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Improvement of Soil Properties through Stabilization Using Beta-Glucan and Coir Fiber

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Abstract: This paper investigates the geotechnical behavior of locally sourced soil modified with a combination of coir fiber and beta-glucan. To evaluate the effects of these additives, a series of laboratory tests were conducted, including Standard Proctor, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) tests, using two concentrations (1% and 1.5%) of both beta-glucan and coir fiber. The compaction characteristics, strength, and stiffness of the treated soil were analyzed to assess the impact of these modifications on the soil's engineering properties. The results indicate that the inclusion of coir fiber and beta-glucan leads to substantial improvements in soil properties, including increased strength, improved load-bearing capacity, and enhanced compaction behavior. The findings highlight the effectiveness of these materials in improving soil performance, providing a promising, sustainable, and cost-effective alternative for ground improvement, especially in areas where soil stabilization is critical for construction and infrastructure development.

I. INTRODUCTION

Land scarcity in urban areas is a persistent issue, often requiring the use of sites with suboptimal soil conditions [1, 2]. Rapid urbanization and industrial expansion further exacerbate the demand for land reclamation and the use of unstable, environmentally compromised ground. These conditions create significant challenges during the design, construction, and maintenance of civil engineering projects, as poor soil often cannot provide sufficient support [3, 4]. This leads to issues like excessive settlement or inadequate subgrade bearing capacity, which jeopardize the stability of the structures above [5, 6]. When removal of unsuitable soil is not feasible, improving its engineering properties becomes crucial. Structural failures, particularly due to poor foundation design and excessive settlement, are common when soils are not adequately addressed. Various ground improvement techniques have been explored and documented to enhance soil behavior, ensuring it can withstand applied loads without excessive shear failure or settlement. In modern construction, these techniques play a critical role in preventing structural failures. This paper presents some major ground improvement methods used to address weak soil conditions.

A. Soil Stabilization Using Biopolymers

Beta-glucan is gaining popularity as a biopolymer for soil improvement due to its eco-friendly nature [7-9]. As shown in Fig. 1, its chemical structure contributes to its effectiveness in enhancing soil properties. Derived from renewable sources, Beta-glucan is biodegradable, offering a significant environmental advantage over traditional stabilizers like cement and lime, which have a much higher carbon footprint. Beta-glucan's ability to form cross-linked networks enhances the soil's resistance to deformation by increasing cohesion between soil particles. Additionally, its hydrophilic nature allows it to retain moisture, making it particularly beneficial for drought-prone and arid regions. The binding properties of Beta-glucan also help reduce soil erosion and improve slope stability[10]. Unlike synthetic polymers, Beta-glucan naturally degrades over time, reducing its long-term environmental impact [11].

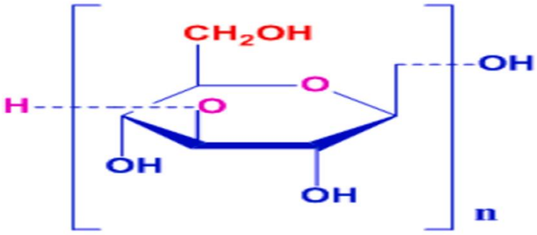

Fig. 1. Molecular structure of Beta-Glucan

B. List of Biopolymers with their Applications

1) Beta-1, 3/1, 6 Glucan: This biopolymer, derived from sources such as yeast, fungi, cellulose, cereals, and certain bacteria, forms a gelatinous solution when dissolved in water. Widely used in the medical field, it is also being explored for its potential in soil stabilization within civil engineering applications.
2) Alginate: Extracted from brown seaweed, alginate is composed of mannuronic and guluronic acids arranged in linear, unbranched chains. Known for its film-forming, ionic crosslinking, and gelling properties, alginate is used in a variety of applications, including waterproof fabrics, pharmaceuticals, and dye printing.
3) Carboxymethyl Cellulose (CMC): Produced by reacting cellulose with chloroacetic acid under alkaline conditions, CMC serves as a thickening agent, viscosity modifier, and emulsion stabilizer. Its applications range across the medical, food, and culinary industries.
4) Guar Gum: Sourced from guar beans, guar gum is a water-soluble, non-ionic polysaccharide known for its thickening and stabilizing properties. India dominates global production, accounting for 80% of the supply. It is used widely in the food industry as a thickener and binder, as well as in pharmaceuticals and other industries.
5) Chitosan: Derived from the chitin found in shrimp and other crustacean shells, chitosan is biocompatible, biodegradable, and non-toxic. It has diverse applications in medicine, biotechnology, agriculture, and other fields.

II. DETAILS OF EXPERIMENTS: MATERIALS AND METHODS

The soil used in this study was basically the local soil of Muzaffarpur. The soil of Muzaffarpur is basically alluvial soil [12]. To obtain the soil first top vegetation was removed. After this, soil was dug out and a sample of soil was obtained from a depth of 1.5 m to avoid the roots of the plants and brought to the laboratory. The particle size distribution of the soil was evaluated as per IS: 2720 (part 4). The grain size distribution curve is presented in Fig. 2.

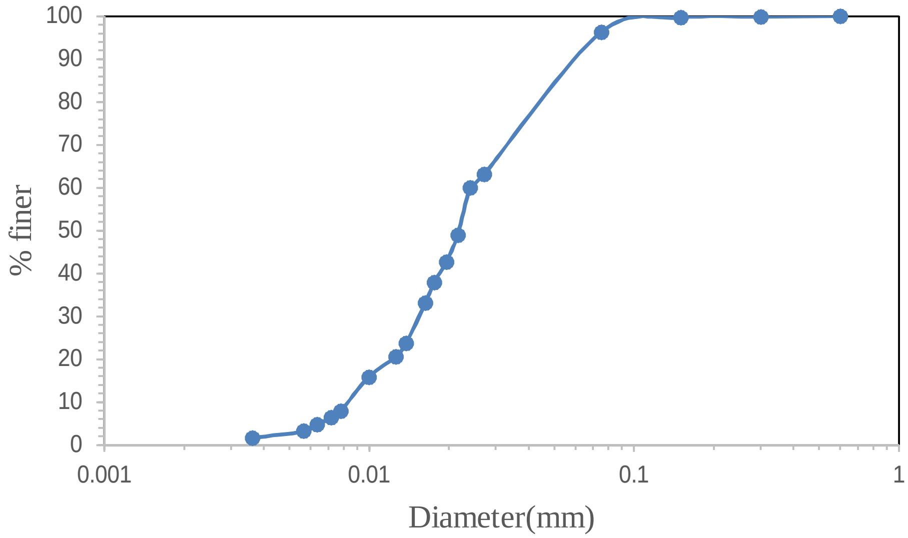

Fig. 2. Grain size distribution of soil used in this study

Fig. 3 (a) Beta-glucan used in this study. (b) Coir fiber used in this fiber

A. Test Program

To evaluate the combined effect of Beta-glucan and coir fibre on soil properties, four test series were conducted. Series 1 involved soil alone, Series 2 tested soil with Beta-glucan (1% and 1.5%), Series 3 with coir fibre (1% and 1.5%), and Series 4 combined Beta-glucan (1% and 1.5%) with coir fibre (1.5%). The Compaction test, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) tests were performed on all four-test series.

III. RESULT AND DISCUSSION

A. Compaction Behavior of Soil mixed with Beta-Glucan and Coir Fiber

Compaction tests on soil mixed with Beta-glucan (BG) and coir fiber (CF) showed that adding CF decreased maximum dry density (MDD) and increased optimum moisture content (OMC). Incorporating BG further increased both MDD and OMC. The compaction curve shifted towards the ZAV line, indicating reduced air voids. The soil mixture became more water-sensitive due to BG's water affinity and CF's water absorption capacity.

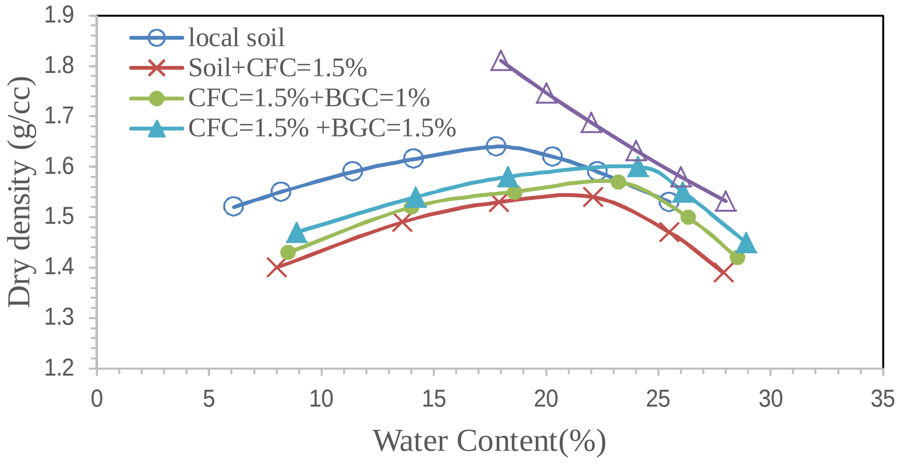

Fig. 4 Compaction curve of soil mixed with Beta-glucan and Coir fiber

B. Performance of Soil mixed with Beta-Glucan and Coir Fiber under CBR test

The combined effect of Beta-glucan (BG) and coir fiber (CF) on the California Bearing Ratio (CBR) is shown in Fig. 5. Both soaked and unsoaked CBR values improve significantly with BG and CF, showing about 7 times improvement in soaked and 6 times in unsoaked conditions, outperforming individual admixtures. BG contributes cementitious properties, while CF provides reinforcement, enhancing soil strength when used together.

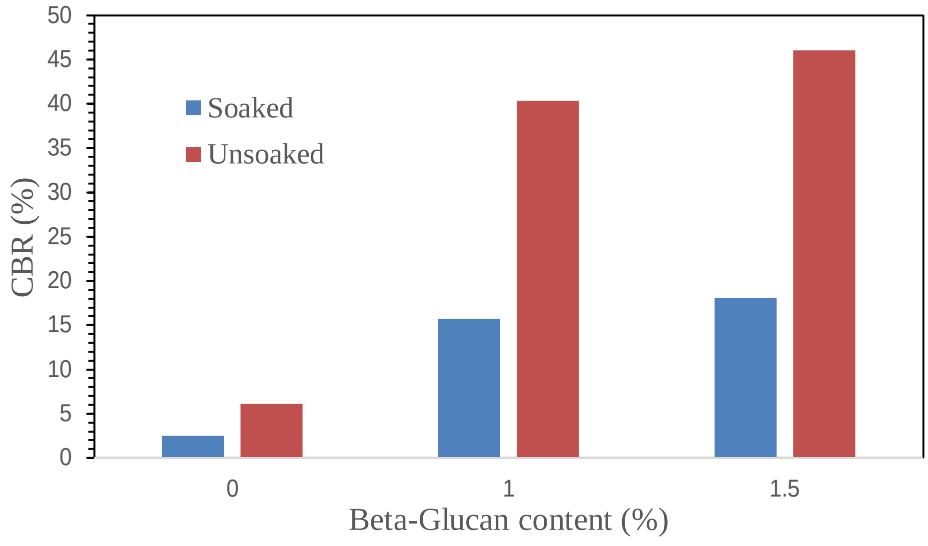

Fig. 5.CBR of soil mixed with different content of Beta-Glucan and Coir fiber (CFC=1.5%)

C. Performance of Soil mixed with Beta-Glucan and Coir Fiber under UCS test

The impact of Beta-glucan (BG) and coir fibre (CF) on Unconfined Compressive Strength (UCS) is shown in Figs. 5.3 and 5.4. With 1.5% CF, UCS increases with BG content, reaching 1183 kPa at 1.5% BG after 7 days, and 1893 kPa after 28 days. Strength improves by 1.5–1.6 times with increased curing, highlighting BG's role in strength development.

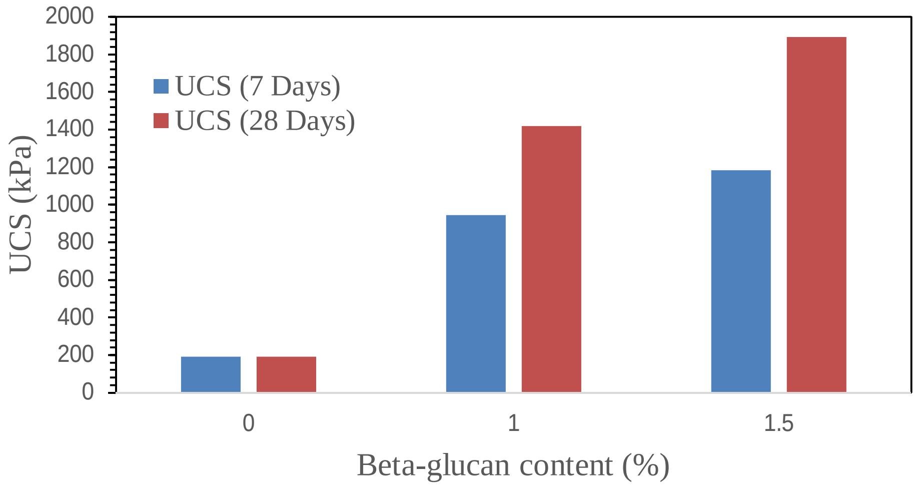

Fig. 6. UCS of soil mixed with different Content of Beta-Glucan and Coir fiber (CFC=1.5%)

IV. CONCLUSIONS

The study demonstrated the significant impact of Beta-glucan (BG) and coir fiber (CF) on the compaction and strength properties of soil. The incorporation of BG led to an increase in Maximum Dry Density (MDD) and a decrease in Optimum Moisture Content (OMC), while CF exhibited the opposite effect, increasing OMC and decreasing MDD due to its water absorption and lightweight characteristics. When combined, BG and CF further modified the compaction behavior, increasing OMC and improving the overall soil structure. In terms of strength, both the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) showed notable improvements with increasing concentrations of BG and CF. BG contributed to the cementitious properties of the mix, significantly enhancing UCS, while CF improved the soil's load-bearing capacity and stiffness by binding the soil particles.

Additionally, the curing process played a crucial role in strength development. UCS increased by approximately 1.5 to 1.6 times when the curing period was extended from 7 to 28 days, primarily due to the activation of BG’s cementitious behavior over time.

Overall, the combined use of BG and CF was found to be more effective than individual treatments, resulting in enhanced soil strength, stiffness, and compaction characteristics. This synergistic effect significantly improved the soil's load-bearing capacity, making the mixture a promising solution for soil stabilization in civil engineering applications.

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