A COMPARATIVE REVIEW OF SOIL MODIFICATION METHODS

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ABSTRACT
One of the major focuses of geotechnical engineering, foundation engineering and soil mechanics is to make the soil upon which every civil engineering project is founded more ideal and one that meets the requirements of every civil construction. This technique is known as soil stabilization or modification. The present review paper tries to bring to limelight that soil stabilization or soil modification methods and in essence compares the advantage of one over another. This will assist researchers and geotechnical engineers in making and choosing from many stabilization methods based on materials available. From the foregoing, it has been established from previous geophysical studies over the years that mechanical stabilization technique of soil is the best soil stabilization method in Nigeria today because of its availability and affordability. Consequently, the present work advises constructors on the benefits of choosing mechanical stabilization method over the others.

Keywords: soil modification, comparative review, geotechnical engineering, foundation engineering, mechanical stabilization.

INTRODUCTION
Soil stabilization is a very useful technique for road, airfield construction and other major civil engineering works. To utilize the full advantage of the technique, quality control must be adequate. Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. Soils may be stabilized to increase strength and durability or to prevent erosion and dust generation. Regardless of the purpose for stabilization, the desired result is the creation of a soil material or soil system that will remain in place under the design use conditions for the design life of the project. Engineers are responsible for selecting or specifying the correct stabilizing method, technique, and quantity of material required. This study is aimed at helping to make the adequate decisions. Many of the procedures outlined are not precise, but they will “get you in the ball park.” Soils vary throughout the world, and the engineering properties of soils are equally variable.

RELATED LITERATURE
The use of soil stabilization products for the stabilization of fine-grained soils is quite widespread across the United States. The traditional methods of stabilization include the use of cement, lime and coal fly ash, however as technology and the understanding of the soil stabilization mechanisms improve; additional stabilization products have been developed. These products, typically called nontraditional stabilizers, are compiled into five groups after Scholen (1992): electrolytes, enzymes, mineral pitches, clay fillers and acrylic polymers.

In 1996 the construction of Yttre Ringvägen, a ring road around Malmö Sweden, was started. The soil in the area consists of clay till and silty till. This type of soil is very sensitive to variation in water content Gulati, (1978). At an early stage it was discovered that the bearing capacity of the embankments was too low to meet the requirement of the road, which is the general technical construction specification for roads from the Swedish National Road Administrations (SNRA) NLA (2004). To fulfill the requirement of the road, either soil stabilization or soil replacement can be used.

The United States Army Corp of Engineers (USACE) has performed multiple studies on the stabilization of soils using nontraditional stabilizers.

According to Jean-Pierre (1997), the goal of many of these stabilizer studies was to find a soil-stabilizer mixture that could cure within 1 to 7 days, weigh approximately 50% less than traditional stabilization mixtures (i.e., Portland cement) and provide strength improvements (a UCS value of 50 psi greater than the unstabilized soil) to marginal soil for use in airstrips. The general conclusions drawn from the USACE studies was that polymers provided the most consistent engineering property improvements for a variety of soil types, especially sands, of the nontraditional stabilizer groups. However, not all polymers were successful at improving UCS strength over the control, stressing that the stabilizers should be tested in the laboratory before being used in the field Arora (2003).

Newman and Tingle (2004) performed a study on the use of emulsion polymers for soil stabilization of airfields following the earlier USACE studies after determining that polymers showed the most potential to stabilize the most soils. It was noted that polymer emulsions are also very useful as they do not require a solvent carrier, are easily cleaned up using water and detergent and often do not pose an environmental risk when used in bulk Abood *et al*. (2007).

The soil tested for this study was a silty-sand (SM) and 6 polymer emulsions (called P1-6 respectively) and 3 concentrations of Portland cement were tested as stabilizers. They found that all of the polymers used increased the UCS over the unmodified soil after 28 days of cure time for both the wet and dry testing. The P1 polymer modified soil produced significantly higher toughness values after 28 days of cure compared to the other polymer modified soils. The P1, P2 and P4 modified soils had significantly higher toughness values than the 9% cement modified soil. All of the additives improved retained wet strength and toughness, and the polymer additives had slightly higher wet retained toughness than the cement stabilized soil after 28 days of cure. Interestingly enough, the polymer's basic chemical makeup did not produce any consistency in results (i.e., both P1 and P5 were both acrylic vinyl acetate copolymers, but P1 significantly outperformed P5).

METHODS OF STABILIZATION

Basic considerations

Deciding to stabilize existing soil material in the theater of operations requires an assessment of the mission, enemy, terrain, troops (and equipment), and time available (METT-T).

Mission: What type of facility is to be constructed - road, airfield, or building foundation? How long will the facility be used (design life)?

Enemy: Is the enemy interdicting lines of communications? If so, how will it impact on your ability to haul stabilizing admixtures delivered to your construction site?

Terrain: Assess the effect of terrain on the project during the construction phase and over the design life of the facility. Is soil erosion likely? If so, what impact will it have? Is there a slope that is likely to become unstable?

Equipment: Do you have or can you get equipment needed to perform the stabilization operation?

Time available: Does the tactical situation permit the time required to stabilize the soil and allow the stabilized soil to cure (if necessary)?

There are numerous methods by which soils can be stabilized; however, all methods fall into two broad categories. They are:

- Mechanical stabilization
- Chemical admixture stabilization
- Some stabilization techniques use a combination of these two methods

COMPARISON

Mechanical stabilization relies on physical processes to stabilize the soil, either altering the physical composition of the soil (soil blending) or placing a barrier in or on the soil to obtain the desired effect (such as establishing a sod cover to prevent dust generation).

Chemical stabilization relies on the use of an admixture to alter the chemical properties of the soil to achieve the desired effect (such as using lime to reduce a soil's plasticity).

Mechanical stabilization through soil blending is the most economical and expedient method of altering the existing material. When soil blending is not feasible or does not produce a satisfactory soil material, geotextiles or chemical admixture stabilization should be considered. If chemical admixture stabilization is being considered, determine what chemical admixtures are available for use and any special equipment or training required to successfully incorporating the admixture.

MECHANICAL STABILILIZATION

Mechanical stabilization produces by compaction an interlocking of soil-aggregate particles. The grading of the soil-aggregate mixture must be such that a dense mass is produced when it is compacted. Mechanical stabilization can be accomplished by uniformly mixing the material and then compacting the mixture US Army, (1994). As an alternative, additional fines or aggregates maybe blended before compaction to form a uniform, well graded, dense soil-aggregate mixture after compaction. The choice of methods should be based on the gradation of the material. In some instances, geotextiles can be used to improve a soil's engineering characteristics. The three essentials for obtaining a properly stabilized soil mixture are:

- Proper gradation
- A satisfactory binder soil
- Proper control of the mixture content

To obtain uniform bearing capacity, uniform mixture and blending of all materials is essential. The mixture will normally be compacted at or near OMC to obtain satisfactory densities. The best aggregates are those that are made up of hard, durable, angular particles. The gradation of this portion of the mixture is important, as the most suitable aggregates generally are well-graded from coarse to fine. Well-graded mixtures are preferred because of their greater stability when compacted and because they can be compacted more easily Smith and Smith, (1998). Satisfactory materials for this use include:

- Crushed stone
- Crushed and uncrushed gravel
- Sand
- Crushed slag

Many other locally available materials have been successfully used, including disintegrated granite, talus rock, mine tailings, caliche, coral, limerick, tuff, shell, slinkers, cinders, and iron ore.

NOTE: If conditions are encountered in which the gradation obtained by blending local materials is either finer or coarser than the specified gradation, the size requirements of the finer fractions should be satisfied and the gradation of the coarser sizes should be neglected.

Mechanical soil stabilization may be used in preparing soils to function as - Sub grades, Bases, Surfaces.

Objective

The objectives here are to

- Increase the drainability of the soil
- Increase stability
- Reduce volume changes

Control the undesirable effects associated with clays.

The objective of mechanical stabilization is to blend available soils so that, when properly compacted, they give the desired stability.

CHEMICAL ADMIXTURE STABILIZATION

Chemical admixtures are often used to stabilize soils when mechanical methods of stabilization are inadequate and replacing an undesirable soil with a desirable soil is not possible or is too costly. Over 90 percent of all chemical admixture stabilization projects use:

- Cement
- Lime
- Fly ash
- Bituminous materials

When selecting a stabilizer additive, the factors that must be considered are the:

- Type of soil to be stabilized
- Purpose for which the stabilized layer will be used
- Type of soil quality improvement desired
- Required strength and durability of the stabilized layer
- Cost and environmental conditions

CEMENT

Cement can be used as an effective stabilizer for a wide range of materials.

Soil-cement mixtures should be scheduled for construction so that sufficient durability will be gained to resist any freeze-thaw cycles expected.

Portland cement can be used either to modify and improve the quality of the soil or to transform the soil into a cemented mass, which significantly increases its strength and durability. The amount of cement additive depends on whether the soil is to be modified or stabilized. The only limitation to the amount of cement to be used to stabilize or modify a soil pertains to the treatment of the base courses to be used in flexible pavement systems.

Modification

The amount of cement required to improve the quality of the soil through modification is determined by the trial-and-error approach. To reduce the PI of the soil, successive samples of soil-cement mixtures must be prepared at different treatment levels and the PI of each mixture determined.

The minimum cement content that yields the desired PI is selected.

LIME

Experience has shown that lime reacts with medium-, moderately fine-, and fine-grained soils to produce decreased plasticity, increased workability and strength, and reduced swell. If the soil temperature is less than 60 degrees Fahrenheit and is not expected to increase for one month, chemical reactions will not occur rapidly. Thus, the strength gain of the lime-soil mixture will be minimal. If these environmental conditions are expected the lime may be expected to act as a soil modifier.

Lime-soil mixtures should be scheduled for construction so that sufficient durability is gained to resist any freeze-thaw cycles expected. If heavy vehicles are allowed on the lime stabilized soil before a 10- to 14-day curing period, pavement damage can be expected. Lime gains strength slowly and requires about 14 days in hot weather and 28 days in cool weather to gain significant strength. Un surfaced lime-stabilized soils abrade rapidly under traffic, so bituminous surface treatment is recommended to prevent surface deterioration. Lime can be used either to modify some of the physical properties and thereby improve the quality of a soil or to transform the soil into a stabilized mass, which increases its strength and durability. The amount of lime additive depends on whether the soil is to remodify or stabilized.

The lime to be used may be either hydrated or quicklime, although most stabilization is done using hydrated lime. The reason is that quicklime is highly caustic and dangerous to use.

When lime is added to a soil, a combination of reactions begins to take place immediately. These reactions are nearly complete within one hour, although substantial strength gain is not reflected for some time. The reactions result in a change in both the chemical composition and the physical properties. Most lime has a pH of about 12.4 when placed in a water solution. Therefore, the pH is a good indicator of the desirable lime content of a soil-lime mixture.

FLY ASH

Fly ash is a pozzolanic material that consists mainly of silicon and aluminum compounds that, when mixed with lime and water, forms a hardened cementitious mass capable of obtaining high compression strengths. Fly ash is a by-product of coal-fired, electric power-generation facilities. The liming quality of fly ash is highly dependent on the type of coal used in power generation. Fly ash is categorized into two broad classes by its calcium oxide (CaO) content.
They are:

Class C
Class F

Class C

This class of fly ash has a high CaO content (12 percent or more) and originates from sub-bituminous and lignite (soft) coal. Fly ash from lignite has the highest CaO content, often exceeding 30 percent. This type can be used as a standalone stabilizing agent. The strength characteristics of Class C fly ash having a CaO less than 25 percent can be improved by adding lime.

Class F

This class of fly ash has a low CaO content (less than 10 percent) and originates from anthracite and bituminous coal. Class F fly ash has an insufficient CaO content for the pozzolanic reaction to occur. It is not effective as a stabilizing agent by itself; however, when mixed with either lime or lime and cement, the fly ash mixture becomes an effective desired lime content.

BITUMINOUS MATERIALS

Types of bituminous-stabilized soils are:

- Soil bitumen: A cohesive soil system made water-resistant by admixture.
- Sand bitumen: A system in which sand is cemented together by bituminous material.
- Oiled earth: An earth-road system made resistant to water absorption and abrasion by means of a sprayed application of slow- or medium-curing liquid asphalt.
- Bitumen-waterproofed, mechanically stabilized soil. A system in which two or more soil materials are blended to produce a good gradation of particles from coarse to fine. Comparatively small amounts of bitumen are needed, and the soil is compacted.
- Bitumen-lime blend: A system in which small percentages of lime are blended with fine-grained soils to facilitate the penetration and mixing of bitumen into the soil.

Types of bitumen

Bituminous stabilization is generally accomplished using:

- Asphalt cement
- Cutback asphalt
- Asphalt emulsions

The type of bitumen to be used depends - on the type of soil to be stabilized, the method of construction, and the weather conditions. In frost areas, the use of tar as a binder should be avoided because of its high-temperature susceptibility.

Asphalts are affected to a lesser extent by temperature changes, but a grade of asphalt suitable to the prevailing climate should be selected. Generally the most satisfactory results are obtained when the most viscous liquid asphalt that can be readily mixed into the soil is used. For higher quality mixes in which a central plant is used, viscosity-grade asphalt cements should be used. Much bituminous stabilization is performed in place with the bitumen being applied directly on the soil or soil-aggregate system.

The mixing and compaction operations are conducted immediately thereafter. For this type of construction, liquid asphalts (cutbacks and emulsions) are used.

Emulsions are preferred over cutbacks because of energy constraints and pollution control effects. The specific type and grade of bitumen depends on the characteristics of the aggregate, the type of construction equipment, and the climatic conditions.

CONSTRUCTION PROCEDURES

Mechanical soil stabilization

This section provides a list of construction procedures, using mechanical stabilization methods, which will be useful to the engineer in the field of operations.

Preparation

Shape the area to crown and grade. Scarify, pulverize, and adjust the moisture content of the soil, if necessary.
Reshape the area to crown and grade.

Addition of imported soil materials

Use one of the following methods;

Distribute evenly by means of an improved stone spreader.

Use spreader boxes behind dump trucks, Tailgate each measured truck, loading to cover a certain length, Dump in equally spaced piles, then form into windrows with a motor grader before spreading.

Mixing

Add water, if required, to obtain a moisture content of about 2 percent above optimum and mix with a rotary mixer, pulvimixer, blade, scarifier, or disk.

Continue mixing until the soil and aggregate particles are in a uniform, well-graded mass. Blade to crown and grade, if needed.

Compaction

Compact to specifications determined by the results of a CE 55 Proctor test performed on the blended soil material.

Select the appropriate type(s) of compaction equipment, based on the gradation characteristics of the blended soil.

Lime stabilization

Lime stabilization involves the following steps:

Preparation

Shape the surface to crown and grade, Scarify to the specified depth, partially pulverize the soil.

Spreading

Select one of the following methods;
Use about 1/2 of the total lime required.

Spot the paper bags of lime on the runway, empty the bags, and level the lime by raking or dragging.

Apply bulk lime from self-unloading trucks (bulk trucks) or dump trucks with spreader.

Apply the lime by slurry (1 ton of lime to 500 gallons of water). The slurry can be mixed in a central plant or in a tank truck and distributed by standard water or asphalt tank trucks with or without pressure.

Preliminary mixing, watering, and curing

Mix the lime and soil (pulverize soil to less than a 2-inch particle size exclusive of any gravel or stone). Add water.

CAUTION

The amount of water need to be increase by approximately 2 percent for lime stabilization purposes.

Mix the lime, water, and soil using rotary mixers (or blades).

Shape the lime-treated layer to the approximate section.

Compact lightly to minimize evaporation loss, lime carbonation, or excessive wetting from heavy rains.

Cure lime-soil mixture for zero to 48 hours to permit the lime and water to break down any clay clods. For extremely plastic clays, the curing period may be extended to 7 days.

Final mixing and pulverization

Add the remaining lime by the appropriate method.

Continue the mixing and pulverization until all of the clods are broken down to pass a l-inch screen and at least 60 percent of the material will pass a Number 4 sieve, Add water, if necessary, during the mixing and pulverization process.

Compaction

Begin compaction immediately after the final mixing.

Use pneumatic-tired or sheep-foot rollers.

Final curing

Let cure for 3 to 7 days, Keep the surface moist by periodically applying an asphaltic membrane or water.

Cement stabilization

Cement stabilization involves the following steps:

Preparation

Shape the surface to crown and grade, scarify, pulverize, and pre-wet the soil, if necessary.

Reshape the surface to crown and grade.

Spreading

Use one of the following methods;

Spot the bags of cement on the runway, empty the bags, and level the cement by raking or dragging, Apply bulk cement from self unloading trucks (bulk trucks) or dump trucks with spreaders.

Mixing: Add water and mix in place with a rotary mixer.

Perform by processing in 6- to 8-foot-wide passes (the width of the mixer) or by mixing in a windrow with either a rotary mixer or motor grader.

Compaction

Begin compaction immediately the final mixing (no more than 1 should pass between mixing compaction), otherwise cement hydrate before compaction completed. Use pneumatic-tired and sheep foot rollers. Finish the surface with steel-wheeled rollers.

Curing

Use one of the following methods;

Prevent excessive moisture loss by applying a bituminous material at a rate of approximately 0.15 to 0.30 gallon per square yard.

Cover the cement with about 2 inches of soil or thoroughly wetted straw.

CONCLUSIONS

This study shows that the strength of soil can be considerably improved by stabilization. The strength attainable depends on the composition of the added stabilizer and on the choice of stabilization.

From the study, it can be said that soil can be stabilized to satisfy the following needs:

- Limited financial resources to provide a complete network road system to build in conventional method.
- Effective utilization of locally available soils and other suitable stabilizing agents.
- Encouraging the use of Industrial Wastages in building low cost construction of roads.

Finally, mechanical stabilization is observed to be the best technique for soil stabilization in the world today, because of its availability and affordability.

RECOMMENDATION

The present work recommends that researchers and geotechnical engineers see a great point of reference to make use of the more economical method of soil stabilization suggested here and require that further research should be carried out in the laboratory to establish a more reliable procedure based on the prevailing geophysical conditions.

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