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A Review on Soil Stabilization Principles and Techniques

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Abstract: Constructing roads, dams, and foundations in areas with poor or low-quality soils poses a significant challenge for engineers. Often, the natural state of subgrade soils is unsatisfactory, but they can be enhanced using geotechnical methods. Mechanical stabilization involves blending different soil types to enhance the properties of the original soil, while other techniques involve adding additives like cement, lime, grouts, or chemicals to modify the soil and improve its engineering characteristics. This process renders it suitable for various applications, including highway subgrades and other engineering structures. Each soil stabilization method has its advantages and limitations, making them suitable for specific engineering purposes while less suitable for others.

Keywords: Soil Stabilization, Mechanical Stabilization, Grouting, Additives, Engineering Properties.

1. Introduction:

Soil stabilization involves a range of techniques aimed at enhancing the strength, stability, and other physical properties of a given soil mass. It becomes necessary when the existing soil is unsuitable for the intended construction purposes. By stabilizing the soil, engineers aim to improve its engineering performance while minimizing risks such as washing or collapse, by increasing shear strength, enhancing load-bearing capacity, and managing shrink-swell properties. Various processes such as compaction, pre-consolidation, and drainage are involved in soil stabilization.

The composition of the soil is a primary consideration for stabilization, as pure sands and pure clays exhibit different behaviors in the field. Sandy soils with particles larger than 75 microns contribute strength and hardness but lack cohesion, making them prone to erosion on unstable slopes. Conversely, clay soils with particles smaller than 75 microns offer binding force but lack shear strength, particularly when saturated. The presence of water exacerbates issues with clay soils but provides apparent cohesion for sandy soils. Mixing these two soil types in appropriate proportions often results in a soil with superior engineering properties.

Soil stabilization can be achieved without adding any admixture or by incorporating additives like lime, lime-pozzolana, or cement. Additionally, geotextiles or reinforcements may be used to tailor the soil for specific construction requirements. While the primary aim of soil stabilization is to prepare natural soil for highway and airfield construction, it also addresses permeability and compressibility issues in earth structures, regulates soil and aggregate grading for bases and sub-bases, and addresses unsuitable sub-soils in various construction projects.

This process can effectively treat a wide range of sub-grade materials, from expansive clays to granular substances.

2. Methods of Soil Stabilization

A. Mechanical Stabilization

Mechanical stabilization involves blending two or more types of natural soil to alter its gradation and enhance its properties. This method aims to combine the engineering characteristics of the soil constituents by reducing the void ratio, filling the gaps between larger granular particles with finer soil particles through blending soils of different granular sizes, and compacting thoroughly. This approach, also known as granular stabilization, ensures that the void ratio decreases, thereby improving soil strength parameters like cohesion (C) and angle of internal friction (Ø) (Garg, 2007).

In mechanical stabilization, soils can generally be categorized into two groups (Arora, 2011):

a. Aggregates: These soils have an average particle size exceeding 75 microns (75M) and typically consist of sturdy, well-graded, somewhat angular particles of sand and gravel. They form a skeletal framework that provides internal friction and incompressibility to the soil.

b. Binders: These soils have an average grain size less than 75 microns and primarily offer cohesion, plasticity, and impermeability to the soil. They are predominantly composed of clays and silts.

B. Lime Stabilization

When lime is mixed with soil, it initiates a chemical reaction involving the exchange of cations because each soil particle carries an electrical charge, either positive or negative (Lambe and Whitman, 1979). These soil particles attract ions weakly held on their surface, making them easily replaceable. Similarly, water is attracted to soil particles, but since it attaches to exchangeable ions, they can be replaced through a process known as "absorption" (Craig, 1978).

In clay soils, for example, when lime reacts with them, cation exchange occurs in the absorbed water layer, reducing the soil's plasticity and making it more friable than the original clay. This transformation renders the soil more suitable for construction, such as for subgrades, base courses for pavements (Dana, 1994), embankment slopes, and canal linings.

The reaction of lime with wet soil alters the nature of the absorbed layer through Base Exchange (Arora, 2011), with calcium ions replacing sodium or hydrogen ions. This process depresses the double layer due to increased cation presence but may also expand due to the high pH value of lime. Additionally, when lime chemically reacts with available silica and alumina in soils, it forms a natural substance composed of calcium alumino silicate complexes, acting as cement. This reaction depends on the effective concentration of reactants and host temperatures.

Lime stabilization decreases the soil's liquid limit but increases the plastic limit, thereby reducing the plasticity index. Consequently, it has been extensively used in stabilizing highly unstable, plastic, and swelling clayey soils (Garg, 2007). Lime treatment renders the soil more friable and workable while generally enhancing its strength. This improvement results partly from decreased soil plastic properties and partly from the formation of cementing material. The unconfined compressive strength of the soil can increase up to 60 times its original strength with lime addition, achieving maximum density under higher optimum moisture content compared to untreated soil. Lime treatment also increases the size of clay particles through coagulation to silt-sized particles, altering soil structure and stabilizing it by reducing swelling tendencies.

Fig. 1: An Image of Soil Stabilization Using Fly Ash

C. Cement Stabilization

Cement stabilization involves mixing pulverized Portland cement with soil, along with water, and compacting the mixture to achieve a robust material with increased strength, durability, and minimal moisture fluctuations (Behzad and Huat, 2008). Cement stabilization has proven effective for all soil types except clay (Garg, 2007). The presence of organic matter or water in soil can reduce the effectiveness of cement stabilization; for instance, soils containing sulphates are unsuitable for improvement with cement.

According to Mitchell (1976), soil cement can be classified into three categories:

a. Normal soil cement: This comprises about 5 to 14% cement by volume, mixed with soil to create durable construction material. The water content should be sufficient for cement hydration and workability. Normal soil cement is weather-resistant and strong, suitable for stabilizing low-plasticity soils like sandy soils.

b. Plastic soil cement: Similar to normal soil cement, this mix contains about 5 to 14% cement by volume but with a higher water content, yielding a wet consistency akin to plastic mortar during placement. It can be used on steep or irregular slopes, for waterproofing canal linings and reservoirs, and for protecting slopes against erosion.

c. Cement-modified soil: This type contains less than 5% cement by volume, semi-hardened and somewhat inferior to the other two types. Despite the small cement quantity, it interacts with silt and clay fractions, reducing their water affinity and swelling characteristics.

The proportion of cement added to soil typically ranges from 5% for sandy soils to 15% for well-graded soils, determined experimentally through compressive strength and durability tests. This proportion should be adjusted higher to compensate for less efficient mixing in the field compared to laboratory conditions. Proper compaction of soil cement is crucial for achieving sufficient strength and durability, maintaining optimum moisture content. Similarly, experimental determination of the required cement proportion must make assumptions about field conditions. Soil cement finds applications as economical materials for road sub-bases or bases, for pitching river and canal banks (Garg, 2005), and for lining irrigation canals.

Fig. 2: Soil Cement Stabilization

D. Stabilization by Grouting

The soil stabilization technique known as grouting involves injecting specialized fluid-like materials, called grouts, into the ground either in suspension or solution, under high pressure, to enhance the soil's properties. Grouting typically employs stabilizers with high viscosity, making it effective for soils with high permeability, but less suitable for clay soils due to their low permeability. This method is particularly suitable for stabilizing confined zones, such as strata beneath dams, and for stabilizing soils that should not be disturbed. Grouting serves to decrease void spaces and enhance the soil's load-bearing capacity.

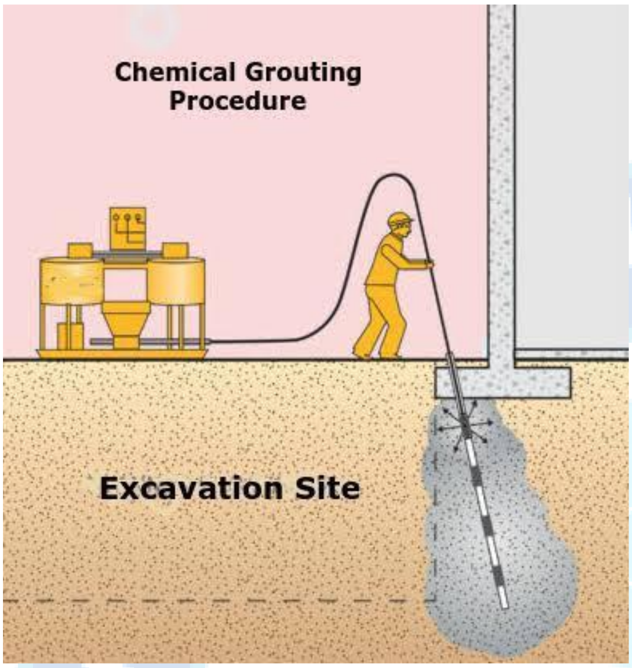

Fig. 3: An Image Showing Chemical Grouting Procedure

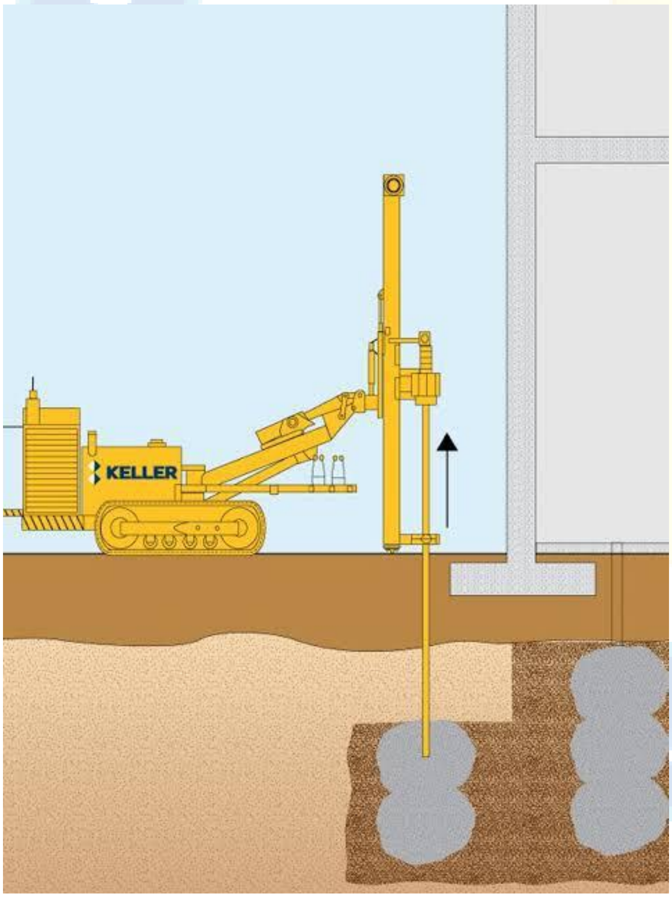

Fig. 4: Image Showing Compaction Grouting

E. Bituminous Stabilization

Bitumens are hydrocarbon-based substances that are insoluble in water but soluble in carbon disulfide. They include materials like asphaltic bitumen, tar, and emulsions, which can be utilized to stabilize soil, particularly for subgrades or road bases, especially effective for granular sandy soils. Tars are obtained through the destructive distillation of organic materials like coal, while asphalts are primarily derived from natural or refined petroleum bitumens. These bituminous additives act as binders and waterproofing agents when applied to soil layers.

Asphalts are often too thick to use directly, so they are thinned with solvents like gasoline or used in emulsions, although this requires a longer drying time. When sprayed onto moderately cohesive road bases, these treatments provide satisfactory service during dry periods, although they may become slippery after rains (Garg, 2007). Cut-back bitumens can also be mixed and pulverized with soils, similar to cement, to create stabilized soils.

Inorganic soils that can be mixed with asphalt are suitable for bituminous stabilization, although dry conditions are essential. In cohesionless soils, asphalt acts as a bonding or cementing agent, binding soil particles together. In cohesive soils, asphalt protects the soil by filling its voids and waterproofing it, helping maintain low moisture content and increasing bearing capacity. The amount of bitumen required typically varies between 4 to 7% by weight, determined through trial and error.

3. Conclusion

One of the primary challenges in the field of engineering involves addressing inadequate soil conditions during construction and exploring methods to enhance suitable soils through stabilization. Various stabilization techniques come with distinct conditions, advantages, and drawbacks, all of which should be carefully evaluated before selecting a method, taking into account its environmental impact. The economic advantages gained from the stabilization process play a crucial role in determining its feasibility.

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