Recent Development in ground improvement Techniques and Its Application

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Abstract:

In recent years, infrastructure in major cities has grown quickly, but there has been a shortage of good land. This has forced builders to improve the soil so that it can support the weight of buildings, bridges, roads, trains, etc. Engineering methods for improving the ground are removal and replacement, pre-compression, vertical drains, in-situ densification, filling, stabilization with admixtures, and strengthening. The goal of these methods is to improve the soil's ability to support weight and lessen settling to a large degree. One way to improve the ground is to use materials like steel, stainless steel, aluminium, fibres, fibre glass, nylon, polyster, polyamides, and other strips or grids and Geo-textiles to strengthen the soil. The main goal of strengthening a mass of soil is to make it more stable by increasing its holding capacity and reducing settlements and sideways movements. Geo-textiles and geo-membranes are both made of manmade threads that are used to make buildings on dirt more stable. Geo-synthetics is the new, widely used term for all of these man-made products. Geo-synthetics include knitted, woven, or non-woven materials that can let water through or keep it out, as well as polymer grids and pores. Geo-synthetic materials play different roles in different situations because they can be used to strengthen, separate, filter, protect, contain, hold fluids, and contain dirt to make it stronger. Geo-cell reinforcement is a new method for making dirt stronger. It has a honeycomb-like structure made of geo-grid cells that are plastic and three-dimensional. The cells are linked at their joints. Better designs need ways to choose methods for improving the ground, better research, knowledge of long-term success, and an understanding of how variability affects designs. The following article looks at how techniques for improving the ground have changed in the past few years.

Keywords: Geo-textiles, Geo-synthetic materials, , stainless steel, aluminum, fibers, fiber glass, nylon, Polyester, polyamides, Geo-cell reinforcement

1.0 Introduction

Presently the most important thing is to use ground improvement methods to turn weak ground or dirt into the right kind of safe ground for different civil engineering uses. It started with Henri Vidal's work in 1960 and then moved on to Binquet and Lee's early work. Ground improvement techniques are recommended when the mechanical properties of the ground aren't strong enough to support the weight of the infrastructure that will be built on top of them. This includes collapsible soils, soft soils, organic soils, and peaty soils, karst deposits with sinkholes, foundations on dumps and sanitary landfills, handling dredged materials for foundation beds, and handling hazardous materials that come into contact with the soil. If a project site runs into any of the above problems, possible solutions include avoiding the site, making the planned structure flexible or rigid, removing and replacing unsuitable soils, trying to change the existing ground, allowing for more cost-effective foundation design, reducing the effects of contaminated soils, and making sure that construction projects are sustainable by using ground improvement techniques. Even though it might not be obvious at first glance, methods for improving the ground have come a long way since the 20th century, when most of the techniques we use today were developed. This paper looks at study and development in the area of improving the ground.

2.0 MECHANICAL IMPROVEMENT TECHNIQUES

In this approach, mechanical force is used to make the soil more dense. For example, compact roller and plate vibrators are used to pack down the top layers of soil. This method is also categorised as:

2.1 Dynamic Compaction

2.2 Vibro-Compaction

2.3 Compaction Grouting

2.4 Pre loading and Pre-fabricated Vertical Drains

2.5 Blast densification

2.1 Development of Dynamic Compaction

Louis Menard came up with this technique and began to advertise it as early as 1969, but he didn't get a patent for it in France until May 29, 1970. The idea behind this method is to improve the soil's mechanical features by sending high-energy hits to the soil by dropping a heavy weight called a "pounder" from a high place. When it is possible, dynamic compression is probably the most popular way to improve grainy soils because it is often the most cost-effective way to do so (Mitchell, 1981).Depth of impact or change is the depth at which there is little or almost no increase in the dirt. Menard and Broise (1975) made an estimated calculation in which the depth of effect, D, was a function of the square root of the impact energy, which is the product of the pounder weight (in metric tonnes) times the drop height (in metres). Later, based on more site observations, others added a coefficient that was less than 1, and Varaksin (Chu et al., 2009) made the link even better by adding coefficients for drop type and energy function. Hamidi et al. (2011a) looked at the changes in dynamic compression rigs' tools. Menard did his first work with dynamic compression by dropping 80 kN pounders from 10 m. Soon, he was able to find heavy-duty cranes that could lift and lower pounders weighing up to about 150 kN with just one cable line. Menard then made his own rigs that could lift anywhere from 250 to more than 1,700 kN pounders. Even though these special rigs had their uses, they were made for a specific purpose, only a few were made, and they couldn't be made on a large scale or for business use.

Fig.1 DYNAMIC COMPACTION

But since a new breed of cranes came out that can lift pounders with just two single cable lines, the industrial lift capacity has gone up to 250 kN. With the help of these tools, pounders were able to lift more weight. However, the impact energy can still be made more efficient by letting the pounder drop in free fall. So, the next big change in dynamic compression was the creation of the Menard Accelerated Release System (MARS), which allows the pounder to be released from the lifting device as the "free fall" starts. In this method, digital devices can now record the location of the impact point, the height of the drop, the number of drops at each point, and the speed of the impact. This lets the expert improve quality control and find the best way to do the job. This method is best for making loose granular sands more solid

2.2. Development of Vibro-compaction

Applying a vibrating tool put into the ground, this method makes loose dirt more solid. It is a way to treat soft soils that was created in Germany in the 1930s. It is a deep compaction method. In this method, a moving electric or hydraulic device called a "vibro-flot" or "vibro-probe" is pushed into the ground and loose sands to make them denser. The features of vibro-flots haven't changed much in the last 70 years, and most of the equipment still looks remarkably comparable to the untrained eye, ground improvement companies now make vibro-probes that can do different things.

Now, the vibration the frequencies are closer to the natural frequency of the soil, and the power range of the plant lets each machine be used in a certain way. Vibro-compaction works well on open sand soils that have an original SPT value between 5 and 10 near the surface. It does not work on clays. Up to 85% relative density can be acquired

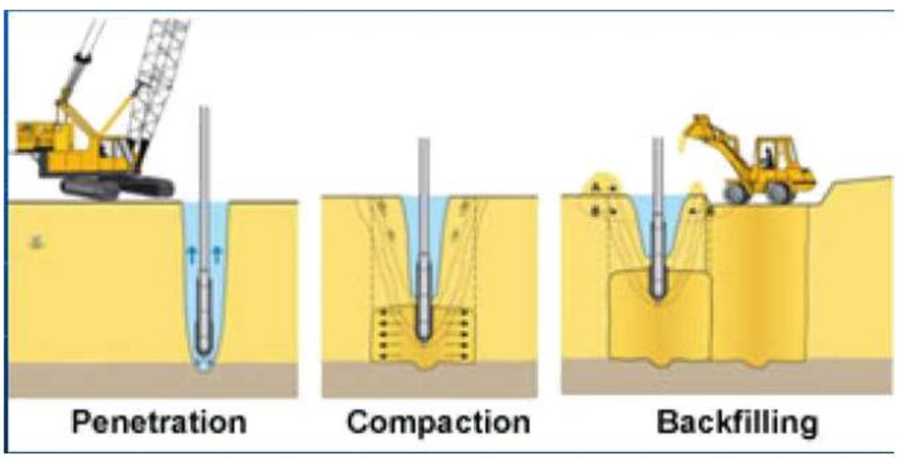


Fig.2 PROCESS OF VIBRO COMPACTION

2.3 Development of Compaction Grouting

The process of compacting grouting is a method of treating the ground that includes injecting a thick, soil-cement grout under pressure into the soil mass. This makes the soils in the area denser, which is the goal. Pressure-densification fills the empty space with the grout mass that was introduced. Pump pressure, which is sent through grout with low movement, causes compaction by moving soil at depth until the weight of soils on top stops it. Packing and sealing When pumped into very thick soils or rocks, compaction grout stays mostly in place because the material around it is also very dense. But when grout is put into dirt that is not well-packed or not well-consolidated, it can "push" these materials away. When grouting treatment is done in a grid design, the shifted soils are packed down better and the treated soil mass is more regular. As an additional benefit, the grout columns that are made add strength along the vertical plane because the compression strengths of grout are usually higher than those of the soils around them. Compaction grouting can be used to make foundation soils denser, raise and lower buildings and foundation parts, reduce the risk of liquefaction, increase pile capacity and fix piles and make utility trench backfill soils denser.

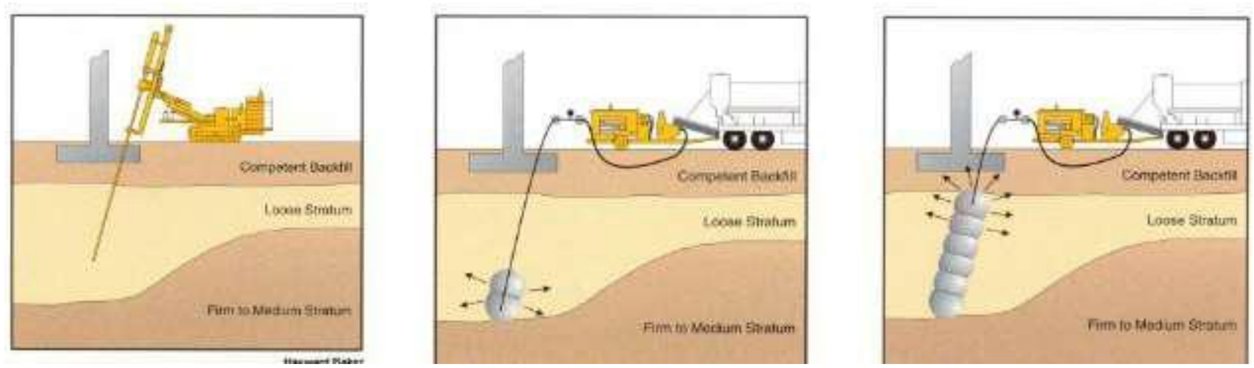


Fig 3. (a) The Development of Compaction Grouting

For a case in Shanghai (Liu et al., 2005), the method was also used to help dig deep into soft ground. Welsh and Burke (2000) give a few more examples. Naudts and Van Impe (2000)

also came up with a different method for compaction filling that uses geo-textile bags. With this method, regular sleeve pipes are set up to the depth needed. Geo-textile bags have straps that go over some or all of the arms. The geo-textile bags are filled with a balanced, stable, low viscosity cement-based solution grout that has a high resistance to pressure filtration. This is done with a double packer. At the same time, several bags (on different lines) are filled. The process of blowing up the bags is done in steps so that the water can slowly (under pressure) filter through the bags. At each step of filling, the pressure is steadily raised. The distance between the grout lines has to be big enough that the soils are put under more vertical stress than they will be later on. With the method described by Naudts and Van Impe (2000), you can use math to determine how much the surrounding soils have shrunk due to the pressure of the grouting, as well as how far its effects reach. This, in turn, tells you how far apart the grout pipes should be. The alternative compaction grouting method can lead to a more controlled and reliable compaction system for projects where soil density is the main concern.

2.4 Soil Modification by Pre-fabricated Vertical Drains

Thereby applying brief surcharge on the soil's surface, this method enhances the ground's the capacity to hold the weight and decreases its ability to be crushed. Surcharge is usually more than what it can be expected to hold. It works best on soft, sticky ground. Vertical sand drains or premade vertical drains could speed up the process. These drains are put in place to help wet, sticky soil settle faster and get stronger. Only main consolidation is sped up by vertical drains. As it has a lot to do with water flow. Only a small amount of water runs out of the earth during secondary consolidation. Vertical drains do not speed up secondary settlement. Vertical drains work best on dirt that doesn't let water through very easily. Soils that are more open will become less porous when they are charged. When there are many horizontal sand or silt layers in a clay deposit, vertical drains serve properly.

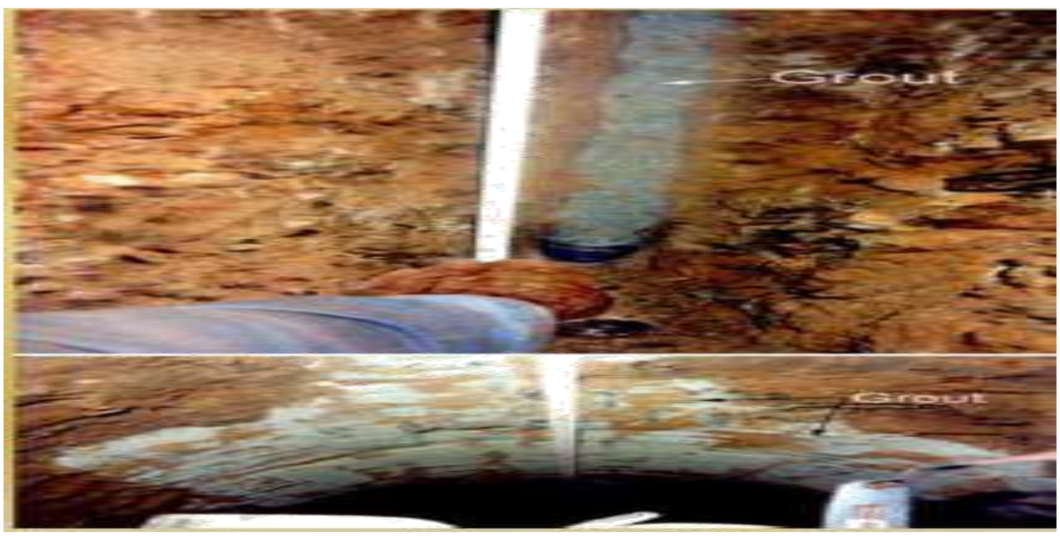


Fig.3 COMPACTION GROUTING

2.5 soil modification by blast densification

Blast-densification is a way to make open, generally clean, and cohesion-less soils more solid. It makes loose sand and gravel layers above or below the water table more solid.

The explosion wave briefly turns the soil into a liquid, which causes the soil particles to reshape themselves into a more dense structure as the extra pressure in the pores goes away. It has been used to treat dirt up to 40 metres deep. As you go deeper, you need a bigger charge to break up the soil's structure and turn it into mud. There is a relationship between the ratio Nh = W 1/3/R, where Nh is Hopkin's number, W is the weight of the explosives in kilogrammes of TNT, and R is the distance from the point of the explosion in metres. If Nh is less than or between 0.09 and 0.15, there is no liquefaction, and the equation can be used to figure out how far away from an explosion it is safe to be. Example W = 10kg and Nh = 0.12 Distance from the point of the blast in a circle, R = 17.95m Granular dirt can be made more solid by blasting. This method has been used for a long time. The idea behind this method is to make grainy soil ground or fill settle by making the soil become liquid or packed with shock waves and vibrations made by blasting. In the past, this method was mostly used to stop liquefaction in sand fill that was put in with water. The method has also been called "explosive compaction" because of this. Mitchell (1981) wrote a summary of how this method was developed and used up until the early 1980s. Explosive compaction is a good choice because it is cheap and easy to treat big depths. But the method hasn't been widely used because it's still based on experience instead of theory. Some field studies have been done (Charlie et al. 1992; Gandhi et al. 1998; Gohl et al. 1998; 2000) to learn more about how blasting works. To improve the design and analysis, Henrch (1979), Wu (1995), Van Court and Mitchell (1995), and Gohl et al. (1998) used cavity expansion theories and blasting mechanics to do theoretical studies and computer models. In recent years, explosive compaction has also been used in the mining industry to shake up waste ponds that hold silt and sand-sized pieces that don't stick together. By doing this, the amount of current tailings is decreased. This makes the tailings pond able to hold more tailings and reduces the need to raisethe height of the top of the tailings containment wall. The rapid compaction method can be used to treat a wide range of soil types, from silt tailings to gravel cobbles and rocks.

3. 0 HYDRAULIC MODIFICATION

The unrestricted water in the soil pores is forced toward of the soil through sewers or wells. This changes the soil's features. For coarse-grained soils, this is done by pumping water out of boreholes or ditches. For fine-grained soils, this is done by applying long-term loads from the outside (preloading) or electrical forces (electrometric stabilization). Some of the ways that hydraulics can be changed are:

3.1 Preloading using fill
3.2 Preloading using fill with vertical drain
3.3 Vacuum preloading with vertical drains
3.4 Combined fill and vacuum preloading

3.1 Preloading Using Fill

Preloading is the process about bringing an extra load on the ground before putting a building or external load on it. The following is done to strengthen the soil until most of the main settling has occurred. This makes the ground stronger and less likely to collapse.

Most of the time, the brief surcharge on the ground is more than what the ground can normally hold. It works better on soft ground that sticks together.

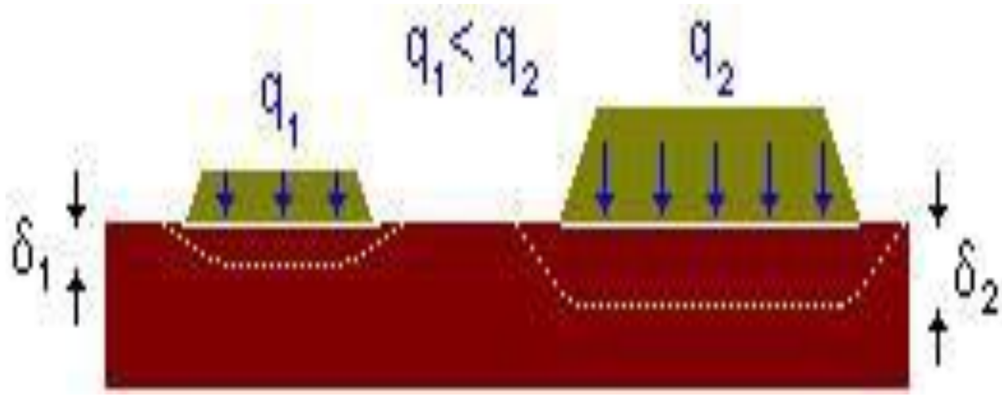


Fig.4 Preloading Using Fill

3.2 Preloading using fill with vertical drain

The method utilized works the same as what was said before, except that vertical drains are used to provide horizontal drainage and speed up consolidation by cutting down on the number of drainage lines. This speeds up the process of soft, compact soil settling and makes it stronger. Vertical drains only speed up the process of main consolidation. As it is connected to a lot of water flow. Only a very small amount of water drains out of earth after it has been consolidated again. Vertical drains do not speed up the process of secondary settlement.

The method of preloading with fill has been used for a long time and is thought to be one of the more mature ways to improve soil. Since PVDs were added to the preloading processes, this method has made a lot of progress. After a lot of study and testing in the field, the PVD method has been set up in an orderly way, from analysis to building. Many papers, like Holtz et al. (1991), Bo et al. (2003), Moseley and Kirsch (2004), and Raison (2004), have summed up what has happened in the past. There have also been a lot of case studies, like Hansbo (2005) and Moh and Lin (2005). But there are still a few new things about PVDs that are important to talk about. The first is making design rules or design guidelines. These include the Code of Practice for Installation of Prefabricated Drains and the Quality Inspection Standard for Prefabricated Drains, both of which were made in China (JTJ/T256-96 1996, JTJ/T257-96 1996), as well as the European Standard on Execution of Special Geotechnical Works—Vertical Drainage (pr EN 15237, 2005). Second, new types of drains are becoming popular, such as the electric vertical drain with a metal foil inserted in the drains as anodes and cathodes for electro-osmosis (Shang 1998; Bergado et al. 2000) and the integrated drain with the filter glued to the code using heat melting (Liu and Chu 2009). The combined drain is stronger and can drain more water than a regular drain made of the same materials and with the same dimensions. There are also PVDs that are used in the geoenvironment. (Schaefer et al., 1997), PVDs have been used to help make a method for extracting steam.For use in the environment, Chu et al. (2005) say that the PVD materials may need to be made in a way that makes them resistant to acid erosion.

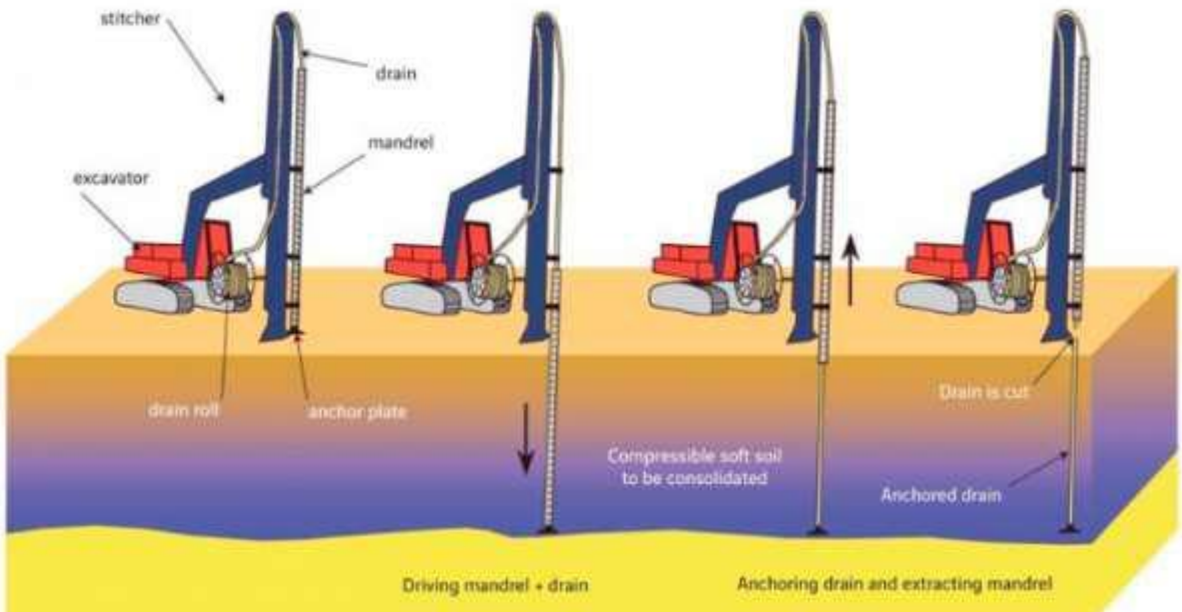


Fig.5 Vertical Drains

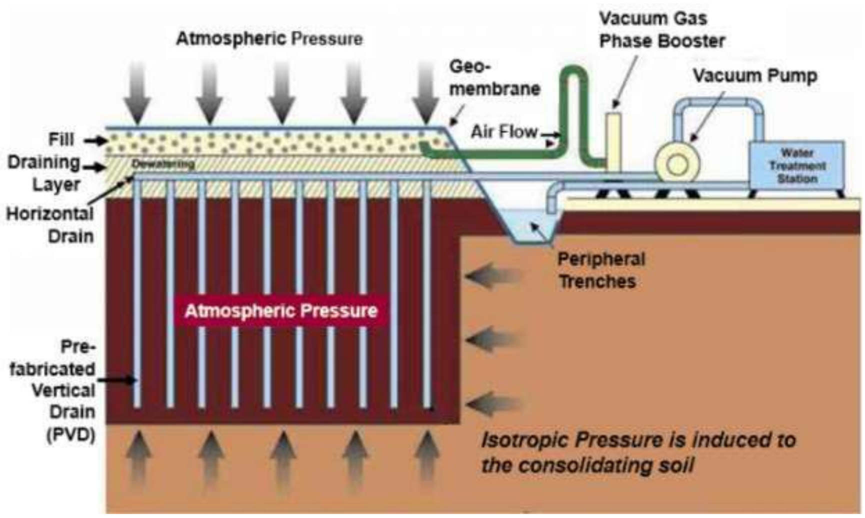
The process of vacuum preloading has advanced into a mature and effective way to work with soft clay. Many soil improvement and land restoration projects all over the world have used this method successfully (Holtz 1975; Chen and Bao 1983; Cognon 1991; Bergado et al. 1998; Chu et al. 2000; Yee et al. 2004; Indraratna et al. 2005).In the past few years, this method has

become even better as new materials and technologies have been added to it. In the early 1980s, China possibly used vacuum preloading for the first time on a big scale to build the Tianjin Harbour (Chen and Bao 1983). Because there weren't enough coarse fill materials to use for restoration, clay slurry had to be used instead. In the past, sand drains and premade vertical drains (PVDs) were used to spread the vacuum pressure and get rid of pore water when this method was used. In theory, a load of 90 kPa can be put on the vacuum. In reality, though, the vacuum pressure used is usually less than this. Chu and Yan (2005) also gave an outline of the Tianjin method's basic ideas, techniques, and ways of using them. This method has been used to bring back thousands of hectares of land in Tianjin (Chen and Bao 1983; Yan and Chu 2005). Several case studies have been written up (Chen and Bao 1983, Choa 1989, Tang and Shang 2000, Chu et al. 2000, Yan and Chu 2003, 2005). In other places of China and in additional nations, this method has been used a lot.

3.3 Vacuum preloading with vertical drains

The aforementioned technique is a mix of what has been talked about in 3.2 and 3.3. It is used when a higher pressure is needed than the vacuum pressure. The method can be used on ground that is mostly made up of wet sands that don't let much water through. When there is a problem with fill surcharge's safety, the method can be used. If needed, this method can also be used to get dirty water from the ground. When the total vacuum and fill fee is higher than the most the vacuum pressure can do, a surcharge can be added. In this case, the fill extra is added after the soil has been compacted to make it strong enough. As the fill surcharge creates excessive pore-water pressure that is higher than the hydrostatic or initial in-situ pore-water pressure, the vacuum pressure may speed up the release of the excess pore-water pressure, making the combined fill and vacuum preloading method more effective than using vacuum or fill surcharge alone for the same amount of total surcharge.

Fig. 6 Vacuum preloading with vertical drains



4.0 MODIFICATION, BOTH PHYSICAL AND CHEMICAL

Soil enhancement is accomplished via physical mixing of adhesives with surface layers or columns of soil in this procedure. Natural soils, industrial byproducts or waste materials, cementations, or other substances that react with one other and the ground comprise the adhesive. Grouting is the technique of injecting adhesives under pressure via boreholes into cavities inside the ground or between it and a structure. Thermal techniques of alteration include soil stabilization by heating and freezing the earth. The following are some examples of physical and chemical alteration methods:

4.1 Grouting
4.2 Electro-osmosis
4.3 Soil Cement
4.4 Heating
4.5 Freezing
4.5 Vitrification

4.1 Grouting

Grouting technology has grown into a popular way of ground improvement that is widely utilized in subterranean and foundation projects. Grouting is the technique of filling holes or cavities in soil or rock with a liquid form substance to reduce permeability and enhance shear strength by enhancing cohesion when it is set. Cement base grout mixtures are widely used for treating gravely layers or fissure rock. However, the particle size of the solution may be too large to penetrate sand or silty-sand layers. Chemical or organic grout mixtures are also employed in this circumstance. The availability of ultrafine grout mixtures in recent years has increased the performance of hydraulic base grout for soil remediation. The sandy gravel soil was treated with an ultrafine cement mix. The grout mix is divided into four distinct kinds:

a. **Mortar and pastes such as cement to fill in holes or open cracks.**
b. **Suspensions such as ultra-fine cement to seal and strengthen sand and joints.**
c. **Solutions such as water glass (silicate).**
d. **Emulsions such as chemical grout.**

The performance limitation of various grout mixes are determined by the kind of soil and particle size distribution. Grouting may be classified as follows:

Penetration grouting
Displacement grouting
Compaction grouting
Grouting of Voids

Jet grouting

The grout-ability of soil with particle grouting has been examined using the N value, which is defined as N = (D15)Soil / (D65)Grout (Mitchell and Katti 1981). Grouting is regarded viable when N > 24 and impractical when N 11. Nc = (D10)Soil / (D95)Grout is

another possibility. Grouting is regarded viable when Nc > 11 and impractical when N 6 (Karol 2003).Many case studies of particle grouting have been published (e.g., Littlejohn 2004a; Schmall et al.07). Brachman et al. (2004) conducted a field study of three distinct permeation grouts, namely sodium silicate, microfine powder, and microfine cement, in a medium-dense, silty sand outwash deposit. According to the findings of this investigation, the sodium silicate grout zone was equally penetrated and had a huge structure. The grout seemed to infiltrate the outwash sand but did not solidify in the earth. The microfine cement grout's particular composition resulted in just distinct veins of grouted sand. This project included cross-hole seismic velocity testing. Average shear wave velocities recorded across the grout zone were 480 m/s for sodium silicate and 340 to 420 m/s for microfine cement or microfine powder. The ungrouted sand had a shear wave velocity of around 230 m/s (Brachman et al. 2004). Karol (2003) and Powers et al. (2007) provide many case studies of chemical grouting applications. Chemical grouting has been employed in the building of many important hydraulic or dam projects in China, including the Three Gorges Dam and other projects (Tao et al. 2006). Many investigations on the qualities of grouted soil have lately been conducted. However, there have been fewer case studies published. Palardy et al. (2003) used chemical grouting to repair an underwater road tunnel in Montréal, Canada, while Gallagher et al. (2007) conducted a field experiment using colloidal silica grouting for liquefaction mitigation.

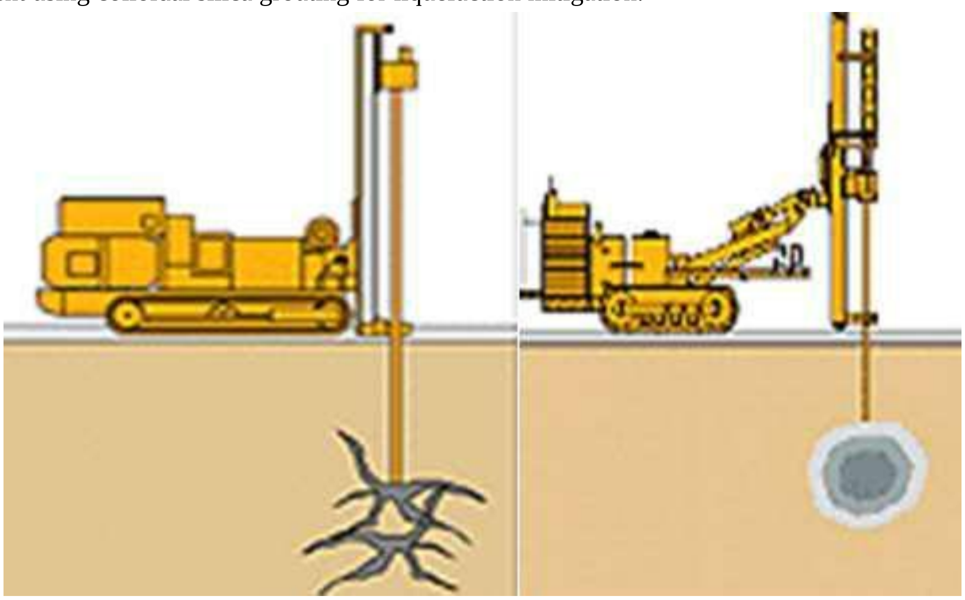


Fig.6 GROUTING METHODS

4.2 Electro-osmosis

It is a word used to describe the method used to increase electrochemical hardness during electro osmosis by adding chemicals to the anode, such as sodium silicate or calcium chloride. These chemicals infiltrate the ground under the influence of the electric field, flowing in the direction of the Cathode, while the Anode becomes a grout injection pipe.

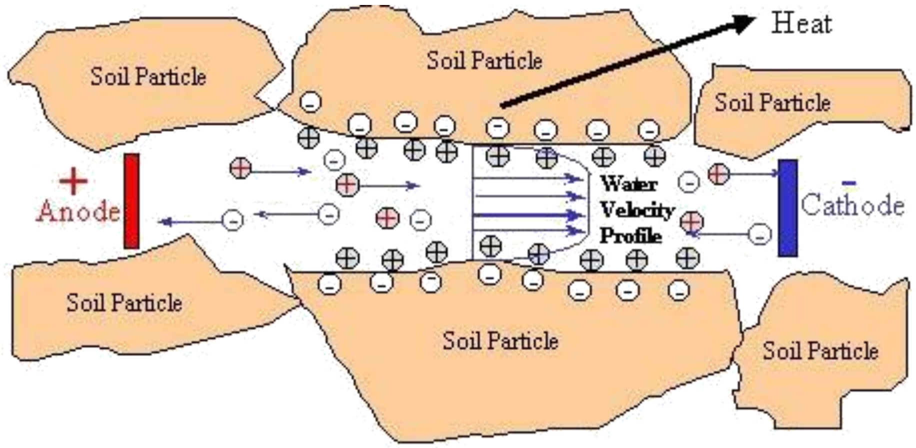


Fig.7 Electro-osmosis Techniques

4.3 Soil Cement

Various geotechnical and transportation engineering projects have used cement and other admixtures such as fly ash and blast furnace slag for stabilization. These uses include: a) shallow depth treatments for improving highway subgrade, sub-base, and base course material, and b) stabilization of deep soil deposits such as soft soils and peaty soils.

The use of modest amounts of cement proved effective, and the degree of strength/ stiffness necessary is the foundation for design and has been employed in roadway and embankment stabilization.

In large-scale applications, depending on the strength and stiffness needed based on the kind of soil, the quantities required are enormous, necessitating large-scale apparatus and particular techniques in the stabilization of weak deep soils (e.g., peaty soils).

Benefits of the method are:

a. **Increased strength and stiffness**
b. **Better volume stability**
c. **Increased durability**
d. **Factors influencing the strength and stiffness improvement**
e. **Cement content, water content combined into water/ cement(w/c) ratio.**
f. **Method of compaction.**
g. **Time elapsed between mixing and compaction.**
h. **Length of curing.**
i. **Temperature and humidity.**
j. **Specimen size and boundary effects**

Terashi (2003), Topolnicki (2004), Larsson (2005), Essler and Kitazume (2008), and Arulrajah et al. (2009) provided comprehensive reviews and explanations of the numerous deep mixing techniques and applications. Deep mixing standards, such as BS EN 14679 (2005), have been created. Recent advancements have mostly occurred in process optimization and tool optimization for mass manufacturing.

4.4 Heating

Heating influences the characteristics of the soil, making it harder and more durable. Temperature enhances the settlements of clays with a given applied tension, according to laboratory experiments. Heat treatment of a clay soil to 400°C causes significant changes in engineering qualities. Heating is an energy-intensive process, requiring 50 to 100 liters of fuel oil to stabilize one m3 of soil. It is no longer advised except in areas where it is already present as intrinsic energy in waste goods and landfills. However, the usage of geothermal piles as heating systems is common in locations such as the United Kingdom. Marques and Leroueil (2005) tried pre-consolidation of clay in a cold environment using a combined vacuum and heating process in Quebec. Pothiraksanon et al. (2008) recently conducted another field study in which hot water was fed through the PVDs to raise the ground temperature. However, these technologies are still in the experimental stage, and no large-scale field applications have been made. Another kind of heating technology is the heat exchange pile, which has been extensively explored by Brandl (2006) and Laloui et al. (2005). Van Impe (1989) describes several other strategies of applying heat for soil improvement.

4.5 Freezing

The efficiency of thawing is dependent on the availability of water, which creates ice, cements the particles, and increases the strength of the earth to that of soft or medium rock. The earth will become impermeable if it is wet or almost so. If the moisture does not fill the pores, more water may be required. The strength obtained is determined by the freezing temperature, moisture content, and soil type. Freezing may be especially successful in stabilizing silts that are too fine for injection of conventional grouts. Water increases in volume by roughly 9% when frozen, which does not impose any significant loads and strains on the soil unless the water is kept inside a limited volume. After the initial freezing is complete and the frozen barrier is in place, the required refrigeration capacity to maintain the frozen barrier is significantly reduced. Because freezing can be imposed uniformly on a wide range of soil types in a single operation, it may provide greater security in mixed ground than treatment by injection of various grouts. The approach has the following 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

Tunneling through a full face of granular soil

Tunneling through mixed ground Soil stabilization

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.

4.6 Vitrification

Vitrification is a method of melting and refreezing soil to form a glass-like solid that captures inorganic pollution and isolates it from the environment. Organic contamination is destroyed by the high temperatures necessary to melt soil. Vitrification may therefore cure soil polluted with both organic compounds and minerals. Six vitrification methods have been explored so far through the Superfund Innovative Technology Evaluation (SITE) Program of the United States Environmental Protection Agency. Vitrification has been proposed as a potentially beneficial method of treating soil polluted with organic compounds as well as metals. The high temperatures necessary to melt soil (2012-2642°F, 1100-1450°C) allow organic contaminants to rapidly volatilize and decompose.

5.0 INCLUSION AND CONFINEMENT MODIFICATION

In this approach, soil characteristics are modified by utilizing reinforcement in the form of fibers, strips, bars, meshes, and textiles, which add tensile strength to a formed soil mass. Nails and anchors are used for in-situ reinforcing. Constricting soil using concrete, steel, or fabric components and Geocell may also result in a stable earth retaining structure. In recent years, there has been a significant growth in the usage of admixtures for ground improvement in both cohesive and non-cohesive soil. Sand compaction piles, stone columns, dynamic replacement, semi-rigid and rigid inclusions, and geotextile confined columns are all examples of confined columns. The next paragraph provides a short summary of each approach used in this procedure.

5.1 Vibro replacement or stone columns

Vibro Replacement is a method of improving the load bearing and settling properties of stone columns by building them through fill material and weak soils. Fine-grained soils (such as clays and silts) do not densify efficiently under vibrations, in contrast to clean granular soils. As a result, stone columns must be formed to strengthen and enhance fill materials for poor cohesive and mixed soils.To build columns, a hole is jetted into soft, fine-grained soil and backfilled with firmly compacted gravel or sand.

The vibro concrete column is a version of the stone column technique that is erected utilizing dry bottom feed vibro machinery with stone aggregate substituted with a high slump concrete mix. Serridge and Synacy (2007) discuss one use of the vibro concrete column for a highway embankment over soft clay. The rammed aggregate pier method is another technique related to stone columns. This technique also uses crushed stone to erect columns. The building procedure, on the other hand, is distinct. In the rammed pier technique, instead of being horizontally vibrated into position, the stone is heavily crushed by vertical ramming in around 0.3 m layers.

A revolutionary bevelled tamper uses static down force and vertical impact ramming energy to ram each layer of aggregate, resulting in improved strength and stiffness. The tamper compacts the aggregate vertically and presses it laterally into the loose matrix soil. This improves the matrix soil and provides good interaction with the surrounding soils, resulting in reduced liquefaction potential and extremely dependable settlement management. Rammed aggregate piers may be used to strengthen a wide range of soils, including loose sands, silts, and mixed soil layers such as clays, uncontrolled fill, and soils below the ground water table.

5.2 Dynamic replacement

The materials are forced into the soil by high intensity dynamic impact to create columns in this approach. Backfill materials include sand, gravel, gemstones, and demolition waste. When dynamic compaction is ineffective owing to the high fines concentration of the in-situ soils, the approach enhances the strength of saturated cohesive soils and soft organic soils.

Lo et al. (1990), Wong and Lacazedieu (2004), Ong et al. (2007), and Godlewski et al. (2007) reported case studies of soil rehabilitation initiatives employing the dynamic replacement approach. The DR approach was also used for the Sabkas soil remediation project at KAUST (King Abdullah University of Science and Technology). DR columns with an average diameter of 2.5 m were put on a 3.80 m × 3.80 m square grid into top loose sand to extremely soft Sabkas soil at depths of up to 9 m.

5.3 Sand compaction piles (SCP)

SCP has become a method of dynamic replacement that may be utilized in both clayey and sandy soil. The approach was developed in Japan and is extensively utilized in that country and other Asian nations. The technology is noteworthy because the building procedures involved in sand compaction piles vary from those engaged in vibro compaction or stone columns. Sand is delivered into the ground via a casing pipe and compressed by vibration, dynamic impact, or static excitation to create columns in the formation of sand compaction piles. Sand compaction piles may be used to improve both sandy and clayey soil. This is not the same as vibro compaction. SCPs are mostly used for sandy terrain to avoid liquefaction and minimize settlement.

5.4 Geotextile confined columns (GCC)

The GCC technique involves embedding or shaking a steel casing 80 cm in diameter into the ground's bearing soil, followed by the placement of a seamless cylindrical closed bottom geotextile "sock" with tensile strength ranging from 200 to 400 kN/m. After that, it is filled with sand to produce a sand column. The primary idea behind this approach is to alleviate strain on soft soil without significantly affecting the underlying structure. To build a column, sand is put into a closed bottom geotextile lined cylindrical hole.

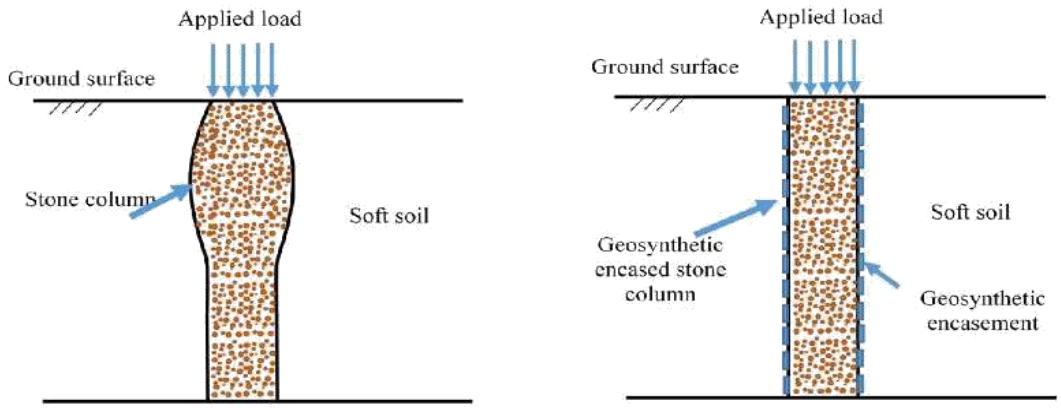


Fig.8 Geotextile confined columns (GCC)

5.6 Rigid inclusions (or composite foundation)

Piles, stiff or semi-rigid bodies, or columns that are either prefabricated or produced in-situ to support soft ground are used in this approach. Rigid inclusions are the use of semi-rigid or stiff integrated columns or bodies in soft ground to enhance overall ground performance by decreasing settlement and increasing bearing capacity. Stone columns, SCPs, and GCCs are all examples of stiff inclusions. They are addressed individually, however, since the materials utilized for those columns (sand, granules, or stones) have dissolved and the columns generated cannot stand without the lateral support of soil.

The solid inclusion approach is analogous to the usage of piles. However, for economic considerations, the strength and stiffness of rigid inclusions are often substantially lower than that of piles.

5.7 Geosynthetic reinforced column or pile supported embankment Geosynthetic-reinforced columns/pile supported embankment, or the so-called piled embankment system, has often been utilized for road or rail projects over soft ground. To sustain an embankment on soft soil, piles or columns are utilized in conjunction with a load transfer platform in this design. To improve embankment stability and decrease settlement, piles may be concrete piles, stone columns, GCC, or any of the stiff features listed aforementioned.

5.8 Microbial methods

Microbial materials are employed in this approach to change soil to improve its strength or decrease its permeability. The basic idea behind microbial treatment is to employ microorganisms to induce bonding and cementation in soil to enhance shear strength and decrease permeability. Microorganisms that are suitable for this purpose include:

a. **Facultative anaerobic bacteria**

b. **Micro-aerophilic bacteria**
c. **Anaerobic fermenting bacteria**
d. **Anaerobic respiring bacteria**
e. **Obligate aerobic bacteria**

6.0 CONCLUSIONS

This investigation searched for to provide an overview of current advancements in ground improvement methods, which are extensively employed in the area of geotechnical engineering and will play a significant role in field and earthwork building projects of various sorts in the next years. As previously said, various technologies are currently accessible, some of which are extremely ancient and others of which are continuously evolving and emerging but may not yet be suitable for everyday use. Among the significant challenges, some areas for additional investigation include:

- **How to best incorporate sustainability considerations in ground improvement method selection and implementation giving consideration to embodied energy, carbon emissions, and life cycle costs.**
- **How to improve and simplify constitutive modelling.**
- **Development of practical, economical and environmentally safe biogeochemical methods for soil stabilization and liquefaction risk mitigation.**
- **Development of databases for variability of soil and material parameters required in the design of ground improvement**
- **Development of improved and more reliable methods for evaluating the long term durability of soils mixed with binder. Understanding creep mechanisms in soils and interaction of creep with semi-rigid inclusions**

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