10 Foundation Soil Improvements

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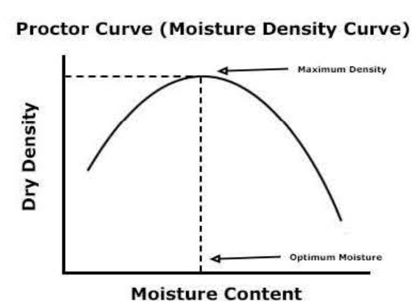
10.1 Introduction

- Alternation of any property of the soil to improve its engineering performance.
- Involves procedures or steps to increase the shear strength and decrease the compressibility of the soil so that the bearing capacity of the soil is increased and the settlement is reduced.
- Involves the following:
  - Increasing the shear strength.
  - Reducing permeability.
  - Reducing compressibility.
- **Methods are:** Mechanical Compaction, Dynamic Compaction, Preloading, sand and stone columns, use of admixtures, injection of suitable grouts, etc.
- Process of improvement of soil engineering properties and making it more stable.
- Required when the soil available for construction is not suitable for intended purpose.

10.2 Mechanical Compaction

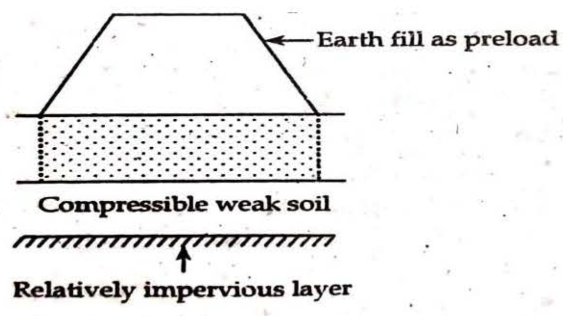
- Process of increasing the density of soil by the application of mechanical energy as temping, rolling and vibration.
- Reduction in air voids of soil thereby causing decrease in volume of soil.
- Purpose of mechanical compaction includes:
  - To increase shear strength
  - To reduce compressibility
  - To reduce permeability
  - To control swelling and shrinkage



- ➢ To obtain maximum dry density at optimum moisture content (OMC)
- ➢ To reduce liquefaction potential
- ➢ For cohesive and moderately cohesive soil, OMC should be determined and compaction should to done at or near OMC to achieve maximum dry density of soil with sheep-footed rollers.
- ➢ For cohesionless soil, compaction can be best achieved by means of vibrations using vibratory rollers.

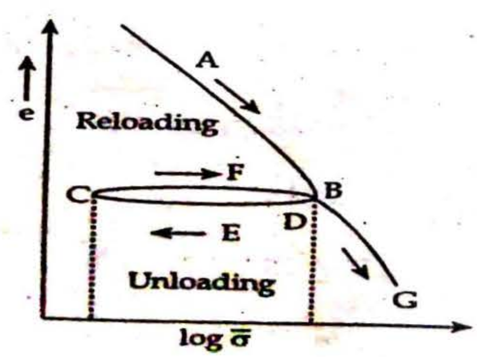
10.3 Preloading

- The modification of soil by applying the compressive load on site of intensity equal or greater than the possible load of proposed structure before the construction of corresponding structure is known as **preloading or precompression or surcharging**.
- Generally used for soft clays and silty soils.
- The purpose of preloading includes:
  - ➢ To ensure enough settlement of soil before construction so that settlement of soil after construction is within permissible limit.



  - ➢ To increase the bearing capacity of soil at site so that performance of proposed foundation can be improved or deep foundation can be replaced by cheaper shallow foundation.

- Can be described by using Consolidation Theory as follows:
  - ➢ The surcharge fill is kept on the ground for a long time to cause consolidation of the soil in the ground. The height of the surcharge fill varies from 3 to 10 m in most cases.



- The surcharge fill should extend beyond the perimeter of the site of construction by at least 10m on all sides so that uniform compression of the soil at the site of construction occurs.
- The principle of precompression can be explained as:
    - The effect of loading, unloading and reloading of the soil is explained with the help of figure.
    - The curve AB indicates the decrease in the void ratio of the soil during initial loading.
    - The curve BEC shows the increase in the void ratio during unloading.
    - The curve CFD indicates the decrease in the void ratio when the soil is reloaded.
    - It is observed that the decrease in the void ratio during reloading is much less than the decrease in the void ratio during initial loading from A to B.
    - During precompression, when the surcharge fill is applied to the soil in the field, the soil follows the initial loading curve AB.
    - When the surcharge fill is removed, unloading occurs along BEC.
    - When the foundation is constructed on the pre-compressed soil, the reloading occurs along the curve CFD.
    - The decrease in the void ratio during reloading is considerably smaller than that in the soil in initial loading.
    - The soil properties are also improved, the compressibility of the soil is decreased. Thus, the settlement of the structure will be decreased. Moreover, the shear strength of the soil is increased and hence the bearing capacity of the soil is improved.
    - The pre-compressed soil behaves as an over-consolidated soil.

Advantages of Preloading

- Simple and convenient
- The method is inexpensive if the soil required for surcharge fill is available in the vicinity of the site

- Precompression ensures uniformity of improvement of the ground because it eliminates local inhomogeneities and weak spots.
- The progress of consolidation of the soil can be easily monitored by installing simple settlement plates and piezometers.
- Improves shear strength of soil which results in improved bearing capacity.

Disadvantages of Preloading

- Time of consolidation is very long (If the construction of the structure cannot be delayed that long, other methods of constructions are adopted).
- The method requires a large space around the site of construction to raise surcharge fill. If the site is in congested area, the method cannot be used.
- The method is expensive if suitable material for surcharge fill is not easily available at low cost.

10.4 Sand compaction piles and stone columns

Sand compaction piles

- Cohesionless soils can be densified by installing compaction piles.
- For construction of a compaction pile at the site, a close-ended, hollow tubular pipe is first driven into the ground. The loose soil surrounding the pipe is compacted due to vibration during its driving.
- The pipe is then extracted and the hole is backfilled with sand to form a compaction pile.
- Compaction piles are constructed at several locations on a grid pattern. Thus, a uniform deposit much denser than the original soil is formed.
- The radius of influence around the compaction pile in which the sand is densified depends upon the diameter of the pile. The radius of influence is about 3 to 4 times the pile diameter.

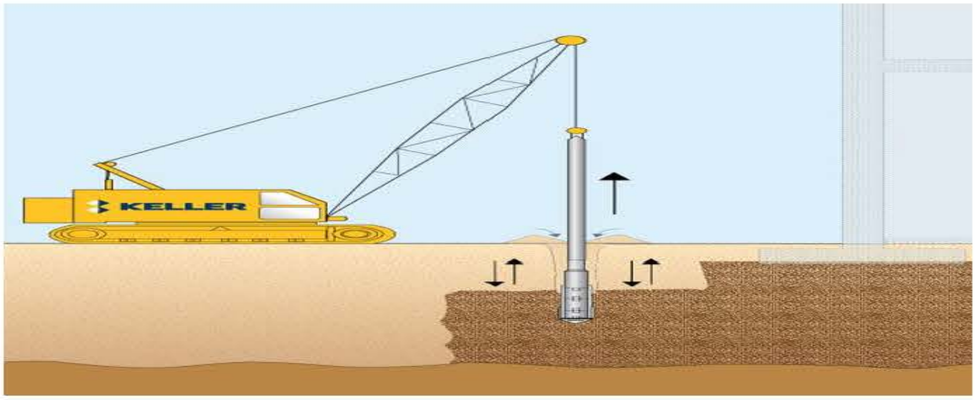


Fig: Sand compaction piles

Stone columns

- Stone columns are used for soft clays.
- Stone columns are constructed by making holes in the deposit and then filling these holes with gravel (or small stones) of size 6 to 40 mm.
- For making a hole in the soil deposit, a vibroflot is used.
- A vibroflot consists of a cylindrical tube, about 2 to 3m long and 300 to 500 mm in diameter, fitted with jets at the bottom and at the top.
- A rotating eccentric mass inside the vibroflot causes a horizontal vibratory motion.
- The vibroflot is sunk into the clay deposit using the lower water jets. The hole should extend up to a firm stratum below.
- The gravel is then filled into the hole and densified by vibroflot as it is taken out. Thus, a stone column is formed. The required number of stone columns are constructed.
- The spacing of the stone columns is generally between 1.5 to 3 m centre to centre. The diameter of the stone columns is usually 0.5 to 0.75 m.

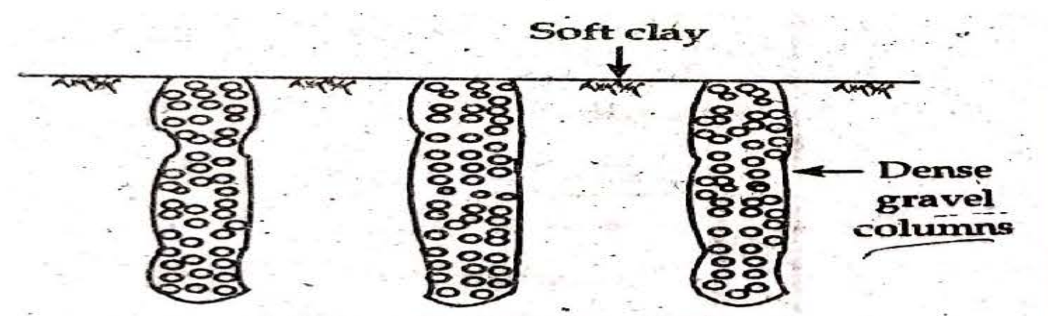


Figure: Stone column

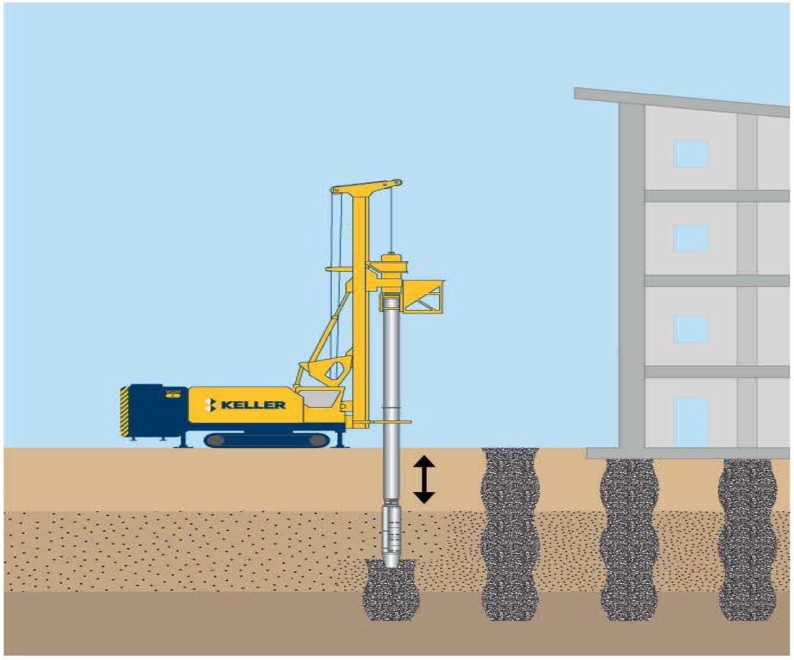


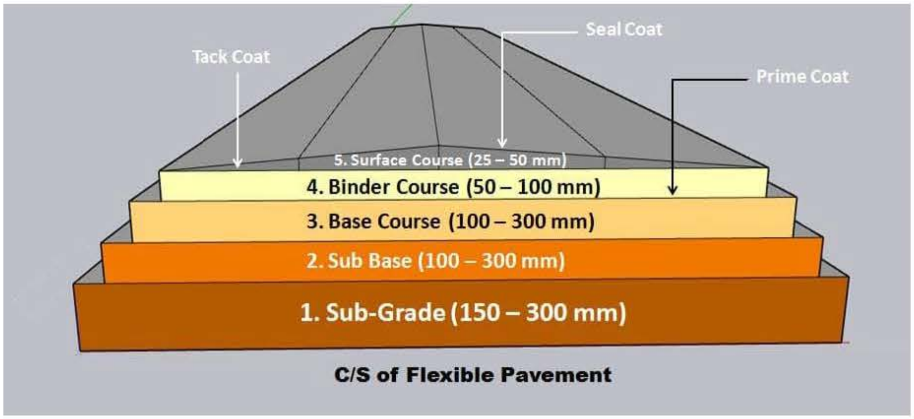
Fig: Stone Columns

Fig: Vibroflot

10.5 Soil stabilization by the use of admixtures

- The process of improving engineering properties of soil is known as stabilization.
- Due to stabilization, the soil becomes more stable by the reduction in permeability and compressibility. Hence, shear strength of soil is increased.

- Widely used admixtures are lime, cement and bitumen giving rise to lime stabilization, cement stabilization and bitumen stabilization respectively.
- These methods are applicable only for shallow foundation or base courses of roads.



Soil Lime Stabilization

- Soil is stabilized by using lime.
- Improves strength, stiffness and durability of fine-grained materials.
- Used as a stabilizer for base course of pavement system.
- Lime produces a decrease in plasticity Index of soil and also reduces Swelling Index of clayey soils.
- The lime required for stabilization varies between 2% to 10%.

Fig: Soil Lime Stabilization

Soil Cement Stabilization

- In cement stabilization, pulverized soils and cement in suitable proportion are mixed with water and the resulting mixture is compacted by compacting equipment such as rollers by maintaining Optimum Moisture Content (OMC)
- The material obtained by mixing cement and soil is called soil-cement.
- When cement hydrates and develops strength, the soil – cement becomes a hard and durable structural material.
- It is used to increase strength, durability and minimize moisture variations in soil.
- It is used in sub- base of roads and for lining irrigation canals.
- The cement required for stabilization depends upon graduation of soil.
    - Well – graded soil (5%)
    - Poorly – graded (9%)
    - Uniform soil (9%)
    - Plastic Clay (13%)

Fig: Soil Cement Stabilization

Bituminous Stabilization

- Bituminous materials such as asphalts and tars are used to improve engineering properties of soil.
- In cohesive soil, asphalt acts as a binder and water proofing agent. Hence, improves bearing capacity and soil strength at low moisture content.
- In Cohesionless soil (Sands), it acts as a cementing agent and produces a stronger, more coherent mass.
- It is used in surface course or base or sub – base courses of roads for stabilizing soils.
- Amount of bitumen required for stabilization:
  - Cohesive soil = 4% to 7%
  - Cohesionless soil = 4% to 10%

Fig: Bituminous Stabilization

Mechanical Stabilization

- The change in gradation of original soil stabilizes the soil.
- The soils are grouped into two categories:
  - Aggregates (Sands and Gravels)

- Binders (Silts and Clays)

- When different soils are mixed together in definite proportion, a soil possessing required internal friction and cohesion is obtained.
- When properly placed and compacted, the material becomes mechanically stable.
- Generally used to improve sub-grade of low bearing capacity.
- Used in construction of bases, sub – bases and surfacing of roads.

Fig: Mixing various sized aggregate for mechanical stabilization

10.6 Soil stabilization by injection of suitable grouts

- Grouting is the process by which fluid like materials, either in suspension or in solution form, is injected into the voids of the underground soil or rock, and is allowed to solidify.
- Helps in reducing voids and hence increase in bearing capacity of the soil
- Reduce in permeability of soil.
- Grouting is beneficial (effective) in following situations:
  - When construction works are to be carried below ground water table, grouting has better performance than dewatering.
  - When access to foundation level is difficult. Examples are city works, tunnel shafts, sewers and subway construction.
  - When foundation comprises many boundaries and contact zones with complicated dimensions as in case of dams.

- When adjacent structures require that soil cannot be excavated. For example, extension of existing foundation into deeper layers.

- **There are mainly two types of grouts – cement grout (Grouting in suspension) and chemical grout (Grouting in solution).**
- Cement grout is formed by adding water to cement and making a slurry that hydrates after it has been injected into the ground. Thus, a solid mass is formed around the point of injection.
- Chemical grout contains chemicals such as silicates and resins.
- Chemical grouts are used for injecting into fine sand or silt deposits because cement grout is not effective for such soils.
- Chemical grouts are quite expensive and are used only in special cases. Moreover, chemical grouts can be toxic and corrosive.

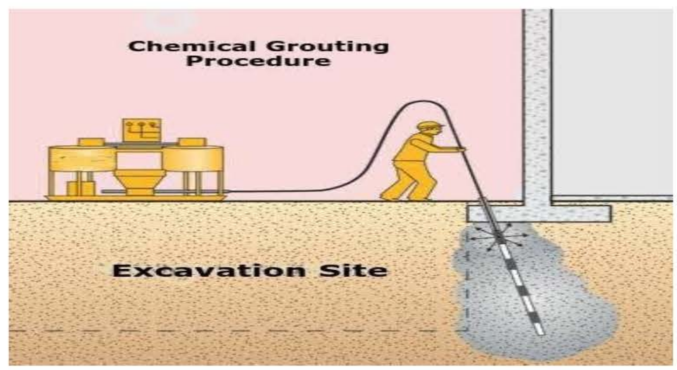


Fig: Cement Grouting and Chemical Grouting

Intrusion Grouting

- Joints and fractures in rocks or soils are filled by injecting grout into them.
- The pipes are first inserted into the ground from the surface. Sometimes, the pipes are inserted from tunnels or other openings in the ground.
- The grout is then injected by pumping it into the pipes.
- The main advantage of intrusion grouting is that the permeability of the rock or the soil deposit is decreased.
- The method is commonly used for the foundation of water-retaining structures such as dams, to reduce that seepage.

Permeation Grouting

- Injection of thin grouts **into the soil.**
- Once the soil cures, becomes a **solid mass.**
- Done using **chemical grouts.**
- Used for creating **groundwater barriers** or **preparing ground before tunneling.**

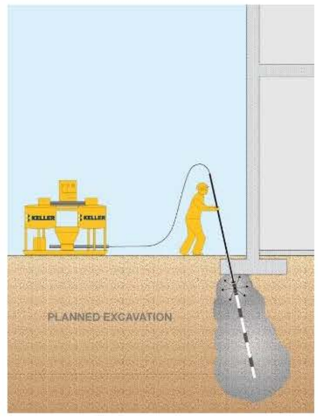


Fig: Permeation Grouting

Jet Grouting [Developed in Japan]

- Uses a special pipe with horizontal jets that inject grout into the ground at **high pressures.**
- Jet grouting is an erosion/replacement system that creates an engineered, in situ soil/cement product known as **Soilcrete^{sm}.**
- Effective across the **widest range of soil types**, and capable of being performed around **subsurface obstructions** and in confined spaces.
- jet grouting is a versatile and valuable tool for **soft soil stabilization**, underpinning, excavation support and groundwater control.

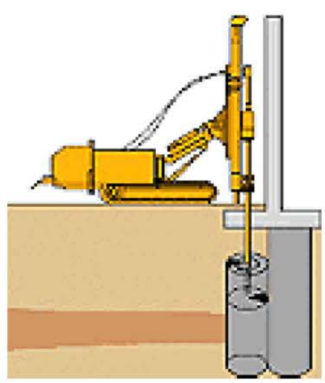


Fig: Jet Grouting

Compaction Grouting

- Compaction grouting is also called displacement grouting.
- In this method, a thin grout is injected into the ground under a high pressure through a pipe to form a series of intrusions in the deposit.
- The main effect of the grout in the deposit is to compact the adjacent soil. Consequently, the strength of the soil is increased.
- When low-slump compaction grout is injected into granular soils, **grout bulbs** are formed that displace and densify the surrounding loose soils
- Used to **repair structures** that have excessive settlement
- The compaction grouting method is particularly well suited 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.

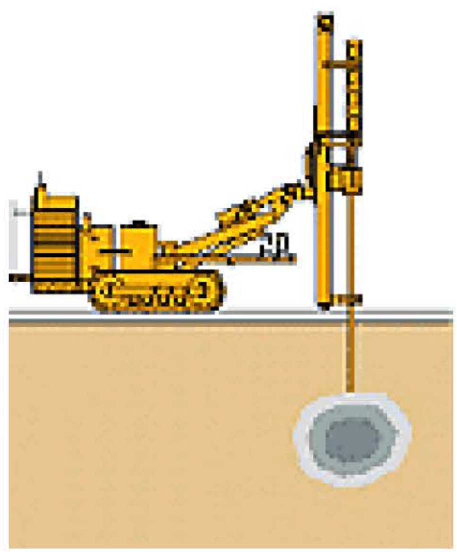
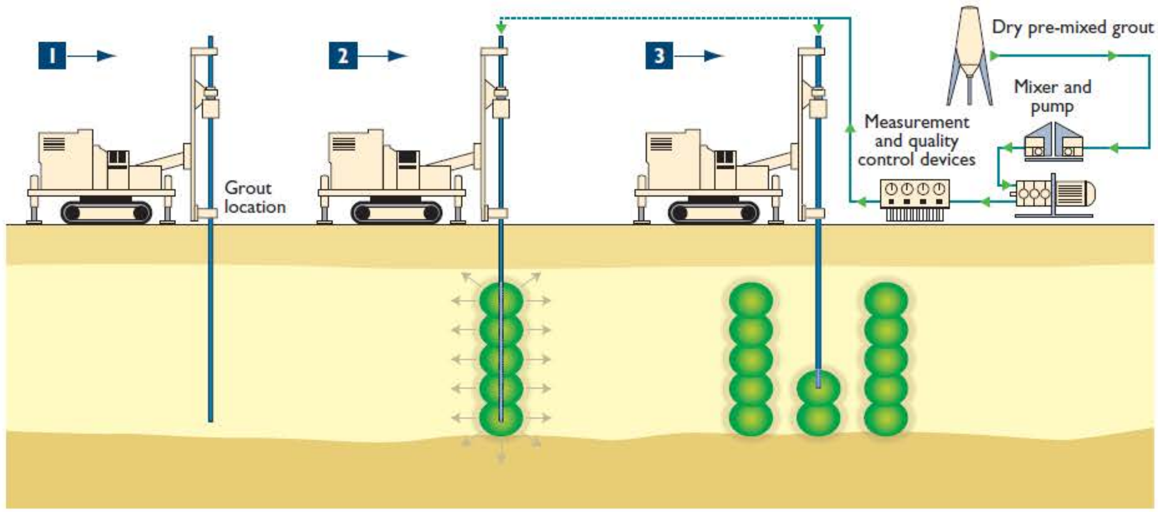


Fig: Compaction Grouting



1 Installation of the Grout Pipe
The grout pipe is either installed by means of a drill rig or a vibro hammer, depending on the soil and on the treatment requirements.

2 Compaction Grouting
The grout paste is prepared in the mixing plant and pressed into the soil by means of a custom-built grout pump.
While gradually pulling or penetrating the grout pipes, individual intersecting grout bulbs are consecutively formed, thus creating column shaped structural elements.

3 Staged Compaction
In order to achieve a uniform compaction of the soil, the injections are at first executed in a large primary grid, and may be compacted further by means of a secondary grid.

Ultra-Fine Cement Grouting

- Uses micro-fine cément (Particle size ranges from 1 to 10 microns) can penetrate fine sand.
- Used to increase bearing capacity of sand under existing footings and/or reduce potential settlement
- Can be used to retain shallow excavation in loose sand.
- Unconfined compressive strength can exceed 100 psi.