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# Application of Biopolymers in Geotechnical Engineering Practices: An Eco-Friendly Approach

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**Abstract:** Before construction, it is essential to enhance the engineering properties of soft soil. The most common technique, cement stabilisation (either alone or in combination with other methods), causes a number of environmental issues. Efforts have been made to find alternatives to the commonly used techniques for soil stabilization, various strategies have been investigated. Biopolymers an eco-friendly material is one of the sustainable solutions as an alternative for soil improvement. This study examines the relationship between biopolymers, particularly xanthan gum, and weak soil. The results indicate that biopolymer improved the weak soil's geotechnical properties. The improvement varies with the percentage of biopolymer added to the soil. In this study 0.5%, 1%, 1.5%, 2% & 2.5% of xanthan gum added to week soil. Their impact on the strengthening of weak soil was evaluated. Index properties, unconfined compressive strength and resilient modulus is determined. A very minute amount of biopolymer improves the soil's mechanical properties. Therefore, biopolymer have a very strong potential to replace cement as the conventional soil binder in context of development to replace the conventional method.

**Keywords:** Cement stabilization, Biopolymers, Xanthan gum, Index properties, Unconfinedcompressive strength, Resilient modulus.

## 1. Introduction

To achieve the desired and ideal performance of the week soil, soil stabilization is the targeted improvement of the geotechnical characteristics of the week soil. A geotechnical engineer should establish the most cost-effective and efficient approach of soil treatment. Based on the type of soil, the desired level of improvement and environmental friendliness of the method are among the most important parameters to be considered. The selection of the appropriate treatment method is the most effective part of a geotechnical engineer to stabilize the week soil [1]. Since the beginning of human civilization, people have used many different things and methods to make soils better. Materials like mud and straw come from the earth [2]. Rome and Roman concrete are made from volcanic ash, aggregates, and binders (i.e., gypsum or lime) [3]. Particularly after the Industrial Revolution i.e., 20$^{th}$ century, Portland cement has become the utmost used material for construction and soil treatment [2].

In the building and construction industry, Portland cement is a substance that offers a number of well-known advantages, including affordability, durability and workability. The manufacture and use of cement, however, are linked to some environmental concerns. The most pressing problems of the last few decades have been associated with global warming and climate change. According to reports, one of the main contributors to worldwide $CO_2$ emissions, cement use accounts for approximately 8% of all $CO_2$ emissions [1,4]. In an effort to reduce these effects on the environment, researchers have been making new, better applications that reduce damage in the environment [5]. Sustainable techniques have been used to create environmentally friendly materials, notably microbial biopolymers, for application (i.e., microbes that produce high-molecular polysaccharides). These biopolymers were developed as a replacement to conventional soil remediation techniques [6,7]. Several studies have showed that biopolymer application significantly strengthens soil due to direct ionic interactions with tiny particles or the creation of a continuous matrix phase among coarse particles. Geotechnical Engineering has explored numerous applicability for these biopolymers to address soil issues [2].

In recent years, the majority of research is on the application of biopolymers have included experimental data, characterization evaluations, and, in a few instances, case studies of actual implementation. The most frequently mentioned biopolymers in the literature are guar gum, polyacrylamide, xanthan gum, gellan gum, agar, and polyacrylamide. In this study, the xanthan gum-treated soil's index properties, unconfined compressive strength (UCS), and resilient modulus (RM) are assessed.

## 2. Materials in present study

### 2.1 Biopolymers selection

In this study biopolymer i.e., Xanthan Gum (XG) is procured from PC industries, Jodhpur, India. With a global industrial output of 30,000 tons per year, XG is an EPS produced by the bacterium Xanthomonas campestris [8]. The strong demand for XG in the food industry led to the development of a number of alternative techniques to create it, including the fermentation of bacteria and yeast as well as the use of other low-cost substrates, nutrients, and raw materials [8,9]. By adding a little amount of XG, an aqueous system's viscosity can be increased, creating a pseudo-plastic solution [10]. Therefore, with a substantial improvement in strength, these natural biopolymers bind non-cohesive and dispersive geomaterials. [11]. The characteristics and environmental impacts of Xanthan Gum is listed in Table.1

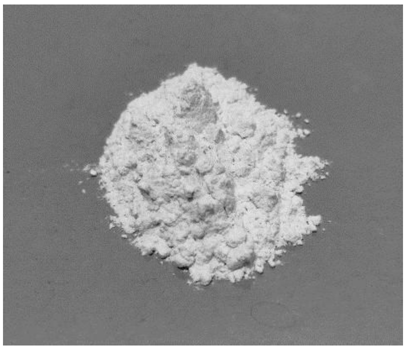

Fig.1 Xanthan Gum Powder

**Table 1.** Characteristics of XG used for soil treatment & their effects on the environment [12]

| | |
|---|---|
| **Source** | Bacterial fermentation of glucose / sucrose by Xanthomonas campestris. |
| **Charge Type** | Anionic |
| **Water Solubility** | Soluble |
| **Potential Impact on Environment** | 0.1 kg CO2 per kg of biopolymer produced, with no anionic land usage |

### 2.2 Collection of soil sample

Soil sample collection is done from Antagarh town, from Kanker district located in the state of Chhattisgarh, India. The Basic Geotechnical and strength properties of the collected soil sample is evaluated as per Indian Standards has been tabulated in Table.2 and Table.3

**Table 2.** Basic Geotechnical Properties of the soil

| Name of the test | | Test property | Test method | TestResult |
|---|---|---|---|---|
| Grain size analysis (%) | Coarse sand fraction | Particle size analysis | IS 2720 (Part – IV) 1985 Reaffirmed 1995 | 22.8% |
| | Medium sand fraction | | | 32.2% |
| | Fine sand fraction | | | 17.5% |
| | Silt + Clay | | | 27.5% |
| Atterberg's limits | | Liquid Limit ($W_L$), % | IS 2720 (Part – V) 1985 Reaffirmed 1995 | 32.0% |

| | | | |
|---|---|---|---|
| | Plastic Limit ($W_P$), % | | 20.0% |
| | Plasticity Index ($I_P$), % | | 12.0% |
| | Shrinkage limit, % | IS 2720 (Part – VI)1972 Reaffirmed1995 | 8.6% |
| Free Swell index | Swell potential, % | IS 2720 (Part – XL) 1977 Reaffirmed 1997 | 31% |
| Specific Gravity (G) | | IS 2720 (Part III/Sec 1 & 2) 1980 (Reaffirmed 1997) | 2.47 |
| Soil Classification as per IS 1498 – 1970 | | | SC |

**Table 3.** Strength properties of soil

| Name of the test | Strength property | Test method | Test Result |
|---|---|---|---|
| Modified Proctor Test | Maximum dry density, kN/m$^3$ | IS 2720 (Part – VIII)1980 (Reaffirmed 1997) | 16.25 |
| | Optimum moisture content, % | | 21 |
| Unconfined Compressive Strength (UCS) Test | Compressive Strength, Mpa | IS: 2720 (Part-X) 1991(Reaffirmed 1995) | 0.60 |
| Resilient Modulus | Modulus of elasticity, Mpa | AASHTO T307 | 115.32 |

## 3. Experimental methodology

In this study 0.5, 1, 1.5, 2 and 2.5 percentages of biopolymer, Xanthan Gum (XG) were used to examine the index and strength properties of the soil bound with biopolymer.

The commercially available dry powdered biopolymer is mixed dry before being introduced. Before the water is added, dry mixing involves combining the biopolymer and soil in the form of a proportion determined by the weight of the soil. The biopolymers are confined during dry mixing. The mentioned procedure is the process adopted for the preparation of soil samples. The demolded soil samples were individually kept for

7 and 28 days of curing, which were wrapped tightly in polyethylene bags to minimize moisture loss before being stored inside the desiccator. With the intention of keeping the relative humidity inside the desiccator at a steady state, a small amount of water was retained at the device's base. The desiccator was covered and stored in a room set at about 21°C [13] [14]

## 4. Results and Discussions

### 4.1 Index properties of soil treated with biopolymer

From Fig.1 the liquid limit of the biopolymer treated soil varies in a range of 35 to 38% and the plastic limit in a range of 23 to 25%. There is an increment in both the liquid and plastic limit values as the percentage of biopolymer increases. However, the type, content, and material characteristics of the biopolymer used were related to the rate of fluctuation. The addition of a biopolymer modifies the liquid limit through a variety of important mechanisms. Inclusion of biopolymers decreases flowability by making the pore solution more viscous. Additionally, the added biopolymer interacts with the soil matrix and free water to create a cross-linked hydrogel network or hydrogel bonding [15]. The creation of hydrogels helps to boost the liquid limit and plastic limit value by increasing the shear resistance of biopolymer modified soil. The liquid limit for virgin soil was determined to be 32%, whereas the plastic limit was 20%.

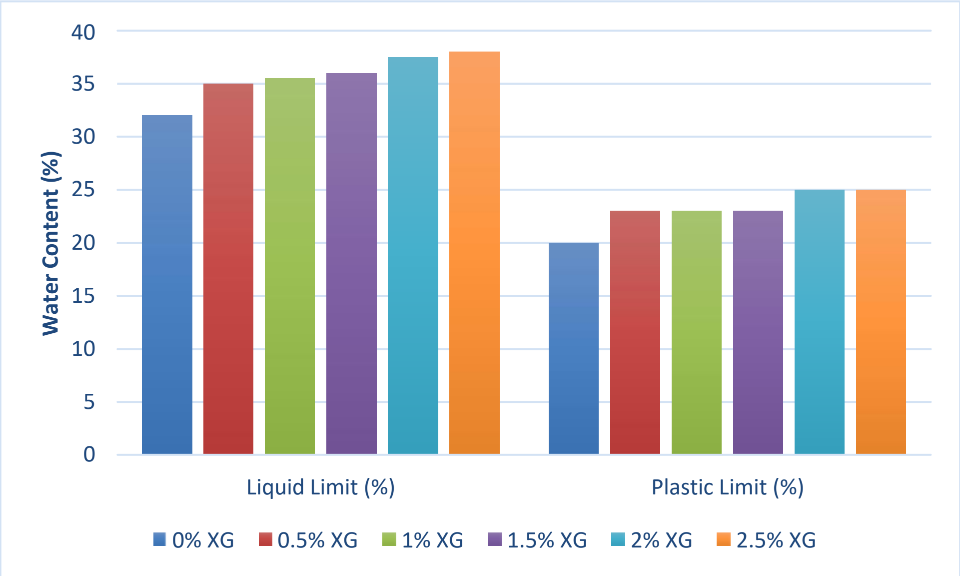


**Fig.1** Liquid and Plastic Limit of soil treated with Biopolymer

### 4.2 Strength properties of Biopolymer treated soil

#### 4.2.1 Maximum dry density and Optimum moisture content of soil treated with biopolymer

The moisture content of the biopolymer treated soil varies in a range of 22 to 26%, an increase is observed, and a decrement of dry density is observed as stated from Fig.2. As the proportion of biopolymer increased, the maximum dry density (MDD) and optimum moisture content (OMC) of the biopolymer-treated soil decreased and increased, respectively. The biopolymer when mixed with soil and water produce a highly viscous solution that resists compaction, lowering MDD and increasing OMC for biomodified soil [14]. The decrease in dry density of biopolymer treated soils ranges from 15.8 to 14.4kN / $m^3$.

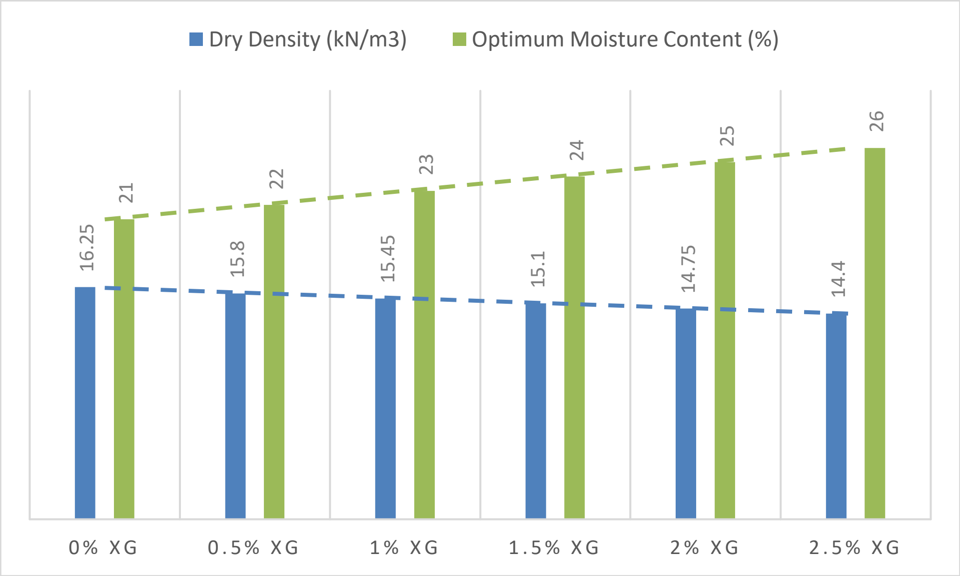


**Fig.2** Maximum dry density (MDD) and Optimum moisture content (OMC) of biopolymer treated soil

#### 4.2.2 Unconfined compressive strength of soil treated with biopolymer

The unconfined compressive strength of soil treated with biopolymer for 7days ranges from 0.4 to 1.7 MPa, the peak strength for 7 days is 1.7Mpa at a 1.5% concentration of Xanthan gum. The unconfined compressive strength for 28 days curing ranges from 1.08 to 4.6Mpa, the peak strength for the entire 28-day period is 4.6Mpa at a 1.5% concentration of Xanthan gum. More biopolymer concentration leads the solution to become more viscous and less workable [15]. It might be a significant factor in the highest strength at 2.5% of concentration being lower than at 1.5-2%.

The material unconfined compressive strength (UCS) is a crucial geotechnical parameter to assess its suitability for building purposes and to understand how the addition of a biopolymer affects the material's shear strength. Fig.3 displays the outcomes of the unconfined compressive strength test performed on soil treated with a biopolymer. This improves the soil strength after the biopolymer and soil are mixed. During curing, the hydrophilic biopolymers absorb the water and hydrogel networks were formed in the soil pores. Biopolymer that covers the soil grains connects the loose particles by building bridges between them, which enhances the strength properties of the weak soil. Lower biopolymer concentration causes hydration process more quickly, and a high saturation rate causes the peak strength to decrease [16]. As the biopolymer concentration rises, the peak stress rises along with the corresponding strain, which indicates a strain-hardening characteristic and ductile failure. It is concluded that treated soil behaves better than untreated soil and can withstand loads to a greater extent.

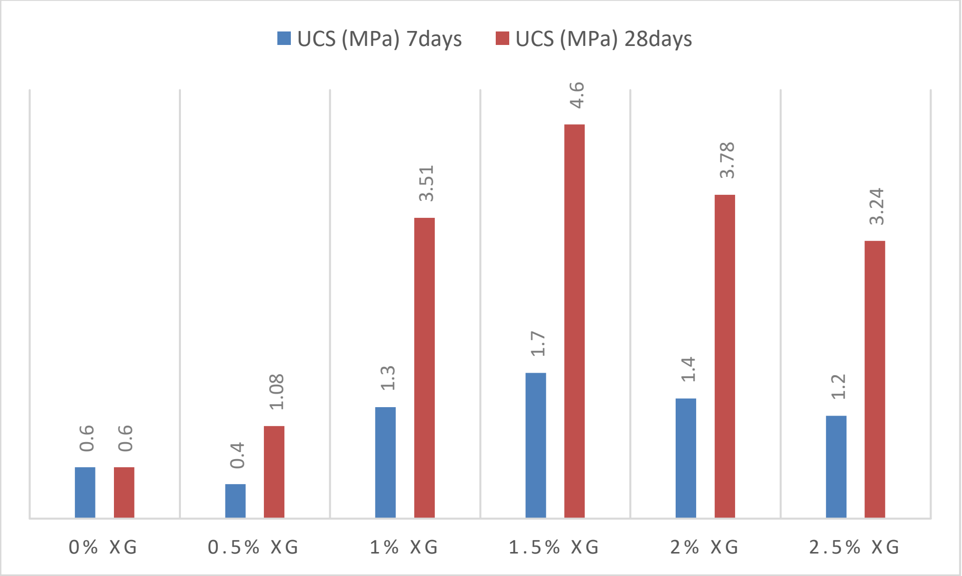


**Fig.3** Unconfined compressive strength (UCS) of biopolymer treated soil for 7 & 28 days

### 4.2.3 Resilient Modules for biopolymer treated soil

Resilient modulus is regarded as the suitable input for the linear elastic theory selected in these guidelines for the study of flexible pavements because it is measured in a repeated load test while only accounting for the elastic or resilient component of the specimen's deformation or strain. The repeated tri-axial test outlined in AASHTO T307-99 can be performed to determine the resilient modulus of soils in the laboratory [17].

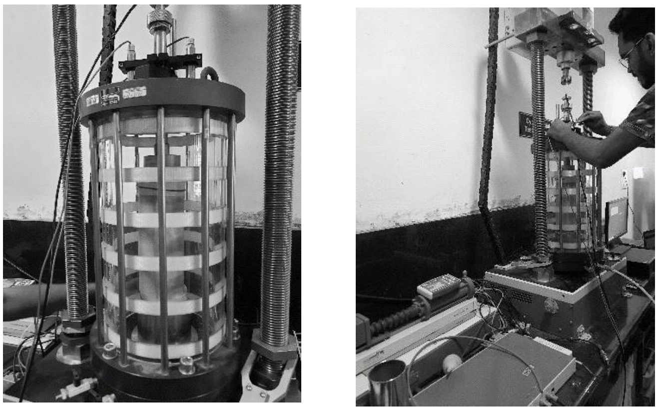

**Fig.4** Resilient modules testing for biopolymer treated soil

Resilient modulus is the most important criterion for evaluating the stabilized pavement layer. The biopolymer-treated soil works better because it forms a gel-like structure that fills the pores and keeps the soil particles together. From Fig.5 we can see that the resilient modulus of soil treated with biopolymer varies from 86.73 to 258.32Mpa for 7 days, with a 1.5% concentration of xanthan gum producing the highest modulus value 258.32Mpa. The resilient modulus of soil treated with biopolymers for 28 days ranges from 183.96 to 687.32Mpa, with 1.5% xanthan gum concentration producing the highest modulus value of 687.32Mpa.

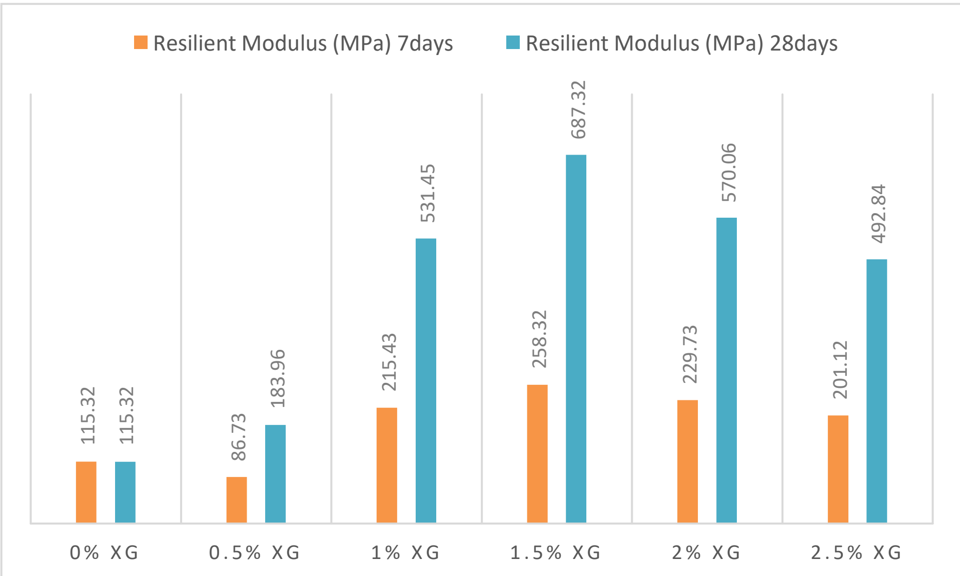


**Fig.5** Resilient modulus of biopolymer treated soil for 7 & 28 days

## 5. Conclusion

The incorporation of biopolymer as a binder is one of the most efficient methods in soil treatment. In these findings, xanthan gum is used to improve weak soil, and difference in the geotechnical properties of the soil is observed.

- The addition of biopolymer has an impact on the physical characteristics of soil, resulting in higher liquid and plastic limit. This may be due to adsorption of polymer and cross linkage with soil particles which plays an very important role in biomodification of week soil.
- Due to the biopolymer concentration and the soil type, both the ideal moisture levels and the maximum dry densities are varying. Moisture content is a crucial parameter for improved soils to achieve the desired compaction conditions.
- Upon curing for 7 and 28 days, the strength parameters are observed to increase by 2.5 times.
- As per the results of unconfined compressive strength, the values of biopolymer treated soil depict that, the ideal biopolymer percentage is observed as 1.5% by weight of the soil.
- The results of resilient modulus values observed from the biopolymer treated soils depict that, the treated soil satisfied the criteria of low and high-volume roads in accordance with IRC 37-2018 codal provision.
- Thus, this study assists that, the biopolymers are eco-friendly material that can replace cement in ground improvement, which decreases the carbon foot print.
- A relatively low percentage is needed to obtain the compressive strength that is equivalent to more conventional materials like cement and lime, which is one benefit of using a biopolymer as a binder.
- Finally, this study observed that, biopolymer additive gives required strength characteristics at minimal percentages as compared with conventional additives like cement or lime etc. however this study may further be extended to other soils at different moisture levels.

## References:

1. Nicholson, Peter G. *Soil improvement and ground modification methods*. Butterworth-Heinemann, 2014.
2. Ivanov, V.; Chu, J. Applications of microorganisms to geotechnical engineering for bioclogging and biocementation of soil in situ. Rev. Environ. Sci. Biotechnol. 2008, 7, 139–153.
3. P. Brune, R. Perucchio, A. R. Ingraffea, and M. D. Jackson, “The toughness ofimperial roman concrete,” in Proceedings of the 7th International Conference on Fracture Mechanics of Concrete and Concrete Structures, Jeju Island, Korea, May 2010

4. Murphy, E.M.; Ginn, T.R. Modeling microbial processes in porous media. Hydrogeol. J. 2000, 8, 142–158.
5. Basu, D.; Misra, A. Sustainability in Geotechnical Engineering. In Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris, France, 2–6 September 2013.
6. Narjary, B.; Aggarwal, P.; Singh, A.; Chakraborty, D.; Singh, R. Water availability in different soils in relation to hydrogel application. Geoderma 2012, 187–188, 94–101
7. Murthy, V.N.S. Geotechnical Engineering: Principles and Pratices ofSoil Mechanics and Foudation Engineering; Marcel Dekker, Inc.: New York, NY, USA, 2016.
8. Palaniraj, A., Jayaraman, V., 2011. Production, recovery and applications of xanthan gum by Xanthomonascampestris. J. Food Eng. 106 (1), 1–12.
9. Silva, M.F., Fornari, R.C.G., Mazutti, M.A., Oliveira, D.D., Padilha, F.F., Cichoski, A.J., Cansian, R.L., Luccio, M.D., Treichel, H., 2009. Production and characterization of xantham gum by Xanthomonascampestris using cheese whey as sole carbon source. J. Food Eng. 90 (1), 119–123.
10. Chen, R., Zhang, L., Budhu, M., 2013. Biopolymer stabilization of mine tailings. J. Geotech. Geoenviron. 139 (10) https://doi.org/10.1061/(ASCE) GT.1943–5606.0000902.
11. Dehghan, H., Tabarsa, A., Latifi, N., Bagheri, Y., 2018. Use of xanthan and guar gums in soil strengthening. Clean Technol. Environ. Policy 21, 155–165. https://doi.org/ 10.1007/s10098-018-1625-0.
12. Determining the resilient modulus of soil and aggregate materials AASHTO Designation: T 307-99 (2007)
13. Kaniraj, Shenbaga R., and V. Gayathri. "Factors influencing the strength of cement fly ash base courses." *Journal of transportation engineering* 129.5 (2003): 538-548.
14. Turkane, Sagar D., and Sandeep K. Chouksey. "Design of flexible pavement thickness using stabilized high plastic soil by means of fly ash-based geopolymer." *International Journal of Pavement Engineering* (2022): 1-15.
15. Fatehi, Hadi, et al. "Biopolymers as green binders for soil improvement in geotechnical applications: A review." *Geosciences* 11.7 (2021): 291.
16. Guidelines for the design of flexible pavements IRC: 37-2018
17. Mahamaya, Mahasakti, et al. "Interaction of biopolymer with dispersive geomaterial and its characterization: An eco-friendly approach for erosion control." *Journal of Cleaner Production* 312 (2021): 127778.
18. Sujatha, E.R., Saisree, S., 2019. Geotechnical behaviour of guar gum-treated soil. Soils Found. 59 (6), 2155–2166.
19. IS: 2720 (Part 4) - 1985 – Methods of test for soils – Grain size analysis, Bureau of Indian Standards, New Delhi (1985).
20. IS: 2720 (Part 5) - 1985 – Methods of test for soils – Determination of Liquid and Plastic Limit, Bureau of Indian Standards, New Delhi (1985).
21. IS: 2720 (Part XL) - 1977 – Methods of test for soils – Determination of Free Swell Index of Soils, Bureau of Indian Standards, New Delhi (1978).

22. IS: 2720 (Part – III/ Sec 1 & 2) - 1980 – Methods of test for soils – Determination of Specific Gravity of Soils, Bureau of Indian Standards, New Delhi (1980).
23. IS: 1498 – 1970 – Classification and Identification of Soils for General Engineering Purposes, Bureau of Indian Standards, New Delhi (1972).
24. IS 2720 (Part 8) - 1980 – Methods of test for soils – Determination of Water Content – Dry Density Relation Using Heavy Compaction, Bureau of Indian Standards, New Delhi (1984).
25. IS: 2720 (Part 10) - 1991 – Methods of test for soils – Determination of Unconfined Compressive Strength, Bureau of Indian Standards, New Delhi (1991).
26. AASHTO T 307-99 (2007) – Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials, American Association of State and Highway Transportation, 2007.