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SOIL IMPROVEMENT METHODS

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ABSTRACT

When choosing a specific location to build a building. Usually when a particular building is to be constructed, which leads to problems in the design of the foundations, whether economically or expose the foundations in the future to problems of settlement in the soil layer. And because some areas in our country (Iraq) have problems of poor soil, so came the idea of this research

Keywords: Soil, buiding, construction etc.

1. INTRODUCTION

When choosing a specific location to build a building, soil problems appear in terms of soil tolerance and Sudden settlement or long-term settlement, which leads to problems in the design of the foundations, whether economically or expose the foundations in the future to problems of settlement in the soil layer

Especially the differential settlement, which leads to the generation of high bending torque in the foundations system leads to its failure and thus the occurrence of collapse or settlement of the entire building below normal ground level, as happened in several famous incidents of buildings in various locations in the world.

And because some areas in our country (Iraq) have problems of poor soil, so came the idea of this research It is an expansion of a lesson delivered by Prof. Dr. Sabah Rizouki at the National Center for laboratories and structural examinations, which we expanded by adding information from some sources and web locations in order to provide the structural designer with modern methods, which are considered economic solutions to overcome the problems of soil in the construction of large buildings, Especially as our country is ahead of the stage of reconstruction and large investment projects that need these ideas or modern economic alternatives.

Soil improvement method

Usually when a particular building is to be constructed, the right location is chosen for this building and then start conducting soil tests and investigations of the location to know the properties of the soil in terms of type and depth of the layer and its bearing in case it is known that the soil is weak or unable to withstand the forces The appropriate way to solve this problem should be chosen.

2. STEPS TO SOLVE THE PROBLEM

1. When constructing large projects such as airports and dams, it is expensive to improve the soil and it is better to choose a location with good soil without improvement (i.e., if the location of the building can be changed)
An example is the Mosul Dam, which is built on gypsum soil, so that the soil always needs to be ground-based (grouting).
2. Raise the bad layer of soil and place in its place a curled gravel (subbase)
but This method will be so expensive especially for large spaces.
3. Use the Deep Foundation method:-
This method depends on Pile Foundation or Caisson Foundation
To get to the strong layer that can hold the building.
But This is an expensive process because it requires specialized equipment and Specialized workers in this field.
4. Improve the soil in the same Location:-
This optimization method is used to obtain high bearing strength for soil
Using several methods such as compaction, Reduce settlement, Reduce differential settlement, Reduce permeability (reducing water loss by injection using clay or cement sand)

Methods of soil improvement depending on its location

Soil improvement methods are often used depending on its location for their effectiveness and low cost of such methods: -
These are some Methods
1. Compaction: It is the process of mechanical stabilization of the soil and this method is used for soils with shallow depths to reduce the likelihood of settlement.

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2. Preloading and surcharging: This is done by loading the soil with either dirt or any heavy materials to settle the soil.
3. vertical drains: It is a method that deliberately exits the water by using of vertical drains to accelerate the consolidation of the soil.
4. Electro-osmosis method: This is done using a direct electric current to reduce soil water content (moisture content).
5. The modern French method (dynamic consolidating).
6. Stone columns method: This is done by partially replacing the soil by digging (bore holes) and then filling with gravel it will be like a gravel pile.
7. Grouting: It is used in archaeological projects where mud is mixed with cement when the water level is low.
8. Soil Stabilization with additives

These are some additives Used to Soil Stabilization

- Cement
- Lime
- Lime + cement
- Asphalt
- Direct fibers geogrids and geotextiles
- Metallic powder

9. Freezing the water inside the soil to Less than zero (- 30C) to avoid the phenomenon of Creep that leads to failure.

The following is a simplified explanation of some methods of soil improvement depending on its location and according to modern technologies available in different countries of the world.

3. VIBRO FLOTATION TECHNIQUE

This technique is used to improve the thick layers of weak sandy soils located at depths. It uses a vibrator (Vibroflotation), which is a capsule 2 m long and 15 inch diameter with holes for water from the bottom and from the top (Figure 1).

Fig. no.(1)

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At the start of the process, the holes open at the bottom of the vibrator and the water is pumped at high pressure (Figure 2), forming a bore hole up to a depth of 20 m.

Fig. no.(2)

The lower holes are closed, the upper ones are opened, and water is pumped into them, and then we add sand from the top to fill the gap that occurred and make a compaction.

This process leads to increasing its stability and endurance as well as reducing the differential settlement that occurs in this soil (Figure 3).

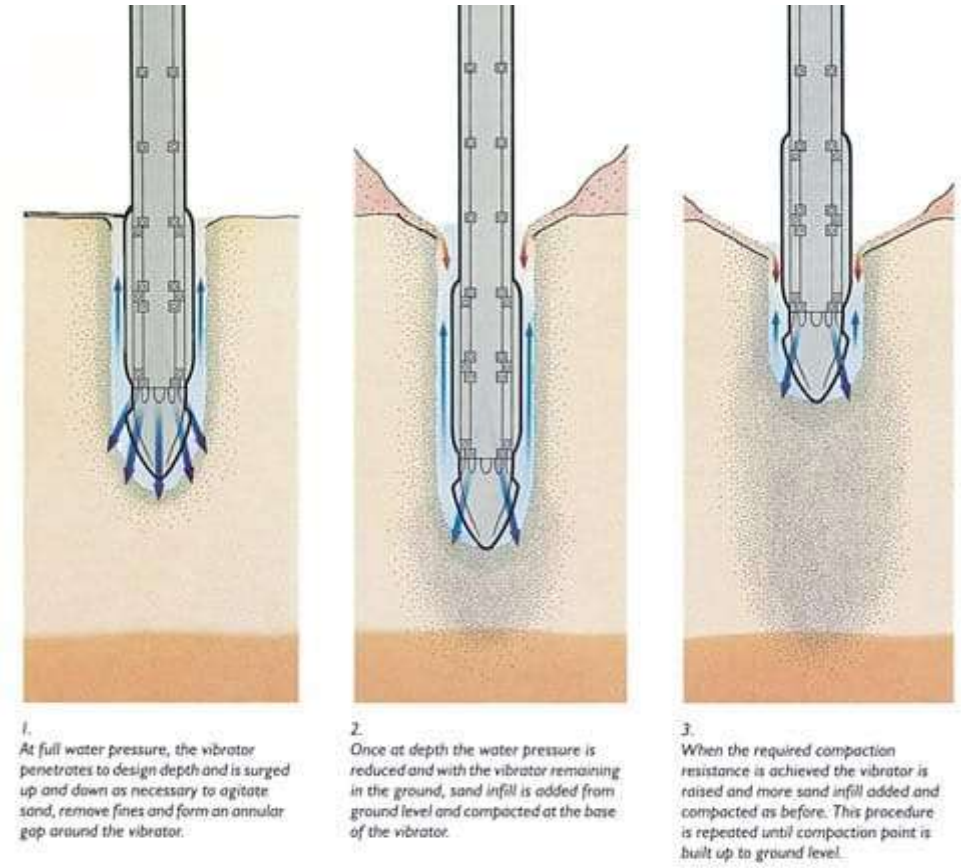

Fig. no.(3)

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One of the features of this Technique is that it is used for sandy soils that contain little gravel and Little silt and We'll get a great result in a relatively short time It is considered a cheap method in comparison with Deep Foundation In which the section of the substrate is large where it is possible to knock substrates displacement of the soil either of the type (steel hollow pile) so that its end is blocked or of the type (precast concrete pile) where this process will work to shift the soil sideways along the axis of the substrate knock, which reaches the soil compaction in the vicinity of the substrate and so In this process, we get a high safety factor of up to (2.5), but it's an expensive method compared to the Vibro Flotation.

4. STONE COLUMNS OR GRAVEL PILES METHOD

This method is used in soils of the type (soft silts & clays , loose silty sand) and is characterized as one of the methods that help to partially replace the weak soil layer by making a hole (bore hole) and filling it with stones or boulders Where the diameter of the granule ranges from (0.25 - 1.5) inches, using the same method of stacking by vibrator with the difference of substitution with stones for this purpose (Figure 4), and the benefits of this method include: -

1. Increase the bearing capacity of the soil.
2. Reduce precipitation (settlement).
3. Allowing free water to come out in the clay layer helps to quickly join the soil in the clay layers where it acts as a filter column.
4. Reduce loosening in the soil, especially in slopes and earthen dams.

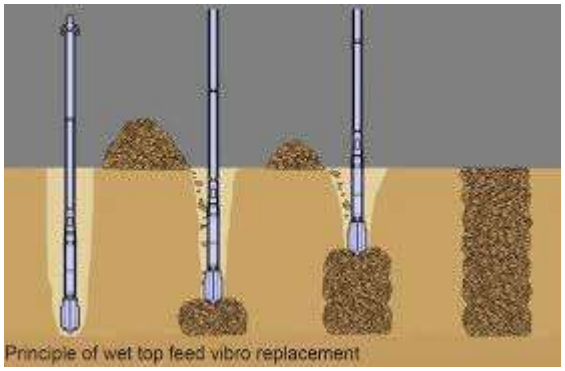

Fig. no.(4)

Working method

There are two types of stone columns and each type depends on the diameter of the column to be constructed and this depends on the loads projected from the building and the endurance required by the stone column.to reduce costs and at low loads that do not require a large diameter or length, we use the type (mini-column), where the diameter of the column ranges from (200-400) mm. such a type is created by hammering an iron pipe with a closed end so that it is detachable when pulling the pipe to the required depth and then filling it with stones and after the completion of the operation the pipe is pulled.

The second type has a diameter between (750 – 1100) mm, where the working method is the same as that used in the vibro-flotation technique (fig.).

To calculate the bearing column of the Stones is the same as the method of calculation used in the calculation of the carrying pillars of concrete where the improved frequency of hand to reduce the settlement depends on the diameter of column distance between columns.

But the difference between the two is that the stone column is characterized by a bulge in the center of the column when loading it due to the lack of cohesion of the Stones apart from the friction force between the stone particles and the degree of improvement (n) depends on the diameter of the column and the distance between them

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As well as soil qualities as shown in the figure (no.5) and according to the following equation: -

$$n = 1+\frac{AC}{A}\left[\frac{5-AC/A}{4*Kac*(1-\frac{AC}{A})}-1\right] \quad , \quad Kac = \tan^2(45 - \varphi c/2)$$

where: A: foundation bearing area ,
Ac: area of stone columns in bearing area

After completing this process, checks must be made on the treated soil to measure its improvement through a (C.P.T) test to assess the success of the operation as shown in the chart (Fig. 6). We notice that there is a significant improvement in soil resistance.

One of the projects implemented using this method is this example (Fig. 7), which shows the implementation of the foundations for liquid gas tanks where each tank has a diameter of approximately (84 m) and a height of about (35 m) and a capacity of up to (160,000 m^3) Where the pressure on the foundations was due to the total load of the tank (130 t / m^2) and because the soil at the work place was of the type (loose to medium dense silty sand) and for a depth of up to(16 m), the expected settlement was about (12 cm). So we had to choose an economic alternative to make these foundations so that we could avoid this compromise. Therefore, the stone column method was carried out using Vibroflotation technique, where the diameter of the stone column was (1m) and the length was (16)m distributed in the form of a square grid dimension between one column and another (2.41)m.

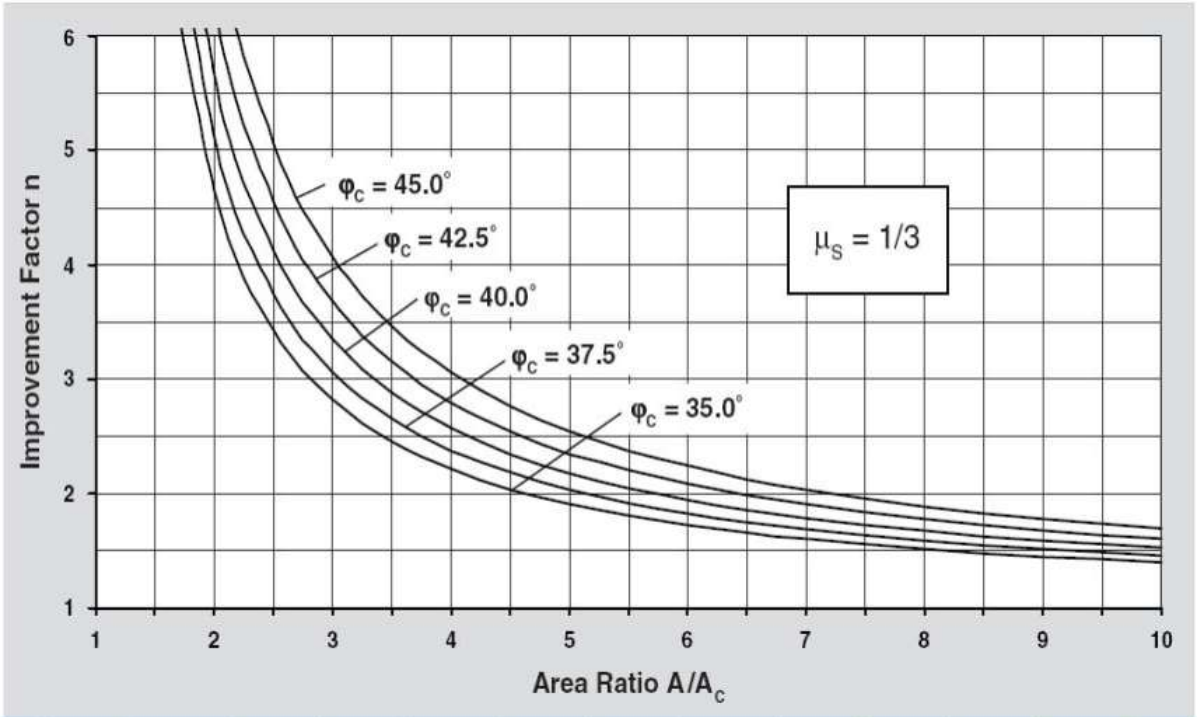

Figure No. (5) a graph showing the relationship between the degree of soil improvement and the column diameter for different types of soil

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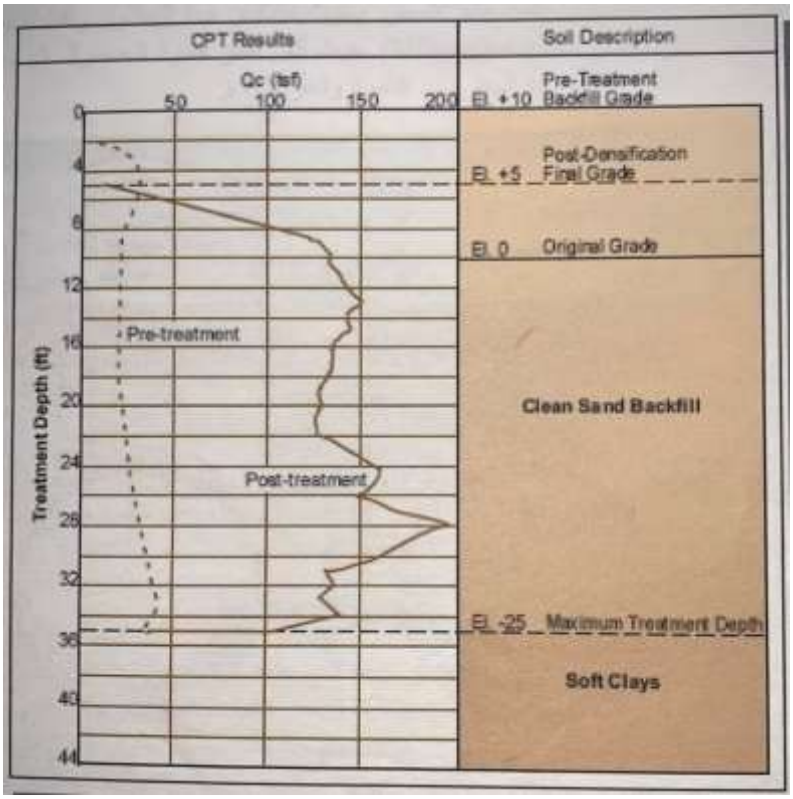

Figure No. (6) a flowchart to evaluate the success of the operation

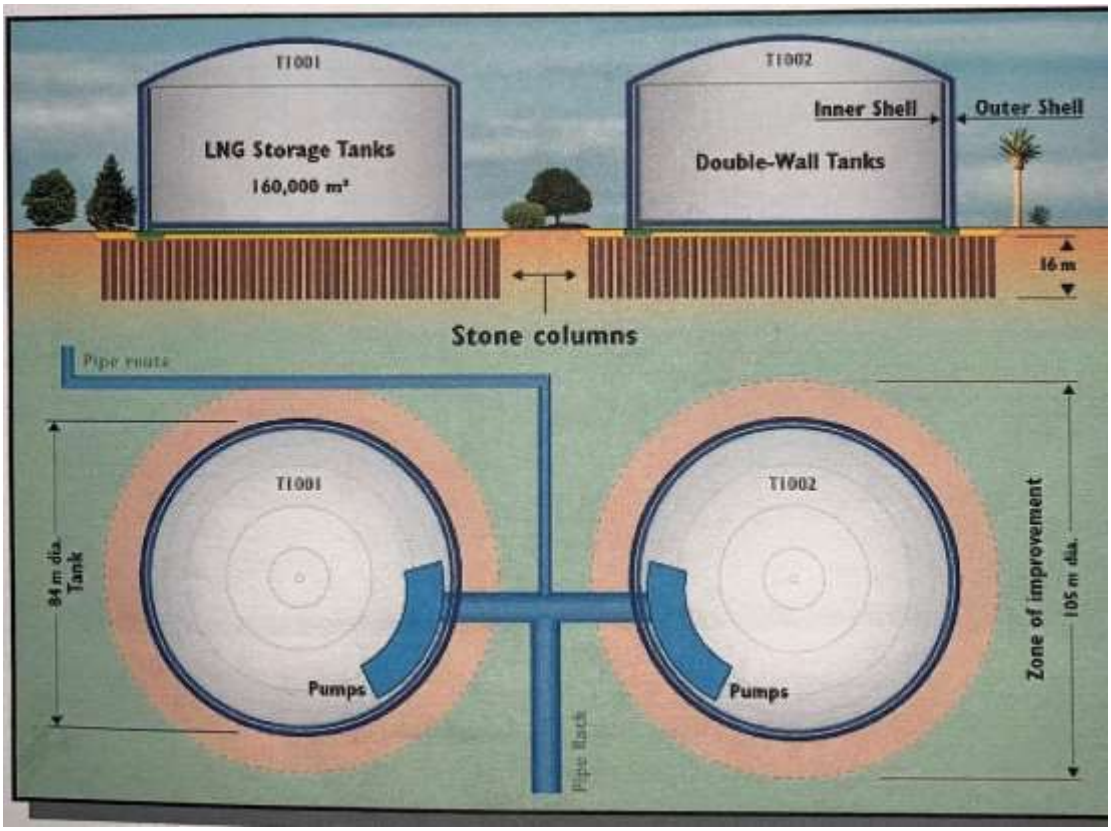

Figure No. (7) reservoirs whose foundations were executed by the stone column method

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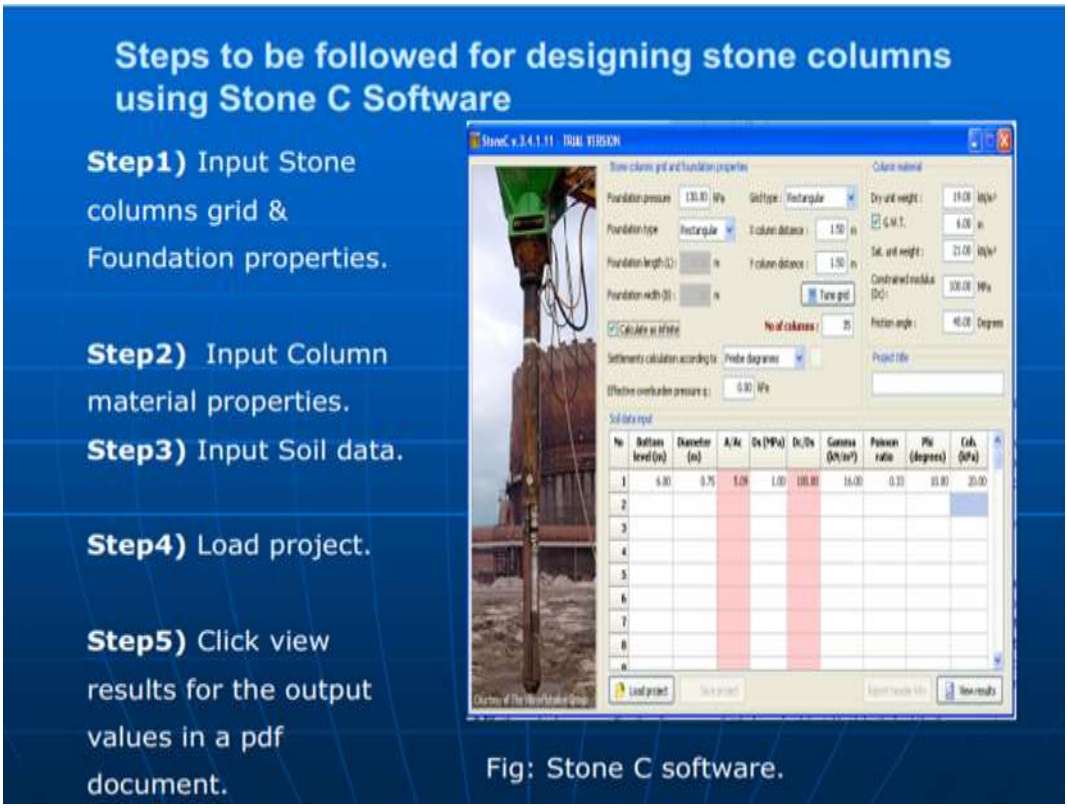
We can also use Stone C to design the stone column as shown below:



5. VERTICAL DRAINS METHOD

This method is used in clay soils, especially in the deep clay layers, which contain a high level of water table, which leads to the process of consolidation when the loads are shed, causing a settlement in the clay layer, which seriously affects the building, especially in the differential settlement Where high bending torque is generated in the foundations system Which causes them to fail.

The working principle of this method is based on the well-known consolidation mechanism in clay soils where we provide an easy flow of water and then we spread a distributed load over the clay layer so that it generates less stress than the soil load so that the stresses generated do not lead to soil failure.

Working method

In this method we drill several vertical holes in the clay layer (bore holes) so that they are distributed regularly on the work site and fill them with sand and then we cover the drill group with a layer of porous soil that permits water to penetrate the permeable soil, then we spread a distributed load on the space of this layer which leads to the movement of water in the direction of the drilling and then pull it out.(fig. No.8).

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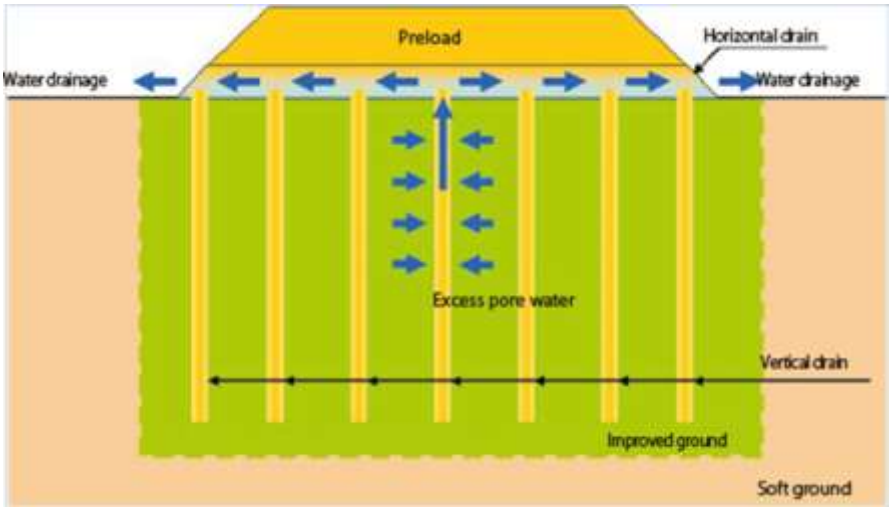

(Fig. No.8)

The drilling process is carried out through a drilling snail (auger) where it has a hole at the end of which feeds the hole with sand as shown in Figure no. (9) or through an iron pipe (mandrel) driven into the soil. and the drilling process may be done by the method of water extrusion (water jetting) and the use of (plastic drainage) where this condition occurs in the clay layer, which is interspersed with light layers of lime (lamination).

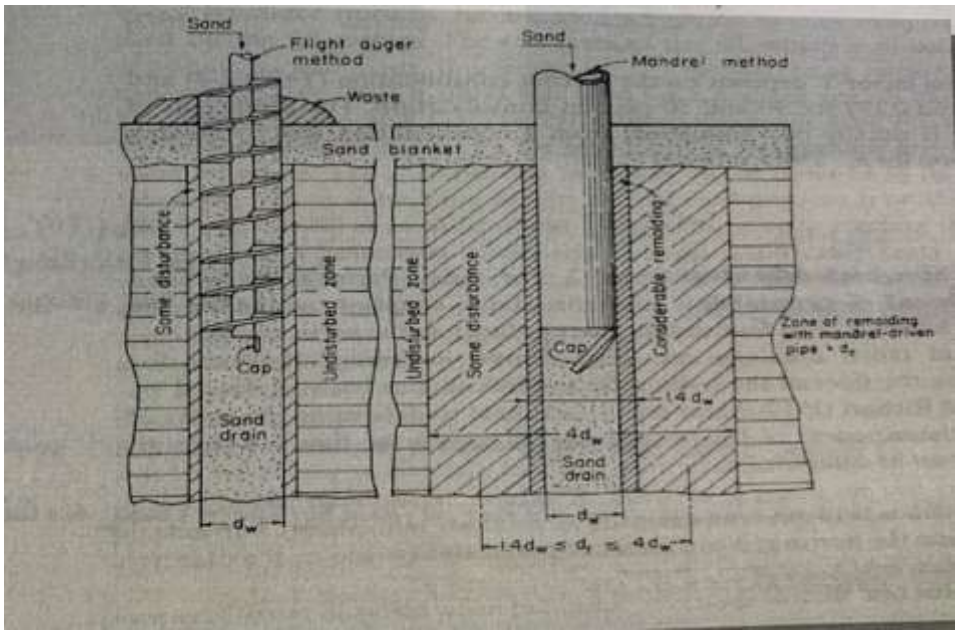

Figure (9) shows the drilling methods for the vertical filters' operation

The figure (NO.10) shows the modern method of this method, in which the bore holes are connected to an upper layer of horizontal pipes with high pores to drain water and dispose of water outward, called Prefabricated vertical drains.

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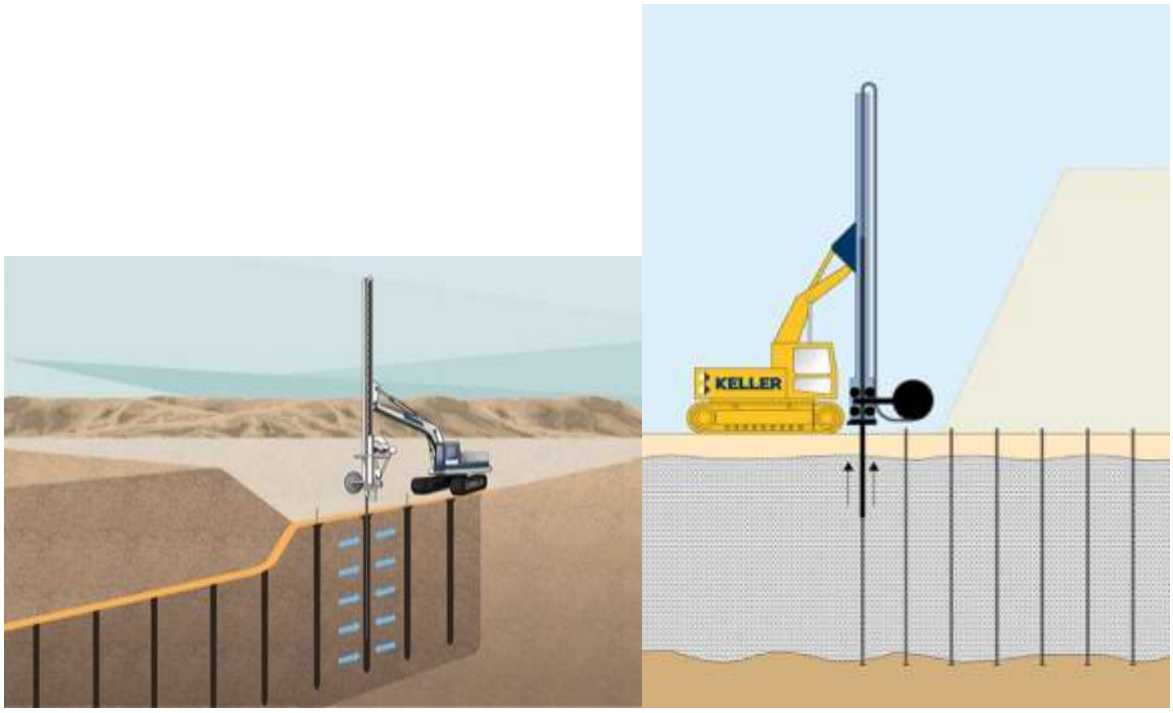

(Fig. No.10)

The time required to complete this process depends in fact on the distances between one pit and another and the determination of the distances depends on the available discharge of the clay layer in terms of its permeability and porosity where it is determined laboratory by the designation of porosity and permeability and the necessary time and distances can be determined by the following equation:

$Tr = Ci.t / re^2$

Where to:

Tr = the time period needed to get join in Vertical Drains

T = real time period

re = radius of the horizontal path of the water molecule to reach the Drain

Ci = joining coefficient in the horizontal flow

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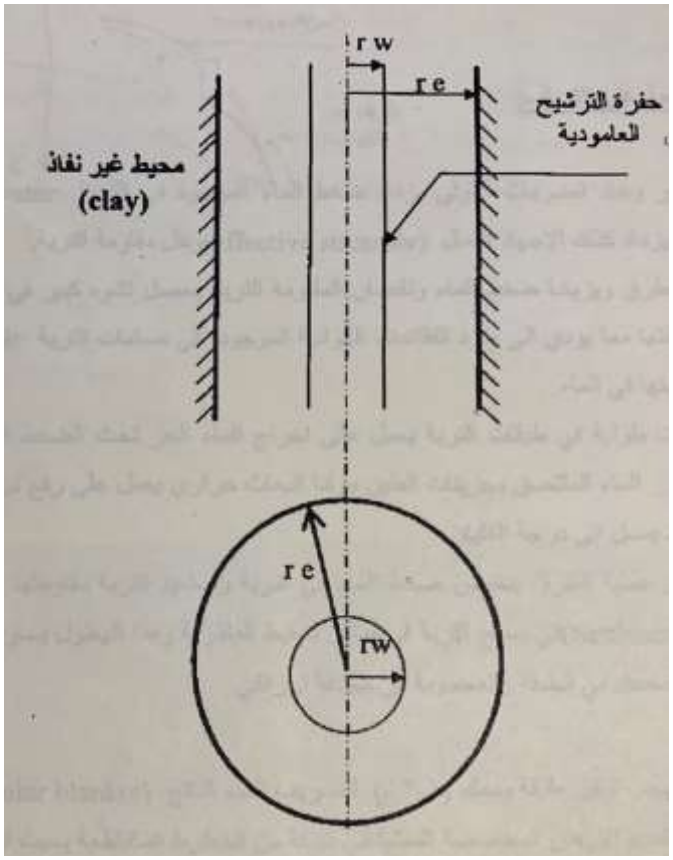

Fig. No.11 Diagram showing the dimensions of the filter column and the circular area it serves

6. DYNAMIC CONSOLIDATION METHOD

This method began to be used at the end of the seventies of the last century, where it is considered an economical method in terms of cost, speed of completion and record time By projecting shock waves on the soil by means of a hammer that is dropped from a high height ranging from (16-40)m using a crane, The weight of the hammer ranges from (20-40)tons and when the hammer hits the surface of the soil a gap occurs above its surface As well as strong waves that travel deep into the soil, they create cracks in the clay layer that cause water to exit the surface of the soil As well as a final settlement occurs at the place of the Hammer Drop and the impact of shocks reaches a depth of (26)m below the surface of the earth.

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(Fig. No.12) Demonstrates the equipment used in the Dynamic consolidation method

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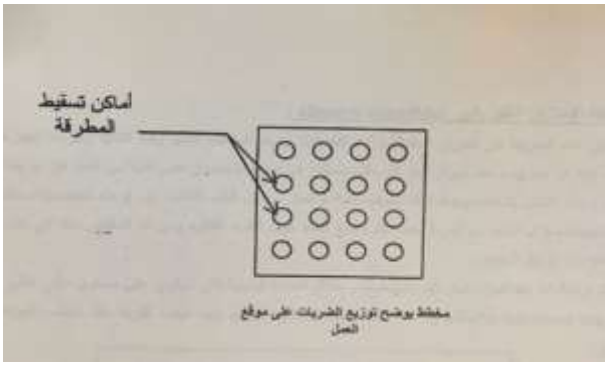

Fig. No. 13 Demonstrates drop strikes at the job site

Shock effects on the soil

1.at the beginning of the first strikes, the water pressure in the soil increases (pore water pressure) and the effective stress δv increases and the resistance of the soil decreases.

2. By keeping dropping and increasing the pore water pressure while decreasing the resistance of the soil, you get a significant deformation of its structure, which leads to the expulsion of air bubbles in the pores of the soil (micro air bubbles) and dissolved in water.

3. There are longitudinal cracks in the soil layers that work to release free water under high water pressure in addition to releasing the water adhering to the clay particles, creating a thermal emission that raises the temperature of the water outside may reach the boiling point.

4. After the completion of the Knock process, the water pressure in the soil decreases and the soil resistances are restored with a large precipitation(settlement) in the soil surface in the places of the hammer drop this settlement is equal in value to the settlement value in the layer calculated from the terzaki equation.

Working method

At first, a 1 – 2m thick layer should be provided to drain the resulting water (thick granular blanket) and After this process, the land allocated to the facility is divided into a network of intersecting lines so that the intersection points represent the drop point of the hammer, taking into account the distance between the workplace and the existing facilities not less than (70 m).

Calculation of hammer weight

Before starting the process of calculating the weight of the hammer this method needs a special laboratory to examine the soil and extract the necessary results of this method Calculating the weight of the hammer is not enough alone, but the time between one stroke and another As well as the settlement account which shall be reached to ensure that full accession, which will determine the impact energy required to reach the desired results.

$D = 0.5\sqrt{wh}$ for cohesionless

$D = \sqrt{wh}$ for cohesive soil (clay),

where D: depth of compaction, w: weight of hammer, h: height of fall

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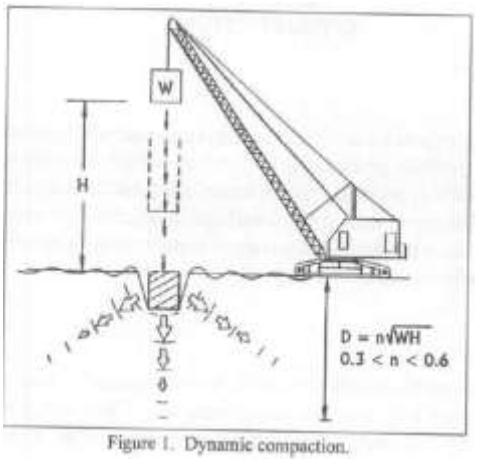

Figure 1. Dynamic compaction.

7. ELECTROSTATIC ADSORPTION METHOD

This method is one of the modern methods and has wide applications for its simplicity, low cost and fast completion Where, as is known, when a constant electric current is passed into the middle of something that contains an amount of water the water molecules will charge positively. So, it's going to be turned or adsorbed by the cathode pole. (-) This property has been exploited in soil water removal applications Where the Water is collected around the cathode electrode and then disposed off site by pumping. It has been observed that when a continuous electric current is passed through the clay with a high water content (fully saturated clay), water collects at the cathode negative pole while the soil dries at the anode positive pole.

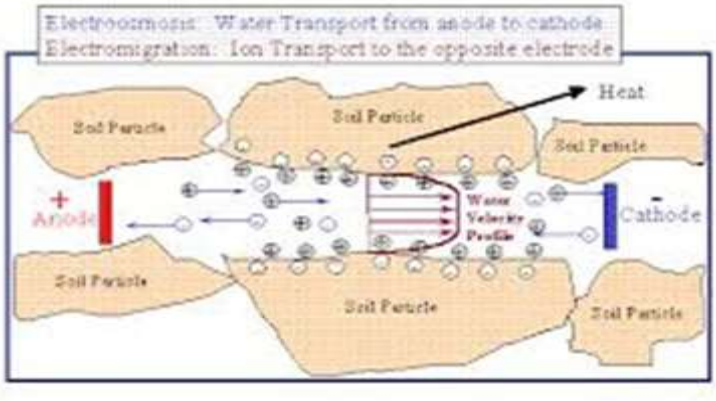

Figure No. 14: shows the effect of the electric field on the movement of groundwater in the clay layer

Working method

This method initially needs special tests that differ from the rest of the methods where the conductivity of the existing soil and its electrical resistance must be determined as well as the examination of groundwater and its content of natural elements dissolved or not dissolved all this helps to choose the required electrical capacity Where The value of the current depends on the depth required to puncture the water, where the electric current is passed through special equipment that generates a constant electric current in the form of signals (puls) at a certain voltage commensurate with the type of soil

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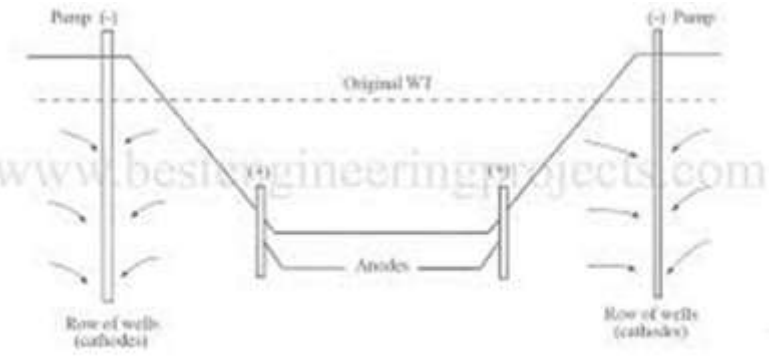

Fig 1 Electro-osmosis Method

Fig. No. 15

The negative part is connected with perforated tubes prepared for this purpose that are inserted into the clay layer and at the required depth and The positive electrode is connected with metal rods inserted into the ground and after a while we will observe the pool of water at the metal tube and the dryness of the area at the iron bars Where the Water is continuously drawn from the metal tube as shown in the diagram

This process will help reduce soil settlement as well as increase its resistance in a short period of time But the price factor of the electrical unit as well as the value of the electrical capacity that depends on the type of soil and the availability of the rest of the methods remains the economic factor that determines the feasibility of using this method Where the price of the electric unit as well as the soil needs (70 kw/m2) while in France you need (200kW/m2) and elsewhere less so where it reaches (0.5 kw/m2).

This method also has other applications such as water puncture from basements that leaches from concrete walls and foundations as well as in the treatment of contaminated soil where some of the contaminated substances in the soil can be eliminated by adsorption from one of the electrodes.

8. THE PROCESS OF FIXING THE SOIL WITH ADDITIVES

This method is carried out by the technology of injecting the soil with chemicals that help the soil to stabilize and increase its tolerance and Most of these additives are cement, lime and other stabilizing substances.

Where this method is one of the methods that improve the soil without replacing it, by means of special equipment that works to inject the soil with these additives under proper pressure where it works to form a solid mass inside the soil consisting of a mixture of additives alone or a mixture of additives and soil, works to stabilize the soil and increase its It should be noted that when this process is carried out there is no displacement of the soil in the Earth's surface.

1. Control water table problems by filling cracks and pores in the soil, especially in soils which porosity is more than (10^{-5} M/s).
2. Prevent the effect of increasing the density of sandy soils (i.e. increasing their density see method on Page 4) in the case of the use of hammering substrates in this soil near buildings close to the location of the hammering, where the process of transferring the hammering effect to the adjacent foundations works.
3. Strengthen the soil by stacking it by injection.
4. Reduce vibration by increasing the strength of the soil.
5. Reduce soil settlement by filling pores in the soil as well as in the case of longitudinal cracks in the soil layer.
6. Get soil improvement at the lowest possible cost, especially if there is not enough space in the workplace where the injection equipment does not need as much space for movement as in the figure

There are many methods of injection and the method of execution of these methods depends on the company that performs the execution.

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These are two examples of two methods that are the most common according to HAYWARD BACKER and these two methods are:

1. Injection method by extrusion
2. Injection stacking method

Each of these methods has a special method and equipment that differs from the other in terms of application as well as the case for which they are used:

1. Injection method by extrusion (Jet Grouting): -

In this method, the additives are injected into the soil by pumping the additives under high pressure where the extrusion speed reaches (200 m/sec) by inserting a special drill pipe to the required depth and then the additives are extruded in the form of a solution While the tube is lifted upwards and this process leads to the formation of a vertical block (fig.no.16) consisting of a mixture of soil and additives and this process is in fact a replacement of the soil without removing the existing soil as the resulting mass of the mixture is of new and improved qualities different from the previous soil This process is referred to as
"soil create".

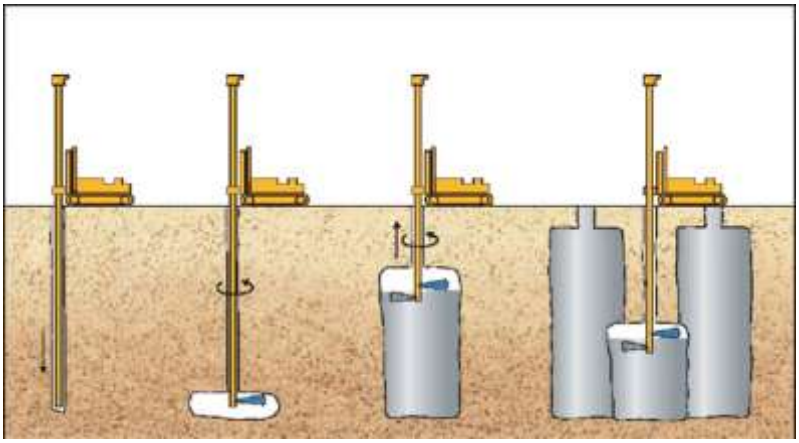

Fig. no. 16 Injection steps

The diameter of the drill depends on the drill pipe used in the injection process as well as the type of soil and the degree of improvement needed where there are three types of drill pipe as shown below (fig. no. 17): -

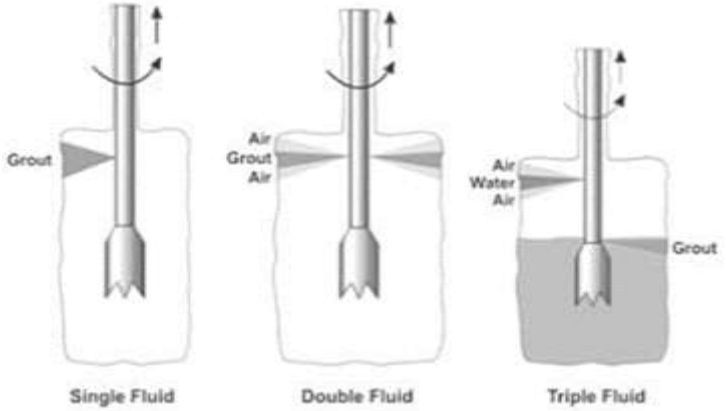

Fig. No. 17 shows types of drilling pipes

Type I

It is the single fluid Type where the additive is pumped (grout) only and alone and by the pressure shed and with a speed of up to (200 M/S) which works to break up the soil and thus mix it with the additive where this type is used in Sandy and saline soils (loos, silty sand) and with a column diameter ranging from (0.6 – 1.2)m.

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Type II

It is a double fluid type where in addition to the additive compressed air is pumped to increase the effect of fragmentation and erosion of the soil surrounding the drilling pipe through two holes in the pipe that are at the same level, this pipe is used in cohesive soil where we can reach a column diameter ranging from (1 – 1.8)m.

Type III

It is the triple fluid type and in this type compressed air is pumped with water as shown in Figure no. (17) in two different lines on one side while on the other opposite side the additive is pumped through a hole in the tube that is lower than the level of pumping air and water and The speed is less than the speed in the first type, where in this type control the process of erosion and fragmentation of the soil on the one hand as well as control of the additive in terms of efficiency and can reach a diameter ranging from (0.9-1.5)in cohesive soil.

The selection of any of these types depends on the soil's susceptibility to erosion and fragmentation, since the weaker the soil, the easier the process is, as shown in Figure.

Where the injection process is done by lowering the drill pipe to the required depth and then start the process of pumping the solution at a high speed and at the same time the pipe is raised to the top and Regularly maintaining a constant rotation speed while crumbling material is lifted from the soil by pressure to the surface of the pit and The depth in the pits can be reached up to (50) m below ground level where the resulting mass from the injection is used as a support for drilling or as a barrier to groundwater as in the subsequent example, which acts as a sand wall to prevent water leakage where the injected material is controlled by checking its resistance to shearing and bending (bending, shear) after I Harden, and freeze resistance resulting on the type of soil injected where increasing resistance over time and to resist the final within (60) days, where you think this is an important point in the success or failure of the injection process.

2- Injection stacking method:

In this method, cement mortar is injected into the soil using special mechanisms under high pressure so that the bubbles of the mortar work to displace the soil around the pumping point, which leads to compaction of the soil and increase its density and thus improve the effect of this process is similar to the effect of vibratory compaction (Densification).This method is used in addition to improving the soil in the process of getting rid of the settlement obtained in buildings by injecting cement mortar under high pressure under the foundations of the building suffering from settlement due to the displacement of the soil below the foundation due to injection of cement mortar The settlement obtained is compensated and the base level is returned to normal as much as possible To control this process by controlling the direction of injection.

This process is done by inserting the injection tube to the required depth and then starting the injection process where the cement mortar is injected with a characteristic mechanism under appropriate pressure this pressure works on the injection of cement mortar so that it displaces the soil at the injection point and replaces the cement mortar instead.

Which is of very low operability where the loss reaches settlement in the examination (slump loss) to (25 mm) so we may use plasticized additives to facilitate the injection process and this property of operability helps the injected mass to maintain its texture so that it leads to the displacement of the soil evenly in all directions.

When performing the injection process must take into account the following:
The injection molding process is good efficiency in unsaturated Sandy and saline soils and is an inefficient method in gravel and clay soils because it is not densification process so it should be avoided and check the soil tests before starting the work.

The pressure applied during the injection process should be sufficient to help to displace the soil at the injection point and replace the cement mortar.

The rate of injection speed should be taken into account when working in saturated soils as the injection in this case works to increase the water pressure, which affects the soil compaction process and thus reduce the

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efficiency of soil improvement so you must inject at a slow speed so that we allow the water pressure to leak to complete the process efficiently.

The soil improvement process can be confirmed by checking the density of the soil after the injection process, in which case the density of the soil after improvement should be greater than the density before improvement as well as the work of cone inspection (CPT) to measure the soil tolerance.

There are other methods of injection such as the injection of ground cracks as well as the injection of gypsum soil, and in general the efficiency of the injection method varies according to the soil as shown in the following table:

Ground Type	Relative Effectiveness
Sands	Excellent
Silty Sands	Marginal to Good
Silts	Poor
Clays	Not Applicable
Mine Spoils	Good (if clean granular)
Dumped Fill	Dependent on Nature of Fill
Garbage	Not Applicable

9. GROUND FREEZING METHOD

This method invented about a hundred years ago (figure No. 18)where it was observed in some cold places where the freezing of the soil that the frozen soil acquires new properties completely different from what it is in the natural state where it acquires the strength of the convergence of the strength of the concrete in endurance as well as less permeability for water(permeability) to tunnels or mines located within an area with high water pressure or sandy soil with water content which It is considered a problem in the process of soil attribution because it is an incoherent soil.

Form No. (18) soil freezing method

Working method

This method basically requires special portable refrigerators Its freezing capacity must be according to the energy required for the work and is mostly similar in the basis of the work where it is mostly used liquid nitrogen, which is characterized by a very low boiling point (-196 ° C) and there are special systems that use ammonia in the freezing process with some minor differences.

The freezing of the soil is done by connecting a network of special pipes for this process to the refrigerators, which are embedded in the ground and distributed as needed, where the freezing gas is passed in the form of cycles until the appropriate degree of freezing, which is at least (30 m) in the case of shedding loads on the soil to avoid the state of creep of ice.

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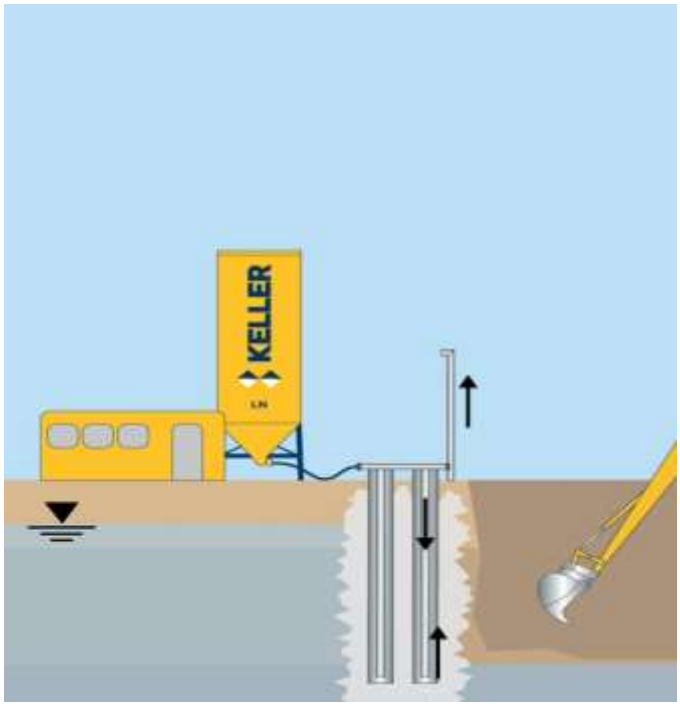
The duration of freezing depends on the depth and area to be frozen, as well as the conductivity of the soil, which is determined by its quality (Figure 19)



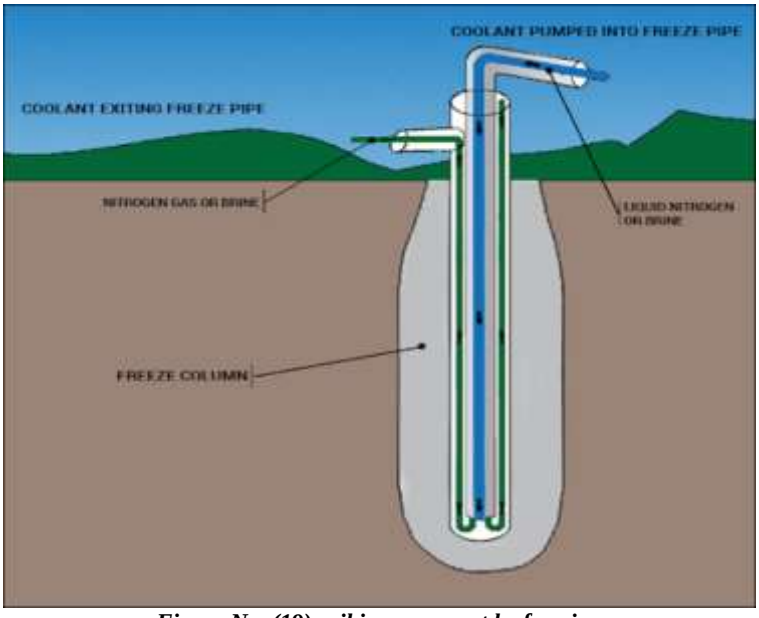


Figure No. (19) soil improvement by freezing

10. CONCLUSION

In all ways, with different methods, the results were the same, which is either to improve the soil to withstand loads or to avoid problems of soil weakness as seen in the tunneling process in the case of a high level of groundwater, fig.

We have seen that there are ways to use in one place and not in another, so several criteria must be set to choose the right method, namely:

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First: cost

Cost is an important factor in this time, as the availability and transport of machinery and equipment has an important impact on the cost in terms of local availability, import or lease, since there are methods that require special substances such as liquid nitrogen, as in the soil freezing method this material is available in industrialized countries, so its cost is normal, as in the United States of America, where the cost per square meter of the freezing method is only ($25), whereas in another country the cost is much higher, especially in non-industrialized countries.

Second: time

Where the time required to complete the process may be very important and according to the beneficiary and we saw that there are methods that perform the same effect but there is a difference in the time of completion such as the method of Dynamic Consolidation and the method of vertical Drains, where the goal of both operations is to get rid of the settlement due to the Consolidation of the clay layer but there is a big difference in delivery time in Dynamic Consolidation.

Three: technical availability

This aspect is very important as for each method there is a specialized cadre and special equipment as in Electrostatic adsorption method and ground freezing Method work so when choosing must take into account the availability of appropriate cadres and equipment so that they are available at the site where the work is done.

Fourth: building

Where the type of building and The Shape of the proposed foundations have an effect in the case of choosing the appropriate method, for example in sand wall we used the grouting method, while in the case of tunneling we used ground freezing Method, and in both cases we wanted to control the movement of groundwater.

The circumstances surrounding the building also affect the process of choosing the appropriate method as seen in the case of the use of the injection method in confined spaces as the injection equipment does not need a large space for movement and can move easily in confined spaces.

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