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Experimental Analysis of Banana Fiber and Phosphogypsum in Soil Stabilization

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Abstract: This study investigates the potential of banana fiber as a natural reinforcement material for soil stabilization, specifically in conjunction with phosphogypsum. With construction often reliant on soils with inadequate bearing capacity and shear strength, enhancing soil properties is crucial. The research employs banana fibers extracted from the pseudo stems of banana plants, assessing their effects on soil characteristics at various reinforcement percentages (0%, 0.1%, 0.3%, and 0.5%). Key parameters evaluated include Unconfined Compression Strength (UCS), Maximum Dry Density (MDD), and Optimum Moisture Content (OMC) through standardized laboratory tests. The findings reveal that the inclusion of banana fibers significantly raises the OMC of the soil, indicating improved moisture retention capabilities. Notably, the OMC values for the reinforced samples increased with higher fiber content, peaking at 12.3% for Sample 1 and 13.5% for Sample 2 at 0.5% fiber. Additionally, the UCS tests demonstrated enhanced compressive strength, with the highest value recorded at 1.70 MPa for Sample 1 at 0.5% fiber content. These results suggest that banana fibers effectively improve the mechanical properties of soil, making it more suitable for construction applications. This research highlights the potential of utilizing agricultural waste, such as banana fibers, for sustainable soil stabilization practices, offering an eco-friendly alternative to synthetic materials.

Keywords: Banana fiber, soil stabilization, phosphogypsum, UCS, MDD, and OMC, agricultural waste, sustainable construction, natural reinforcement.

1. Introduction: Soil is one of the most critical resources in nature, serving as the foundation for various civil engineering structures, including buildings, roads, and bridges [1] [2]. However, many types of soil possess inadequate bearing capacity and shear strength, rendering them unsuitable for construction [3]. This is particularly true for expansive clays, silts, and poorly compacted soils, which can lead to structural failures, increased maintenance costs, and ultimately, unsafe conditions for inhabitants [4]. Therefore, enhancing the properties of such soils has become an essential focus within the domain of geotechnical engineering.

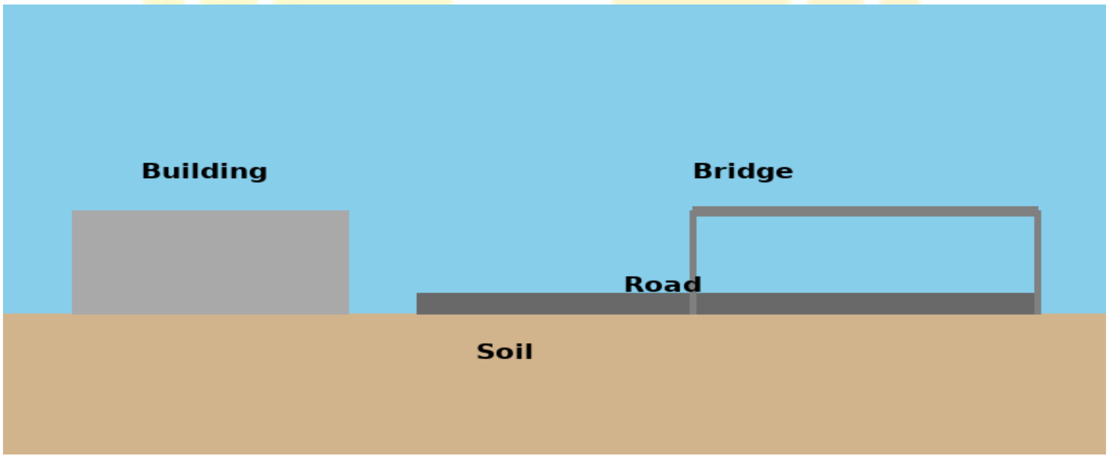

Figure 1: illustrating the role of soil in civil engineering structures

Problem Statement: The increasing demand for urbanization and infrastructure development poses significant challenges for construction in areas with weak soil [5] [6]. Traditional methods of soil stabilization, such as the use of chemical additives or synthetic materials, can be both costly and environmentally damaging [7] [8]. Chemical stabilizers may leach harmful substances into the soil, causing concerns to both health of humans and the environment [9] [10]. Given these challenges, there is a pressing requirement for sustainable, cost-effective alternatives that can enhance soil properties without compromising environmental integrity. This research focuses on utilizing natural fibers, specifically banana fibers, combined with phosphogypsum, as an innovative method for soil stabilization.

Significance of the Study: Natural fiber reinforcement is gaining attention as an environmentally friendly method for soil stabilization. Natural fibers are biodegradable, abundant, and provide a low-cost alternative to synthetic materials [13]. Among these, banana fibers have shown promise due to their tensile strength, availability, and environmental benefits. The use of banana fibers not only improves soil characteristics but also contributes to waste reduction in agricultural practices, as the pseudo stems of banana plants are often discarded after harvest.

Phosphogypsum, a byproduct of the phosphate fertilizer industry [11], is another material that has shown potential for soil stabilization [12]. Its application can enhance the mechanical properties of soils and also provide an effective means of recycling industrial waste. Combining banana fibers and phosphogypsum could yield significant improvements in soil properties while promoting sustainable practices in civil engineering.

Objectives of the Study: the Following objectives are under consideration for this study:

To Evaluate the Effect of Banana Fiber Reinforcement: This research aims to analyse how varying percentages of banana fiber reinforcement (0%, 0.1%, 0.3%, and 0.5% of the soil mass) impact the UCS, MDD, and OMC of the soil.

To Assess the Role of Phosphogypsum in Soil Stabilization: Investigating the influence of phosphogypsum in combination with banana fibers will help determine its effectiveness in improving soil characteristics.

To Compare the Engineering Performance of Stabilized Soil: This research will compare the engineering properties of the reinforced soil samples against unreinforced control samples to establish the best reinforcement percentage that optimizes soil stability.

To Promote Sustainable Practices in Civil Engineering: The study seeks to highlight the benefits of using natural fibers and industrial byproducts for soil stabilization, thus contributing to more sustainable construction practices.

Scope of the Study: This research is focused on the use of banana fibers and phosphogypsum for soil stabilization in the context of civil engineering applications. The study will primarily concentrate on the geotechnical properties of soils with varying fiber content and the effects of these reinforcements on soil performance. The findings of this research aim to contribute to the body of knowledge in geotechnical engineering by providing evidence-based insights into sustainable soil stabilization techniques. Additionally, the study seeks to encourage the adoption of natural materials in engineering practices, promoting environmental sustainability and cost-effectiveness.

2. Methodology:

This study looks into the stabilization of soil using banana fibers and phosphogypsum by examining changes in soil properties such as bearing capacity, shear strength, as well as moisture content. The methodology focuses on systematic soil sample collection, the introduction of banana fibers in different percentages, and conducting relevant soil stabilization tests.

Soil Sample Collection: The samples of soil used in this research were collected from two distinct construction sites with poor bearing capacities, making them suitable candidates for stabilization. The collection process was performed under standard conditions to prevent contamination. Samples were collected from shallow depths (up to 1 meter) since the top layers of soil are usually most affected by external factors like water erosion or load-bearing capacity. After collection, soil samples were stored in air-tight containers to maintain their moisture content until laboratory testing.

Banana Fiber Collection and Preparation: The banana fibers used for reinforcement were extracted from the pseudo stems of banana plants. The pseudo stems, which are typically considered agricultural waste, provide a sustainable source of natural fibers. The fibers were processed and air-dried, then chopped into uniform lengths for better soil-fiber interaction. Four different fiber reinforcement percentages (0%, 0.1%, 0.3%, and 0.5% of the soil mass) were used in this study. The preparation steps were as follows:

Soil Preparation without Fibers (0% Fiber): The soil sample was first air-dried, after which water was added according to the OMC value. The samples were mixed to achieve homogeneity.

Soil Preparation with Fibers (0.1%, 0.3%, and 0.5% Fiber): Air-dried soil was manually mixed with banana fibers in small increments. This ensured even distribution of fibers across the soil mass. Once the fibers were incorporated, water was added, maintaining the OMC for each mix. This method ensured a homogeneous soil-fiber mixture suitable for conducting various tests.

Test Procedures: Several tests were conducted on the unreinforced and banana fiber-reinforced soil samples to evaluate their performance. These tests help measure properties like the soil's compressive strength, moisture retention, and compactness.

Optimum Moisture Content (OMC) Test: The OMC of soil is the moisture level at which the soil reaches its MDD during compaction [14]. OMC is an essential parameter as it helps in determining how much water is required for effective soil compaction, especially when banana fibers are added. The soil samples were tested for OMC using a Proctor test. The OMC for both soil samples without fiber (control samples) and with fiber (0.1%, 0.3%, 0.5%) were determined.

Proctor Compaction Test (PCT): The PCT was performed to measure the relationship between the dry density of the soil and its moisture content [15]. The aim was to identify the MDD and corresponding OMC for different fiber-reinforced soil samples. This test helps to calculate the compaction characteristics of the soil. The equipment used includes a cylindrical mold, base plate, collar, and a 2.5 kg hammer. After mixing the soil and fibers with water (based on OMC), the sample was compacted in the mold using a standard number of hammer blows. The dry density of each compacted sample was measured, and a curve was plotted for moisture content versus dry density.

Unconfined Compression Strength (UCS) Test: The UCS test was conducted to measure the compressive strength of the soil samples. Cylindrical soil specimens of 38 mm diameter and 76 mm length were tested. The UCS test is critical for determining the strength of stabilized soil, which directly influences its load-bearing capacity.

The test results were plotted against different percentages of banana fibers to evaluate the increase in strength with fiber reinforcement.

3. Results and Discussion:

Results and Discussion: The following sections discuss the results of the tests conducted on both unreinforced and banana fiber-reinforced soil samples.

Optimum Moisture Content (OMC): The OMC test was performed to calculate the moisture content at which the soil achieves its MDD under compaction. OMC values for both soil samples were measured with and without banana fiber reinforcement. The results showed a gradual increase in OMC as the percentage of fiber increased.

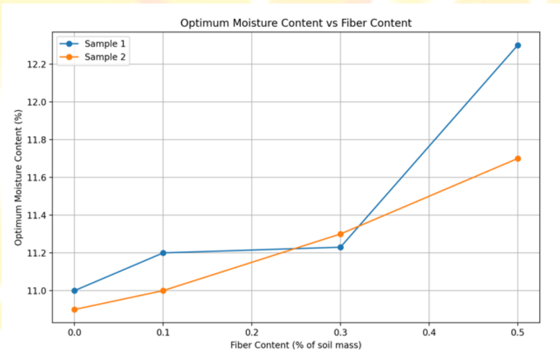

Figure 2: Optimum Moisture Content vs. Fiber Content

Table 1: Optimum Moisture Content and Fiber Reinforcement Effects

Soil Sample	Fiber Content (% of soil mass)	Optimum Moisture Content (%)
Sample 1	0.0 (Without Fiber)	11.0
	0.1 (With Fiber)	11.2
	0.3 (With Fiber)	11.23
	0.5 (With Fiber)	12.3
Sample 2	0.0 (Without Fiber)	10.9
	0.1 (With Fiber)	11.0
	0.3 (With Fiber)	11.3
	0.5 (With Fiber)	11.7

The results show that the OMC increased with increasing banana fiber content, which can be ascribed to the fibers' capacity to absorb water. The higher moisture content was necessary to achieve proper compaction when fibers were added to the soil.

Proctor Compaction Test (PCT): The results from the PCT indicated that the MDD decreased slightly with increasing fiber content. This is expected because the fibers introduce voids in the soil structure, which reduces the overall density of the compacted soil.

Table 2: Comparative Analysis of Optimum Moisture Content with Fiber Inclusion

Soil Sample	Fiber Content (% of soil mass)	Optimum Moisture Content (%)
Sample 1	0.0 (Without Fiber)	10.0
	0.1 (With Fiber)	11.0
	0.3 (With Fiber)	11.0
	0.5 (With Fiber)	11.6
Sample 2	0.0 (Without Fiber)	10.3
	0.1 (With Fiber)	9.3
	0.3 (With Fiber)	13.0
	0.5 (With Fiber)	13.5

The results indicate that the OMC varies with the addition of banana fiber, showing an increase for both soil samples. Sample 1 reached a maximum OMC of 11.6% at 0.5% fiber content, while Sample 2 exhibited a peak OMC of 13.5% at the same fiber content, demonstrating the fibers' influence on moisture retention in the soil.

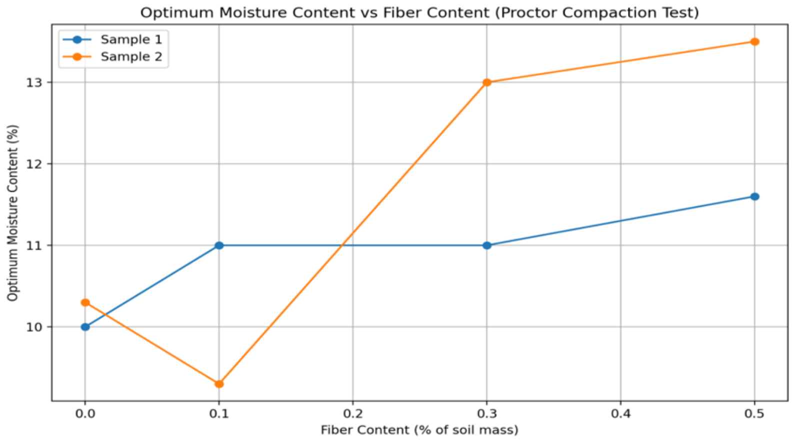

Figure 3: Optimum Moisture Content vs. Fiber Content (Proctor Compaction Test)

Unconfined Compression Strength (UCS): The UCS test results showed significant raises in the compressive strength of the soil samples with banana fiber reinforcement. This suggests that banana fibers contribute to the tensile strength of the soil, making it more resistant to compressive loads.

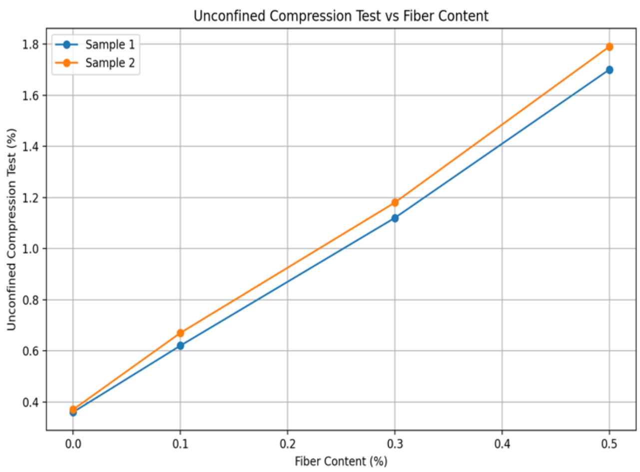

Figure 4: Unconfined Compression Test vs. Fiber Content

Table 3: Unconfined Compression Strength Results of Fiber-Reinforced Soil Samples

Fiber Content (%)	Unconfined Compressive Strength (MPa)
0.0	0.36
0.1	0.62
0.3	1.12
0.5	1.70

The results demonstrate that the highest strength was achieved at 0.5% fiber content. This proves the effectiveness of banana fiber as a soil stabilizer.

4. **Conclusion:** The experimental study on banana fiber reinforcement of soil stabilization with phosphogypsum demonstrated that banana fibers can significantly improve the soil's mechanical properties. The key findings of this study are as follows:

Increased OMC (Optimum Moisture Content): The addition of banana fibers increased the OMC of the soil. This was due to the water retention capability of the fibers, which required higher moisture content for compaction.

Reduced Dry Density: As banana fiber content increased, the MDD decreased. This was a result of the introduction of fibers creating more voids in the soil structure. However, the reduction in dry density did not significantly affect the soil's compaction efficiency.

Improved Compressive Strength: The UCS test showed a marked improvement in soil strength with raising fiber content. The highest UCS value was obtained with 0.5% fiber content, indicating that banana fiber reinforcement effectively enhances the load-bearing capacity of the soil.

Overall, banana fiber is an environment friendly, cost-effective, and sustainable material for soil stabilization. It offers substantial benefits in terms of improving soil strength, particularly in areas where soils are weak and require stabilization for construction purposes. Additionally, the combination of banana fibers and phosphogypsum provides a sustainable solution for utilizing agricultural and industrial waste materials in civil engineering applications. The study recommends further investigation into the long-term performance of fiber-reinforced soils under varying atmospheric conditions, as well as the potential for using other natural fibers in soil stabilization projects. This research opens avenues for more sustainable and environmentally responsible construction practices.

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