distilled water and kept in water for 1 day.
5. Fibers were then extracted by the Rolling and Hammering process.
6. The fibres were dried in an oven to reduce the moisture content.

Figure 4: Dried bamboo fibres

IV. RESEARCH METHODOLOGY

Different laboratory tests have been carried out to check the properties of natural soil and soil blended with various properties of bamboo fibre (0.25%, 0.5%, 0.75% & 1%). For studying the stabilized soil properties, the Standard Proctor test, direct shear test & CBR test have been carried out.

1. Proctor Compaction Test

The proctor compaction test is done by IS 2720 (part v)-1985. This test is carried out to check the optimum moisture content (OMC) and maximum dry density (MDD) of the soil. For examination of the bamboo fibre effect, soil is initially air-dried, ground into powder, and sieved. Subsequently, a defined percentage of the bamboo fibre (e.g., 0.25%, 0.5%, 0.75%, 1% by dry soil weight) is weighed out and blended thoroughly with the dry soil to ensure even distribution. Water is added gradually to the fibre–soil mixture, and the mixture is compacted in layers into a Proctor mould with normal energy. The weight and moisture content of each sample are noted after compaction. The test is repeated for various moisture contents to obtain the dry density vs. moisture content curve from which OMC and MDD for every fibre percentage are established.

2. Direct Shear test

The direct shear test is conducted in accordance with IS 2720 (Part XIII) – 1986 to determine the shear strength parameters of soil, namely cohesion (c) and internal friction angle (φ). In this test, soil samples are prepared by first air-drying, pulverizing, and sieving the soil. Bamboo fibres are then added at specified percentages (0.25%, 0.5%, 0.75%, and 1% by dry soil weight) and thoroughly mixed with the dry soil to ensure uniform distribution. Water is added to bring the mixture to its respective optimum moisture content (OMC), and the samples are compacted into the shear box in three layers to achieve maximum dry density (MDD).

The sample is then subjected to a normal load (e.g., 50 kPa, 100 kPa, and 150 kPa) in the shear box apparatus. A horizontal force is applied at a constant strain rate until failure occurs along the predefined shear plane. The shear force and corresponding horizontal displacement are recorded throughout the test. This procedure is repeated for each fibre content and normal stress level. The peak shear stress values obtained at failure are used to plot the shear stress vs. normal stress graph, from which the cohesion and internal friction angle of the fibre-reinforced and unreinforced soil samples are determined.

3. California Bearing Ratio test

California Bearing Ratio (CBR) test is done in accordance with IS 2720 part (XVI)-1987. It is used to determine the strength and load-carrying capacity of soil. Soil samples are prepared by incorporating different percentages of bamboo fibre (0%, 0.25%, 0.5%, 0.75%, 1% by dry weight) into the soil to investigate the influence of bamboo fibre. Each combination is compacted at its maximum dry density (MDD) and optimum moisture content (OMC) as derived from the Proctor test. The specimen is then soaked or unsoaked, depending on the test, and subjected to the CBR test using the CBR apparatus. The load–penetration readings are taken, and the CBR value is derived. Test results assist in deciding the best content of bamboo fibre that provides maximum CBR improvement, reflecting improved soil strength and applicability as subgrade or base courses.

V. RESULTS AND DISCUSSION

1. *Effect of Bamboo Fibre on OMC and MDD*

The Optimum Moisture Content (OMC) shows a slight decrease to 11.7% at 0.25% fibre content, followed by a consistent decrease with higher fibre additions. At 0.5%, 0.75%, and 1% fibre content, the OMC drops to 9.52%, 8.85%, and 7.45%, respectively. This reduction is due to the lightweight and non-cohesive nature of bamboo fibres, which replace part of the soil matrix that would otherwise require moisture for compaction. As a result, the overall water requirement decreases, while the fibres contribute to improved soil structure and mechanical stability.

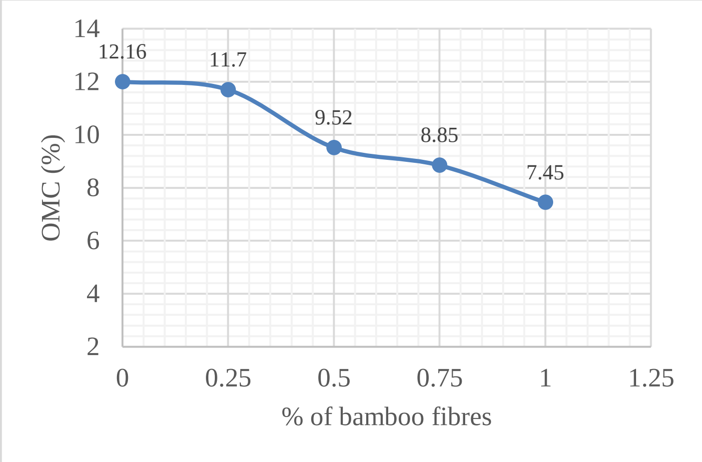

Figure 5: Optimum Moisture Content vs % of bamboo fibre

The graph shows the variation of Maximum Dry Density (MDD) of soil with different percentages of bamboo fibre. From the graph, it is observed that the MDD initially increases with the addition of bamboo fibres, reaching a peak value of 2.30 g/cc at about 0.75% fibre content, and then slightly decreases when the fibre content is further increased. At 0% fibre content, the MDD is the lowest (1.87 g/cc), while the addition of 0.25-0.75% bamboo fibres results in higher MDD values (2.26-2.30 g/cc). However, at 1% fibre content, the MDD decreases to 2.24 g/cc. This trend occurs because the addition of bamboo fibres up to an optimum percentage improves the soil structure by filling the voids and binding the soil particles together, thereby reducing air gaps and increasing the dry density. The fibres act as reinforcement, distributing compaction energy more effectively and allowing the soil mass to densify better. However, when the fibre content exceeds the optimum level, the extra fibres create more void spaces instead of filling them, leading to a reduction in dry density.

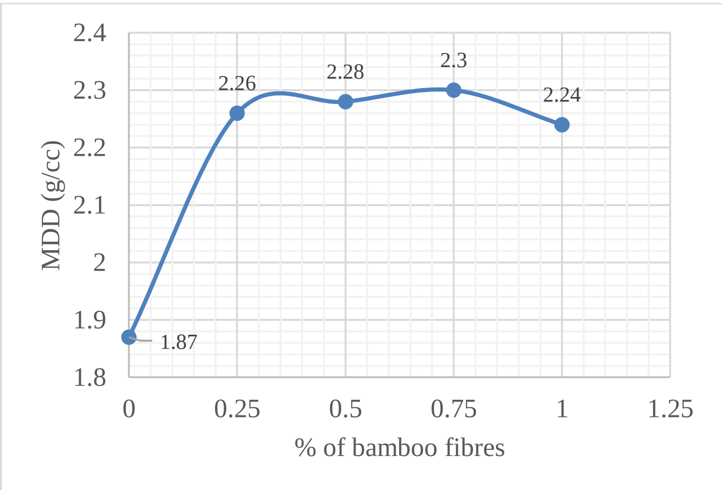

Figure 6: Maximum Dry Density vs % of bamboo fibre

2. *Effect of shear strength on different percentages of bamboo fibre*

The graph shows the effect of varying percentages of bamboo fibres (from 0% to 1%) on the shear strength of soil under three different confining pressures: 50 kPa, 100 kPa, and 150 kPa. Across all three pressure levels, a clear trend is observed: shear strength increases progressively as the percentage of bamboo fibres increases from 0% to 0.75%, followed by a slight decrease at 1% fibre content.

At 50 kPa, the shear strength rises from 29.5 kPa at 0% bamboo fibre to a maximum of 35.33 kPa at 0.75%, then slightly reduces to 34.13 kPa at 1%. A similar pattern is seen at 100 kPa, where the strength increases from 57.01 kPa at 0% to a peak of 66.33 kPa at 0.75%, before falling to 60.06 kPa at 1%. The highest values are observed under 150 kPa, with shear strength increasing from 84.53 kPa at 0% to 97.33 kPa at 0.75%, then decreasing to 93.98 kPa at 1%.

This consistent pattern across all pressures suggests that the addition of bamboo fibres enhances the soil's shear strength up to an optimal point (0.75%), likely due to improved interparticle bonding and fibre reinforcement. However, beyond this optimum, excess fibres may lead to clumping or poor distribution within the soil matrix, reducing the effectiveness of reinforcement.

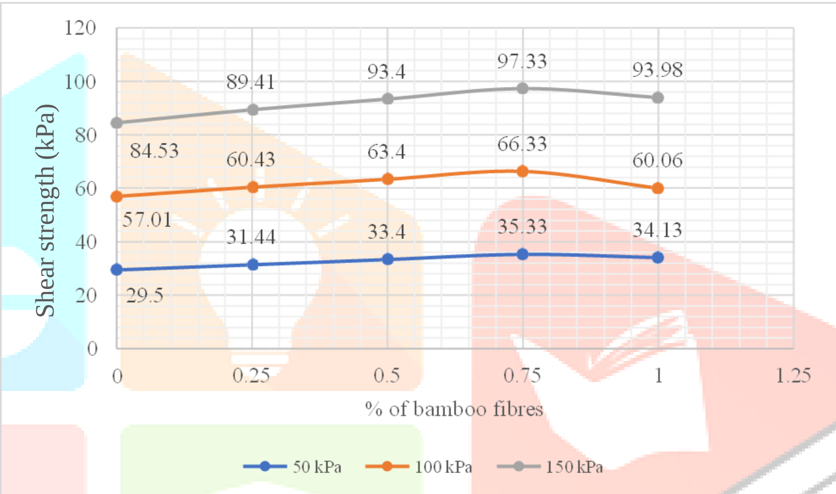

Figure 7: Shear strength vs percentage of bamboo fibres

3. *Effect of CBR on different percentages of bamboo fibre*

The graph shows that the CBR value increases with the addition of bamboo fibres up to an optimum content of 0.75%, where the CBR reaches a peak of 8.32% compared to the initial 5.02% at 0% fibre. This improvement is due to the reinforcing effect of bamboo fibres, which enhance the tensile strength and load distribution of the soil. However, beyond 0.75%, the CBR value decreases to 6.03% at 1% fibre content, likely due to excessive fibre causing poor bonding, clumping, and the formation of voids, which reduce the overall strength. Hence, 0.75% is identified as the optimum fibre content for maximum soil strength.

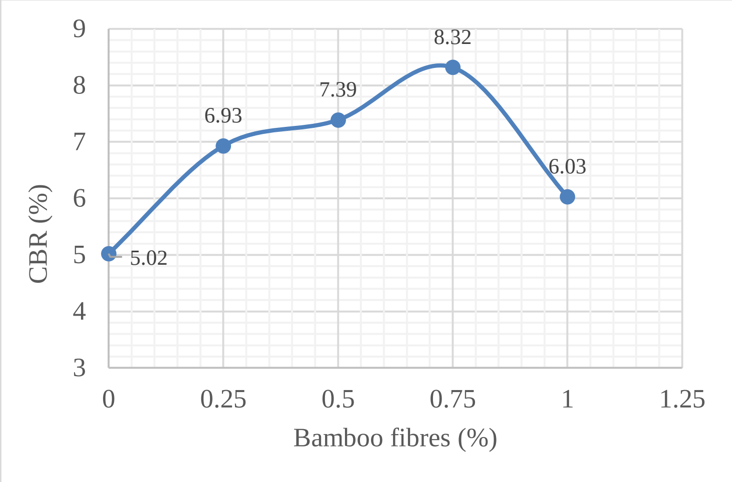

Figure 8: California Bearing Ratio vs percentage of bamboo fibre

VI. Conclusion

1) With the addition of bamboo fibres, the Optimum Moisture Content (OMC) decreases, and the Maximum Dry Density (MDD) increases, indicating better compaction characteristics.

2) In the Direct Shear Test, shear strength increases with the addition of bamboo fibres.

3) 0.75% bamboo fibre content is found to be the optimum percentage, giving the best results in terms of MDD and shear strength.

4) The CBR value improves with the addition of bamboo fibres, indicating improved bearing capacity.

5) Overall, bamboo fibre is an eco-friendly and cost-effective material for soil improvement, especially when used at 0.75%.

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