

# STABILIZATION OF SOIL USING CHITOSAN BIOPOLYMER AND SISAL FIBER

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**Abstract:** *This study presents an experimental evaluation of the geotechnical behavior of soil treated with chitosan biopolymer and sisal fiber. Locally available soil was selected to ensure practical relevance and site-specific applicability. The chitosan biopolymer (CB) and plant fiber (PF) were incorporated into the soil at two dosage levels—1% and 1.5%—to investigate their impact on soil characteristics. Both CB and PF were sourced from nearby markets, highlighting their economic feasibility and accessibility for field implementation. A series of laboratory tests, including the Standard Proctor Test (SPT), California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS), were conducted in accordance with Indian Standard (IS) codes to ensure methodological consistency and reliability. The findings revealed that the combined use of chitosan biopolymer and sisal fiber significantly enhanced the soil's strength, stiffness, and compaction performance. These results underscore the potential of these natural additives as sustainable and effective solutions for soil stabilization and ground improvement.*

**Keywords:** Stabilization of soil, Chitosan Biopolymer and Sisal Fiber Geotechnical Properties of soil and Ecofriendly.

## 1. INTRODUCTION

The rapid expansion of the global population, coupled with shrinking availability of suitable construction land, has significantly increased the practice of land reclamation and infrastructure development on marginal soils. These problematic soils—including soft clays, loose sands, peat, and other organic materials—often lack the necessary bearing capacity and stability, posing considerable challenges for civil and geotechnical engineers. Such conditions are particularly prevalent in rapidly urbanizing areas, where demand for space outweighs geotechnical suitability. Unstable soils can lead to structural issues such as foundation failure, differential settlement, pavement cracking, and slope instability, jeopardizing both public safety and economic investment. As a result, soil stabilization has become a critical component of modern construction practices.

To address these challenges, various soil improvement methods are employed. Physical techniques such as dynamic compaction, vibroflotation, and drainage systems aim to densify or dewater weak soils. Chemical methods—including lime, cement, fly ash, and slag treatments—modify soil chemistry to enhance strength and reduce plasticity. In recent years, biological and polymer-based stabilizers like Xanthan gum, chitosan, and guar gum have emerged as sustainable alternatives, offering benefits such as lower carbon emissions, biodegradability, and reduced environmental impact.

These ground improvement strategies are not only essential for infrastructure development but also play a vital role in waste management, landfill stabilization, and erosion control. Their effectiveness has been well-documented in numerous studies. Notable contributions from researchers such as Hoek and Brown (1980), Bromhead (1992), and Terzaghi et al. (1996) have laid the foundation for understanding soil behavior and the consequences of inadequate ground treatment. Their work highlights the importance of selecting appropriate stabilization techniques to avoid geotechnical failures such as tunnel collapses, embankment instability, and landslides—ensuring safe, durable, and resilient infrastructure development.

### A. Stabilization Using Biopolymer

Biopolymer-based soil stabilization has emerged as a sustainable and eco-friendly alternative to conventional ground improvement techniques. Derived from natural sources such as plants, animals, and microbial activity, biopolymers—including chitosan, xanthan gum, guar gum, and lignin—offer a biodegradable, non-toxic approach to enhancing soil properties. Unlike traditional chemical stabilizers like cement and lime, which contribute to environmental degradation through high carbon emissions,

biopolymers present a greener solution with minimal ecological impact.

These organic compounds improve soil strength, cohesion, and water retention by forming a gel-like matrix that binds soil particles together. This results in improved load-bearing capacity, reduced erosion, and better resistance to deformation. The application of biopolymers is particularly advantageous in sandy and clayey soils, where they enhance structure without significantly altering the soil's natural composition.

Moreover, biopolymer-treated soils show increased durability under cyclic wetting and drying conditions, making them ideal for long-term infrastructure projects. Their compatibility with other natural reinforcements, such as plant fibers, further expands their potential in sustainable engineering practices. Ongoing research and field applications continue to demonstrate the effectiveness of biopolymers in various geotechnical contexts, positioning them as a promising solution for environmentally conscious soil stabilization in modern construction and land development.

## **B. List of Biopolymers with their Applications**

1. *Beta-1,3/1,6 Glucan* :- Sourced from organisms like yeast, fungi, certain cereals, bacteria, and plant cellulose, Beta-1,3/1,6 Glucan is a naturally occurring biopolymer that forms a viscous gel upon hydration. While its primary application has traditionally been in the medical field for its immune-boosting and healing properties, recent research has begun to explore its potential role in civil engineering, particularly for soil stabilization due to its binding and moisture-retention capabilities.
2. *Alginate*:- Extracted from brown algae, alginate is a linear polysaccharide made of mannuronic and guluronic acid units. Renowned for its gelling, film-forming, and ionic crosslinking behavior, alginate is widely utilized in industries such as pharmaceuticals, textiles (for waterproof coatings), and dye printing. Its ability to form stable gels makes it a strong candidate for environmental and geotechnical applications.
3. *Carboxymethyl Cellulose (CMC)* :- This cellulose derivative is synthesized by treating cellulose with chloroacetic acid under alkaline conditions. CMC acts as a thickener, stabilizer, and viscosity enhancer in various sectors. Its utility spans food processing, healthcare, and industrial applications due to its excellent water solubility and stability.
4. *Guar Gum* :- Derived from the seeds of the guar plant, this non-ionic polysaccharide is well-known for its thickening and emulsifying properties. India leads global production, contributing approximately 80% of the world's supply. Guar gum is extensively used in food processing, pharmaceuticals, and industrial formulations for its stabilizing abilities.
5. *Chitosan*:- Obtained through the deacetylation of chitin—primarily from shrimp and crab shells—chitosan is a versatile, biodegradable, and non-toxic biopolymer. Its multifunctionality has been harnessed in fields such as medicine, agriculture, biotechnology, and increasingly, in geotechnical engineering, where it is valued for improving soil cohesion and water resistance.

## 2. DETAILS OF EXPERIMENTS AND METHODOLOGY USED

A series of experiments were carried out to examine the synergistic effects of incorporating Chitosan Biopolymer (CB) and Sisal Fiber (SF) into soil.



Fig.1 (a) Chitosan biopolymer Powder (b) Chitosan Structure (Nader Hataf et al., 2017, pp- 1495)



Fig.2 (a) Sisal Fiber

The soil selected for this investigation was of alluvial origin from the sheikhpura district of Bihar.. Initially, surface vegetation was cleared to access the underlying soil. Excavation was then carried out, and soil samples were collected from a depth of approximately 1.5 meters to eliminate the influence of plant roots and organic matter. The particle size distribution was analyzed in accordance with IS: 2720 (Part 4), and the resulting grain size distribution curve is illustrated in Figure 1. Furthermore, the Atterberg limits—specifically the liquid limit and plastic limit—were determined following the guidelines of IS: 2720

(Part 5), yielding values of 35% and 21%, respectively. Based on the soil classification system outlined in IS: 1498, the tested soil was categorized as CL, indicating clay of low plasticity.

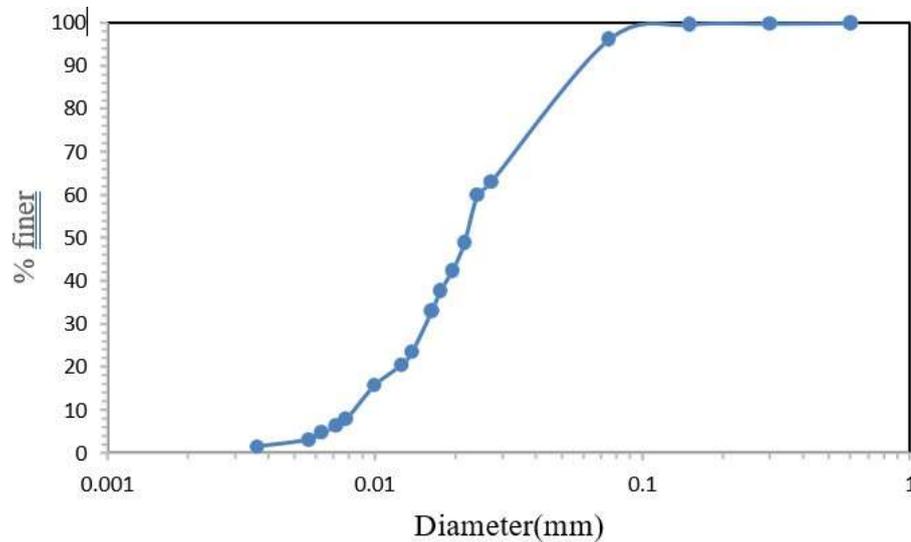


Fig. 3 Grain size distribution of soil used in this study

To assess the combined impact of CB and SF on the soil's compaction and strength behavior, four sets of tests were carried out. Table 3.3 displays the specifics of the test series. The strength behavior of the soil was evaluated, and tests for unconfined compressive strength (UCS) and California bearing ratio (CBR) were performed in order to analyse the compaction behavior of mixed standard proctor tests. This study varies the amount of chitosan biopolymer (CB) and sisal fiber (SF). Series 1 was conducted solely on soil. The soil mixed with SF was subjected to series three, while the soil mixed with CB was subjected to series two. Series 2's CBC and Series 4's SF fluctuated by 1%, 1.5%, and 2%, respectively. The soil that was combined with SF and CB underwent Series 4. The CB ranged from 1% to 1.5% to 2%, while the cumulative impact of the SFC was assessed at 1.5%.

Table 2 Details of Test Series

Series No.	Details of mix	Variable
1	Virgin Soil	-
2	Virgin Soil + CB	CBC= 1%, 1.5%, 2%
3	Virgin Soil + SF	SFC= 1%, 1.5%, 2%
4	Virgin Soil + CB + SF	CBC= 1%, 1.5%, 2% & SFC = 1.5%

#### A. Sample Preparation

The initial oven-dried sample was taken to prepare the soil sample alone. The soil was then crushed to break up any lumps. The appropriate amount of water was then added in accordance with the specifications of the UCS, CBR, and compaction tests. The soil sample mix with Chitosan biopolymer was prepared using dry soil, and the required CBC was obtained. Equation 1 defines CBC, as illustrated below. After adding the appropriate amount of water in accordance with the test requirements, the chitosan biopolymer and soil were initially combined in a dry environment.

$$CBC = \frac{\text{Weight of Chitosan Biopolymer}}{\text{weight of soil} + \text{weight of CB}} \times 100 \quad (1)$$

Similarly, it was mixed with SF to prepare the soil sample and dry soil, and SF was taken as required. SF is defined according to equation 2.

$$SFC = \frac{\text{Weight of SF}}{\text{weight of soil} + \text{weight of SF}} \times 100 \dots\dots\dots (2)$$

In the same way, to prepare a mix of soil, SF, and CB, all the ingredients were first taken in dry condition. After this, all these materials were mixed in dry condition. After this desired amount of water was added, the content of the admixture can be defined as follows in equation 3

$$\text{Content of admixture} = \frac{\text{weight of admixture CB or SF}}{\text{weight of admixture} + \text{weight of soil}} \times 100 \dots\dots\dots (3)$$

### 3. RESULT AND DISCUSSION

#### A. Compaction Behavior of Soil mixed with Chitosan biopolymer and Sisal Fiber

In this study, all soil mixtures incorporated a consistent sisal fiber content (SFC) of 1.5%, and the effects of various combinations with chitosan biopolymer (CB) were evaluated through Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), and compaction characteristics. Standard Proctor Tests (SPTs) were conducted to assess the compaction performance. Figure 5.13 illustrates the compaction curves for soil treated with SF, CB, and their combinations, alongside untreated soil and soil treated with only SF for comparative analysis. The introduction of 1.5% SF alone led to an increase in the optimum moisture content (OMC) to 14.37%, while the maximum dry density (MDD) dropped to 1.64 g/cc. When 1% CB was combined with SF, the OMC rose to 16.98%, and the MDD improved to 1.71 g/cc. A further increase in CB content raised the OMC to 19.42%, although MDD slightly decreased to 1.66 g/cc. This progression suggests that CB enhances both moisture retention and compaction characteristics when used with SF.

The compaction curves trend closer to the Zero Air Void (ZAV) line as CB is added, indicating a reduction in air voids and improved packing. This effect is attributed to the synergistic behavior of CB and SF—CB’s strong water-binding capacity and SF’s fibrous structure enhance moisture retention. Additionally, compared to the flatter compaction curve of untreated soil, the SF-CB blends demonstrate greater water sensitivity. This behavior highlights significant changes in soil structure, density, and moisture equilibrium due to the combined influence of CB and SF.

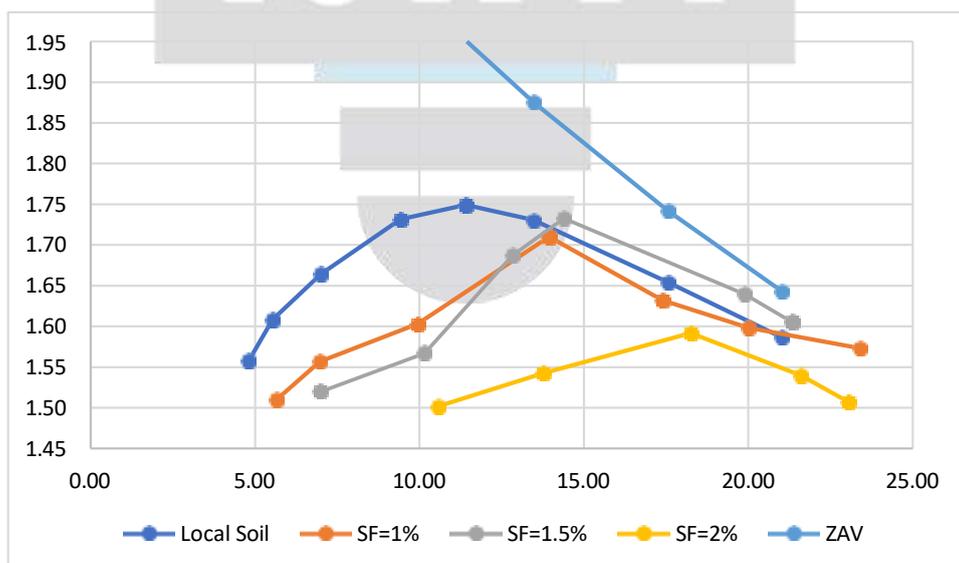


Fig. 4 Compaction curve of soil mixed with SF

### B. Performance of Soil mixed with Chitosan Biopolymer and Sisal Fiber under CBR test

Chitosan Biopolymer CB and SF together affect the CBR of soil that has both SF and CB mixed. In both damp and unsoaked conditions, adding CB and SF greatly increases the soil's CBR. Soaped CBR shows an improvement of nearly two times, while unsoaked CBR shows an improvement of about three times, which is significantly greater than the individual admixture. Cementitious and reinforcing action is facilitated by the CB and SF. When both admixtures are used combined, the soil's CBR rises more due to both effects. Furthermore, when the CB content rises by up to 1.5%, the CBR of the soil also rises. Then, a decrease in the CBR was noted. This highlights that 1.5% is the optimal dosage of CB when combined with SF and soil for enhanced performance.

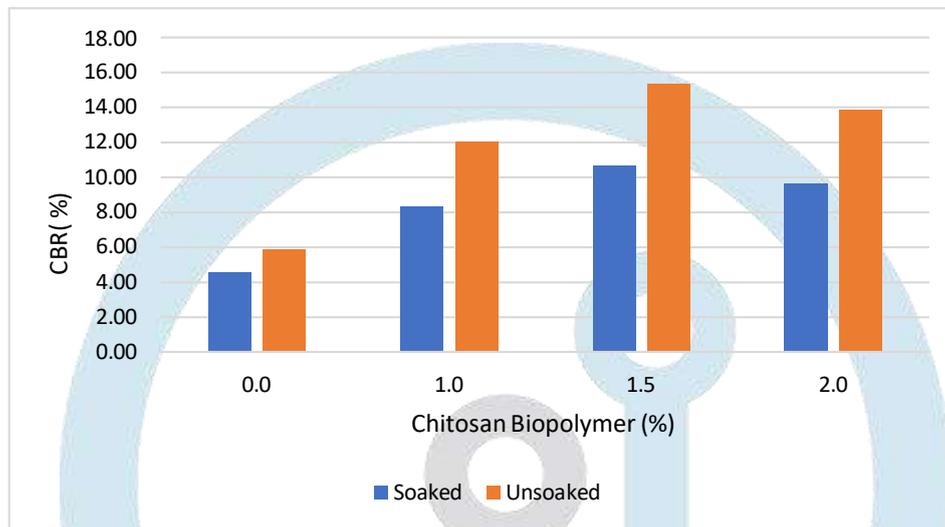


Fig. 4 CBR of soil mixed with different content of CB and SF

### C. Performance of Soil mixed with Chitosan Biopolymer and Sisal Fiber under UCS test

The influence of Chitosan Biopolymer (CB) and Sisal Fiber (SF) on the Unconfined Compressive Strength (UCS) of treated soil was analyzed by varying the CB content while maintaining a constant 1.5% Sisal Fiber Content (SFC). As illustrated in Figures 5.15 and 5.16, the UCS increased significantly with both higher CB content and extended curing duration. After 7 days of curing, soil treated with 1% CB exhibited a UCS of approximately 188 kPa, which increased to 242 kPa with 1.5% CB. The strength further improved after 28 days, reaching 235 kPa and 302 kPa for 1% and 1.5% CB content, respectively. This highlights that both CB dosage and curing time play crucial roles in enhancing the strength of stabilized soil.

A deeper look into curing effects shows that the UCS of the 1.5% CB mix improved by nearly 1.6 times from 7 to 28 days, while the 1% CB mix showed an increase of around 1.5 times. This indicates that prolonged curing significantly contributes to strength development, especially at the optimal CB level. Interestingly, a CB content of 2% resulted in a drop in UCS, pointing to 1.5% as the ideal CB concentration for achieving maximum strength—aligned with the California Bearing Ratio (CBR) results.

The strength enhancement is largely attributed to CB's hydrophilic nature, which allows it to form a gel-like matrix during curing. This matrix binds soil particles, increasing cohesion and resistance to compressive forces. Meanwhile, SF adds structural support, reducing deformation. Together, CB and SF synergistically improve soil performance, offering a sustainable and effective method for stabilization.

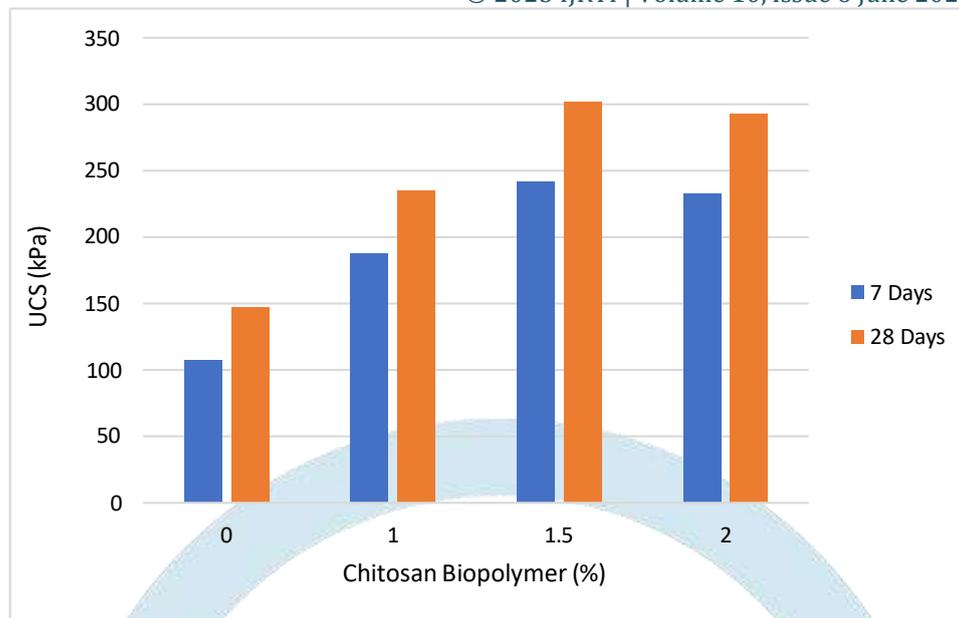


Fig. 5 UCS of soil mixed with different Content of CB and SF

#### 4. CONCLUSION

This research focused on evaluating the influence of Chitosan Biopolymer (CB) and Sisal Fiber (SF) on the geotechnical performance of soil. To assess their effects, CB and SF were incorporated at varying concentrations of 1%, 1.5%, and 2%. The experimental results provided valuable insights into how these additives impact soil behavior. The key conclusions derived from this investigation are outlined below:

- Combined Effect of CB and SF on Compaction Characteristics:** The joint application of CB and SF had a marked impact on the soil's compaction behavior. Their synergistic interaction caused a noticeable increase in Optimum Moisture Content (OMC). CB's gel-forming nature and SF's ability to retain moisture altered the compaction conditions, requiring more water for effective densification. This indicates a change in the soil's water retention and distribution pattern, ultimately affecting the compaction curve.
- Combined Effect on Soil Strength:** The integration of CB and SF considerably enhanced the strength properties of the treated soil, as indicated by both California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) results. CB contributes to improved particle bonding and cohesion, while SF provides tensile reinforcement, reducing the soil's susceptibility to cracking and deformation. The cooperative action between the two materials resulted in greater performance than when used individually, underlining their effectiveness as a combined soil stabilization strategy. This synergistic response demonstrates the potential of CB and SF in producing durable and stable soil structures.

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