

A Review on Soil Stabilization, its Types and Components

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ABSTRACT: In The Broadest Sense the Soil Stabilization is the alteration of any inherent property of a soil to improve its engineering performance. Improvement of stability or bearing power, density, shear parameter, reduce compressibility, permeability, swelling and shrinkage property by the use of controlled compaction, proportioning and or the addition of suitable admixtures or stabilizers. In this article we will go through the types and components of soil stabilization and will also through some light on how soil stabilization is must before any engineering project.

Keywords: soil, stabilization, types, components, engineering, roads, constructions etc.

INTRODUCTION

Stabilization is the process of blending and mixing materials with a soil to improve the soil's strength and durability. The process may include blending soils to achieve a desired gradation or mixing commercially available additives that may alter the gradation, change the strength and durability, or act as a binder to cement the soil. Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two. Usually, the technology provides an alternative provision structural solution to a practical problem. The simplest stabilization processes are compaction and drainage (if water drains out of wet soil it becomes stronger). The other process is by improving gradation of particle size and further improvement can be achieved by adding binders to the weak soils. Through soil stabilization, unbound materials can be stabilized with cementitious materials (cement, lime, fly ash, bitumen or combination of these). The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil (Keller brochure 32-01E). The method can be achieved in two ways, namely; (1) in situ stabilization and (2) ex-situ stabilization. Note that, stabilization not necessary a magic wand by which every soil properties can be improved for better (Ingles and Metcalf, 1972). The decision to technological usage depends on which soil properties have to be modified. The chief properties of soil which are of interest to engineers are volume stability, strength, compressibility, permeability and durability (Ingles and Metcalf, 1972; Sherwood, 1993; Euro Soil Stab, 2002). For a successful stabilization, a laboratory tests followed by field tests may be required in order to determine the engineering and environmental properties.

USES OF STABILIZATION

Pavement design is based on the premise that specified levels of quality will be achieved for each soil layer in the pavement system. Each layer must:

- a) Resist shearing within the layer.
- b) Avoid excessive elastic deflections that would result in fatigue cracking within the layer or in overlying layers.
- c) Prevent excessive permanent deformation through densification.

As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area is generally increased enough to permit a reduction in the required thickness of the soil and surface layers. Stabilization is commonly used for better soil gradation, reduction of the PI or swelling potential, and increased durability and strength. Soils stabilized by additives often provide an all-weather working platform for construction operations.

Types of Stabilization

- a) Mechanical Stabilization
- b) Geosynthetic Stabilization
- c) Chemical Stabilization

Mechanical Stabilization

This is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts, or undercutting the existing soils and replacing them with granular material. A common remedial procedure for wet and soft sub grade is to cover it with granular material or to partially remove and replace the wet sub grade with a granular material to a pre-determined depth below the grade lines. The compacted granular layer distributes the wheel loads over a wider area and serves as a working platform.

To provide a firm-working platform with granular material, the following conditions shall be met. The thickness of the granular material must be sufficient to develop acceptable pressure distribution over the wet soils. The backfill material must be able to withstand the wheel load without rutting. The compaction of the backfill material should be in accordance with the Standard Specifications. Based on the experience, usually 12 to 24 in. (300 to 600mm) of granular material should be adequate for sub grade modification or stabilization. However, deeper undercut and replacement may be required in certain areas.

The undercut and backfill option is widely used for construction traffic mobility and a working platform. This option could be used either on the entire project or as a spot treatment. The equipment needed for construction is normally available on highway construction projects.

Geosynthetic Stabilization

Geogrid has been used to reinforce road sections. The inclusion of geogrid in subgrades changes the performance of the roadway in many ways. Tensile reinforcement, confinement, lateral spreading reduction, separation, construction uniformity and reduction in strain have been identified as primary reinforcement mechanisms. Empirical design and post-construction evaluation have lumped the above described benefits into better pavement performance during the design life. Geogrid with reduced aggregate thickness option is designed for urban area and recommendations are follows;

Excavate subgrade 9 in. (230 mm) and construct the subgrade with compacted aggregate No. 53 over a layer of geogrid, Type I. This geogrid reinforced coarse aggregate should provide stable working platform corresponding to 97 percent of CBR. Deeper subgrade problem due to high moisture or organic soils requires additional recommendations. Geogrid shall be in accordance with 918.05(a) and be placed directly over exposed soils to be modified or stabilized and overlapped according with the following table.

Table 1: Soil stabilization and overlapping table

| SPT blow Counts per foot (N) | Overlap |
|------------------------------|-----------------|
| > 5 | 12 in. (300 mm) |
| 3 to 5 | 18 in. (450 mm) |
| less than 3 | 24 in. (600 mm) |

Chemical Stabilization

The transformation of soil index properties by adding chemicals such as cement, fly ash, lime, or a combination of these, often alters the physical and chemical properties of the soil including the cementation of the soil particles. There are the two primary mechanisms by which chemicals alter the soil into a stable sub grade:

1. Increase in particle size by cementation, internal friction among the agglomerates, greater shear strength, reduction in the plasticity index, and reduced shrink/swell potential.
2. Absorption and chemical binding of moisture that will facilitate compaction.

Strength requirements for stabilization and modification

The reaction of a soil with quick lime, or cement is important for stabilization or modification and design methodology. The methodology shall be based on an increase in the unconfined compression strength test data. To determine the reactivity of the soils for lime stabilization, a pair of specimens measuring 2 in. (50 mm) diameter by 4 in. (100 mm) height (prepared by mixing at least 5% quick lime by dry weight of the natural soil) are prepared at the optimum moisture content and maximum dry density (AASHTO T 99) . Cure the specimens for 48 hours at 120° F (50° C) in the laboratory and test as per AASHTO T 208.

The strength gain of lime-soil mixture must be at least **50 psi** (350 kPa) greater than the natural soils. A strength gain of **100 psi** (700 kPa) for a soil-cement mixture over the natural soil shall be considered adequate for cement stabilization with 4% cement by dry weight of the soils and tested as described above. **In the case of soil modification**, enhanced subgrade support is not accounted for in pavement design. However, an approved chemical (LKD, cement, and fly ash class C) or a combination of the chemicals shall attain an increase in strength of **30 psi** over the natural soils when specimens are prepared and tested in the same manner as stabilization.

COMPONENTS OF STABILIZATION

Soil stabilization involves the use of stabilizing agents (binder materials) in weak soils to improve its geotechnical properties such as compressibility, strength, permeability and durability. The components of stabilization technology include soils and or soil minerals and stabilizing agent or binders (cementitious materials).

Soils

Most of stabilization has to be undertaken in soft soils (silty, clayey peat or organic soils) in order to achieve desirable engineering properties. According to Sherwood (1993) finegrained granular materials are the easiest to stabilize due to their large surface area in relation to their particle diameter. A clay soil compared to others has a large surface area due to flat and elongated particle shapes. On the other hand, silty materials can be sensitive to small change in moisture and, therefore, may prove difficult during stabilization (Sherwood, 1993). Peat soils and organic soils are rich in water content of up to about 2000%, high porosity and high organic content. The consistency of peat soil can vary from muddy to fibrous, and in most cases, the deposit is shallow, but in worst cases, it can extend to several meters below the surface (Pousette, et al 1999; Cortellazzo and Cola, 1999; Åhnberg and Holm, 1999). Organic soils have high exchange capacity; it can hinder the hydration process by retaining the calcium ions liberated during the hydration of calcium silicate and calcium aluminate in the cement to satisfy the exchange capacity. In such soils, successful stabilization has to depend on the proper selection of binder and amount of binder added.

Stabilizing Agents

These are hydraulic (primary binders) or non-hydraulic (secondary binders) materials that when in contact with water or in the presence of pozzolanic minerals reacts with water to form cementitious composite materials. The commonly used binders are:

- a) cement
- b) lime
- c) fly ash
- d) blast furnace slag
- e) Bituminous
- f)

a) Cement

Cement is the oldest binding agent since the invention of soil stabilization technology in 1960's. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required (Sherwood, 1993; EuroSoilStab, 2002). Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil (EuroSoilStab, 2002). This can be the reason why cement is used to stabilize a wide range of soils. Numerous types of cement are available in the market; these are ordinary Portland cement, blast furnace cement, sulfate resistant cement and high alumina cement. Usually the choice of cement depends on type of soil to be treated and desired final strength. Hydration process is a process under which cement reaction takes place. The process starts when cement is mixed with water and other components for a desired application resulting into hardening phenomena. The hardening (setting) of cement will enclose soil as glue, but it will not change the structure of soil (EuroSoilStab, 2002). The hydration reaction is slow proceeding from the surface of the cement grains and the centre of the grains may remain unhydrated (Sherwood, 1993). Cement hydration is a complex process with a complex series of unknown chemical reactions (MacLaren and White, 2003). However, this process can be affected by

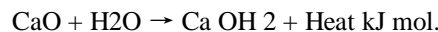
- presence of foreign matters or impurities
- water-cement ratio
- curing temperature
- presence of additives
- specific surface of the mixture.

Depending on factor(s) involved, the ultimate effect on setting and gain in strength of cement stabilized soil may vary. Therefore, this should be taken into account during mix design in order to achieve the desired strength. Calcium silicates, C3S and C2S are the two main cementitious properties of ordinary Portland cement responsible for strength development (Al-Tabbaa and Perera, 2005; Euro Soil Stab, 2002). Calcium hydroxide is another hydration product of Portland cement that further reacts with pozzolanic materials available in stabilized soil to produce further cementitious material (Sherwood, 1993). Normally the amount of cement used is small but sufficient to improve the engineering properties of the soil and further improved cation exchange of clay. Cement stabilized soils have the following improved properties:

- I. decreased cohesiveness (Plasticity)
- II. decreased volume expansion or compressibility
- III. increased strength (PCA-IS 411, 2003).

b) Lime

Lime provides an economical way of soil stabilization. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction (Sherwood, 1993). In soil modification, as clay particles flocculates, transforms natural plate like clays particles into needle like interlocking metalline structures. Clay soils turn drier and less susceptible to water content changes (Roger et al, 1993). Lime stabilization may refer to pozzolanic reaction in which pozzolana materials reacts with lime in presence of water to produce cementitious compounds (Sherwood, 1993, EuroSoilStab, 2002). The effect can be brought by either quicklime, CaO or hydrated lime, Ca (OH)₂. Slurry lime also can be used in dry soils conditions where water may be required to achieve effective compaction (Hicks, 2002). Quicklime is the most commonly used lime; the followings are the advantages of quicklime over hydrated lime (Rogers et al, 1996). - higher available free lime content per unit mass - denser than hydrated lime (less storage space is required) and less dust - generates heat which accelerate strength gain and large reduction in moisture content according to the reaction equation below:



Quicklime when mixed with wet soils, immediately takes up to 32% of its own weight of water from the surrounding soil to form hydrated lime; the generated heat accompanied by this reaction will further cause loss of water due to evaporation which in turn results into increased plastic limit of soil i.e. drying out and absorption (EuroSoilStab, 2002; Sherwood, 1993). The effect can be explained from Figure 1 for soil at a moisture content of 35% and plastic limit 25%. Addition of 2% lime will change the plastic limit to 40% so that the moisture content of the soil will be 5% below plastic limit instead of 10% above plastic limit (Sherwood, 1993). Sherwood (1993) investigated the decrease in plasticity as brought about in first instance by cation exchange in which cations of sodium and hydrogen are replaced by calcium ions for which the clay mineral has a greater water affinity. Even in soils (e.g. calcareous soils) where, clay may be saturated with calcium ions, addition of lime will increase pH and hence increase the exchange capacity. Like cement, lime when reacts with wet clay minerals result into increased pH which favors solubility of siliceous and aluminous compounds. These compounds react with calcium to form calcium silica and calcium alumina hydrates, a cementitious product similar to those of cement paste. Natural pozzolanas materials containing silica and alumina (e.g. clay minerals, pulverized fly ash, PFA, blast furnace slag) have great potential to react with lime. Lime stabilizations technology is mostly widely used in geotechnical and environmental applications. Some of applications include encapsulation of contaminants, rendering of backfill (e.g. wet cohesive soil), highway capping, slope stabilization and foundation improvement such as in use of lime pile or lime-stabilized soil columns (Ingles and Metcalf, 1972). However, presence of sulphur and organic materials may inhibit the lime stabilization process. Sulphate (e.g. gypsum) will react with lime and swell, which may have effect on soil strength.

c) Fly-Ash

Fly ash is a byproduct of coal fired electric power generation facilities; it has little cementitious properties compared to lime and cement. Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form cementitious compound that contributes to improved strength of soft soil. Fly ashes are readily available, cheaper and environmental friendly. There are two main classes of fly ashes; class C and class F (Bhuvaneshwari et al, 2005, FM 5-410). Class C fly ashes are produced from burning subbituminous coal; it has high cementing properties because of high content of free CaO. Class C from lignite has the highest CaO (above 30%) resulting in self-cementing characteristics (FM 5-410). Class F fly ashes are produced by burning anthracite and bituminous coal; it has low self-cementing properties.

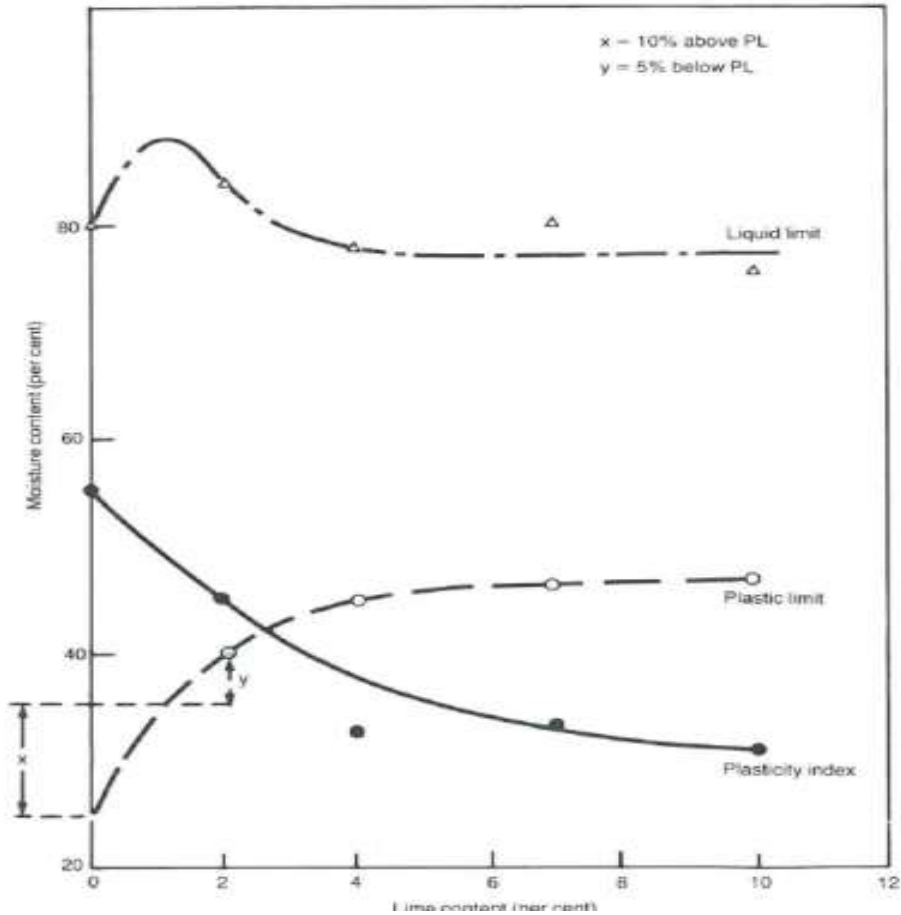


Figure 1: Effect of the addition of the lime on plasticity properties of clay amount of free CaO available for flocculation of clay minerals and thus require addition of activators such as lime or cement



Figure 2: A road reclaimer mixes soil with moist conditioned fly ash. Soil to be stabilized shall have less moisture content; therefore, dewatering may be required. Soil-fly ash mixture cured below zero and then soaked in water are highly susceptible to slaking and strength loss. Sulfur contents can form expansive minerals in soil-fly ash mixture, which reduces the long term strength and durability.

d) Blast Furnace Slags

These are the by-product in pig iron production. The chemical compositions are similar to that of cement. It is however, not cementitious compound by itself, but it possesses latent hydraulic properties which upon addition of lime or alkaline material the hydraulic properties can develop (Sherwood, 1993; Åhnberg et al, 2003). Depending on cooling system, Sherwood (1993) itemized slag in three forms, namely:

- i) **Air-cooled slag** Hot slag after leaving the blast furnace may be slowly cooled in open air, resulting into crystallized slag which can be crushed and used as aggregate.
- ii) **Granulated (merit 5000) or Pelletised slag** Quenching (i.e. sudden cooling with water or air) of hot slag may result into formation of vitrified slag. The granulated blast furnace slag or Merit 5000 (commonly known in Sweden) is a result of use of water during quenching process, while, the use of air in the process of quenching may result into formation of pelletised slag.
- iii) **Expanded slag** Under certain conditions, steam produced during cooling of hot slag may give rise to expanded slag.

e) BITUMINOUS

Most bituminous soil stabilization has been performed with asphalt cement, cutback asphalt, and asphalt emulsions. Soils that can be stabilized effectively with bituminous materials usually contain less than 30 percent passing the No. 200 sieve and have a PI less than 10. Soils classified by the USCS as SW, SP, SW-SM, SP-SM, SW-SC, SP-SC, SM, SC, SM-SC, GW, GP, SW-GM, SP-GM, SW-GC, GP-GC, GM, GC, and GM-GC can be effectively stabilized with bituminous materials, provided the above-mentioned gradation and plasticity requirements are met.

Conclusions

Recent technology has increased the number of traditional additives used for soil stabilization purposes. Such non-traditional stabilizers include: Polymer based products (e.g. cross-linking water-based styrene acrylic polymers that significantly improves the load-bearing capacity and tensile strength of treated soils), Copolymer Based Products, fiber reinforcement, calcium chloride, and Sodium Chloride.

Traditionally and widely accepted types of soil stabilization techniques use products such as bitumen emulsions which can be used as a binding agents for producing a road base. However, bitumen is not environmentally friendly and becomes brittle when it dries out. Portland cement has been used as an alternative to soil stabilization.

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