TOWARDS SUSTAINABLE SOIL STABILIZATION: A REVIEW OF INNOVATIVE TECHNIQUES

Abstract

The innovative soil stabilization techniques, such as Portland cement, fly ash, and recycled tire rubber, are examined in this review research. Soil stabilization is an essential part of civil engineering, and this technique offers a lot of promise for enhancing soil quality for a variety of uses. While Portland cement is well known for improving load-bearing capacity and compressive strength, fly ash serves as a sustainable cementitious material that minimizes environmental impact. Additionally, adding scrap rubber from old tires makes soil more resilient and less brittle, especially under conditions of dynamic stress. The study addresses how various materials could cooperate to improve technical properties and promote environmentally friendly behavior. However, a number of challenges must be resolved, including figuring out the best dosage ratios and doing long-term performance assessments. Overall, this integrated approach offers a practical and long-term solution for effective soil stabilization, assisting in the development of stronger, more robust infrastructure.

Keywords: Soil Stabilization, Impact, Resilient, Fly Ash, Scrap rubber, Portland Cement, Stress.

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I. INTRODUCTION

Soil stabilization is important in civil engineering and construction because it comprises a wide variety of procedures targeted at improving the engineering qualities of soil. The major goals are to increase the soil's load-bearing capacity, minimize settlement, and enhance overall stability. Soil stability is critical because it directly affects the longevity and safety of critical engineering projects such as bridges, buildings, embankments, and dams. Weak or unstable soils offer considerable concerns such as settlement, subsidence, and potentially catastrophic collapses, putting lives in peril and generating significant financial losses. Engineers and builders face several challenges because of soil variability and unpredictability. Soil qualities, composition, and behavior are all influenced by geology, climate, and environmental factors. To solve these challenges and assure infrastructure projects' long-term efficacy and sustainability, efficient soil stabilizing solutions must be devised. The goal of soil stabilization is to transform ordinary soil into a robust and stable material that can endure external pressures including traffic loads, dynamic forces, and environmental impacts while safely holding high loads. Traditional techniques of soil stability include chemical and mechanical stabilization, as well as more new and ecologically friendly alternatives such as biological stabilization.

Chemical stabilization is the process of altering soil characteristics by injecting chemical substances such as lime, cement, fly ash, or other stabilizers into the soil to create a more stable matrix. Mechanical stabilization procedures, on the other hand, employ physical methods to compact or reinforce the soil, so improving its density and strength. Biological stabilization, on the other hand, is based on plant roots and vegetation binding and fortifying the soil, providing a natural and sustainable method of reducing and stabilizing soil erosion.

This study examination delves into the intricacies of soil stabilization, looking into the concepts, efficacy, benefits, and drawbacks of various approaches. Case studies of successful soil stabilization projects will be examined, with an emphasis on the practical applications and outcomes of these approaches. In consideration of the growing global concerns with building and environmental sustainability, understanding and creating soil stabilization technologies is becoming more and more crucial. Engineers and researchers may assist to build safer, more durable, and environmentally responsible infrastructure by understanding the complexities of soil behavior and the many stabilizing methods available.

The purpose of this research article is to provide light not only on the relevance of soil stabilization in current practices, but also on potential future developments in civil engineering. By integrating current knowledge and research, it strives to inspire new ideas and encourage the adoption of the most effective soil stabilization technologies, so promoting the expansion and sustainability of the built environment.

1. **Positive Outcomes of Soil Stabilization:** Numerous advantages of soil stabilization have a good effect on several facets of civil engineering, building, and environmental management. The following are some of the main advantages of soil stabilization:

   - The strength and load-bearing capacity of the soil are improved by soil stabilization, enabling it to support larger loads with the least amount of settlement and distortion.

This benefit is especially important when building roads, highways, bridges, and other infrastructure under heavy traffic loads or dynamic pressures.

- Reduced Settlement: Because unstable soils frequently cause settlement problems, uneven and sometimes dangerous ground conditions result. Maintaining a level and stable surface is essential for ensuring the appropriate performance of buildings and pavements, and soil stabilization is an efficient way to accomplish this aim.
- Effective soil erosion control may be achieved by applying certain stabilizing techniques, such as biological stabilization utilizing plants. Because plant roots bind soil particles together to act as a natural erosion barrier, they may be employed to safeguard riverbanks, embankments, and coastal areas.
- Soil stabilization improves the soil's general stability and toughness by giving it resilience against a variety of factors such cyclic loading, weathering, and erosive impacts. Buildings may last longer and keep their structural integrity by maintaining stable soils, which eventually results in lower maintenance and repair expenditures over time.
- Construction is completed more quickly because soil stabilization increases the strength of the soil base. With faster project completion and less downtime during construction, efficiency has grown.

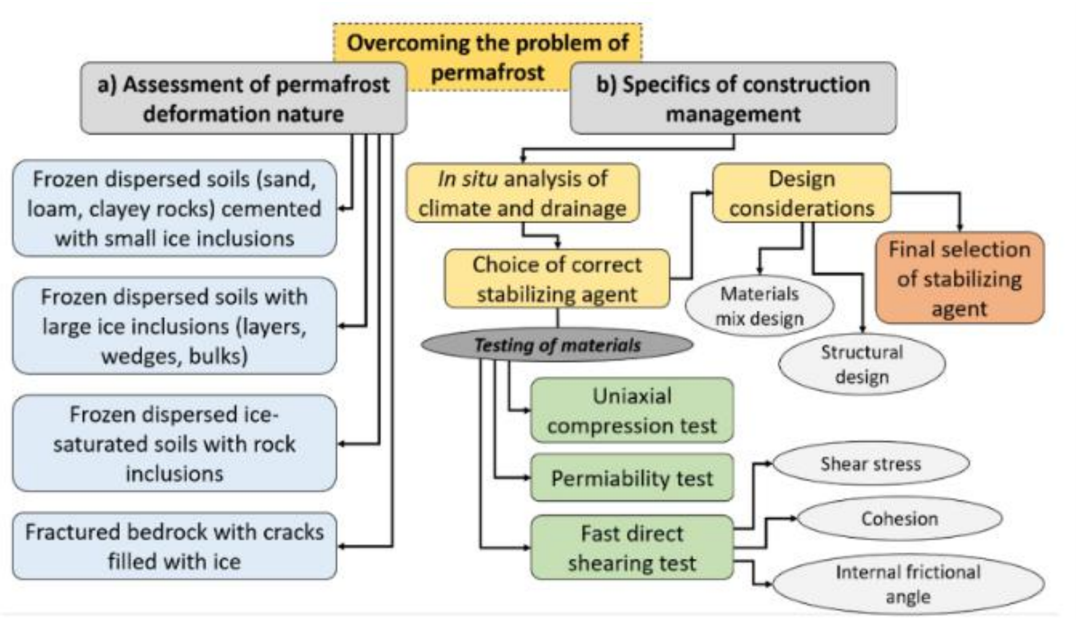

Figure 1: Permafrost Deformation Nature (a) and its Construction Management Specifics at Stabilization (b)

2. **Possible Problems due to Stabilization:** While soil stabilization has many advantages, it can also present certain obstacles and possible issues. These elements must be considered to guarantee successful implementation and to limit any negative consequences. Some potential issues with soil stabilization include:

- The stabilization procedure by itself could not totally reduce the dangers when dealing with contaminated soil that contains dangerous substances or contaminants. To successfully handle these pollutants, a complete site investigation and remediation may be necessary prior to stabilization.

- The permeability of the soil may be reduced by several soil stabilization techniques, particularly chemical stabilization. While this trait can be helpful in certain circumstances, it may also provide drainage issues in other circumstances.
- Prior to soil stabilization in the vicinity of existing structures or utilities, careful consideration is essential to avoid any negative impacts on their stability or proper functioning.
- When used to stabilize soil, cement, lime, and other chemical stabilizers can have a negative impact on the environment. When these materials are handled improperly, they may produce greenhouse gases during production or contaminate water.

II. MATERIALS USED FOR SOIL STABILIZATION

1. **Soil Stabilization with Portland Cement:** Portland cement is frequently used in civil engineering and building projects for soil stabilization.Portland cement may be used to strengthen and extend the life of soil by converting it into a cemented mass.It entails mixing Portland cement into the soil to improve its strength, durability, and load-bearing capability. According to the experimental findings, incorporating lime and cement in peat soil at mixing percentages ranging from 10% to 20% enhances its strength characteristics. Moreover, the peak shear stress is observed to rise, and the displacement also increases with the increment in normal stress.

2. **Process of Soil Stabilization using Portland Cement:**

- **Site Assessment:** It is the first step for soil stabilization. In this step we determine the type of the soil and its engineering behavior and the specific requirement of the project.
- **Soil Testing:** In this step we obtain the sample from the site and perform various laboratory and field for the determination of the Index and Engineering property of the soil.
- **Design mix:** Based on the result obtained from the various test performed on the soil we determine the appropriate mix of Portland cement to achieve the desired property of the soil. Design mix will specify the other additive (if required) to obtain desired property of the soil.
- **Spreading Portland Cement:** After the design mix, we spread the appropriate amount of Portland cement uniformly over the surface of the soil.
- **Mixing:** For the thoroughly mixing of the soil and the cement we use some methods such as (i). Mechanical mixing (ii). Pulverization.For deep soil stabilization the cement and the soil can be mixed by pulverizing the soil and adding cement simultaneously.
- **Water Addition:** For the activation of the cement’s binding property, we use water in the mixture. Quantity of water need to carefully be controlled to achieve Optimum Moisture Content (OMC).
- **Compaction:** When the mixing is completed then we perform compaction on the soil using different compacting equipment (Vibratory Rollers, Sheepsfoot Rollers, Tamping Rollers, Pneumatic Rollers etc.) to achieve Desired property of the soil. Compaction improves the stability and strength of the soil.

- **Curing:** The purpose of the curing in soil stabilization to increase the formation of cementitious bonds, facilitate the proper hydration of cement particles and improving the strength of the soil. Curing also reduces the shrinkage and cracking in the soil.

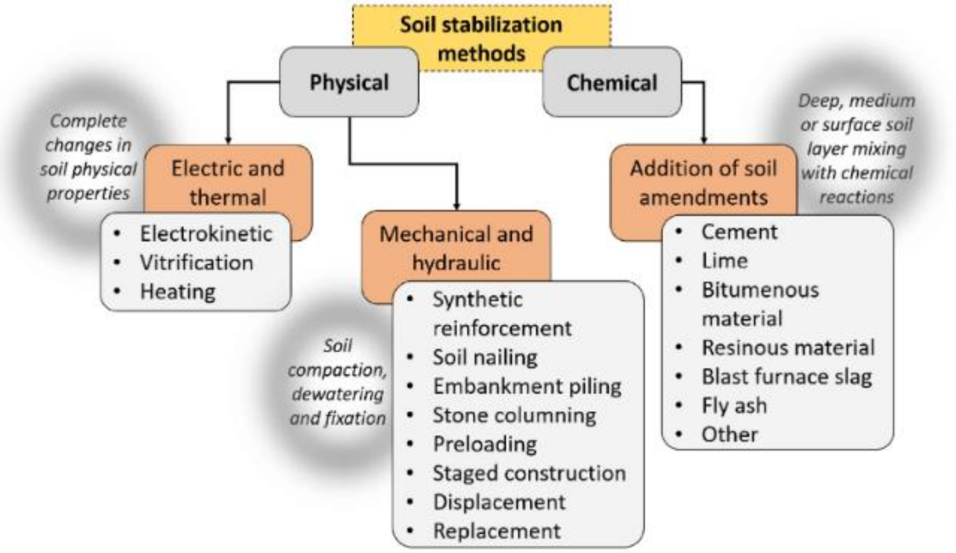

Figure 2: General Soil Stabilization Methods and their Impact on Soil

3. **Soil Stabilization with Fly Ash:** The powdery residue of burning coal in power plants, known as fly ash, is helpful for stabilizing soil. Pozzolanic properties make Class F, generated by burning anthracite or bituminous coal, and Class C, produced by burning sub-bituminous or lignite coal, both ideal for this usage. Class C, which contains a lot of calcium oxide, has better cementitious properties and needs less of it than Class F to be strong enough. The use of fly ash for soil stabilization aids in encouraging environmentally friendly waste recycling methods, sustainable construction, and environmental preservation by strengthening soil, reducing permeability, and strengthening soil.

4. **Benefits of Incorporating Fly Ash for Soil Stabilization:**

- The dry density and the moisture content of organic soil rise gradually when fly ash (classes C and F) is added.
- Unconfined compressive strength (UCS), pH values, liquid limit, plastic limit gradually increasing with the addition of the fly ash.
- The plasticity index decreases with the addition of the appropriate amount of fly ash in different organic soil.
- By the addition of the fly ash the Swelling and shrinkage properties of the various type of soil get reduced.
- The maximum dry unit weight and ideal moisture content both rise with the addition of fly ash.

5. **Soil Stabilization with Scrap Tire:** As a useful advancement for soil stabilization methods, rubber from old tires has shown a lot of potential. An innovative and eco-friendly solution to the issues concerning old tire disposal is to use them in construction projects. To enhance the engineering properties and general performance of soil, scrap tire rubber may be put into it in several ways. This article investigates the various applications and advantages of utilizing rubber from old tires to stabilize soil, emphasizing its potential to aid in the development of environmentally friendly infrastructure while solving waste management challenges.

6. **Benefits of Incorporating Scrap Tire for Soil Stabilization:**

   - Issues with settling and failure of the bearing capacity of clayey soil exist. Rubber tire scraps from industrial trash may, up to a point, strengthen clayey soil.
   - Rubber utilized in old tires has better compressive strength, compressibility, and swelling index properties.
   - The use of 1 to 2 percent scrap tire rubber raises the maximum dry density (MDD) while reducing the ideal moisture level in clayey soil, reduces the void ratio, and minimizes compression and swelling.
   - Through an addition of 2% scrap rubber tire, the compressive strength of the clayey soil increased thrice above the original soil.
   - The incorporation of crumb rubber improves shear strength as when compared with dune sand alone. As the fraction of crumb rubber in the whole compound increases from 10% to 20%, the angle of internal friction increases from 31.3° to 32.75°.
   - Rubber from discarded tires can increase CBR by up to 3%. CBR is reduced to less than 3% by increasing the rubber content in lateritic soil with a low plasticity index.

   Therefore, the shear strength of dune sand is at its highest when there is a 20% crumb rubber content. The 10% crumb rubber powder increases the California bearing ratio of the black cotton soil. Nearly 10% of rubber powder is advised for black cotton soil.

III. RESULT AND DISCUSSION

1. **Outcome of Soil Stabilization Using Portland Cement:** The introduction of cement to the pore water of the soil leads to rapid hydration of the cement, resulting in the formation of hydrated calcium silicates (C2SHx, C4AHx) and hydrated lime Ca(OH)2. Therefore, the soil's liquid limit is reduced [7]. According to the [9], incorporating lime and cement in peat soil at mixing percentages ranging from 10% to 20% enhances its strength characteristics. Moreover, the peak shear stress is observed to rise, and the displacement also increases with the increment in normal stress. Additionally, it has been shown that the displacement increases the normal stress and the peak shear stress.

   In a study conducted by Oyediran and Kalejaiye (2011)[11], the impact of increasing cement content by weight on the strength and compaction parameters of lateritic soil was investigated. Three soil samples were collected from a pit and stabilized using cement at various percentages: 2%, 4%, 8%, 10%, and 20% by weight.

   The results showed that as the cement content increased, the Maximum Dry Density (M.D.D), California Bearing Ratio (C.B.R), and Unconfined Compressive Strength (UCS) of the soil improved. Conversely, the Optimum Moisture Content

(O.M.C) decreased with increasing cement content. However, it was observed that adding more than 10% by weight of cement led to a decrease in M.D.D, UCS, and C.B.R, while causing an increase in O.M.C.

2. **Outcomes of Soil Stabilization Using Fly Ash:** According to Bayshakhi Deb Nath , Md. Keramat Ali Molla, and Grytan Sarkar (Study on Strength Behavior of Organic Soil Stabilized with Fly Ash) [15] The pH values increase as fly ash concentration increases as a percentage, the dry density and moisture content increase with time, the liquid and plastic limits increase, and the plasticity index reduces the UCS. The strength of organic soil can be boosted by adding fly ash in the proper quantity. The amount of fly ash is influenced by the kind of soil classification.

   According to Fusheng Zha , Songyu Liu Æ Yanjun Du Æ Kerui Cui (Behavior of expansive soils stabilized with fly ash) [16] The swelling and shrinking are lessened by treating the swelling black cotton soil with lime fly ash and fly ash. They assert that the maximum dry unit weight and ideal water content both fall when levels of fly ash and lime fly ash grow.

3. **Outcomes of Soil Stabilization Using Scrap Tire:** According to A T Nazaruddin, M S Shakri, M A Ladin, M A Hafez, N F Abd Rahman, M Mohammad (Strength and consolidation index parameters of stabilise clay soil using scrap rubber tyre) [4] Clayey soil has issues with settling and losing its bearing ability. Rubber scrap tires (from industrial waste, etc.) may be used as a fix to solve the stabilizing problems only partially. These researchers claim that adopting this type of boosting technique improves compressibility, compressive strength, and swelling index properties. The maximum dry density is decreased while the optimal moisture content is increased, and the void ratio is decreased. Additionally, they reduce edema by 1% to 2%. The clayey soil's compressive strength quadrupled in comparison to the original soil when 2% recycled rubber tire was added. Nearly 2% is the recommended amount of old rubber tires as a stabilizer.

   According to Ms. Deepti V. Zutting, Prof. (Dr.) P. L. Naktode(Soil Stabilization by using Scrap Tire Rubber)[17] Mixing recycled tire waste with poorly graded dune sand improves its engineering properties. Crumb rubber exhibits more shear strength in combination with sand than dune does on its alone. Crumb rubber is used to increase the internal friction angle. The internal friction angle steadily decreases from 30% to 100% crumb rubber content. Because of this, the shear strength of dune sand increases at 20% crumb rubber concentration but decreases at higher tire percentages. The addition of crumb rubber also lessens the mixture's weight, which lowers the lateral earth pressure.

   According to Ms. Rajvinder Kaur, Er. Dalvir Singh (tyre rubber powder as a soil stabilizer)[18] Black cotton soil gains more shear strength when crumb rubber powder is added, around 10% more specifically. Crumb rubber powder increases the CBR value of the soil by 10%, making 10% the appropriate amount for soil stabilization in black cotton. When the powder content is increased over the ideal level, the soil's strength gradually decreases.

   According to Ibrahim, M. T , Osinubi, K. J ,Umar, S. Y (Stabilization of Lateritic Soil with Scrap Tyre Crumb Rubber) [19] Scrap tire crumb rubber raises the

California bearing ratio by 3% when applied in lateritic soil with a low plasticity index, but after that point, CBR decreases because of an increase in rubber composition. Unsoaked CBR saw increases of 70.50%, 69.70%, and 78.40%, whereas wet CBR experienced increases of 71.00%, 67.90%, and 76.60%.

IV. CONCLUSION

Introduction of cement to soil pore water leads to rapid hydration and formation of hydrated calcium silicates and hydrated lime, reducing the soil's liquid limit.

- Incorporating lime and cement in peat soil at 10% to 20% mixing percentages enhances strength characteristics, with increased peak shear stress and displacement under higher normal stress.
- Increasing cement content in lateritic soil improves Maximum Dry Density (M.D.D), California Bearing Ratio (C.B.R), and Unconfined Compressive Strength (UCS), but adding more than 10% by weight of cement can lead to a decrease in M.D.D, UCS, and C.B.R while increasing Optimum Moisture Content (O.M.C).
- According to research on soil stabilization with fly ash, the parameters of the soil are improved, including pH values, dry density, moisture content, plasticity index, and Unconfined Compressive Strength (UCS). Fly ash can strengthen organic soil and lessen expansive soils' propensity to expand when added properly.
- The research highlights fly ash's potential as a workable and eco-friendly stabilizing agent, providing promising answers for enhancing soil stability and performance in construction applications.
- Scrap rubber tire stabilization improves clayey soil's compressibility, compressive strength, and swelling index properties.
- Adding crumb rubber to dune sand enhances shear strength and lowers lateral earth pressure.
- Crumb rubber powder increases black cotton soil's shear strength and CBR value, but excessive content can lead to reduced strength.
- In lateritic soil, scrap tire crumb rubber increases CBR up to a certain point, beyond which it starts to decrease.

Further study may look at the resilience and long-term effectiveness of soil stabilization using old rubber tires in a variety of climatic conditions. Insightful information for use in real-world civil engineering projects might also be gained by analyzing the cost-effectiveness and potential environmental implications of various stabilizing procedures.

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