Thermal methods of stabilization

Soil stabilization by heating the ground and by freezing the ground come under, Thermal Methods of Modification. Heating evaporates water and causes permanent changes in the mineral structure of soils. Freezing solidifies part or all of the water and bonds individual particles together. Both these methods are very effective in improving the soil. However they are less common since they are expensive owing to huge energy consumption.

Soil heating

The higher the heat input per mass of soil being treated, the greater the effect. Even small increase in temperature may cause strength increase in fine grained soils by reducing the electric repulsion between the particles, a flow of pore water due to thermal gradient and a reduction in moisture content because of increasing evaporation rate.

Temperature(^{0}C)	Effect
100	Can cause drying and significant increase in clay strength
500	Can cause permanent changes in the structure of clays hence decreasing its plasticity
1000	Can cause fusion of clay particles into a solid substance

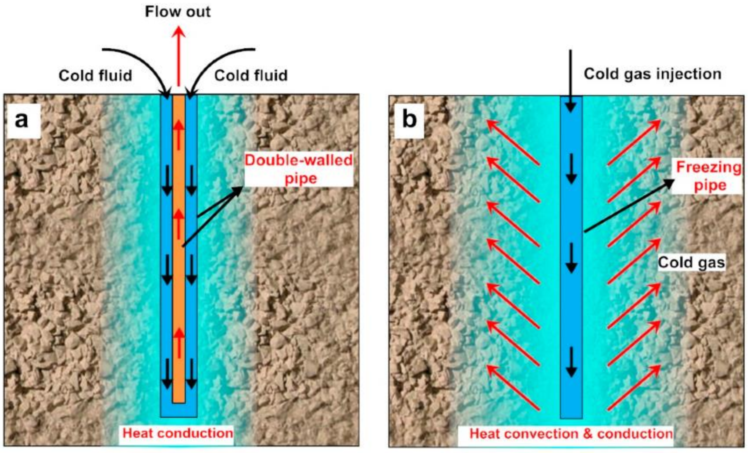
Heating is applied to the soil by burning liquid or gas fuels in boreholes or injection of hot air into 0.15 to 0.2 m diameter boreholes that can produce 1.3 to 2.5 m diameter stabilized zone after continous treatment for about 10 days. This techniques can be effectively used when a large and inexpensive heat source is located near the site.

Ground freezing

Ground freezing is a construction technique used to stabilize soil or create underground barriers by freezing the surrounding ground with the help of coolant pipes. This method involves the intentional freezing of subsurface materials to create a stable, impermeable barrier or provide temporary support during construction projects. The process of ground freezing typically utilizes a refrigeration system to circulate a chilled fluid, such as brine or calcium chloride solution, through a network of freeze pipes or tubes installed in the ground.

Ground freezing is a process of converting pore water or pores into ice by continuously refrigerating the soil. The water bearing soil is very lose and doesn't have enough compressive strength and shear strength to withhold its own loads. To increase these strengths and make the water bearing strata temporarily impermeable ground freezing method is used. This is usually done to provide structural underpinning, temporary support and prevent ground water flow into the site area. When the water-bearing strata is frizzed, the water in it transforms into ice which becomes a seal against the water and strengthens the soil. In grouting, extraneous materials are used. But in this method no extra material is required and after the work is completed, the soil reverts into normal state as before. This method can be use in any type of soil, regardless of size, shape or depth of excavation, soil or rock formation regardless of structure, grain size or permeability. However, it is best suited for soft ground rather than rock conditions. It is applicable to a wide range of soils but it takes considerable time to establish a substantial ice wall and the freeze must be maintained by continued refrigeration as long as required.

The effectiveness of freezing depends on the presence of water to create ice, cementing the particles and increasing the strength of the ground to the equivalent of soft or medium rock. If the soil has doesn't enough amount of water to fill all to pore when they freeze, then it may be necessary to provide extra water so that the pores are complete sealed. This method is very effective in the places where the ground is made up of silts



Soil 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). The binders 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: cement, lime, fly ash and blast furnace slag. Stabilization helps in reducing the compressibility, swelling, shrinkage and permeability of soil.

Cement stabilization

Cement is the oldest binding agent since the invention of soil stabilization technology. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required. Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil. 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. However, this process can be affected by ♣ presence of foreign matters or impurities ♣ water-cement ratio ♣ curing duration and temperature ♣ presence of additives ♣ specific surface of the mixture. Cement stabilized soils have the following improved properties:

• decreased cohesiveness (Plasticity)

• decreased volume expansion or compressibility

• increased strength.

Soil-cement (SC) is an engineered, densely compacted mixture of soil/aggregate, portland or blended cement, other cementitious materials (possibly), and water. The water employed in soil cement should satisfy the conditions similar to what we follow in the production of cement concrete. It has to be clean and free from harmful alkalis, acids or organic matter or debris. As mentioned in standard codes, a quality of water equivalent to the water we drink is the best.

Construction

1. Mixing

Mixing can be carried out in two ways:

At Central Mixing Plant:

Soil, cement, and water are proportioned and mixed in a central plant (usually pugmill type) to ensure uniformity. The mixed soil–cement is then hauled to the jobsite and spread over the prepared subgrade.

At Site (In-Place Mixing):

The required quantity of cement is spread over the in-situ soil, and the soil, cement, and water are mixed thoroughly using suitable equipment.

2. Compaction

The mixed material is compacted to achieve the desired density and maximum strength.

Rollers of various types are used depending on the soil type.

The compacted layer becomes permanently cemented at a high density, ensuring the soil–cement layer does not deform or consolidate further under traffic.

3. Curing

After compaction, the surface is cured to prevent moisture loss and to allow proper cement hydration.

This can be done by applying a light bituminous coating or by maintaining moisture for several days.

Proper curing ensures strength development and long-term durability.

4. Quality Control (Before and During Construction)

Before construction begins, laboratory tests are conducted to establish the cement content, optimum moisture, and compaction requirements.

During construction, field tests are performed to ensure that these requirements are being met so that the soil–cement mixture attains the desired strength and durability.

Advantages of Soil Cement

- Improved Strength and Durability
  - Increases compressive and shear strength of the soil.
  - Produces a strong, stable base or sub-base for pavements and foundations.
- Reduced Plasticity and Compressibility
- Economical Construction
  - Lower cost compared to granular or bituminous base layers.
- Enhances the load-carrying capacity, allowing it to support heavier loads.
- Cementation reduces permeability, improving resistance to erosion by water or wind.
- Can be mixed and compacted using conventional equipment either in-place or at a central plant.

Disadvantages

- The hardened soil–cement behaves like a brittle material; may crack under repeated loading or differential settlement.
- Inadequate curing can lead to poor strength development and surface cracking.
- High organic content or excessive clay minerals may prevent proper cement bonding.
- Over- or under-watering during mixing affects workability and final strength.
- Volume changes due to drying or temperature variations can cause shrinkage cracking.

Lime stabilization:

Lime stabilization is a ground improvement technique that involves adding lime to the soil to improve its properties. Stabilization is achieved when the proper amount of lime is added to a reactive soil and exchange of ions occurs. Clayey soils of moderate to high plasticity are suitable for implementing this technique. Sufficient curing time has to be provided. The gain in strength is also affected by the temperature at which curing takes place. High temperature during curing leads to enhanced strength. Lime stabilization technique is usually used in road construction to improve sub-bases and subgrades and for railroad and airport construction.

Lime in the form of quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – $Ca[OH]_2$), or lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone – $CaCO_3$) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix.

Most lime used for soil treatment is "high calcium" lime, which contains no more than 5 percent magnesium oxide or hydroxide. Lime, either alone or in combination with other materials, can be used to treat a range of soil types. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop. In general, fine-grained clay soils (with a minimum of 25 percent passing the #200 sieve (74mm) and a Plasticity Index greater than 10) are considered to be good candidates for stabilization. Soils containing significant amounts of organic material (greater than about 1 percent) or sulfates (greater than 0.3 percent) may require additional lime and/or special construction procedures.

The Chemistry of Lime Treatment

When lime and water are added to a clay soil, chemical reactions begin to occur almost immediately.

1. Drying: If quicklime is used, it immediately hydrates (i.e., chemically combines with water) and releases heat. Soils are dried, because water present in the soil participates in this reaction, and because the heat generated can evaporate additional moisture. The hydrated lime produced by these initial reactions will subsequently react with clay particles.
2. Modification: After initial mixing, the calcium ions (Ca++) from hydrated lime migrate to the surface of the clay particles and displace monovalent ions of sodium and potassium. This reduces the thickness of the diffuse double layer, bringing clay particles closer together. Clay particles cluster into larger, more stable aggregates.The soil becomes friable and granular, making it easier to work and compact. At this stage the Plasticity Index of the soil decreases dramatically, as does its tendency to swell and shrink. The process, which is called "flocculation and agglomeration," generally occurs in a matter of hours.
3. Stabilization: When adequate quantities of lime and water are added, the pH of the soil quickly increases to above 10.5, which enables the clay particles to break down. Silica and alumina are released and react with calcium from the lime to form calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH). CSH and CAH are cementitious products similar to those formed in Portland cement. They form the matrix that contributes to the strength of lime-stabilized soil layers. As this matrix forms, the soil is transformed from a sandy, granular material to a hard, relatively impermeable layer with significant load bearing capacity.

Construction Overview

Because lime can be used to treat soils to varying degrees, the first step in evaluating soil treatment options is to clearly identify the objective.

The construction steps involved in stabilization and modification are similar. Generally, stabilization requires more lime and more thorough processing and job control than modification. Basic steps include

• scarifying or partially pulverizing soil,

• spreading lime,

• adding water and mixing,

• compacting to maximum practical density, and

• curing prior to placing the next layer or wearing course.

When central (off-site) mixing is employed instead of road (in-place) mixing in either stabilization or modification, only three of the above steps apply: spreading the lime-aggregate-water mixture, compacting, and curing.