UNIT- 4

Physical & Chemical Modification

Chemical admixtures are the ingredients in concrete other than portland cement, water, and aggregate that are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations.

Successful use of admixtures depends on the use of appropriate methods of batching and concreting. Most admixtures are supplied in ready-to-use liquid form and are added to the concrete at the plant or at the jobsite. Certain admixtures, such as pigments, expansive agents, and pumping aids are used only in extremely small amounts and are usually batched by hand from premeasured containers.

dmixtures are classed according to function. There are five distinct classes of chemical admixtures: air-entraining, water-reducing, retarding, accelerating, and plasticizers (superplasticizers). All other varieties of admixtures fall into the specialty category whose functions include corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, workability enhancement, bonding, damp proofing, and coloring. Air-entraining admixtures, which are used to purposely place microscopic air bubbles into the concrete, are discussed more fully in Air-Entrained Concrete.

Water-reducing admixtures usually reduce the required water content for a concrete mixture by about 5 to 10 percent. Consequently, concrete containing a water-reducing admixture needs less water to reach a required slump than untreated concrete. The treated concrete can have a lower water-cement ratio. This usually indicates that a higher strength concrete can be produced without increasing the amount of cement. Recent advancements in admixture technology have led to the development of mid-range water reducers. These admixtures reduce water content by at least 8 percent and tend to be more stable over a wider range of temperatures. Mid-range water reducers provide more consistent setting times than standard water reducers.

Retarding admixtures, which slow the setting rate of concrete, are used to counteract the accelerating effect of hot weather on concrete setting. High temperatures often cause an increased rate of hardening which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete. Most retarders also function as water reducers and may entrain some air in concrete.

Accelerating admixtures increase the rate of early strength development, reduce the time required for proper curing and protection, and speed up the start of finishing operations. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather.

Superplasticizers, also known as plasticizers or high-range water reducers (HRWR), reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete. Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction. The effect of superplasticizers lasts only 30 to 60 minutes, depending on the brand and dosage rate, and is followed by a rapid loss in workability. As a result of the slump loss, superplasticizers are usually added to concrete at the jobsite.

Corrosion-inhibiting admixtures fall into the specialty admixture category and are used to slow corrosion of reinforcing steel in concrete. Corrosion inhibitors can be used as a defensive strategy for concrete structures, such as marine facilities, highway bridges, and parking garages, that will be exposed to high concentrations of chloride. Other specialty admixtures include shrinkage-reducing admixtures and alkali-silica reactivity inhibitors. The shrinkage reducers are used to control drying shrinkage and minimize cracking, while ASR inhibitors control durability problems associated with alkali-silica reactivity.

Lime Stabilisation

1. Stabilization using lime is an established practice to improve the characteristics of fine grained soils.
2. The first field applications in the construction of highways and airfields pavements were reported in 1950- 60. With the proven success of these attempts, the technique was

extended as for large scale soil treatment using lime for stabilization of subgrades as well as improvement of bearing capacity of foundations in the form of lime columns.

Mechanism of lime stabilization

The addition of lime affects the shear strength, compressibility, and the permeability of soft clays. These beneficial changes occur due to the diffusion of lime.

Soil-lime reaction

1. Cation-exchange
2. Flocculation
3. Aggregation (time and temperature dependent)

- **Cation Exchange**

1. It is an important reaction and mainly responsible for the changes occurring in the plasticity characteristics of soil.
2. The cation replacement takes place in order of their replacing power

   $Li^{+} < Na^{+} < H^{+} < K^{+} < NH_4^{+} < Mg^{2+} < Ca^{2+} < Al^{3+}$

3. CEC highly depends on the pH of the soil water and the type of clay mineral in the soil.

Montmorillonite (highest); Koalinite (Lowest).

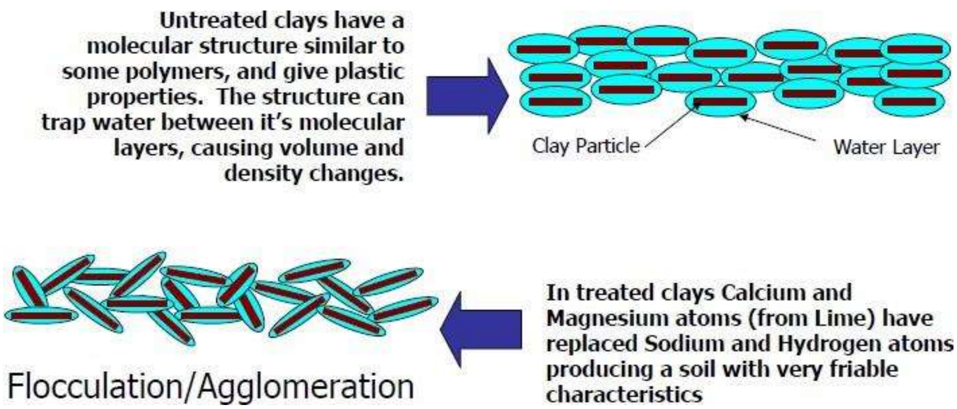
4. $Ca(OH)_2$ [formed either due to hydration of quicklime or when it is used directly] dissociates in the water.

$$CaO + H_2O \rightarrow Ca(OH)_2 + 15.6 \text{ kcal/mole}$$

5. It increases the electrolytic concentration and pH of the pore water and dissolves the silicates (SiO_2) and aluminates (Al_2O_3) from the clay particles.

6. Na^+ and other cations adsorbed to the clay mineral surfaces are exchanged with Ca^{++} ions.

- **Flocculation**



- **Pozzolanic**
  - Literature review reveals that the addition of lime to soil alters the properties of soil and this is mainly due to the formation of various compounds such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) and micro fabric changes (Pozzolanic reaction).
  - $Ca^{2+}+2(OH^-) + SiO_2$—>CSH
  - $Ca^{2+}+2(OH^-)+ Al_2O_3$ —> CAH
  - The reaction is much slower reaction than the hydration of cement and hence some times cement is added to increase the rate of reaction.

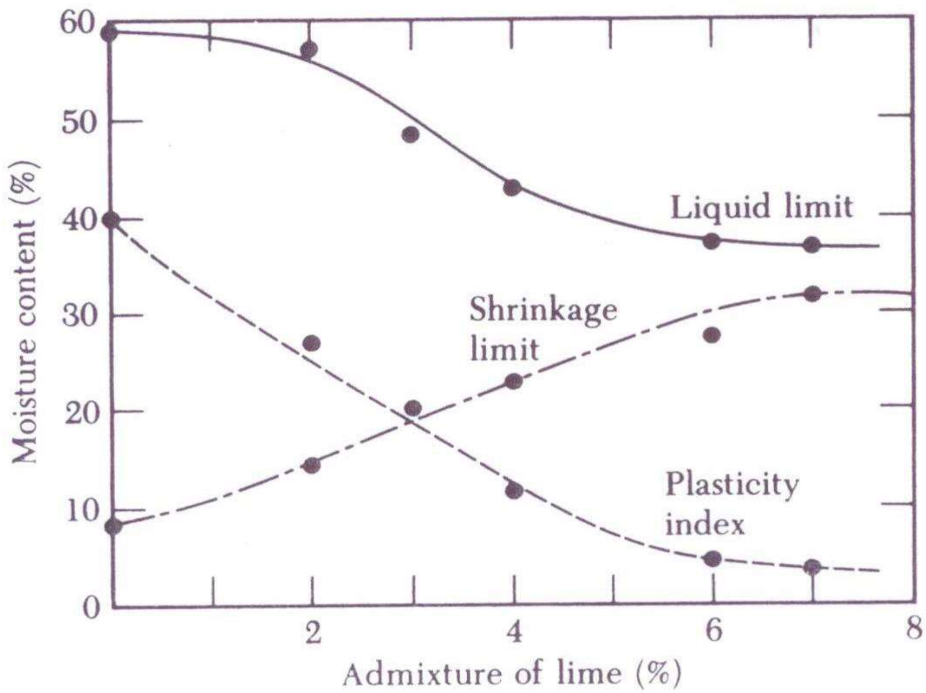
FACTORS CONTROLLING THE CHARACTERISTICS OF LIME TREATED CLAY

1. Type of lime (Quick lime or Hydrated lime)
2. Lime content (Lime Fixation Point and Optimum lime content)
3. Curing time
4. Type of soil
5. Clay mineral

6. Soil pH

7. Curing temperature

Variation of index properties with addition of lime



Preparation of the soil: to remove large elements which might hinder the mixing-in of lime, and it also helps to modify the humidity of the soil. It may be carried out with a ripper, a harrow or a plough.

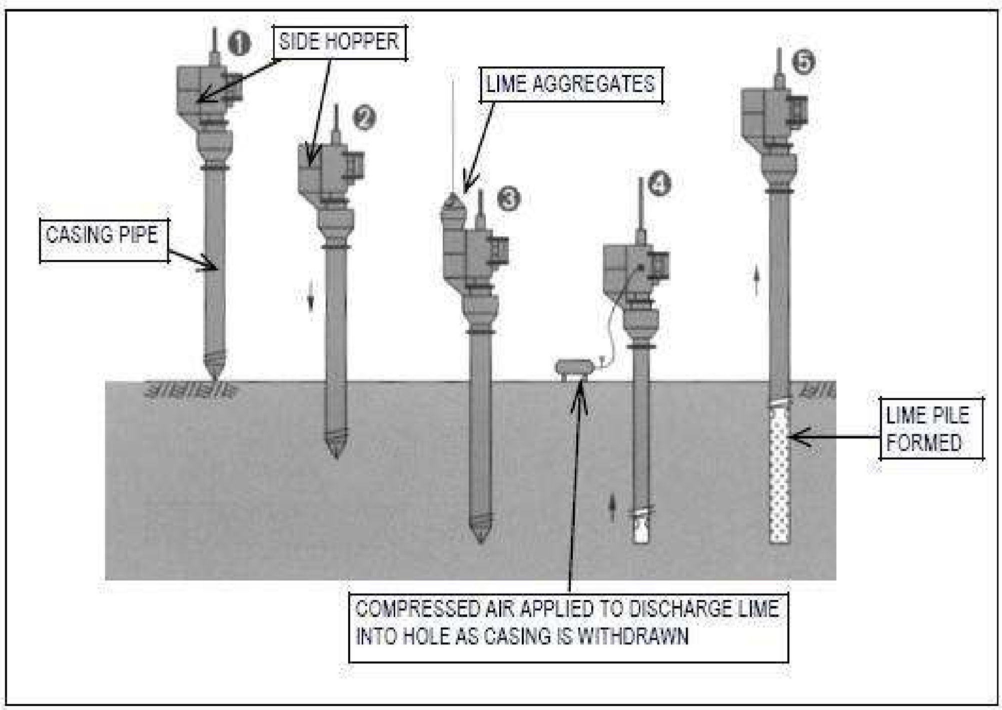
Spreading: the lime is dispersed using a spreader fitted with a weighing device. The lime is supplied pneumatically to the spreader, either directly from the silo vehicle or by using buffer silos.

Mixing: the purpose of this operation is to spread out the soil while at the same mixing the lime evenly into it. this work will be done with pulvimixers, rotary paddle mixers, disk ploughs or plough shares

Compaction: when grading, the layer thickness that can be compacted by rolling should be taken into account. After grading, the treated soil has to be compacted using a compacting machine (pneumatic-tyre roller or tamping roller). In warm weather, mixing should be done after two hours to allow for reactions.

Lime Columns

1. Broms and Bomans (1975, 1979) used a special type of auger to form the bores in which lime was mixed with the soil in-situ.
2. In this technique it was assumed that the improved soil column in the bore was acting as a pile to support the superstructure.
3. Later is found that lime can diffuse in to the surrounding soil and can stabilize a greater volume of soil.



This method produces both a consolidation and strength gain effect on the treated soil, without additional loading, via lateral expansion of the lime columns as they absorb water from the soft soil.

These lime columns have the following effects on the adjacent soil.

a) Consolidation / dewatering effect

Quick lime, CaO, absorbs water from the surrounding ground, causing the lime to swell and forms slaked lime ($Ca(OH)_2$) as per the following chemical reaction

$$CaO + H_2O \rightarrow Ca(OH)_2 + 15.6 \text{ Kcal/mol}$$

b) Ion exchange effect

As the surface of fine particles of clay is negatively charged, calcium ions (Ca^{++}) from the slaked lime are absorbed by the surface of clay particles. As a result, clay particles are bonded with each other and the weak clay is improved with a resultant increase in shear strength.

c) Pozzolanic effect

Calcium ions continue to react with SiO_2 and Al_2O_3 in the clay for a long time forming compounds that cause the clay strength to be improved. This reaction is termed a pozzolanic reaction. The lime piles themselves have considerable strength and therefore act to reinforce the soil as well as alter its properties.

Among all the three effects only consolidation/dewatering effect is the main process by which the strength and stiffness of the soil mass is improved in the shorter term. Other two effects ion exchange effect and pozzolanic effect are ignored.

Shear strength improvement

The shear strength of the soil stabilized in the field (in situ) was much higher than that of the samples prepared in the laboratory. The soil stabilized in situ is subjected to a pressure from the overburden and from the surrounding soil while the confining pressure for the samples that were stored in small containers in the laboratory is small.

GROUND TREATMENT WITH CEMENT

Stabilization using cement and other admixtures such as fly ash, blast furnace slag has been adopted in many geotechnical and highway engineering projects. These applications include

a) Shallow depth applications in the case of improvement of subgrade, sub-base and base course of highways and embankment material

b) Stabilization of deep soil deposits such as soft soils and peaty soils.

- Addition of small quantities of cement proved to be beneficial and the degree of trength/ stiffness required is the basis for design and has been used in the stabilization of highways and embankments.
- In large scale applications, depending on the strength and stiffness required based on the type of soil, the quantities required are huge and need large scale machinery and special procedures are required in stabilization of deep soils which are weak (Eg: peaty soils).

Benefits:

1. Increased strength and stiffness
2. Better volume stability
3. Increased durability

Factors influencing the strength and stiffness improvement

1. Cement content, water content combined into water/cement(w/c) ratio.
2. Method of compaction.
3. Time elapsed between mixing and compaction.
4. Length of curing.
5. Temperature and humidity.
6. Specimen size and boundary effects.

Strength gain is given by:

$$q_u(t) = q_u(t_0) + k \log \frac{t}{t_0}$$

$q_u(t)$ = the UCC (unconfined compression) strength at t days

$q_u(t_0)$ = the UCC strength at t_0 days

k = 480C for granular soils; 70C for fine grained soils

C = Cement content by weight

Effect of adding cement and blast furnace slag leads to the following chemical reactions:

1. Hydration of cement produces $Ca(OH)_2$. The calcium hydroxide generated is upto 25% of the weight of cement.
2. Adsorption of $Ca(OH)_2$ by the clay, cation exchange reaction
3. If the clay is saturated with $Ca(OH)_2$, a pozzolonic reaction between the components occurs.

The design and construction of a soil treatment project is generally as follows:

1. Site exploration discloses geotechnical conditions that don‟t meet design criteria such as density, consistency, strength, or permeability.
2. Alternative treatment methods are evaluated.
3. Specialty contractors are selected.
4. Laboratory mix testing is conducted to provide guideline on in situ soil characteristics, tolerable admixture properties, and optimum mix designs

5. Owner approves contractor‟s equipment, methods, and mix design.
6. Soil at site is treated with close supervision, sampling, and testing in the field to make sure that project requirements are met.

Soil Stabilization

Improving the engineering properties of soils used for pavement base courses, subbase courses, and subgrades by the use of additives which are mixed into the soil to effect the desired improvement.

Shotcreting and Guiting Technology

Shotcrete and gunite are important terminologies associated with the domain of civil construction. Shotcreting or guniting are techniques or processes that have proven to be of immense benefit in diverse subdomains of construction such as slope protection or stabilisation, pools, tunnels, fluid tanks, concrete repair works and many more. Many of us, including this author, have not only studied about shotcreting or guniting but also have practical experience of varying degrees in this particular area.

Yet, when it comes to defining or differentiating between these two terms there would, in all probability, be lack of unanimity. Can‟t blame one though, as some of the established and experienced producers and companies involved in the application of shotcrete or gunite themselves do not seem to converge on an identical interpretation of these terms. While some consider guniting as a type (class) of shotcreting some others still regard them as two completely different processes.

Confusion brewing up already ? Let‟s have a bit more of that. For American Shotcrete Association (ASA), apparently, the terms gunite or guniting simply do not exist – technically. ASA only believes in the term shotcrete and according to to it there exist only dry-mix shotcrete and wet-mix shotcrete. Take your pick.

Nevertheless, what everyone agrees on is that there are two processes involved when it comes to spraying concrete or mortar pneumatically through a spraying gun (nozzle) at high velocity onto a surface. One is called the dry-mix process while the other wet-mix process. Also, whoever uses the terms gunite or guniting uses them to mean the dry-mix process only and never the wet-mix one.

The dry-mix process involves mixing cement and aggregates (fine or both fine & coarse aggregates) completely dry in a bin, rig etc and the pumping the same through a hose pneumatically (ie using compressed air by a compressor) under high pressure to a nozzle (the spray-gun). Water is introduced to the dry mix only at the nozzle (by means of a water feeding line) just before the mix blasts off the nozzle at a high velocity onto the surface being treated. On the other hand, the wet-mix process involves spraying of a pre-mixed or ready-mixed (wet) concrete or mortar under high pressure and at high velocity eliminating the need of adding any water in the nozzle or the spray-gun. Both processes have their unique advantages and requirements. But, the questions still remain as to what exactly is shotcrete and what is gunite, are they the same or different, if different, what are the differences etc etc.

So, let"s turn the heads into the ones who originally coined these terms, developed these techniques or set them in motion since and then see what shows up.

A little bit of study on the subject quickly reveals that it was the term "gunite" that came into existence first. The term was used to describe a then newly developed technique in US in which concrete was used to be sprayed under pressure through a spray-gun at high velocity onto a surfacing requiring such an application. Since the material was sprayed through a gun, the term gunite seems to have surfaced. All these happened at the dawn of the previous century.

Later, the term "shotcrete" came into being for the first time in the early 1930s when the American Railway Engineers Association (AREA) started using it to describe concrete (or mortar) nozzle-sprayed pneumatically at high velocity onto a surface either by dry-mix or by wet-mix process.

In the early 1950s the American Concrete Institute (ACI) too adopted the term "shotcrete" to describe the dry-mix spraying process erstwhile known as guniting. ACI classified the shotcreting process into two types, namely, the dry-mix process and the wet-mix process. They also accepted the term guniting for the dry-mix shotcreting process. In other words, according to ACI, guniting is a type of shotcreting only.

Contrary to that, some seem to regard “gunite” merely as a trademark only. Let‟s take an example. Xerox is a popular trademark while the process involved is photocopying and not xeroxing. Similarly, this section believes that while gunite can exist as a trademark or brand name the term guniting is meaningless and the technically correct term is shotcreting (dry-mix) only. Some others don‟t seem to agree however.

This author would prefer to have the following views and would suggest the same to others as well :- The process or technique that involves pumping of concrete or mortar under high pressure through a hose to a nozzle (spray-gun) and then spraying them at high velocity onto a surface either by dry-mix or by wet-mix process is called shotcreting. Usually, shotcrete is reinforced by using steel or wire mesh, steel rebars, synthetic fibres etc. Since, the dry-mix shotcreting is also called as guniting by some (yet, not by all), better to stick to the terms dry-mix shotcreting & wet-mix shotcreting rather than guniting.

Nevertheless, if one is highly used to the terms gunite and guniting, or, if one is dealing with an entity that is hell bent on using the terms gunite and guniting, the same may be used to mean the dry-mix shotcreting method only. Also, it is to be noted that a mix sprayed under low pressure and at low velocity is usually not regarded as either gunite or shotcrete. One of the basic purpose of these processes is to achieve very high degree of compaction and thus high strength due to the high-velocity ejection from the spray-gun eliminating the need of any further compaction. This also eliminates the need of any formwork. The high velocity of the mix also ensures better adhension with the recieving surface. The velocity is usually well over 100 m/s, say about 150 m/s, but can be even higher if situation demands.

Also, when it comes to guniting, usually, smaller sized coarse aggregates, say max. 10mm or so, are used. For the wet-mix process use of aggregates of max. size of 1 inch or so is not uncommon.

The dry-mix shotcreting process (aka guniting) seems to be the most widely used method worldwide due to certain unique advantages it has to offer as mentioned below:

1. It‟s extremely versatile. This process can be used to give virtually any shape to any element of a structure – curved, undulating, spheroidal and many more. This is a reason why this process is commonly adopted to add special features or shapes to swimming pools, spas, artificial caves & waterfalls etc. It is used in sculpting work as well. It‟s versatility makes it an excellent candidate for a large variety of work such as tunnel lining, refractory lining, slope protection, repair works besides making it suitable for diverse uses in structures like tanks, dams, reservoirs, canals, docks, bridges, pipelines etc.

2. Water content of the mix can be controlled instantly and at any time at the nozzle by the crew while spraying the mix onto a surface. This enables one – at any moment – to render the mix only as much dry or wet as the situation demands by controlling the addition of water at the nozzle.

3. Dry-mix shotcrete (gunite) is quite economical, can be quickly prepared and applied unlike the wet-mix variety. It is quite suitable for overhead application where wet-mix shotcrete may not stick well and may sag or fall off.

4. If very thin linings or coatings are required to be applied on a surface or if the quantum of the work is small or in case of concrete repairs needing finer treatments such as filling up of cracks or small broken patches, damage etc, guniting would be a the choice rather than wet-mix shotcreting.

5. If the application job involves frequent stops of work for some reason or another guniting could be a much better choice over the wet-mix application.

Dry-mix process or guniting needs highly skilled crew. That"s especially true for the nozzleman as he is the one who controls and monitors the water flow at the nozzle. This demands experience and skill.

Another issue with guniting is “rebound”. While spraying the mix onto a surface some amount of the material is bound to bounce off the surface and fall on the ground. This occurrence is known as rebound and is unavoidable in guniting or even in wet-mix shotcreting as well. The rebound-quantity is a complete waste as reuse of the same would result in an inferior product. Lesser rebound not only minimises waste but also indicates a better quality mix and thus a better product. Experience and skill are necessary qualities in order to get the better of the rebound problem partially.

The wet-mix shotcreting process also finds a lots of use. In fact, if stronger linings or coatings are the need of the hour in a particular work, wet-mix shotcrete can be a better choice than gunite as it results in a stronger product. Except where special or curved features are necessary calling for decorative or artistic finishes, wet-mix shotcreting can be applied virtually on all occasions as already mentioned earlier in this article where guniting can be implemented.

A better control over quality of the material is possible in case of the wet-mix process since all ingredients of the mix, including water, are pre-mixed before pumping the same to the spray gun. So, the mix can be precisely designed in accordance with the requirements like strength, durability etc. Also, rebound is much lesser for wet-mix shotcreting as compared to dry-mix shotcreting (guniting). For work involving large quantity of mix wet-mix shotcreting process is quite convenient, especially, if the work is continuous with no or very less stops.

At the end of the day, it"s much more important to choose the right or more suitable process (dry-mix or wet-mix) for a particular work and ensure that the same is properly & skillfully implemented rather than bothering too much about whether to call it dry-mix shotcreting or guniting.

GROUTING.

Grouting is defined as the process of injecting suitable fluid under pressure into the subsurface soil or rock to fill voids, cracks and fissures for the purpose of improving the soil.

The fluid may be colloidal solutions, cement suspensions, chemical solutions etc.

Application of Grouting

1. Producing mass concrete structures and piles
2. Fixing ground anchors for sheet pile walls, concrete pile walls, retaining walls tunnels etc
3. Repairing a ground underneath a formation or cracks
4. Defects on building masonry or pavement
5. Fixing the tendons in prestressed post tensioned concrete
6. Filling the void between the lining and rock face in tunnel works
7. Seepage control in soil
8. Soil stabilization and solidification
9. Vibration control

Various types of grouting.

Suspension grouts
Solution Grouts
Colloidal solution grouts

Suspension grouts

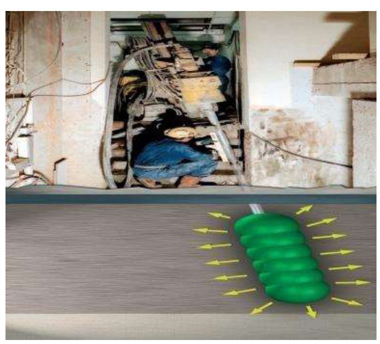
These are multi-phase systems capable of forming sub systems after being subjected to natural sieving processes, with chemical properties which must ensure that they do not militate against controlled properties of setting and strength. Water in association with cement, lime, soil, etc., constitute suspensions. Emulsion (asphalt or bitumen) with water is a two-phase system which is also included under suspension. Solution Grouts These are intimate one-phase system retaining an originally designed chemical balance until completion of the relevant reactions. Silicate derivatives, lignosulphite derivatives, phenoplast resins etc. come under this category. Colloidal solution grouts Solutions in which the solute is present in the colloidal state are known as colloidal solutions. Chemical grouts fall into this category.

Different types of Grouting

i. Compaction grouting
ii. Compensation grouting
iii. Jet grouting

Compaction Grouting

- Compaction grouting is a single-stage grouting with high strength mortar to the ground to create a grout-bulb at the end of drill pipe.
- Grouting Mechanism
    - A stiff grout with a very low slump is injected under relatively high pressure through pipes or casings into soil. The grout exiting the bottom of the pipe forms a bulb-shaped mass that increases in volume.
    - Displacement of the soil is produced by the weight of the overburden pushing back against the expanding grout bulb. Thus it densifies the soft, loose, or disturbed soil surrounding the mass.
    - It can also be used to alleviate settlement problem during the excavation of tunnel or deep basement as the hardened bulb-shaped grout will induce an increase in the soil volume strain to the soil strata and cause heaving of ground at the ground surface.
    - When applying the compaction grouting process usually a stiff to plastic grout is injected into the soil under pressure.
    - It expands in the soil as a relatively homogeneous mass and at the same time is forming almost ball-shaped grout bulbs.
    - The soil surrounding the grouted area is displaced and at the same time compacted.



- Compared to other grouting techniques, the grout material neither penetrates into the pores of the in-situ soil (as is the case with the classical injection) nor are local cracks formed (as is the case with the Soilfrac® technique).
- During the compaction grouting process pressure and grout quantity as well as possible deformations at ground surface, respectively at structures are monitored.

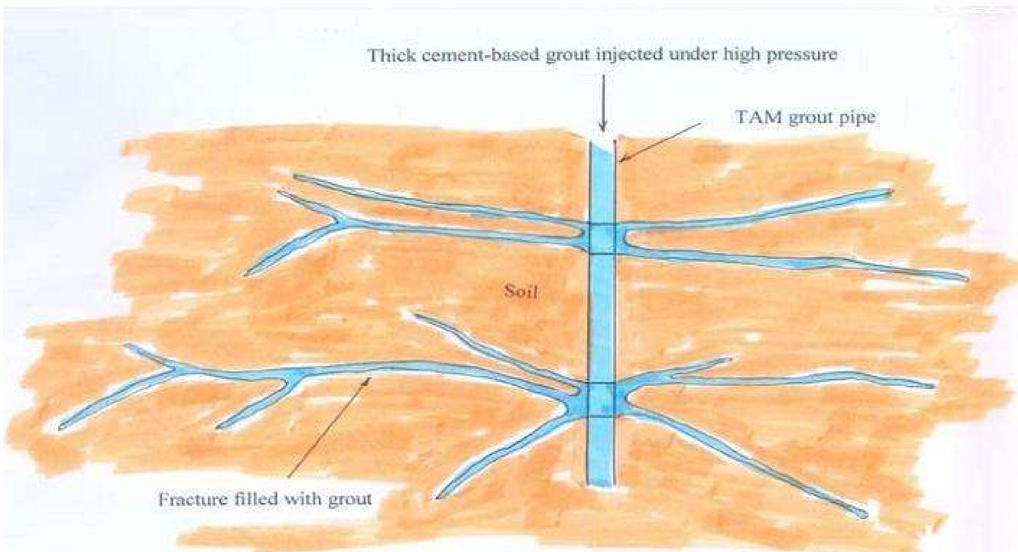
Applications of Compaction Grouting

- The compaction grouting method may be used for the improvement of non-cohesive soils, especially in cases, where soils of loose to medium density are encountered.
- This method is also used in fine-grained soils) in order to install elements of higher strength and bearing capacity in soils of low bearing capacity, thus improving the load bearing behaviour of the soil.
- When using this technique in saturated clayey soil, a temporary increase of the pore water pressure can be observed.
- In principle, the compaction grouting technique can achieve a similar degree of improvement as by the deep vibro techniques.
- The compaction grouting method is particularly well suited as an alternative or supplement to deep vibro techniques in the following cases:
    - confined working space
    - limited working height
    - vibration-free technique required (e.g. because of a highly sensitive structure in the vicinity)
    - compaction at very large depths for intermittent strong soil layers, which cannot be penetrated by a depth
    - vibrator, thus making its use inefficient.

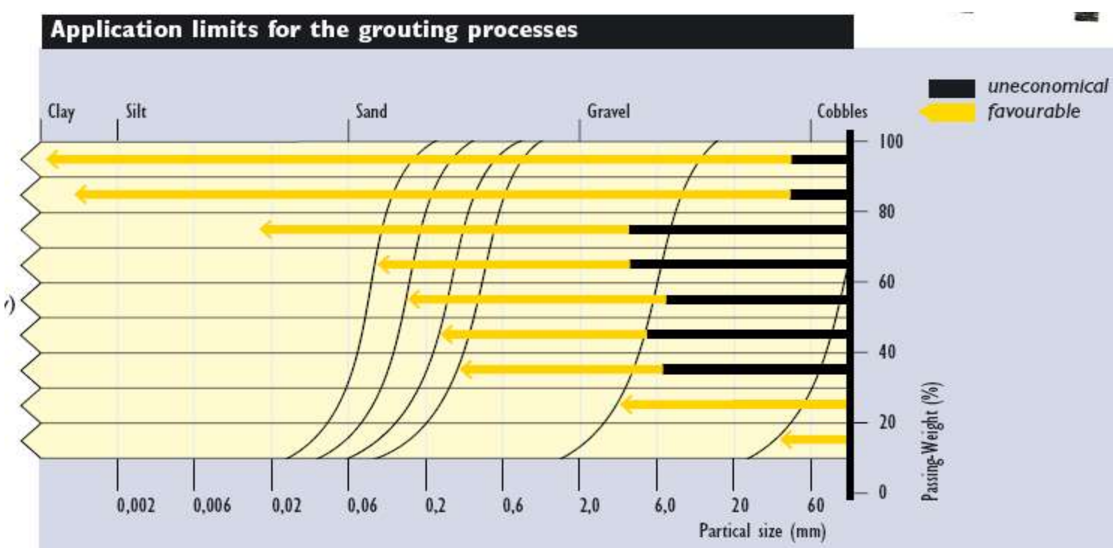
Compensation Grouting

- Compensation grouting is a grout injection that can „compensate" for stress relief and associated ground settlement.
- Grout is injected through grout pipes, which are usually TAM grout pipes, under high pressure into the soil.
- Fractures in soil are created which are then filled with grout.

- The fractures filled with grout will follow the plane with the minor principle stress and formed in layers.
- The increase in volume will compact disturbed soil surrounding the mass, will compensate settlement caused by tunnel Excavation works and can be used to lift up settle structures.



In using this process fractures in the soil are created which are then filled with grout. Each soil formation may be improved by multiple grouting treatments and controlled lifting may be induced.



JET GROUTING / SOILCRETING

- Depending on the nature of soils, Soilcrete®- cut-offs are able to reduce the coefficient of permeability by several decimal powers. High quality requirements in respect of the degree of sealing effect necessitate extensive production efforts.
- For many applications both the strengthening and sealing characteristics of the Soilcrete®-elements are used. The selected suspensions need to be composited accordingly.

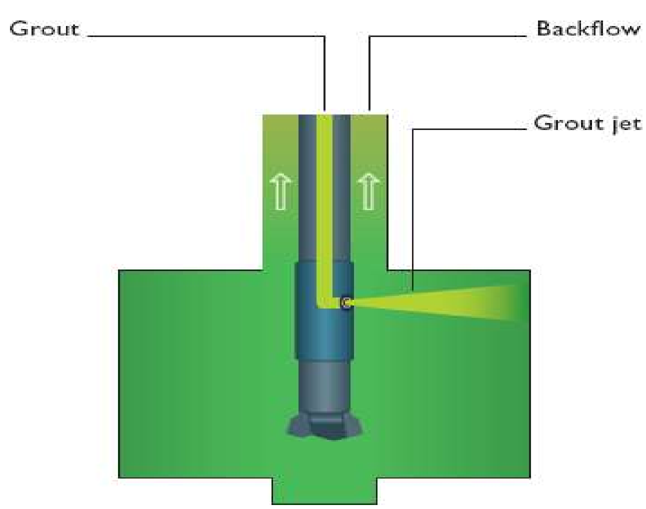
Soilcrete is produced in three different ways.

1. Single Direct Process
2. Double Direct Process
3. Tripple Separation Process

The method to be used is determined according to the prevailing soil conditions, the geometrical form and the required quality of the Soilcrete-elements.

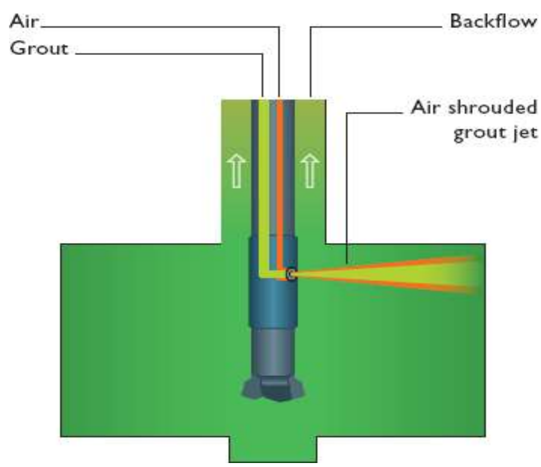
Single direct process:

- Operates with a grout jet of min. 100 m/sec. exit velocity for simultaneous cutting and mixing of the soil without an air schroud.
- The process is used for small to medium sized jet grout columns.



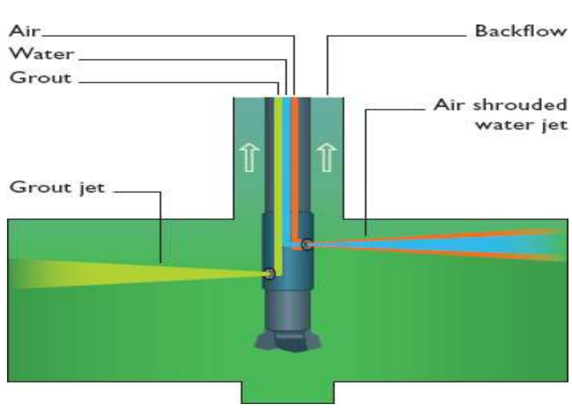
Double direct process:

- operates with a grout jet of min. 100 m/sec exit velocity for simultaneous cutting and mixing of the soil.
- To increase the erosion capability and the range of the grout jet, air shrouding by means of shaped air jet nozzle is used.
- The process is mainly used for panel walls, underpinning and sealing slabs.



Triple separation process:

- Erodes the soil with an air shrouded water jet of min. 100 m/sec exit velocity.
- Grout is injected simultaneously through an additional nozzle located below the water jet nozzle.
- The grout pump pressure ranges above 15 bar.
- The process is used for underpinning works, cut off walls and sealing slabs and is mainly used for the treatment of cohesive soils.



Applications of Jet Grouting

- ☐ The jet grouting technique is developed in the 1960s. However, because of its unique properties, it is becoming quite popular in the civil engineering works. Its main applications are: -
- ☐ Grouting of clay / silt soils which is not suitable for TAM grouting technique.
- ☐ Jet grout wall and roof are used to reinforce tunnel portal excavation works.
- ☐ Sealing of windows of coffer dams
- ☐ Used as jet grout raft to reinforce cofferdam to limit its deflection and thus decrease the settlement caused by the excavation works.

HEATING AND FREEZING METHOD

Changes in soil state due to water content variation are effected by hydraulic modification methods. Changes in soil structure apart from water content variations are brought about using modifications based on temperature and use of appropriate modifiers.

Methods based on temperature control are classified as:

1. Heat treatment method.
2. Ground freezing method.

- ❖ **Heating methods**
- Temperature control methods depend on
  - Thermal conductivity of the soil
  - Heat capacity of the soil
  - Heat of fusion
  - Heat of vaporization

Thermal conductivity of the soil

It is defined as the amount of heat passing through a unit cross-sectional area of soil under a unit temperature gradient.

$$K_T = \frac{q}{A(T_2 - T_1)/L}$$

q = heat flow, watts, W; A = area of cross section, m^2 ; T = temperature, K; L = length of the soil element, m;

At 0°C KT for water = 0.58 W/ m.K, for ice = 2.2 W/ m.K

For denser frozen sand KT = 4 W/ m.K and less in unfrozen state,

For soils, thermal conductivity increases with water content and dry density.

Heat capacity of a soil

It is expressed as the amount of heat required to raise the temperature by 1°C or 1°K. it is expressed in terms of unit volume (volumetric heat capacity) or per unit mass (specific heat capacity)

$$Q = CM\,\Delta T$$

Heat capacity of water C_w = 4.2 kJ/kg °C= 4.2 mJ/m^3 °C.

ice C_i = 2.2 kJ/kg °C = 2.2 mJ/m^3 °C.

Heat capacity of ice is less than that of water.

Latent heat of fusion (L_F)

It is the change in thermal energy when water freeze or ice melts. It is 334 MJ/m^3 of water.

To melt a mass M of ice, heat quality (Q)

$Q = L_F M$

For a 1 m3 of soil with water content w

$$L_{Fs} = \rho_d \, w \, L_F$$

$$= 334 \, \rho_d \, w \text{ KJ/m}^3$$

Heat of vaporization of water

It is the energy required to boil water from liquid state to gaseous state. At atmosphere, Heat of vaporization of water = L_V = 2.26 MJ/kg = 2260 MJ/m^3.

To remove all the free water at 100°C in one m_3 of soil with water content (w), the energy required is

$$L_{Vs} = 2260 \, \rho_d \, W.$$

The above definitions are useful to calculate theoretical estimates, but losses need to be accounted for in design.

Heat treatment of soils

Heat treatment of a clay soil to about 400°C results in pronounced changes in engineering properties.

Heating is energy intensive and to stabilize one m^3 of soil 50 to 100 liters of fuel oil are required.

It is not recommended now a days except in places where it is already available as inherent energy in waste products and in landfills. However use of geothermal piles as heating systems is prevalent in places like UK.

Methods of heating soil in-situ

•Ground surface heating

•Heating through boreholes

•Use of thermally stabilized building blocks

•Thermal piles

Geothermal piles are an innovative system of building foundations for use in combination with ground-source energy technology. Conventional ground-loops are installed in building piles, through which water or another fluid is pumped. The fluid and ground-transfer heat energy is then passed through a heat exchanger in the building to provide cooling or, more commonly, heating in the winter. The geothermal system is essentially the same as closed-loop borehole systems; however, since they are installed in the building foundations, the technology serves a dual purpose.

Ground Freezing

Ground freezing is a process of making water-bearing strata temporarily impermeable and to increase their compressive and shear strength by transforming joint water into ice.

- Freezing is normally used to provide structural underpinning; temporary supports for an excavation or to prevent ground water flow into an excavated area.
- Successful freezing of permeable water-bearing ground affects simultaneously a seal against water and substantial strengthening of incoherent ground.
- No extraneous materials need to be injected and apart from the contingency of frost heave, the ground normally reverts to its normal state.

- 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.
- May be used in any soil or rock formation regardless of structure, grain size or permeability. However, it is best suited for soft ground rather than rock conditions.
- Freezing may be used for any size, shape or depth of excavation and the same cooling plant can be used from job to job.
- As the impervious frozen earth barrier is constructed prior to excavation, it generally eliminates the need for compressed air, dewatering, or the concern for ground collapse during dewatering or excavation.

Principles of Freezing

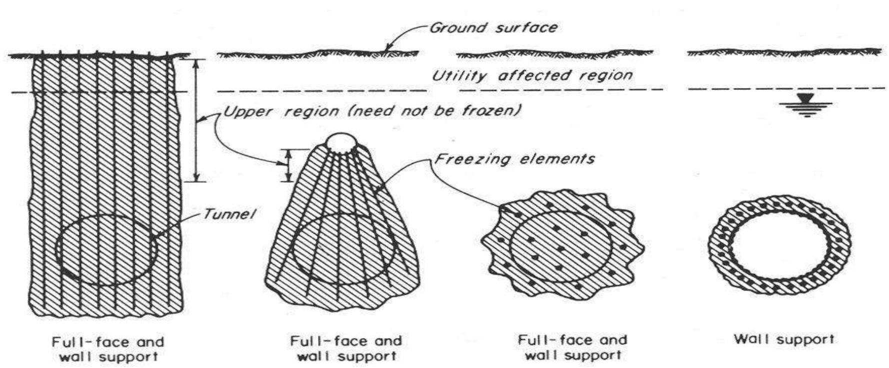
- The effectiveness of freezing depends on the presence of water to create ice, cementing the particles and increasing the strength of the ground to the equivalent of soft or medium rock.
- If the ground is saturated or nearly so it will be rendered impermeable.
- If the moisture does not fill the pores, it may be necessary to add water.
- The strength achieved depends on freeze temperature, moisture content and the nature of the soil.
- Freezing can be particularly effective in stabilizing silts, which are too fine for injection of any ordinary grouts.
- On freezing, water expands in volume by about 9% which does not itself impose any serious stresses and strains on the soil unless the water is confined within a restricted volume. With water content up to about 30% the direct soil expansion may be about 3%. Frost heave which may occur in fine silts and clays, is a slightly different phenomenon.
- In rock and clay ice lenses may build up and enlarge fine fissures so causing increase in permeability after thaw.
- If there is a flow of water through the ground to be frozen the freezing time will be **increased** by reason of the continuing supply of heat energy and, if the flow is large and the water temperature high, freezing may be completely inhibited.

- As in all ground treatment techniques, adequate site investigation is necessary to allow the best system to be chosen and to design the appropriate array of freezing tubes and select plant of adequate power.
- After the initial freezing has been completed and the frozen barrier is in place, the required refrigeration capacity is significantly reduced to maintain the frozen barrier
- Because freezing can be imposed uniformly on a wide range of soil types in a single operation, it may offer greater security in mixed ground than treatment by injection of various grouts.

Applications

- Temporary underpinning of adjacent structure and support during permanent underpinning
- Shaft sinking through water-bearing ground
- Shaft construction totally within non-cohesive saturated ground
- Tunnelling through a full face of granular soil
- Tunnelling through mixed ground
- Soil stabilisation

Once the freezing process has begun, monitoring is required to ensure formation of the barrier wall and also to verify when freezing is complete. During the drilling process, temperature-monitoring pipes are installed to measure the ground temperature. Below are the techniques for temporary support of a tunnel heading by freezing:



Freezing process

Freezing may be:

• Indirect, by circulation of a secondary coolant through tubes driven into the ground

• Direct, by circulation of the primary refrigerant fluid through the ground tubes

• Direct, by injection of a coolant into the ground, such as liquid nitrogen.

Indirect cooling

Primary refrigeration plant is used to abstract heat from a secondary coolant circulating through pipes driven into the ground. The primary refrigerant most commonly used will typically be some alternative to Freon, which due to it‟s ozone-depleting characteristics had to be phased out until 1996. Other primary refrigerants are ammonia, NH4 (–33.3°C) and carbon dioxide, CO2 – now not commonly used. The secondary coolant, circulated through the network of tubes in the ground is usually a solution of Calcium Chloride. With a concentration of 30% such as brine has a freezing point well below that of the primary coolant.

The primary refrigeration process is basically the Carnot cycle of compression and expansion reversed. The time required to freeze the ground will obviously depend on the capacity of the freezing plant in relation to the volume of ground to be frozen and on the spacing and size of freezing tubes and water content in the grounds.

DIRECT COOLING

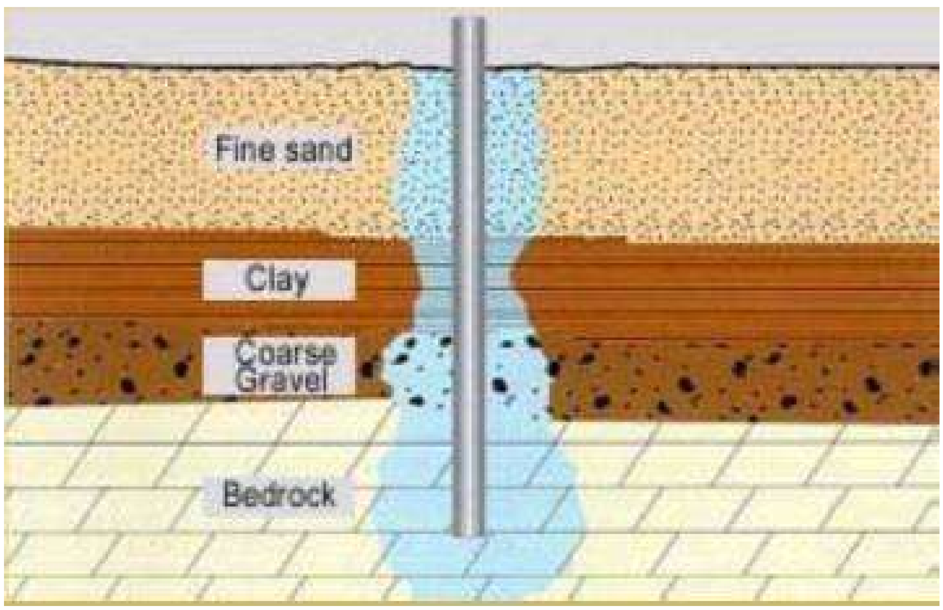
- In these systems the primary refrigerant is circulated through the system of tubes in the ground, extracting directly the latent heat, therefore having a higher efficiency than the indirect process.
- Direct freezing time is similar to that for the indirect process. The choice will depend on plant availability, estimates of cost and perhaps personal preference.

Liquid Nitrogen (LN_2)

- With this method a large portable refrigeration plant is not necessary, and the temp is much lower and therefore quicker in application. The nitrogen under moderate pressure is brought to site in insulated containers as a liquid which boils at –196°C at normal pressure and thereby effects the required cooling. It can be stored on site.
- There is a particular advantage for emergency use, i.e quick freezing without elaborate fixed plant and equipment. This may be doubly advantageous on sites remote from power supplies. In such conditions the nitrogen can be discharged directly through tubes driven into the ground, and allowed to escape to atmosphere. Precautions for adequate ventilation must be observed.

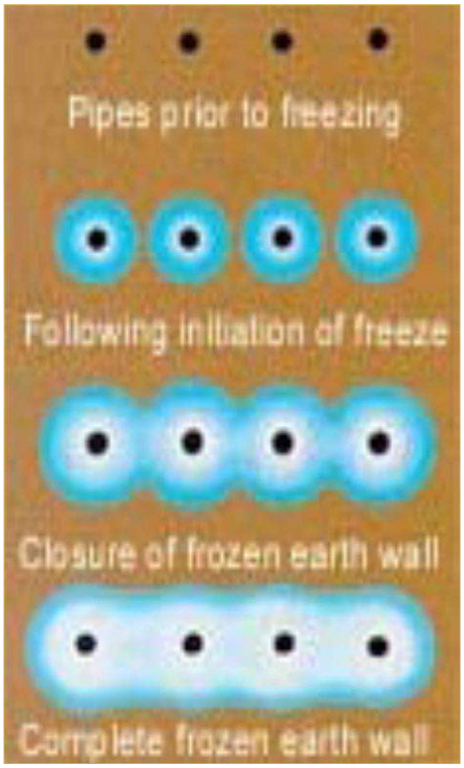
- When there is time for preparation, an array of freezing tubes is installed for the nitrogen circulation, including return pipes exhausting to atmosphere.
- The speed of ground freezing is much quicker than with other methods, days rather than weeks, but liquid nitrogen is costly.

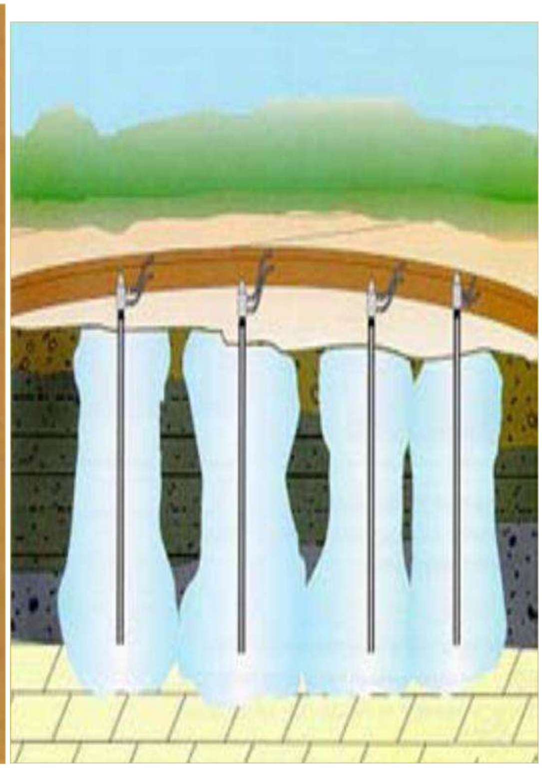
- The method is particularly appropriate for a short period of freezing up to about 3 weeks. It may be used in conjunction with the other processes with the same array of freezing tubes and network of insulated distribution pipes, in which liquid nitrogen is first used to establish the freeze quickly and is followed by ordinary refrigeration to maintain the condition while work is executed. This can be of particular help when a natural flow of ground water makes initial freezing difficult.
- The design of a frozen earth barrier is governed by the thermal properties of the underlying soils and related response to the freezing system.
- Formation of frozen earth barrier develops at different rates depending on the thermal and hydraulic properties of each stratum. Typically, rock and coarse-grained soils freeze faster than clays and silts.



- When soft clay is cooled to the freezing point, some portion of its pore water begins to freeze and clay begins to stiffen. If the temperature is further reduced, more of the pore water freezes and the strength of the clay markedly increases.
- When designing frozen earth structures in clay it may be necessary to provide for substantially lower temperatures to achieve the required strengths.
- A temperature of +20 °F may be adequate in sands, whereas temperatures as low as –20 °F may be required in soft clay.

- The frozen earth first forms in the shape of vertical cylinders surrounding the freeze pipes.
- As cylinders gradually enlarge they intersect, forming a continuous wall.

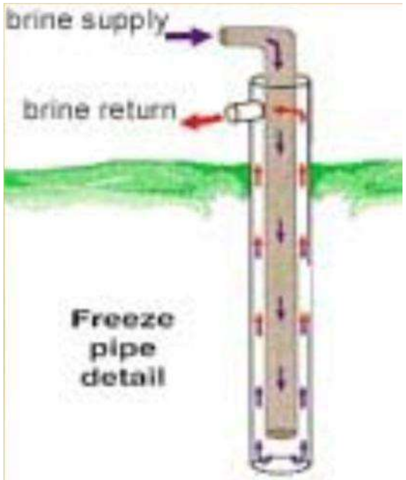


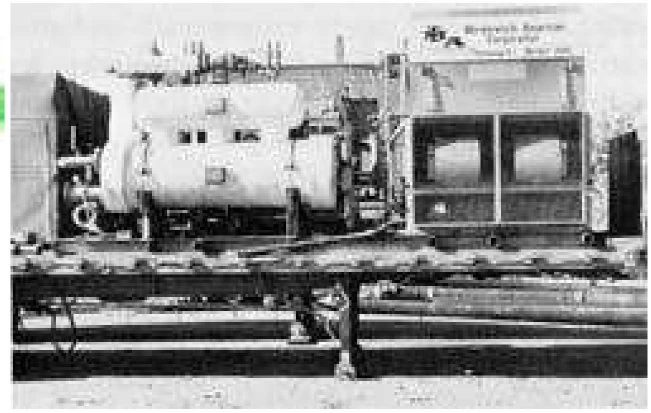


- If the heat extraction is continued at a high rate, the thickness of the frozen wall will expand with time.
- Once the wall has achieved its design thickness, the freeze plant is operated at a reduced rate to remove the heat flowing toward the wall, to maintain the condition.

Freezing Equipment and Methods

- The most common freezing method is by circulating brine (a strong saline solution – as of calcium chloride).
- Chilled brine is pumped down a drop tube to the bottom of the freeze pipe and flows up the pipe, drawing heat from the soil.





Technology finds application in the following construction projects:

•Underpinning

•Tunnel roof freezing

•Freezing of cross-cuts in tunnel tubes

•Clearing out of tunnel fall-ins

•Forcing of framework constructions into railway
embankments

•Foundation skirting

•Removal of intact soil samples

•Rehabilitation measures