Chapter 12 - Foundation Grouting

12. Foundation Grouting

12.1. Introduction:

The construction of structures on weak ground often requires the soil to be improved in order to ensure the safety and the stability of surrounding buildings. Although large deposits of rocks (الترسبات الصخرية الكبيرة) are referred to as solid rocks, in many instances they are not solid. They may contain fissures, cavities or breaks, which make the deposits unsuitable for dams, reservoirs, buildings, bridge piers, etc.

When subsurface investigations of a site disclose the existence of such structural defects, it is necessary to adopt corrective steps to make the formation suitable for the intended use. If the correction is impossible, or expensive, it may be necessary to abandon the site.

An operation to correct the foundation conditions is called Grouting.

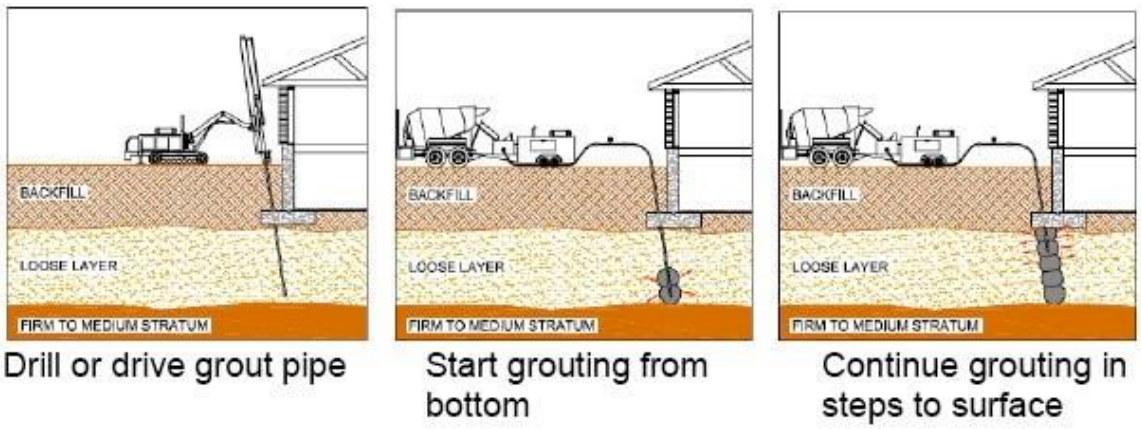

Figure (12.1) – Foundation Grouting

Grouting, as applied to civil and geotechnical construction, involves the injection under pressure of a liquid or suspension into the voids of a soil or rock mass or into voids between the soil or rock mass and an existing structure. The injected grout must eventually form either a solid or gel within the injected voids.

Since first usage in the 19th century, grouting has been performed on the foundation of large dams or other structures, in order to reduce the amount of leakage through the rock, and to strengthen the foundation to support the weight of the overlying structure. Therefore, the purpose of grouting can be either to

improve the strength and durability of a formation or reduce water flow through it (reduce its permeability).

The formation under or adjacent to a structure is grouted for several reasons, such as:

1) To solidify and strengthen the formation in order to increase its capacity to support a load.
2) To reduce or eliminate the flow of water through a formation, such as under a dam or into a tunnel.
3) To reduce the hydrostatic uplift under a dam.

12.2. Exploring to Determine the Need for Grouting:

- The most satisfactory method of determining whether a formation should be grouted is to obtain ***core samples*** from representative locations within the formation area.
- Cores may be obtained with diamond drill (for smaller sizes) and shot drills (for larger sizes). The shot-drilled holes may be 30 in (75 cm) in diameter, so that a man may be lowered into them for visual inspection of the formation.
- The size, number, depth and spacing of the exploratory holes should be planned to provide the greatest amount of information for the lowest practical cost.
- Increasing the number of holes will provide more dependable information, but it will increase the cost of exploration.
- An accurate record should be kept for each exploratory hole, showing the location, size and depth of the hole, with the core recovered, should show the physical nature of the formation.
- If a core is recovered in long, continuous pieces, with little loss in length compared with the depth of the hole, this indicates a solid formation that requires little or no grouting.
- If the core recovered is badly broken, and its length is small in proportion to the depth of the hole, this indicates bad formation condition that requires a large quantity of grout.

12.3. Material Used for Grouting:

The commonly used materials for grouting include:

1) Cement and water.
2) Cement, rock flour and water.

3) Cement, clay, sand and water.
4) Asphalt.
5) Chemicals.

– If cement and water is used as a grouting material to be injected into seams, the ratio will vary from 1 to 2 parts of water to 1 part of cement.
– Rock flour and clay may be added to cement grout in the interest of economy if the seams are small, while sand may be added if the seams are large enough to permit the sand to penetrate.
– ***Grout made of neat cement will give a higher strength than grout containing clay or sand.***

12.4. Types of Grouting:

Grouting is a valuable tool in the field of construction and the type of grouting chosen should be determined by an evaluation of the aspects of a problem including engineering needs, subsurface conditions, materials available, and economic considerations. Some of the types of grouting done may include:

1) Pressure grouting.
2) Compaction grouting.
3) Chemical grouting.
4) Jet grouting.

12.4.1. Pressure Grouting:

Pressure grouting involves injecting a **grout material** into generally isolated pore or void space of which neither the configuration nor volume are known, and is often referred to simply as ***grouting***. The grout may be a cementitious, resinous, or solution chemical mixture.

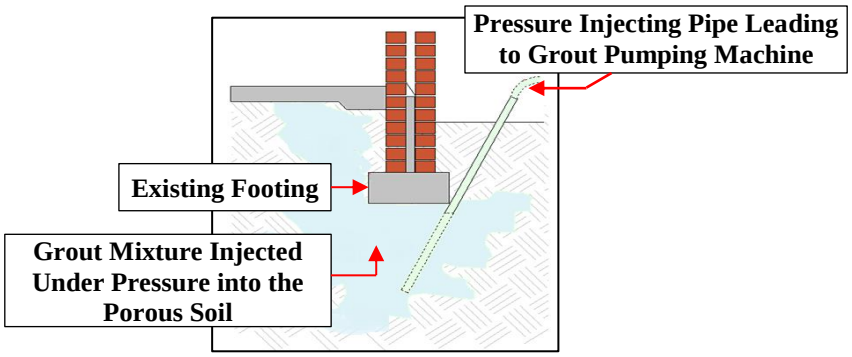

Figure (12.2) – Pressure Grouting

12.4.2. Compaction Grouting:

Compaction grouting is a cost effective technique for the re-compaction and stabilization of sub-soils to greater depths than economically feasible with traditional methods. Depths of (25-75) feet (7-23) meters are not uncommon. Often, soil problems can be traced to poorly compacted fill, loose soils, infiltration of water, and failure to over excavate and re-compact a building site properly.

Compaction Grouting has been found to reduce the possible damage of liquefaction of soils during seismic events. This technique uses a clear low slump grout that can be pumped slowly under high pressure into the soils with predictable results that will densify and re-compact the soils.

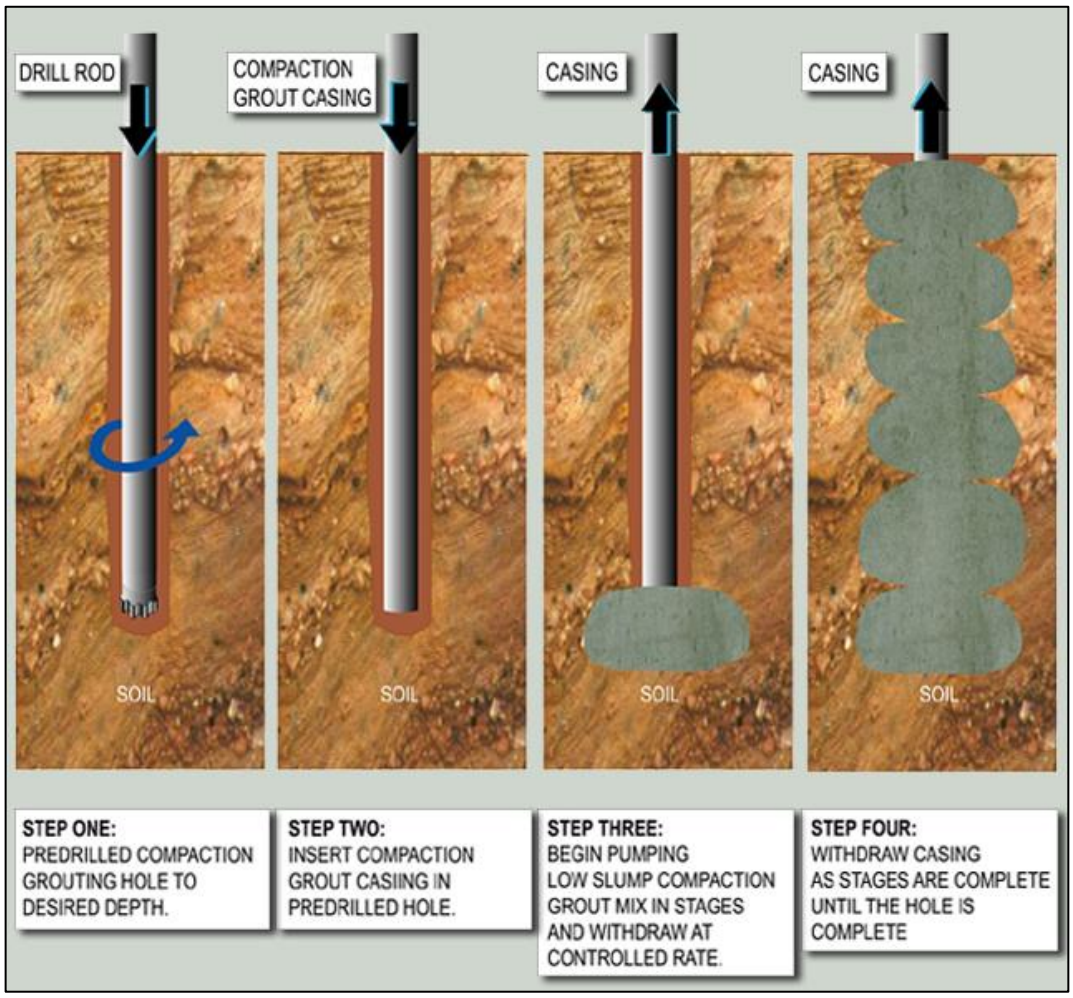

Figure (12.3) – Compaction Grouting

12.4.3. Chemical Grouting:

One of the pioneering techniques in the use of grouting technologies is chemical grouting, which uses formulations that react after a set time to form a gel to fill voids in the soil with chemical solutions Chemicals are mixed with water and

reagents, such as sodium silicates. Sodium Silicate is most commonly used for strength. Because the ingredients are fluids they do not have particles (such as cement) to restrict flow through fine voids.

Chemical grouting is commonly used in granular soils with significant fine sand content to stiffen the ground and prevent excessive movement, to lower the permeability of the soil to prevent excessive water inflows, and to underpin adjacent buildings and other facilities in advance of the tunnel excavation.

One of the advantages of chemical grouting is the ability to introduce grout into soil pores without any essential change in the original soil volume and structure. Another advantage is the ability to be less disruptive and enable tunneling to proceed without over-excavation.

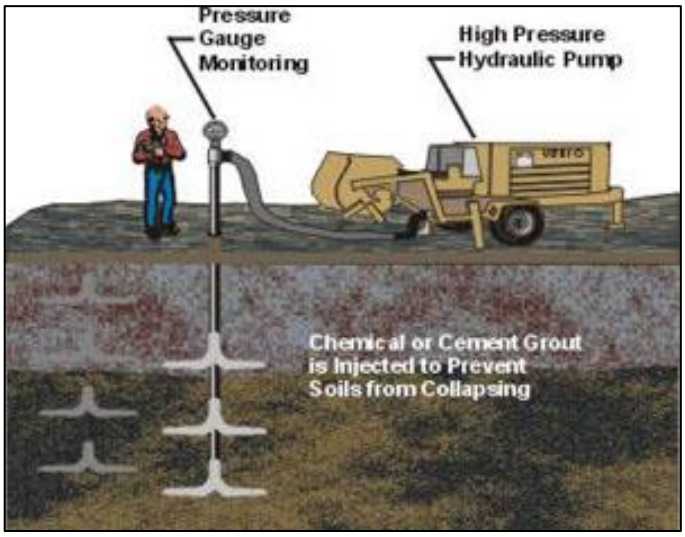

Figure (12.4) – Chemical Grouting

12.4.4. Jet Grouting:

Jet grouting is an in-situ construction technique used to improve the mechanical characteristics of a soil, using a grouting monitor attached to the end of a drill stem. The jet grout monitor is advanced to the maximum treatment depth, at which time high velocity grout jets (and sometimes water and air) are initiated from ports in the side of the monitor. The jets erode and mix the in situ soil as the drill stem and jet grout monitor are rotated and raised.

The technique is used in situations where increased stability and bearing capacity or decreased permeability is required. Because of its design flexibility, jet grouting is an important alternative to more traditional grouting methods.

Depending on the application and soils to be treated, one of three variations is used: the single fluid system (***slurry grout jet***), the double fluid system (***slurry***

grout jet surrounded by an air jet) and the triple fluid system (***water jet surrounded by an air jet, with a lower grout jet***). Jet grouting has been used to underpin existing foundations and construct excavation support walls.

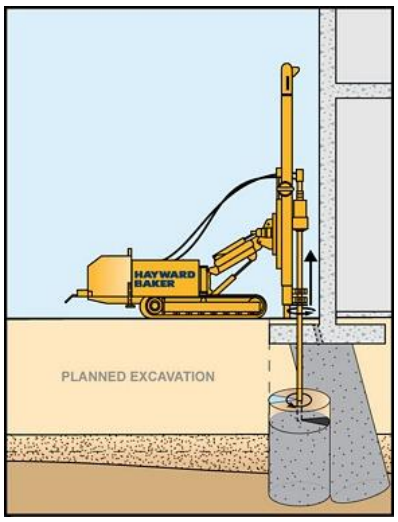

Figure (12.5) – Jet Grouting

12.5. Drilling Patterns:

After a formation has been explored and tested to determine the extent of grouting required, a drilling pattern should be adopted.

- The size, depth and spacing of injection holes should give the best results at the lowest cost.
- It may be necessary to change the drilling pattern if the grouting operations encounter differences in formation conditions.
- Smallest holes that permit the injection of grout are the most desirable, because of their lower cost.

12.6. Drilling Injection Holes:

Holes for the injection of grout may be drilled with:

1. Jackhammers.
2. Wagon drills.
3. Diamond drills or shot drills.

Type of drilling machines depends on:

1. The terrain.
2. Class of formation material.
3. Size and depth of holes.

Diamond drills usually give holes that are uniform in shape and size, which are more satisfactory than holes drilled by other equipment.
Wagon drills are satisfactory for holes whose depths do not exceed (12 m).

12.7. Preparation for Grouting:

The preparation for washing or grouting seams consists of the following:

1. Installing a section of a pipe usually (38-50) mm in diameter and (0.45-0.9) m long, in the grout hole.
2. The top end of the pipe projects out a short distance for connection to an air tube or a pump.
3. The space around the bottom of the pipe is closed with oakum or other suitable material.
4. The balance of space is filled with cement mortar.
5. In order to reduce the danger of weakening the formation through fractures resulting from the application of excessive pressure, uplift gauges should be installed at several locations over the area to detect any lifting of the surface during the grouting operation.

12.8. Washing the Seams:

- When a formation is grouted with neat cement for consolidation purposes, it is desirable to deposit the cement in clean seams from which any clay or unconsolidated materials have been removed. The most effective method of removing such materials is to force a mixture of air and water through the seams.
- The removal of materials may be made more effective by alternately reversing the direction of flow of the air and water.
- It is possible to determine whether a seam is open from one hole to others by injecting water containing a coloring agent, such as fluorescein dye, if the colored water appears from other holes, this indicates open passages through the seam.
- Washing a formation is done as follows:
    1. A pattern of holes is selected.
    2. Some of the holes are capped for water, some for compressed air, and others are left open to permit the outflow of the washed materials.
    3. The direction of flow may be reversed by interchanging the pipe caps.

4. When the water flowing from the uncapped holes clears up, indicating the removal of the unconsolidated materials, the caps are removed to another pattern of holes.

- If the grout holes are deep and pass through several seams of unconsolidated materials, it may be desirable to isolate each seam in order that it may be washed individually. This is done as follows:
  1. By using injection pipe, with the lower end closed.
  2. The pipe is sufficiently long to extend below the lowest seam,
  3. The pipe has a perforated section long enough to extend completely through the seam.
  4. The pipe is equipped with an expandable packer above and below the perforated section, which is set opposite the seam to be washed.
  5. When the injection pipe is lowered into a hole and the packers are expanded, any air or water delivered to the pipe will be confined to a single seam.

12.9. Grouting Pressure:

- It is difficult to determine, in advance, the suitable pressure for grouting operations.
- Some engineers follow a general practice of using a pressure of 1 psi for each foot of depth of hole, (22.6 kN/m^2 for each meter of depth of hole), but there is no logical proof that this is the most satisfactory pressure.
- In the interest of economy and effectiveness it is desirable to use the highest pressure that is safe.
- When grout is forced into a seam under pressure, it is possible that the total upward force on the formation above the seam may exceed the combined weight and resisting strength of the formation. In such situation, the entire formation may be lifted upward, resulting in a fracture that is more serious than the original condition that grouting is supposed to correct.
- Thus, it is possible that grouting may do more harm than good unless it is injected under careful supervision.
- The pressure at which grout is injected varies with ***the depth of injection*** and ***the stage at which the grout is injected***.

12.10. Equipment for Cement Grouting:

The most common method of injecting cement grout is to use piston-type pumps to produce the necessary pressure.

The pumps are air-driven duplex double-acting types, constructed in a way that the number of strokes per minute and the pressure on the grout may be varied regulating the quantity of compressed air supplied to the pump.

The equipment will include:

1) One or more air compressor.
2) One or two grout mixer.
3) One agitator-type reservoir tank.
4) One or more grout pumps.
5) Grout discharge pipe or hose, valves, pressure gauges, etc.

- The grout mixer contains a shaft with paddles, operated by a motor. After the grout is mixed, it is discharged into a tank, with an agitator to prevent separation of the solids from the water. The pumps draw their charges directly from the agitator tank.
- The grout discharge line may be a pipe, a rubber hose or a combination of both.
- The use of a hose will facilitate moving from one hole to another.
- It is good practice to install two grout pumps even though one pump can supply all the grout needed.
- In the event of a pump failure, the auxiliary pump can be placed in operation immediately, thereby reducing the danger of losing a partly filled hole or group of holes.

12.11. Injecting Cement Grout:

- The records kept at the time of drilling the grout holes, together with the records obtained should serve as a guide in estimating the grout mix to use.
- The best results are obtained by using the thickest grout that can be injected without plugging the hole.
- It may be necessary to start with a batch of thin grout, and then thicken the batch by reducing the water-cement ratio until the maximum practical thickness is determined.

- The specifications covering the grouting of a project may require the injection of grout at a given pressure until the rate of injection for a given hole shall diminish to a specified amount or until a hole will not take any more grout at a specified pressure.
- Grout may be injected into the full length of a hole at one time.
- It may be injected into a portion of length only; this is referred to as ***the zone method of grouting***.
- If the zone method of grouting is used, it is possible to apply high pressure in injecting at the bottom of the hole.
- As the depth of injection is reduced, the pressure may be reduced accordingly.
- In order to inject grout by the zone method, it is necessary to use an injection pipe that is long enough to reach the lowest zone of injection.

12.12. Pressure Grouting with Asphalt:

- If a formation contains fissures with water flowing through them, it will be difficult or impossible to consolidate the formation with cement grout.
- The velocity of water tends to sweep the grout through the openings without giving it an opportunity to solidify.
- Therefore, injecting asphalt grout into fissures containing flowing water may seal those fissures and stop or reduce the flow of water.
- After the flow of water is stopped, it is possible to inject cement grout to complete the consolidation operation.
- The primary function of asphalt is to seal off the flow of water in order that cement grout may be retained in the fissures.
- The heated asphalt is injected through a perforated pipe.
- The pipe may have a steam line running through it, to keep the asphalt at the desired temperature until it flows into the formation.
- Another method for heating the asphalt in the injection pipe is to install an electric wire inside the pipe; an electric current passing through the wire will heat the asphalt.
- The equipment required to inject asphalt grout consists of a heating kettle, a piston-type pump, an air compressor or an electric motor to operate the pump, a source of electric current, pipes or hoses, valves and pressure gauges.

12.13. Chemical Grouting:

As previously mentioned in article (12.4.3) the chemical method has several advantages compared with other methods, such as the following:

1) Because it is a liquid it can be pumped into and through small openings.
2) Fewer grout holes are required.
3) Time required to inject the chemicals is usually less than other grouting materials.

If a formation to be grouted is highly porous, with large voids, preliminary grouting should be done using such materials as cement, a mixer of cement and clay, to reduce the rate of flow of water to approximately 10% of the initial rate. Then the final grouting with chemicals can be done.

12.14. Determining the Effectiveness of Grouting:

A question that usually arises in connection with a grouting operation is how to determine whether the operation has been successful. Several methods have been used with varying degrees of success.

Prior to concluding a grouting operation, additional exploratory holes may be drilled at various locations within the area that has been grouted in order to obtain cores from the formation. If these cores show the existence of sufficient grout to produce good consolidation where voids originally existed, this indicates that the grout operation has been successful.

The effectiveness of the grouting operation may be tested by injecting water or grout into the holes from which the cores were obtained. If these holes refuse to take grout, the test indicates that the formation has been consolidated adequately by previous injections.