STABILIZATION OF SOIL USING GELLAN GUM AND JUTE FIBER

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Abstract: Soil stabilization plays a pivotal role in improving the structural integrity and load-bearing capacity of weak or problematic soils, ensuring their suitability for construction and long-term performance. Traditional stabilizers like cement and lime, though effective, are associated with significant environmental drawbacks. This research explores the innovative application of Gellan Gum (GG), an eco-friendly biopolymer, and Jute Fiber (JF), a biodegradable natural reinforcement, as sustainable agents for enhancing the geotechnical performance of alluvial soil. Various proportions of Gellan Gum (1.0%, 1.5%, and 2.0%) and Jute Fiber (1.0%, 1.5%, and 2.0%) were independently tested, along with combined dosages of (1.0% GG + 1.5% JF), (1.5% GG + 1.5% JF) and (2.0% GG + 1.5% JF). Additionally, the influence of Jute Fiber lengths—10 mm, 20 mm, and 30 mm—was examined. The geotechnical performance of the treated soil was evaluated using compaction characteristics (OMC–MDD relationship), California Bearing Ratio (CBR) tests under soaked and unsoaked conditions, and Unconfined Compressive Strength (UCS) tests. The results demonstrated that the combination of 1.5% Gellan Gum with 1.5% Jute Fiber of 20 mm length yielded the highest improvement in strength and compaction behaviour. The findings highlight the effectiveness of biopolymer–fiber synergy in improving soil performance while promoting sustainable and eco-friendly construction practices.

Keywords: Soil Stabilization, Gellan Gum, Jute Fiber, Biopolymer, Natural Reinforcement, Geotechnical Properties, Eco-friendly Materials, Sustainable Ground Improvement.

1. INTRODUCTION

Ground improvement methods play a crucial role in geotechnical engineering by enhancing the load-bearing capacity and stability of weak or problematic soils for safe structural development. Traditional stabilizers like cement and lime, while effective, raise environmental concerns due to high carbon emissions. As sustainable alternatives gain attention, Gellan Gum (GG), a biodegradable biopolymer produced by Sphingomonas elodea, offers promising soil-binding and strength-enhancing properties. It is water-soluble, eco-friendly and widely used in the food and pharmaceutical industries. Similarly, Jute Fiber (JF), a natural and renewable resource abundantly available in India, provides tensile reinforcement and improves soil ductility. This study investigates the combined use of Gellan Gum and Jute Fiber for environmentally friendly stabilization of alluvial soil.

In the field of soil stabilization, Gellan Gum and Jute Fiber present promising eco-friendly alternatives by enhancing soil cohesion, reducing erosion, and improving load-bearing capacity. Soil stabilization methods can be broadly categorized into mechanical, chemical, biological, and physical approaches, each targeting specific improvements in soil performance and behaviour Mechanical approaches modify soil structure through compaction and gradation, while chemical stabilization involves the use of binders like cement, lime or polymers such as Gellan Gum to improve strength and durability. Biological methods, including vegetative cover and microbial processes like Microbially Induced Calcite Precipitation (MICP), naturally enhance soil bonding. Physical and thermal stabilization techniques—such as soil freezing or heating—are applied to modify soil behaviour either temporarily or permanently. The integration of natural fibers like Jute, known for their tensile strength and biodegradability, with biopolymers like Gellan Gum, offers a sustainable pathway to improve geotechnical performance while minimizing environmental impact.

Biopolymers such as xanthan gum, guar gum, carboxymethyl cellulose, chitosan, and beta-glucans have emerged as sustainable alternatives to conventional soil stabilizers. Among these, Gellan Gum is particularly notable for its ability to form strong, stable gels through ionic crosslinking with multivalent cations like calcium, resulting in a three-dimensional matrix that improves soil cohesion, strength, and moisture retention. This makes it highly effective, especially in moisture-sensitive or arid environments. When combined with Jute Fiber, a biodegradable and high-tensile natural reinforcement, the stabilization effect is further enhanced by improving tensile strength, reducing crack formation and increasing ductility. Both materials are renewable, eco-friendly, and non-toxic, aligning with the principles of sustainable construction. Their combined use not only enhances geotechnical properties of soil but also contributes to reducing the environmental footprint of ground improvement practices, offering a modern, green solution for challenging soil conditions.

2. NEED AND SCOPE OF THE STUDY

2.1 NEED OF THE STUDY:

India's rapid economic growth has driven extensive infrastructure development, with its road network exceeding 6.4 million kilometres by December 2023. However, weak subgrade soils in many areas hinder foundation stability. Traditional stabilizers like cement and lime, though effective, contribute heavily to carbon emissions. This highlights the need for eco-friendly alternatives. Biopolymers offer a sustainable solution by improving soil strength while minimizing environmental impact, supporting green and resilient construction.

2.2 SCOPE OF THE STUDY:

This study investigates the use of Gellan Gum, a biodegradable biopolymer, and Jute Fiber, a natural reinforcement material, as sustainable alternatives to conventional soil stabilizers like cement and lime. With their low environmental impact and minimal dosage requirements, both materials show promise in enhancing soil strength, cohesion, and durability. The research focuses on identifying the optimum content and fiber length combinations for various problematic soils through laboratory testing. It also examines the long-term performance and economic feasibility of treated soils. A comparative evaluation with traditional methods is conducted to assess improvements in geotechnical behaviour, environmental sustainability, and cost-effectiveness. The study aims to validate Gellan Gum and Jute Fiber as viable, eco-friendly solutions for modern soil stabilization.

2.3 OBJECTIVES OF THE STUDY

The following objectives were concluded for the present study:

1. To find out Atterberg's limits of the soil and then classifying the soil as per IS code.
2. To assess the baseline engineering properties of untreated soil, including Optimum Moisture Content (OMC), Maximum Dry Density (MDD), Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), and Permeability, for comparison with treated soil.
3. To investigate the effects of varying dosages (1%, 1.5%, and 2% by weight of soil) of Gellan Gum and Jute Fiber—both individually and in combination—on the OMC, MDD, CBR and UCS of the soil, aiming to identify the optimal mix for enhanced geotechnical performance.
4. To compare the geotechnical properties of treated and untreated (virgin) soil and identify the optimum dosage and combination of Gellan Gum and Jute Fiber for effective stabilization of the specific soil type.

3. RESEARCH METHODOLOGY

1. To ascertain the different index qualities of the soil, the Atterberg's limits of the parental soil, the specific gravity of the soil, and wet sieve analysis will be performed first.
2. The heavy compaction test (Modified Proctor Test) will be used to determine the parental soil's Maximum Dry Density (MDD) and Optimal Moisture Content (OMC).
3. The specimens collected from the parental soil will undergo heavy compaction testing at OMC to determine the Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) (both soaked and unsoaked).
4. The soil will be dry-mixed with Gellan Gum (1%, 1.5%, 2%), Jute Fiber (1%, 1.5%, 2%) and combinations (1% GG + 1.5% JF, 1.5% GG + 1.5% JF, 2% GG + 1.5% JF) using fiber lengths of 10 mm, 20 mm and 30 mm. Heavy compaction tests will determine OMC and MDD, followed by

UCS and CBR (soaked and unsoaked) tests at the respective OMCs to evaluate strength enhancement.

5. The optimum dosage of Gellan Gum, Jute Fiber, and their combinations—with fiber lengths of 10 mm, 20 mm, and 30 mm—will be identified by comparing the test results to determine the most effective mix for stabilizing the specific soil type.

4. EXPERIMENTAL DESCRIPTION

1. Soil sample and additives**:** Soil is collected from Nalanda district of Bihar. Gellan Gum was sourced from the IndiaMART online platform, while Jute Fiber was locally procured from the regional market, ensuring ease of availability and cost-effectiveness.
2. Compaction Test: This test aims to determine the moisture content required to achieve maximum dry density, identifying the Optimum Moisture Content (OMC) for effective soil compaction. In this study, a compaction mould with a base plate weighing 2250 grams and a volume of 1000 cm^3 was used. The soil was compacted in five equal layers using a 4.89 kg rammer dropped from a height of 450 mm, applying 25 blows per layer. Following compaction, a soil sample was collected to determine its moisture content. This value was then used to compute the bulk and dry densities of both untreated and treated soil mixtures.
3. California Bearing Ratio (CBR) Test: Originally developed in 1929 by the California Division of Highways, this test evaluates the strength of subgrade soil by comparing the pressure required to penetrate it with a standard plunger (50 mm diameter) at a constant rate of 1.25 mm/min against that required for a standard crushed rock material. The CBR value, expressed as a percentage, is typically determined at penetrations of 2.5 mm and 5 mm. If the 5 mm value consistently exceeds that at 2.5 mm, the higher value is adopted as the representative CBR.
4. Unconfined Compressive Strength (UCS) Test: The UCS test measures the axial load per unit area at which a cylindrical soil sample fails in compression without any lateral confinement. In this study, specimens with a standard diameter of 38 mm and a height of 76 mm were used. For each untreated soil and treated mix, three samples were prepared to ensure consistency and reliability. The specimens were subjected to axial loading at a constant strain rate of 1.25 mm/min until failure or until an axial strain of 20% was reached. The resulting compressive stress–strain curves were analyzed to determine the peak unconfined compressive strength of each sample.

5. RESULT AND DISCUSSION

A . SOIL PROPERTIES:

Sl. No	Test Name	Value
1	Specific Gravity	2.51
2	Liquid Limit (%)	42
3	Plastic Limit (%)	24
4	Max. Dry Density (g/cc)	1.72
5	Optimum Moisture Content (%)	17.8

Table 1. Physical Properties of Soil

B. OPTIMUM MOISTURE AND MAXIMUM DRY DENSITY

Sl. No	OMC	MDD
1	4.9	1.671
2	8.7	1.676
3	13.8	1.688
4	14.6	1.695
5	17.8	1.722
6	19.4	1.687
7	21.7	1.649
8	23.3	1.614

Table 2. OMC and MDD of soil

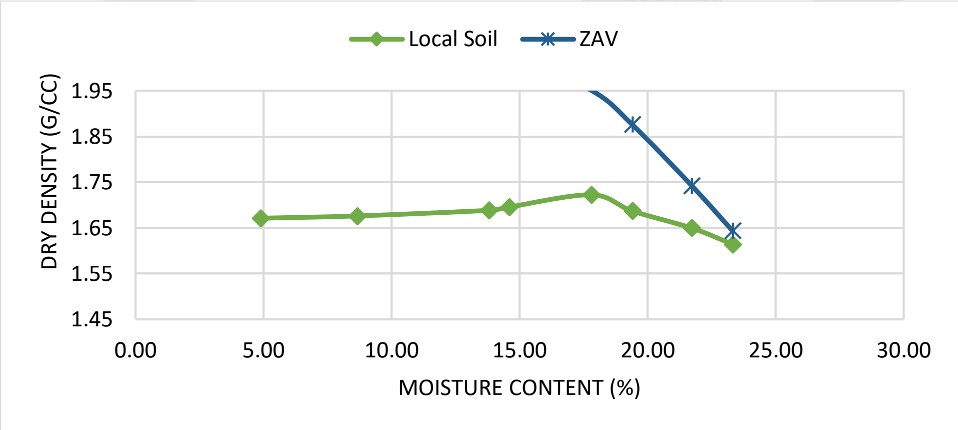

Fig.1 Compaction curve of Parent soil

C. COMPARISON OF THE OMC AND MDD PARENTAL SOIL AND MIXES

Sl. No	Soil Mix	OMC	MDD
1	Parent Soil	17.8	1.72
2	Parent Soil with 1.0% GG	19.5	1.69
3	Parent Soil with 1.5% GG	20.2	1.64
4	Parent Soil with 2.0% GG	22.6	1.61
5	Parent Soil with 1.0% JF	22.56	1.66
6	Parent Soil with 1.5% JF	21.10	1.63
7	Parent Soil with 2.0% JF	22.8	1.59
8	Parent Soil with 1.0% GG+1.5% JF	23.3	1.62
9	Parent Soil with 1.5% GG+1.5% JF	24.52	1.57
10	Parent Soil with 2.0% GG+1.5% JF	24.14	1.58

Table 3. Comparison pf the OMC and MDD Parental Soil And Mixes

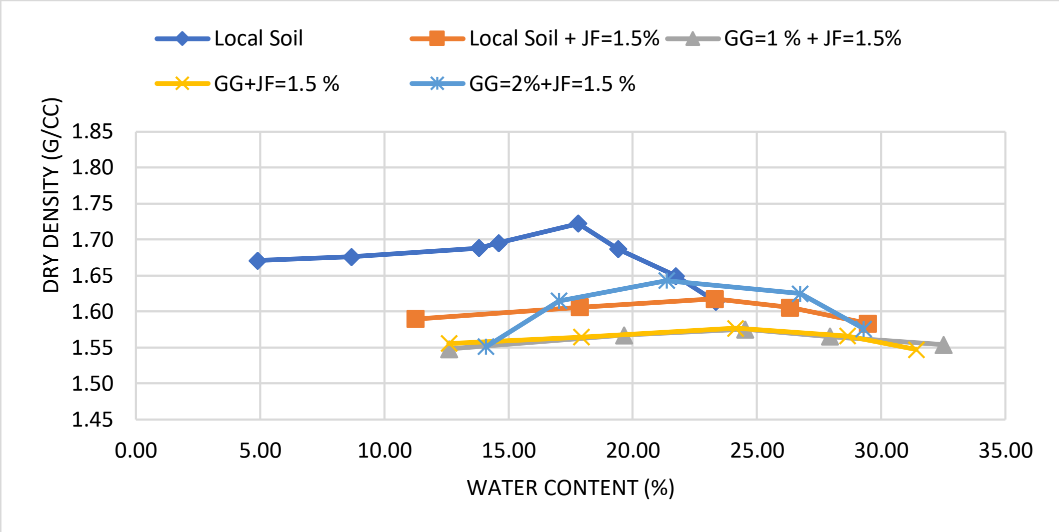

Fig.2 Compaction curve of soil mixed with Gellan Gum and Jute fiber

D. Variation of CBR at different value of Gellan Gum and Jute fiber

Sl. No.	SAC	CBR (soaked)	CBR (Unsoaked)	Load Soaked (Kg)	load unsoaked (Kg)
1	GG (1%)	5.47	9.63	75	132
2	GG (1.5%)	6.71	10.58	92	145
3	GG (2.0%)	6.49	9.48	89	195
4	JF (1%)	5.18	7.98	114	164
5	JF (1.5%)	6.76	9.58	139	197
6	JF (2.0%)	6.27	8.90	129	181
7	GG(1%)+JF(1.5%)	8.51	12.40	175	170
8	GG(1.5%)+JF(1.5%)	10.65	14.96	146	205

Table 4 Variation of CBR at different value of Gellan Gum and Jute fiber

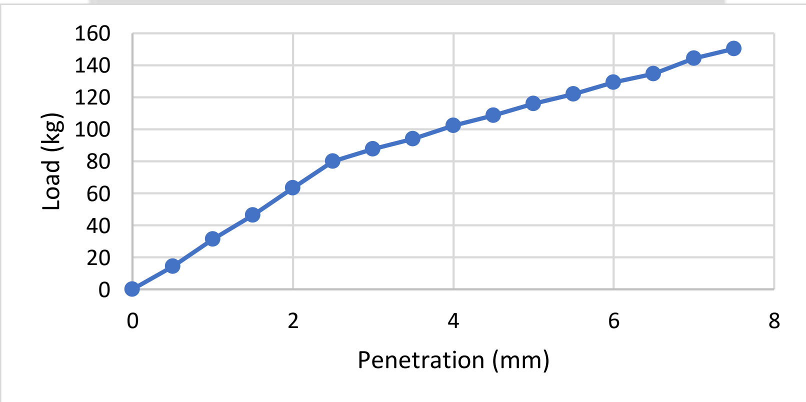

Fig. 3 Load–penetration behaviour of soil used

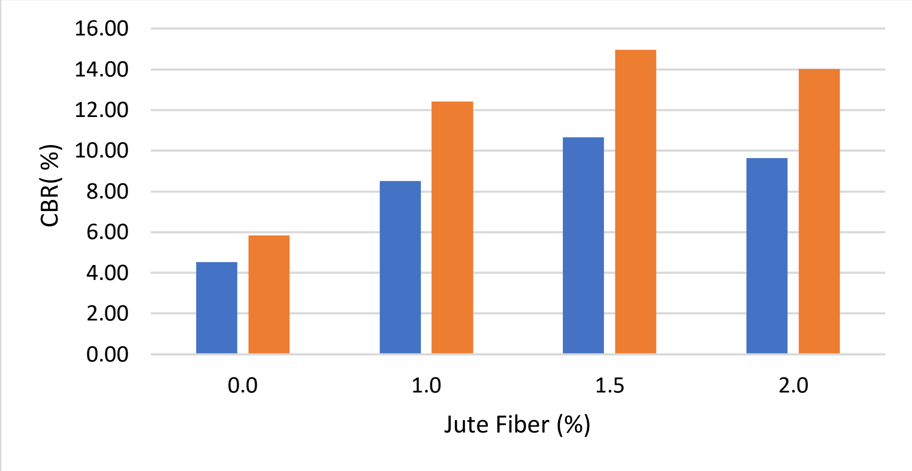

Fig. 4 CBR of soil mixed with different content of GG and Jute fiber

E. Variation of UCS at different value of SAC

SL.NO.	SAC (GG+JF)	UCS (kpa)
1	7 days 1.0% G.G	175.5
2	7 days 1.5% G.G	232.46
3	7 days 2.0% G.G	274.65
4	7 days 1.0% J.F	148.43
5	7 days 1.5% J.F	182.5
6	7 days 2.0% J.F	197.65
7	7 days 1.0%G.G+1.5JF	204.86
8	7 days 1.5%G.G+1.5JF	263.56
9	7 days 2.0%G.G+1.5JF	309.76
10	28 days 1.0% G.G	218.76
11	28 days 1.5% G.G	290.08
12	28 days 2.0% G.G	342.43
13	28 days 1.0% J.F	185.30
14	28 days 1.5% J.F	227.95
15	28 days 2.0% J.F	246.95
16	28 days 1.0%G.G+1.5JF	256.54
17	28 days 1.5%G.G+1.5JF	328.31
18	28 days 2.0%G.G+1.5JF	386.85

Table 5 Variation of UCS at different value of SAC

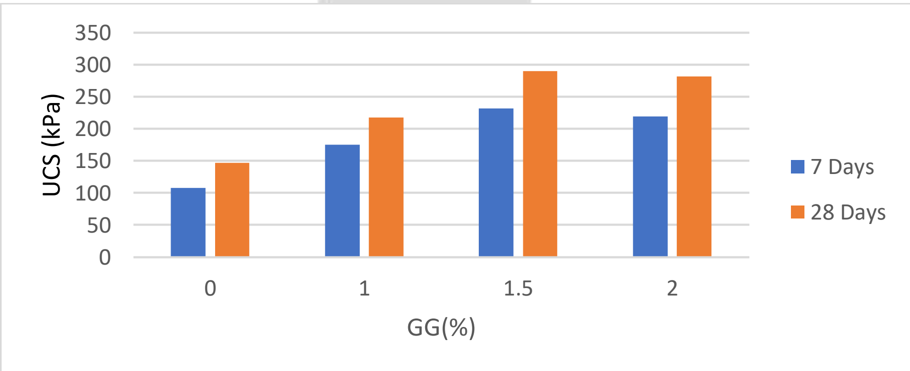

Fig. 5 UCS of soil mixed with different Content of GG and Jute fiber

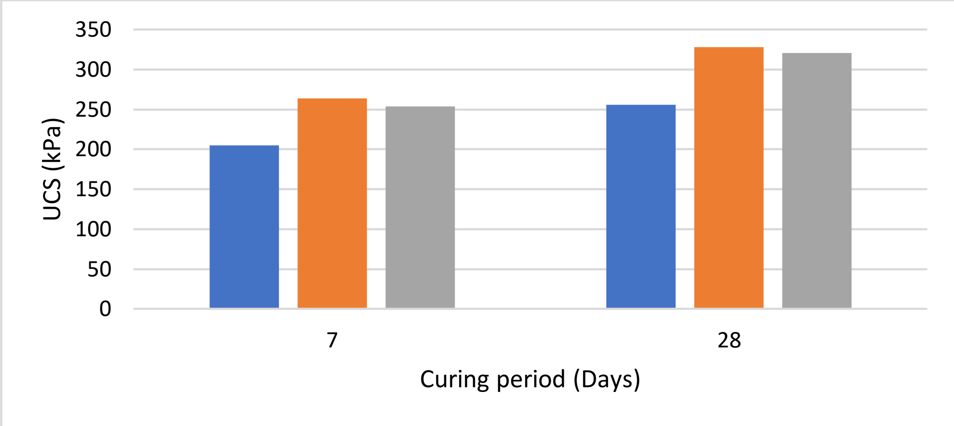

Fig. 6 Impact of curing period on UCS of soil mixed with GG and Jute fiber

6. Conclusion

A) Impact on Liquid Limit on GG: The liquid limit of soil increases significantly with the addition of Gellan Gum (GG). It was around 42% for pure clayey soil, while at 2% GG, it increased to 51%. This increase is attributed to Gellan Gum's hydrophilic nature, which enhances water-holding capacity and reduces soil flowability at lower moisture content.

B) Effect on Plastic Limit and Plasticity Index on GG: The plastic limit also increases with GGC, rising from 24% for untreated soil to 29% at 2% GGC. The Plasticity Index increases as the liquid limit grows more significantly than the plastic limit. This indicates improved workability and deformation capacity of soil over a broader moisture range.

C) Compaction Behaviour on GG: Adding Gellan Gum shifts the compaction curve leftward and upward. The maximum dry density increases from 1.72 g/cc for untreated clay to 1.52 g/cc at 2% GGC, while the optimum moisture content (OMC) increases from 17.8% to 22.69%. This suggests improved compaction efficiency and reduced water absorption with increasing GGC.

D) Improvement in CBR Values on GG: The California Bearing Ratio (CBR) improves steadily with increasing GGC under both soaked and unsoaked conditions. Under wet conditions, the highest CBR value is achieved at 1.5% GG , indicating enhanced load-bearing capacity. Unsoaked soils exhibit even greater CBR values for the exact 1.5% GGC percentages, highlighting the effectiveness of GG in improving soil strength, particularly in dry conditions.

E) Strength Enhancement through UCS on GG: The unconfined compressive strength (UCS) increases substantially with higher GGC. Untreated soil has a UCS of approximately 107 kPa, while at 1.5%GG, the UCS improves by 2.17 times, reaching the highest peak stress among all samples. This improvement is due to GG's binding and cementitious properties.

F) Stress-Strain Behaviour on GG: The stress-strain curves from UCS tests demonstrate that Gellan Gum significantly enhances soil strength and strain capacity. Soils with higher GGC exhibit more significant peak stress and strain before failure, indicating improved deformation resistance and compressive strength.

G) Enhanced Load-Bearing Capacity on GG: GGC-treated soils significantly improve load- carrying capacity under soaked and unsoaked conditions. Soaked soils show a steady increase in load resistance with higher GGC, while unsoaked soils achieve even greater load capacities. Thus, GG-treated soils are suitable for applications requiring high strength and stability in varying moisture conditions.

H) Combined Impact of GG and JF on Compaction Behaviour: The combined use of GG and JF significantly influences the soil's compaction characteristics. Due to their synergistic interaction, the soil mix's OMC increases further. GG's gel-like behaviour and JF's water absorption capacity collectively modify the moisture requirements for compaction.

I) Combined Impact on Strength Performance: Including both GG and JF leads to substantial improvements in the soil's strength properties, as observed in the CBR and UCS tests. The combined effect of GG and JF outperforms their contributions. While GG provides enhanced bonding and cohesion, JF adds tensile reinforcement, making the soil mix more robust and deformation-resistant. This synergistic behaviour highlights the potential of using GG and JF together for efficient soil stabilization.

J) Optimum content: All the strength-based tests have indicated that the optimum content of the GG & JF was 1.5% &1.5%.

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