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Experimental study on the stabilization of laterite soil with chitosan biopolymer for subgrade applications

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Abstract

Laterite soil, commonly found in the Konkan region in Maharashtra, India, often needs better engineering properties, posing challenges for its use in construction. By adding chitosan, a naturally occurring biopolymer derived from chitin, the study aims to enhance the geotechnical properties of laterite soil. Both untreated and chitosan-treated laterite soil samples were subjected to various laboratory tests, including the California Bearing Ratio (CBR), compaction, Atterberg limits, and direct shear testing. The chitosan was added in varying percentages (0.15%, 0.30%, and 0.45 % by weight) to determine the optimal dosage for laterite soil stabilisation. As the chitosan concentration increases from 0% to 0.3%, the Maximum dry density (MDD) value increases from 1.41 gm/cc to 1.92 gm/cc; adding chitosan further slightly decreases the MDD. The un-soaked CBR value of laterite soil containing 0.30% chitosan biopolymer increased by 108.81%, while the soaked CBR value increased by 142.83%. The soil's cohesiveness and internal friction angle increased by 120% and 15%, respectively, with the optimal dose of 0.30% chitosan. Utilising chitosan in T8 subgrade soil costs INR 6.48 crores, which is 2.57 times more than laterite soil, and requires a pavement depth of 1395 mm. In the case of T9 subgrade soil, at a depth of 1495 mm, the cost is INR 8.08 crores, which is 3.14 times more than that of laterite soil. This study highlights the potential of chitosan biopolymer as an eco-friendly and sustainable soil stabilizer for subgrade applications. It also offers a comprehensive cost-benefit analysis for pavement applications, demonstrating the financial feasibility of using chitosan biopolymer despite its higher initial costs.

Keywords: Laterite soil, Chitosan biopolymer, CBR, Shear strength, Pavement design, Costing

1. Introduction

The present study used laterite soil as subgrade soil and stabilised it with chitosan biopolymer. In the construction of roads, the stabilisation of the soil increases the engineering properties of the subgrade soil, hence increasing the capacity of the soil to sustain loads [1]. The subgrade refers to the uppermost layer of soil that serves as the foundation for a road section. The thickness of the various pavement layers in the road's structure is based on the load-bearing capacity of this subgrade. Consequently, the quality of the subgrade significantly influences both the initial construction costs of the road and the costs associated with future maintenance. [2]. Designing a thick and expensive road stretch, strengthening the subgrade with a geosynthetic material [3-5] or adding traditional stabilisers such as lime [6-8] and cement [9, 10] are options for dealing with weak subgrades. Numerous researchers are exploring the enhancement of subgrade soil strength through the use of various additives such as cement kiln dust (CKD) [2], plastic trash [11], fibre-reinforced fly ash [12], natural coir fibres [13], fly ash combined with fibres [14], and bentonite mixed with lime [15]. Biopolymers can enhance the properties of subgrade soil by improving its shear strength, reducing permeability, and increasing resistance to erosion, making it a sustainable alternative for soil stabilisation [16]. Xanthan gum biopolymer is highly effective in enhancing subgrade soil stabilisation by significantly improving the soil's shear strength, offering a sustainable solution for geotechnical engineering [17-20]. The use of guar gum biopolymer improves the strength of laterite soil, offering a more environmentally friendly and sustainable option compared to traditional soil additives [21-23]. During excavations in laterite soil, engineering problems like road failures, instability of slopes, landslides, cavity formation in tunnel works, and foundation settlement can occur [24].

A recent study has explored the potential of biopolymers, particularly chitosan, for soil stabilisation as environmentally friendly alternatives to conventional materials. Chitosan has been shown to improve the mechanical properties of sandy and expansive soils by increasing inter-particle cohesion [25, 26]. In earthen construction, chitosan-stabilized soil exhibited superior compressive and flexural strength compared to cement-stabilized samples [27]. For expansive soils, chitosan effectively reduced the plasticity index and increased the shrinkage limit, mitigating swelling potential [25]. These findings suggest that biopolymers, such as chitosan, offer promising sustainable solutions for soil stabilisation in various geotechnical applications. Chitosan, a biopolymer derived from shrimp shells, is utilised for soil stabilisation. It enhances soil particle interactions, improving mechanical properties and addressing issues like heavy metal absorption, soil erosion, and hydraulic conductivity. [28]. Low concentrations of chitosan significantly increased the shear

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modulus of medium-grained soils. This suggests that chitosan solutions can act as effective and environmentally friendly short-term stabilisers for temporary geotechnical constructions. [29]. Chitosan, derived from shrimp shells, is used to improve the properties of clay soil. The research found that chitosan concentrations of up to 6% enhanced soil strength during freezing and thawing cycles, while 8% chitosan disrupted the balance of the mixture [30]. Chitosan and xanthan gum biopolymers were used to enhance the stability, strength, and erosion resistance of soil, clayey soil. These eco-friendly biopolymers, derived from shrimp shells and the food industry, were tested through compaction and unconfined compression tests to evaluate their effects on soil properties. [31]. Chitosan biopolymer is utilised to enhance the geotechnical properties of desert sand. Tests demonstrated that chitosan significantly improved both shear strength and soil cohesion. The optimal results for strength were achieved with a 7% chitosan content, while the best cohesion was noted at 1-2%. These findings indicate chitosan's potential as an effective solution for soil stabilisation. [32]. Water seeps through the porous laterite soil in the Karnataka, Goa, and Ratnagiri regions owing to the heavy rainfalls in these areas. This seepage often causes water to spill out at the interface of the laterite strata, leading to engineering challenges, safety concerns, and unexpected delays in the project. [33]. It is crucial to improve the properties of laterite soil to prevent disasters. Chitosan enhances the cohesion and bonding between soil particles, resulting in an immediate increase in subgrade strength. This improvement is attributed to its adhesive properties and its ability to form a stable matrix with the soil particles. While chitosan significantly boosts subgrade strength initially, its susceptibility to supporting fungal growth and degrading over time can lead to a reduction in strength. [34]. This study explores the potential of chitosan, a biodegradable biopolymer, as a stabilising agent for laterite soils used in subgrade applications. By examining the mechanical and physical properties of laterite soil after applying varying concentrations of chitosan, this research offers a fresh perspective on soil stabilisation. The findings suggest an innovative and sustainable method for enhancing the performance of subgrade materials, which could transform the construction industry's approach to sustainable soil stabilization.

2. Materials

2.1 Laterite Soil (LS)

Laterite soil is characterised by its reddish or yellowish colour and has low levels of nitrogen and manganese oxides. It forms in regions with high temperatures, abundant rainfall, and alternating wet and dry periods. These conditions lead to soil leaching, resulting in the retention of primarily iron and aluminium oxides. [21]. Laterite soil specimens were obtained for investigation at Lote Parshuram Ghat, Chiplun, Maharashtra (17°33'28.0"N and 73°29'53.0" E). The grain size analysis revealed that the soil contains 28–33% sand, 20–26% silt, and 55–59% clay. According to Indian standards (IS: 1498–1970), these findings classify the soil as highly compressible silt (MH). The liquid limit (LL) of laterite soil ranges from 58-64%, the plastic limit (PL) ranges from 34-39%, and the shrinkage limit (SL) ranges from 17-21%. In the modified Proctor test, the maximum dry density (MDD) ranged from 1.45 to 1.55 gm/cc, and the optimum moisture content (OMC) was between 14% and 17%. The soaked and unsoaked CBR values of laterite soil were 6.10% and 8.25%, respectively. For a road subgrade, the minimum soaked CBR value should be 8% for low-volume roads and significantly higher for high-volume roads. A soaked CBR of 6.10% falls below the acceptable threshold, indicating the need for improvement and stabilisation of soil. The cohesion of the laterite soil ranged from 0.12 to 0.15 kg/cm², and its internal friction angle varied between 12.10 and 16.35 degrees. Table 1 presents the properties of the laterite soil, while Figure 1 displays its particle size distribution curve.

2.1.1 XRD analysis of laterite soil

According to the analysis, Oxygen (O) was the most abundant element in the soil, making up 44.3% of its composition. This was followed by Phosphorus (P) at 21.5%. The elemental makeup of the soil also included notable amounts of Germanium (Ge) at 20.1%, Sodium (Na) at 9.1%, and Aluminium (Al) at 5.0%. These results highlight the diverse chemical composition of laterite soil, indicating that these elements are present in significant quantities, which may influence its chemical and physical properties. Figures 2 and 3 illustrate the intensity versus 2θ values and the chemical composition of the laterite soil based on the corresponding 2θ values.

Table 1 Properties of Laterite Soil

Sr. No.	Properties	Value	Reference
1	**Specific gravity (G)**	2.42-2.70	IS 2720 (Part-3) 1980 [35]
2	**Particle size distribution**		IS: 2720 (Part-4): 1985 [35]
	Sand %	28-33	
	Silt %	20-26	
	Clay %	55-59	
3	**Consistency limits**		IS 2720 (Part-5) 1985 [35]
	LL (%)	58-64	
	PL (%)	34-39	
	PI (%)	24-25	
	SL (%)	17-21	
4	**Soil classification**	MH	
5	**Modified Proctor test**		IS 2720 (Part-8) 1980 [35]
	Max dry density (gm/cc)	1.45-1.55	
	OMC (%)	14 - 17	
6	**CBR Value (%)**		IS 2720 (Part-16) 1987 [35]
	Soaked	6.10	
	Unsoaked	8.25	
7	**Direct shear test**		IS 2720 (Part-15) 1986 [35]
	Cohesion (kg/cm^2)	0.12 - 0.15	
	The angle of internal friction (Degree)	12.10 - 16.35	

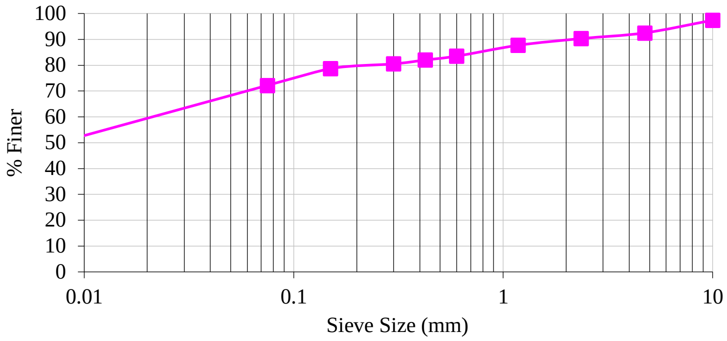

Figure 1 Laterite soil particle size curve

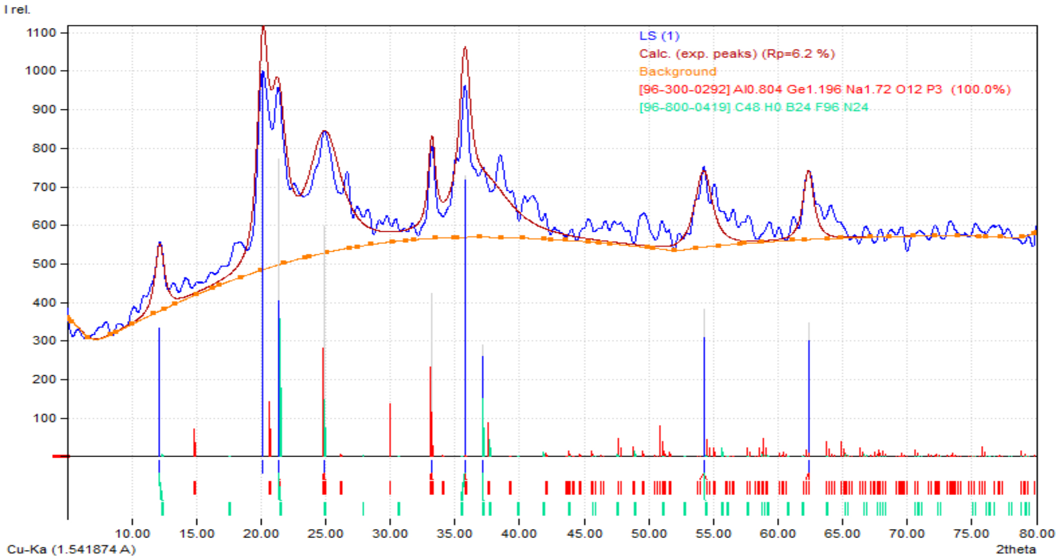

Figure 2 Intensity vs. 2ϴ plot in the XRD analysis of laterite soil

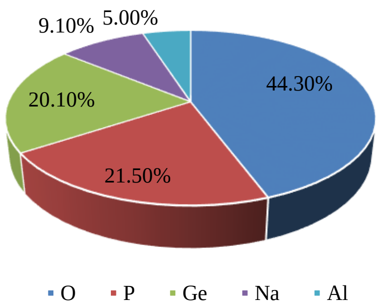

Figure 3 Elemental composition of laterite soil

2.2 Chitosan (CH)

Chitosan is a natural biopolymer obtained from chitin, characterized by its non-toxic, biodegradable, and biocompatible properties. As a result, chitosan holds potential for a diverse array of applications [36]. Decomposed chitin, or chitosan, is a component of crab exoskeletons and fungal cell walls. It is typically produced by reacting sodium hydroxide with alkali [37]. Figure 4 shows the chitosan biopolymer and its chemical structure.

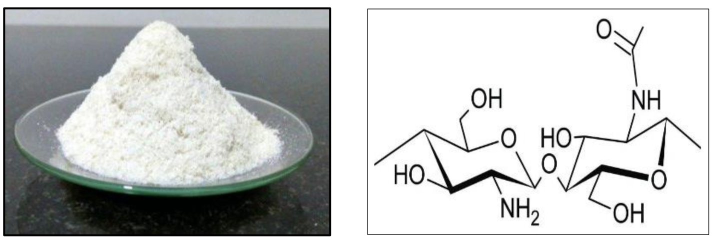

Figure 4 Chitosan biopolymer and its chemical structure

2.2.1 XRD analysis of chitosan biopolymer

Chitosan's carbon content suggests that it can add organic matter to the soil, enhancing its stability by improving its structure [38]. Chitosan's oxygen content indicates that it can enhance the oxygen availability in the soil, facilitating the decomposition of organic material and improving soil stability. Chitosan has excellent binding properties and can effectively bind soil particles, enhancing soil cohesion and stability [39]. It can act as a natural soil stabilizer by reducing erosion, improving load-bearing capacity, and reducing soil susceptibility to weathering and displacement [40]. The chitosan biopolymer used in this study contains 40.70% carbon, 40.70% oxygen, and 5.90% nitrogen, which directly contributes to the structural stability, improving the cohesion and overall strength of the soil. Figures 5 and 6 display the XRD analysis results of chitosan biopolymer, providing valuable insights into its structural properties and crystalline nature. Table 2 shows the physical properties of chitosan biopolymer.

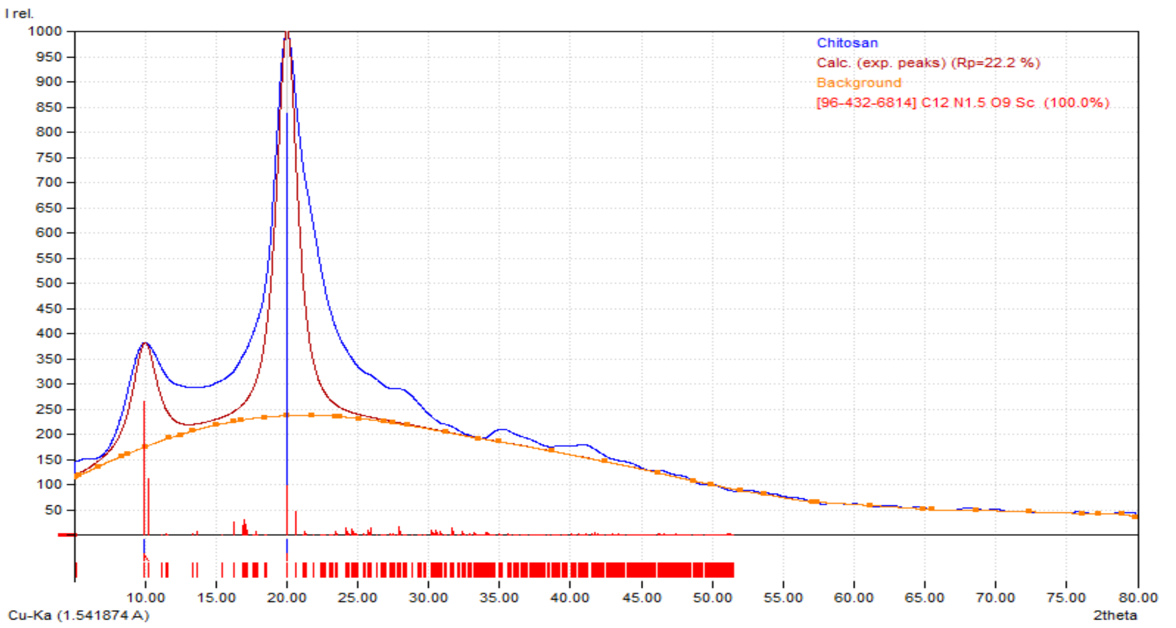

Figure 5 Intensity vs. 2Θ curve in XRD analysis of chitosan

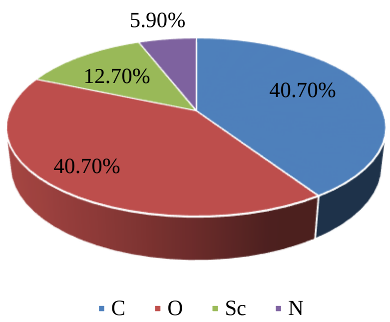

Figure 6 Elemental composition of chitosan

Table 2 Physical Properties of Chitosan Biopolymer

Sr. No.	Property	Specifications of Chitosan Biopolymer
1	Physical state	Yellowish-White
2	pH	6 to 8
3	Viscosity (1 % solution in 1% KCl)	1000-1400 cps
4	Moisture content	Max 5%
5	Particle size	Average particle size 1 mm to 3 mm
6	Ash content	Max 2%

2.3 Sample preparation

In this study, selecting the appropriate dosage of chitosan biopolymer for stabilizing laterite soil was a critical step in ensuring effective soil treatment. To determine the optimal dosages, a comprehensive and systematic approach was adopted, including a detailed review of existing research and previous studies. This review offered valuable insights into the most effective quantities of chitosan biopolymer needed for soil stabilization, allowing for the identification of optimal dosages that would achieve the desired stabilization without compromising the soil's structural integrity.

The chitosan biopolymer was incorporated into the laterite soil using a wet mixing technique, which ensures the uniform distribution of the stabilizing agent throughout the soil. Three different dosages were tested: 0.15%, 0.30%, and 0.45% of chitosan relative to the weight of the soil. These specific concentrations were selected based on prior research suggesting they would provide a balance between effective stabilization and minimal disruption to the soil's natural properties.

A key component of the mixing process was the addition of acetic acid, which served to dissolve the chitosan biopolymer. Acetic acid functioned as a solvent, ensuring the chitosan dissolved properly and was evenly distributed within the laterite soil matrix. This even distribution is crucial for the effectiveness of the stabilization process, as it ensures uniform interaction between the chitosan and soil particles. Additionally, the amount of water used in the wet mixing process, alongside the chitosan biopolymer, was carefully controlled. Specifically, 0.015 ml of acetic acid was used, a quantity determined based on the methodology outlined in the study by Shariatmadari et al. [25]. This ensured that the solvent concentration was optimal for dissolving the chitosan while avoiding excess moisture, which could interfere with the soil stabilisation process. Figure 7 illustrates the chitosan-based biopolymer solution and the laterite soil treated with various concentrations of the chitosan biopolymer. The figure visually highlights the differences in appearance and texture of the laterite soil at each chitosan concentration, demonstrating the effectiveness of the treatment in stabilising the soil at different dosage levels. Table 3 presents the dosages of chitosan biopolymer used in laterite soil and the calculation of the weight of water using acetic acid and chitosan by water ratio.

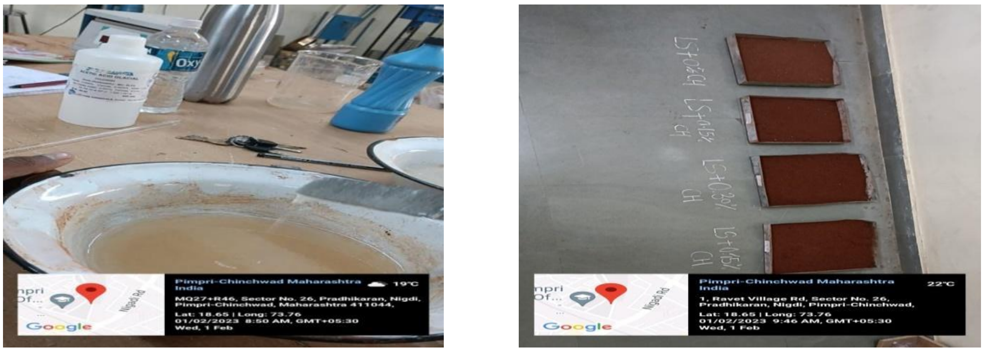

Figure 7 Chitosan biopolymer solution and Lateritic Soil Treated with Varying Chitosan Biopolymer Concentrations

Table 3 Nomenclature, dosages of chitosan in laterite soil and calculation of weight of water

Sr. No.	Type of soil	Name of biopolymer	% Dosage	Name of combination	Mixing method	Mass of soil (gm)	% of chitosan solution	Mass of chitosan (gm)	Acetic acid (ml)	Weight of water (gm)
1	Laterite soil (LS)	Chitosan (CH)	0.15	LS + 0.15% CH	Wet (using acetic acid)	3000	0.15	4.5	0.015	300
2			0.3	LS + 0.30% CH		3000	0.3	9		600
3			0.45	LS + 0.45% CH		3000	0.45	13.5		900

3. Results and discussions

3.1 Plastic behaviour of blended samples

The addition of biopolymers to laterite soil can significantly influence its liquid limit and plastic limit. Biopolymers, which are natural or synthetic polymers derived from biological sources, can modify the behaviour and properties of soil when incorporated. When biopolymers are added to laterite soil, they enhance its engineering properties by increasing plasticity and reducing susceptibility to erosion. For instance, the addition of chitosan, a type of biopolymer, alters the soil's physical properties, resulting in higher liquid and plastic limits. This improvement is due to an increased water-holding capacity, changes in soil structure, and better soil aggregation. (Figure 8).

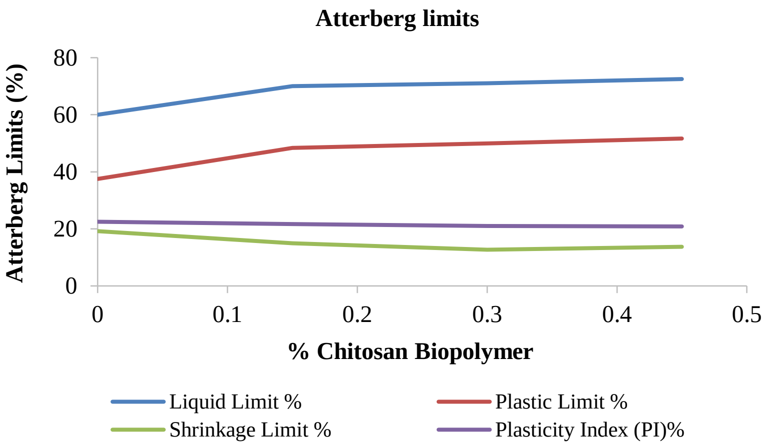

Figure 8 Atterbergs limits results of different laterite soil - chitosan combinations

3.2 Modified proctor test

Chitosan is recognized for its strong bonding capabilities and high molecular weight, which may enhance soil compaction and increase the maximum dry density (MDD). The MDD value rises from 1.41 g/cm³ to 1.92 g/cm³ as the concentration of chitosan increases from 0% to 0.3%. However, with further addition of chitosan, the MDD decreases slightly to 1.59 g/cm³. The data also indicates that the optimum moisture content (OMC) increases from 15.38% to 22.73% in the high compaction test. The introduction of a chitosan biopolymer solution improves the overall moisture content of the soil mixture, which can influence the OMC. The added moisture from the chitosan biopolymer solution alters the moisture-density relationship, resulting in a higher OMC. Figure 9 illustrates the compaction curves for different dosages of the chitosan biopolymer.

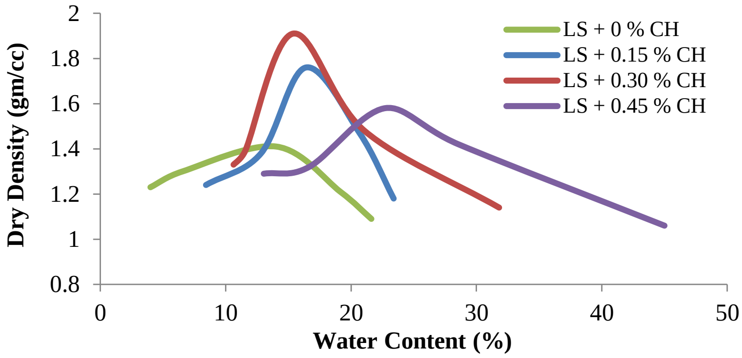

Figure 9 Moisture-density relationship of the laterite soil with chitosan

3.3 Direct shear test

Failure envelopes for each laterite soil-chitosan biopolymer mixture are shown in Figure 10. Using the wet mixing procedure, the chitosan biopolymer was introduced to the laterite soil. The mixture cohesiveness intercept (c) and angle of internal friction (φ) as determined by linear regression analysis. Figure 11 shows how chitosan biopolymer affects the angle of internal friction and cohesiveness. Compared to laterite soil alone, the friction angle increases, and so does the chitosan content. In contrast, the cohesion intercepts increase directly to the amount of chitosan, with a considerable rise in cohesion from 0.15 kg/cm^2 to 0.33 kg/cm^2 at the dose of 0.30% chitosan. Compared to conventional laterite soil, this shows an increase in cohesiveness of about 120%.

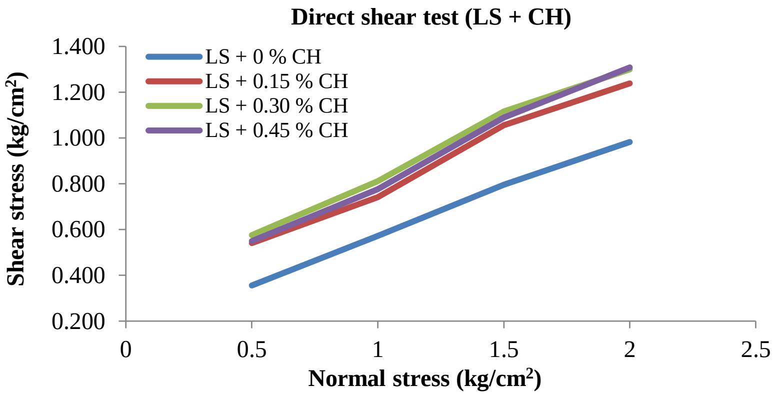

Figure 10 Failure envelopes of laterite soil – chitosan mixes

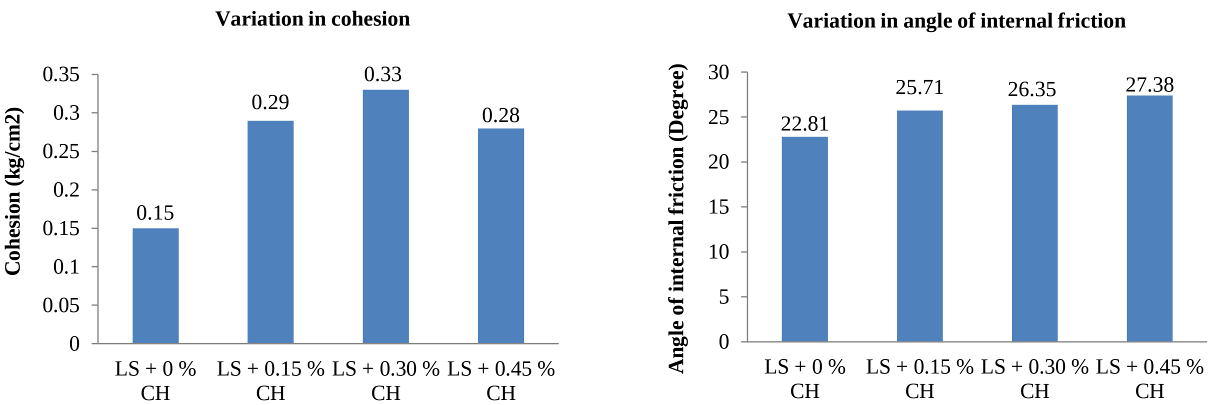

Figure 11 Variation in cohesion and angle of internal friction (Laterite soil – chitosan mixes)

The shear stresses at the point of failure suggest that the total shear strength is likewise getting stronger. Since chitosan concentrations in laterite soil range from 0.15% to 0.45%, no such change in the angle of shearing resistance has been found. Chitosan, which contains 40.7% carbon, can act as a binder, stabilizing soil particles and enhancing soil particle cohesiveness. After introducing the particles and the soil matrix, increased interlocking and bonding forces between soil particles were found because of the formed gelation between the particles.

3.4 CBR Test

The California Bearing Ratio (CBR) values for laterite soil mixed with 0.15%, 0.30%, and 0.45% chitosan biopolymer under soaked conditions were 9.97, 14.74, and 14.09, respectively. It was observed that the CBR values were higher in the unsoaked condition compared to the soaked condition.

Figure 12 illustrates the various CBR values for soaked and unsoaked conditions with different combinations of laterite soil and chitosan biopolymer. In the unsoaked condition, the CBR values for laterite soil containing 0.15%, 0.30%, and 0.45% chitosan were 12.14, 15.39, and 14.74, respectively. The chitosan biopolymer demonstrated higher CBR values than other biopolymers used in the soil. Notably, the unsoaked CBR value of soil with 0.30% chitosan biopolymer showed an increase of 108.81%, while the soaked CBR value increased by 142.83%. Further additions of chitosan biopolymer did not lead to significant changes in the CBR values.

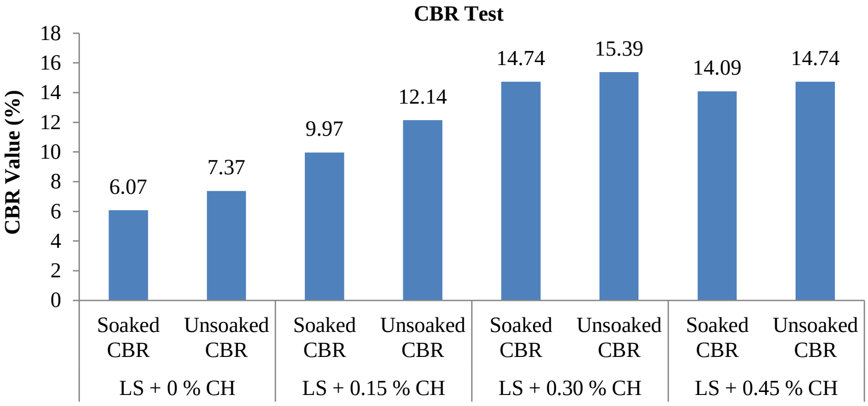

Figure 12 Comparison of CBR value for laterite soil and chitosan biopolymer mixes

3.5 Microstructural analysis

XRD analysis was conducted using a [specific XRD machine] with Cu-Kα radiation (λ = 1.5406 Å). The voltage and current were set to 40 kV and 30 mA, respectively. Scans were performed in the 2θ range of 5°–80° with a step size of 0.02° at a scan speed of 1°/min. An XRD analysis of the laterite soil with 0.3% chitosan biopolymer (Optimum dose) was carried out. Chitosan biopolymer is mixed with laterite soil; the resulting composition of the mixture is 75.9% carbon (C), 14.5% sodium (Na), and 9.6% hydrogen (H). The cationic nature of Chitosan allows it to attract and bind with clay particles in the laterite soil, promoting flocculation and better aggregation. This can enhance the soil's structural integrity, reducing its plasticity and increasing its load-bearing capacity. Chitosan's water-absorbing properties can improve the water-holding capacity of laterite soil. This can help reduce excessive water infiltration, improve drainage, and prevent erosion. Chitosan is a natural biopolymer derived from renewable sources, making it an environmentally friendly option for soil stabilization. Its use can minimize the environmental impact associated with soil treatment and reduce the need for synthetic stabilizers. Figures 13 and 14 show the XRD results of laterite soil and 0.30% CH soil mix and the elemental composition of the soil mix.

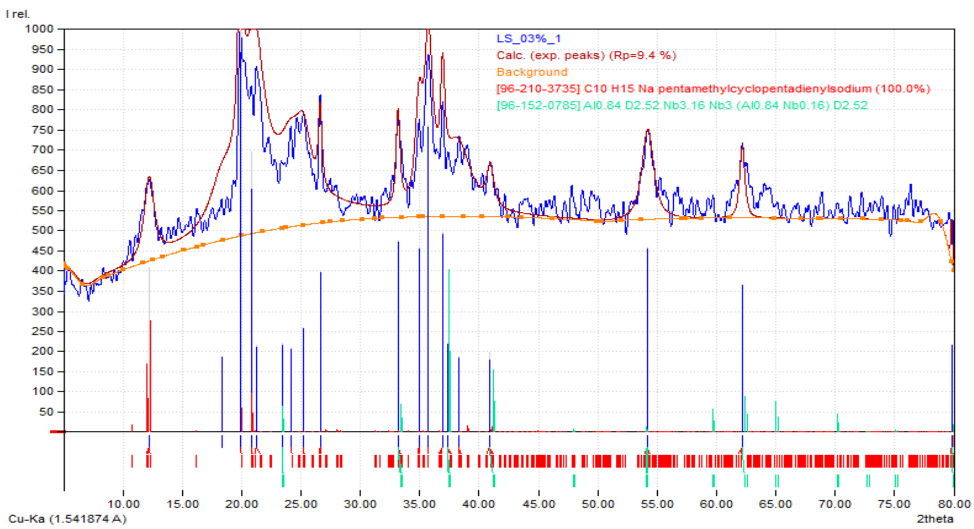

Figure 13 Intensity vs. 2Θ curve in XRD analysis

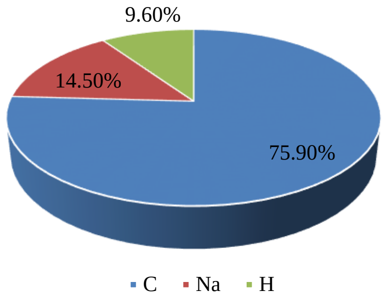

Figure 14 Elemental composition of LS + 0.30 % CH soil mix

SEM analysis was performed using a [specific SEM model] with an accelerating voltage of 15 kV and a working distance of 10 mm. Samples were sputter-coated with gold to enhance conductivity, and secondary electron imaging was used to capture surface morphology. Chitosan boosts the interaction between tiny particles. The cationic characteristics of chitosan cause an electrical contact between the biopolymer, which influences the inter-particle behaviour of the treated laterite soil, and this is where the theory of the micro behaviour of chitosan in soil originates. Soil treated with chitosan has increased cohesion and rigidity of the fine soil particles as a result. Figure 15 shows the SEM images of conventional laterite soil only. The mark circles in Figure 16 show the pores are filled with chitosan gelation.

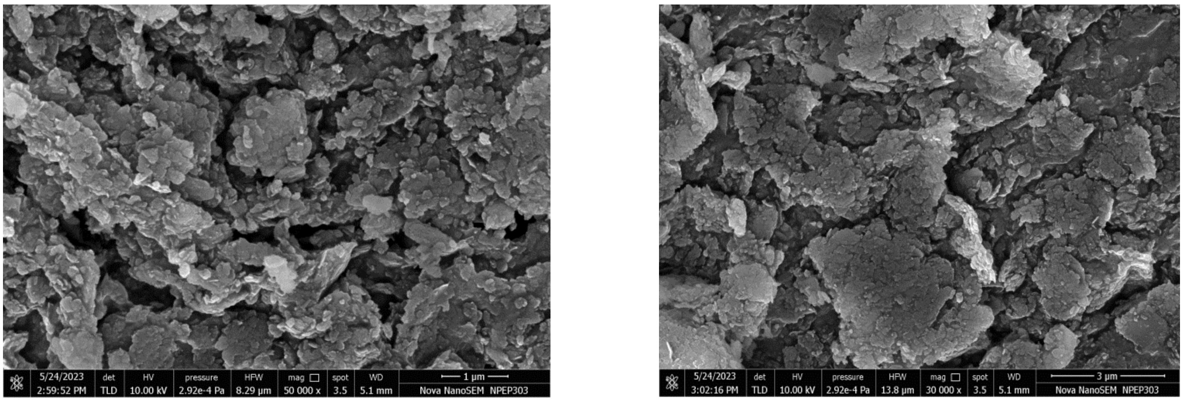

Figure 15 SEM images of Laterite soil (LS)

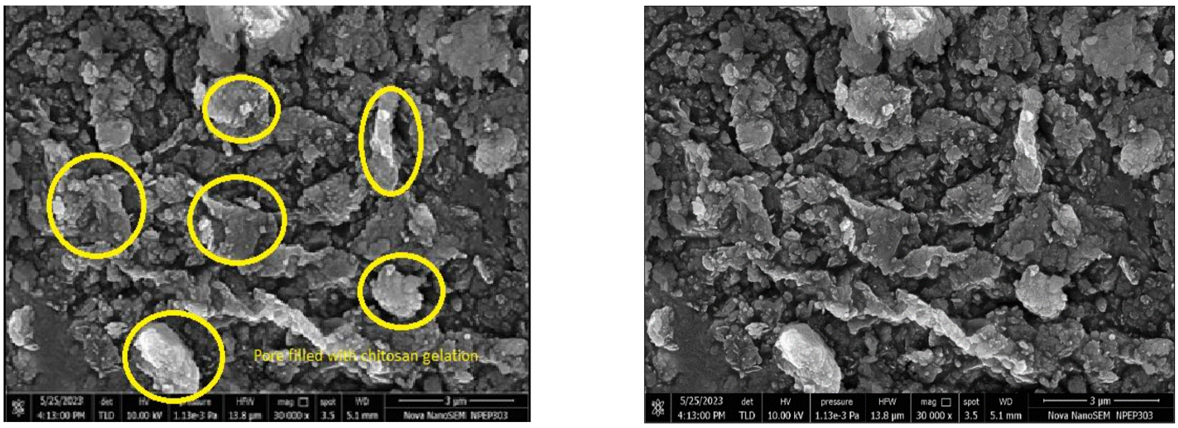

Figure 16 SEM images of LS + 0.30 % CH soil mix

4. Pavement design and costing

Pavement design and cost analysis are vital components of road and highway development projects. The pavement design process involves determining the correct thickness, materials, and structural composition of the pavement layers to ensure they can withstand traffic loads and environmental conditions over their expected lifespan. This process includes evaluating subgrade conditions, selecting appropriate construction materials, and employing design methods to achieve optimal performance, durability, and safety of the roadway.

Cost analysis focuses on the financial aspects of pavement construction and maintenance, ensuring that the selected design is cost-effective throughout its lifecycle. This includes assessing initial construction costs and ongoing maintenance expenses. These pavements are designed according to the requirements specified in IRC: SP:72 - 2015 [41]. Given the complexity of these pavements, a more detailed design approach, as recommended by IRC: 37-2018 [42], is necessary. This study's proposed low-volume pavement design is based on IRC SP:72 - 2015. Traffic is divided into nine divisions (T1-T9) based on Cumulative Equivalent Single Axle Load

(ESAL). The study focused on two traffic groups, T8 and T9, which correlate to certain ESAL ranges. The ESAL values, which measure the cumulative influence of axle loads on the pavement's structural integrity, varied from 1,000,000 to 1,500,000 for T8 and 1,500,000 to 2,000,000 for T9. This investigation, which focuses on T8 and T9, aims to better understand the implications of greater traffic loads on pavement performance.

4.1 Only laterite soil (T8 and T9 category)

Tables 4 and 5 provide an insightful overview of the pavement design and comprehensive cost analysis, focusing exclusively on utilizing laterite soil without incorporating chitosan biopolymer, specifically within the T8 and T9 categories. Within the T8 classification, which pertains to a certain level of road infrastructure, an in-depth examination reveals that the financial outlay necessary for constructing a 1000-meter road stands at Rs. 2.52 crore. Concurrently, in the T9 classification, which denotes a slightly different road categorization, the corresponding expense escalates to Rs. 2.57 crore. The total pavement crust thickness calculated is 1445 mm and 1495 mm in T8 and T9, respectively. The cost of pavement for the T9 category is higher than that for the T8 category due to more thickness required to satisfy the design criteria.

Table 4 Design and cost evaluation of pavement using exclusively laterite soil (T8 category)

Case 2: Only Laterite Soil (T8)									
Length of road (m)	1000								
Biopolymer	No biopolymer								
MDD (kg/m^3)	1410								
Effective CBR (%)	6.07								
Carriageway width (m)	14								
Layer to be used	-								
Dosage	0%								
Subgrade class	S3								
Layer	**OGPC**	**WBM (CBR>100%)**	**WBM Grade-3**	**Modified subgrade**	**Granular sub base (CBR>20%)**	**Embankment**	**Subgrade**	**Total**	**No biopolymer**
Thickness (mm)	20	150	75	100	200	500	400	1445	-
Top width (m)	14	14	14	15.78	14.98	17.38	15.78	-	-
Bottom width (m)	14	14	14	16.18	15.78	19.38	17.38	-	-
Length (m)	1000	1000	1000	1000	1000	1000	1000	-	-
Qty. (cum)	280	2100	1050	1598	3076	9190	6632	-	-
Qty. (kg)	0	0	0	0	0	0	0	-	0
Rate (Rs.)	267	2,180	2,180	3,627	2,039	393	393	-	-
Amount (Rs.)	74,760	45,78,000	22,89,000	57,95,946	62,71,964	36,11,670	26,06,376	-	-
Total								**25,227,716**	
Total in Cr.								**2.52**	

Table 5 Design and cost evaluation of pavement using exclusively laterite soil (T9 category)

Case 2: Only Laterite Soil (T9)									
Length of road (m)	1000								
Biopolymer	No biopolymer								
MDD (kg/m^3)	1410								
Effective CBR (%)	6.07								
Carriageway width (m)	14								
Layer to be used	-								
Dosage	0%								
Subgrade class	S3								
Layer	**OGPC**	**WBM (CBR>100%)**	**Bituminous macadam**	**Modified subgrade**	**Granular sub base (CBR>20%)**	**Embankment**	**Subgrade**	**Total**	**No biopolymer**
Thickness (mm)	20	225	50	0	200	500	500	1495	-
Top width (m)	14	14	14	15.98	15.18	17.98	15.98	-	-
Bottom width (m)	14	14	14	15.98	15.98	19.98	17.98	-	-
Length (m)	1000	1000	1000	1000	1000	1000	1000	-	-
Qty. (cum)	280	3150	700	0	3116	9490	8490	-	-
Qty. (kg)	0	0	0	0	0	0	0	-	0
Rate (Rs.)	267	2,180	7,644	3,627	2,039	393	393	-	-
Amount (Rs.)	74,760	68,67,000	53,50,800	-	63,53,524	37,29,570	33,36,570	-	-
Total								**25,712,224**	
Total in Cr.								**2.57**	

4.2 Chitosan biopolymer used in only subgrade soil and subgrade with embankment soil (T8 category)

When the chitosan biopolymer was used in the T8 subgrade soil, the total pavement depth required was 1395 mm, costing Rs. 6.48 crores. This cost increased 2.57-fold when compared to the sole use of laterite soil. It similarly incorporated chitosan into the subgrade and embankment soils, which required a combined thickness of 1420 mm, costing Rs. 15.11 crores. Compared to the exclusive use of laterite soil, this revealed a significant cost increase of 5.99 times. The optimal chitosan proportion was discovered to be 0.30% relative to the laterite soil's dry weight. Tables 6 and 7 describe pavement design and cost assessment in the context of chitosan biopolymer application.

Table 6 Design and cost evaluation of chitosan for subgrade pavement (T8 category)

Case 3: 0.3% chitosan in only subgrade									
Length of road (m)	1000								
Biopolymer	chitosan								
MDD (kg/m^3)	1910								
Effective CBR (%)	3.26								
Carriageway width (m)	14								
Layer to be used	subgrade								
Dosage	0.3%								
Subgrade class	S2								
Layer	**OGPC**	**WBM (CBR>100%)**	**WBM Grade-3**	**Modified subgrade**	**Granular sub base (CBR>20%)**	**Embankment**	**Subgrade**	**Total**	**Chitosan**
Thickness (mm)	20	150	75	200	150	500	300	1395	-
Top width (m)	14	14	14	15.58	14.98	16.78	15.58	-	-
Bottom width (m)	14	14	14	16.38	15.58	18.78	16.78	-	-
Length (m)	1000	1000	1000	1000	1000	1000	1000	-	-
Qty. (cum)	280	2100	1050	3196	2292	8890	4854	-	27813.4
Qty. (kg)	0	0	0	0	0	0	0	-	
Rate (Rs.)	267	2,180	2,180	3,627	2,039	393	393	-	1,300
Amount (Rs.)	74,760	45,78,000	22,89,000	1,15,91,892	46,73,388	34,93,770	19,07,622	-	3,61,57,446
Total								**64,765,878**	
Total in Cr.								**6.48**	

Table 7 Design and cost evaluation of chitosan for subgrade pavement (T9 category)

Case 4: 0.3% chitosan in subgrade and embankment									
Length of road (m)	1000								
Biopolymer	chitosan								
MDD (kg/m^3)	1910								
Effective CBR (%)	14.74								
Carriageway width (m)	14								
Layer to be used	subgrade & embankment								
Dosage	0.3%								
Subgrade class	S5								
Layer	**OGPC**	**WBM (CBR>100%)**	**WBM Grade-3**	**Modified subgrade**	**Granular sub base (CBR>20%)**	**Embankment**	**Subgrade**	**Total**	**Chitosan**
Thickness (mm)	20	150	75	0	175	500	500	1420	-
Top width (m)	14	14	14	15.68	14.98	17.68	15.68	-	-
Bottom width (m)	14	14	14	15.68	15.68	19.68	17.68	-	-
Length (m)	1000	1000	1000	1000	1000	1000	1000	-	-
Qty. (cum)	280	2100	1050	0	2683	9340	8340	-	101306.4
Qty. (kg)	0	0	0	0	0	0	0	-	
Rate (Rs.)	267	2,180	2,180	3,627	2,039	393	393	-	1,300
Amount (Rs.)	74,760	45,78,000	22,89,000	-	54,70,127	36,70,620	32,77,620	-	13,16,98,320
Total								**151,058,447**	
Total in Cr.								**15.11**	

5. Conclusions

Chitosan, a naturally abundant biopolymer, is critical for creating long-term soil stabilization solutions. The effect of chitosan on soil physical and mechanical properties is determined by the type of biopolymer, its content, and soil-specific characteristics. The findings indicate that employing chitosan at a concentration of 0.30% results in the most substantial improvement in the geotechnical parameters investigated. This study's findings lead to the following conclusions:

- This research demonstrates the potential of chitosan as an effective and eco-friendly solution for improving the performance of laterite soil in subgrade applications.
- Chitosan is an efficient soil stabilizer, mainly when applied to laterite soils, where it can maintain its effectiveness over the long term. Using chitosan biopolymer in laterite soil increases MDD, CBR value, and cohesion.
- Increasing chitosan concentration from 0% to 0.3% significantly increases the Maximum Dry Density (MDD) from 1.41 gm/cc to 1.92 gm/cc, representing a 36.17% increase. However, additional chitosan beyond this concentration leads to only a marginal decrease in MDD.
- Adding 0.30% chitosan significantly enhances the cohesiveness of the material, increasing it from 0.15 kg/cm^2 to 0.33 kg/cm^2, and representing a substantial 120% improvement.
- The un-soaked CBR value of soil containing 0.30% chitosan biopolymer increased by 108.81%, while the soaked CBR value increased by 142.83%. Further addition did not influence CBR values.
- Using chitosan in subgrade soil increases the cost. For T8 subgrade soil, the cost is 2.57 times higher than using laterite soil, and for T9 subgrade soil, it's 3.14 times higher.
- The experimental study demonstrates that stabilizing laterite soil with chitosan biopolymer effectively enhances its properties, making it a viable option for improving subgrade applications.

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