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Recent Developments in Ground Improvement Techniques- A Review

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***Abstract*— In recent years rapid development of infrastructures in metro cities compounded with scarcity of useful land and compelled the engineers to improve the properties of soil to bear the load transferred by the infrastructure e.g Buildings, bridges, roadways railways etc. The engineering techniques of ground improvement are removal and replacement, pre-compression, vertical drains, in-situ densification, grouting, stabilization using admixtures and reinforcement. The purpose of these techniques to increase bearing capacity of soil and reduce the settlement to a considerable extent. The one of the method among ground improvement techniques is reinforcing the soil with materials like steel, stainless steel, aluminum, fibers, fiber glass, nylon, polyster, polyamides in the form of other strips or grids and Geotextiles. The Primary purpose of reinforcing a soil mass is to improve its stability, increasing its bearing capacity and reduce Settlements and Lateral deformations. Geotextiles and geomembranes, broadly speaking are synthetic fibres used to stabilize structures built on soil. The new widely accepted generic term for these non natural materials is Geo-synthetics. Geosynthetics include permeable and impermeable materials that are either of knitted, woven, or non-woven nature, as well as polymer grids and meshes. The role of geosynthetic material varies in different application as it can serve as reinforcement, separation, filtration, protection, containment, fluid transmission and confinement of soil to improve bearing capacity. Geocell reinforcement is a recently developed technique in the area of soil reinforcement having a three dimensional, polymeric, honeycomb like structure of cells made out of geo-grids inter connected at joints. Selection processes for ground improvement methodologies, improved analysis, and knowledge of long term performance and understanding of effects of variability are required to develop more efficient designs. This paper presents a review on recent development in ground improvement techniques.**

***Keywords*— Ground improvement, Geosynthetics, Vibro-compaction, Prefabricated vertical drains, Soil reinforcement.**

I. INTRODUCTION

Ground improvement techniques are given the utmost importance in present days to adapt week ground/soil into the appropriate competent stable ground for different civil engineering applications.

It started with Henri Vidal (1960) and became familiar with the pioneer work of Binquet and Lee. Ground improvement techniques are recommended in difficult ground conditions as mechanical properties are not adequate to bear the superimposed load of infrastructure to be built, swelling and shrinkage property more pronounced, collapsible soils, soft soils , organic soils and peaty soils, karst deposits with sinkhole formations, foundations on dumps and sanitary landfills, handling dredged materials for foundation beds, handling hazardous materials in contact with soils, using of old mine pits as site for proposed infrastructure. When a project site come across any of the above difficult conditions, possible alternative solutions may be one of among as avoid the particular site; design the planned structure (flexible/rigid) accordingly, remove and replace unsuitable soils, attempt to modify existing ground, enable cost effective foundation design, reduce the effects of contaminated soils, ensure sustainability in construction projects using ground improvement techniques. While it may not be immediately apparent, ground improvement methods have made considerable advances since today's commonly practiced techniques began to develop in the 20th century however most techniques have gone through changes. This paper presents a review on research and development in the field of ground improvement.

II. MECHANICAL IMPROVEMENT TECHNIQUES

In this method soil density is increased by the application of mechanical force, including compaction of surface layers by static vibratory such as compact roller and plate vibrators. This technique is further classified as:-

a. Dynamic Compaction
b. Vibro-Compaction
c. Compaction Grouting
d. Pre loading and Pre-fabricated Vertical Drains
e. Blast densification

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A. Development of Dynamic Compaction

This technique was invented and promoted by Louis Menard as early as 1969 but it was not until 29 May 1970 that he officially patented his invention in France. The concept of this technique is improving the mechanical properties of the soil by transmitting high energy impacts to the soil by dropping a heavy weight called pounder from a significant height. When feasible, dynamic compaction is probably the most favorite ground improvement technique in granular soils as it is usually the most economical soil improvement solution (Mitchell, 1981).Depth of influence or improvement is the depth where there are limited or practically insignificant amounts of improvement in the soil. Menard and Broise (1975) developed an empirical equation in which the depth of influence, D, was a function of the square root of the impact energy; i.e. the product of the pounder weight (in metric tons) by the drop height (in metres). Later and based on further site experiences others introduced a coefficient less than unity to the original equation and Varaksin (Chu et al., 2009) has further refined the relationship by introducing drop type and energy function coefficients. Hamidi et al. (2011a) have reviewed the equipment advances of dynamic compaction rigs. Menard performed his first dynamic compaction projects using 80 kN pounders that were dropped from 10 m. He was soon able to identify heavy duty cranes that were capable of efficiently lifting and dropping pounders weighing up to about 150 kN using a single cable line. Menard then developed and manufactured his own rigs that were able to lift 250 and more than 1,700 kN pounders. As much as these special rigs had their applications, they were specifically produced, their numbers were limited and they could not be manufactured commercially or in great numbers. However, the introduction of a new generation of cranes that are able to lift pounders using two single cable lines has now increased lift capacity commercially to 250 kN. The introduction of these rigs was able to increase pounder lift capacity; however it is still possible to improve the efficiency of impact energy by dropping the pounder in free fall. Thus, the next major innovation in dynamic compaction was the development of the Menard Accelerated Release System (MARS) which is able to release the pounder from the lifting device as the pseudo free fall commences. In this method Digital monitoring instruments are now able to record the coordinates of the impact point, drop height, number of drops per point and impact velocity. This enables the engineer to improve quality assurance and optimization of work parameters. This technique is most suitable for densification of loose granular soils.

Fig.1 Dynamic Compaction

B. Development of Vibro-compaction

This technique involves densification of granular soil using a vibratory probe inserted into ground. It is a deep compaction technique that was invented in the mid 1930s in Germany for treating sandy soils. In this technique an electric or hydraulic vibrating unit called a vibroflot or vibro-probe penetrates the ground and the loose sands and causes in enhancement of density. Although the appearance of vibroflots have not changed much during the past seven decades and most equipment would seem very similar to the untrained eye, today specialist ground improvement companies manufacture vibro-probes with different capabilities. Vibration frequencies are now closer to the soil's natural frequency and the power range of the plant allows specific uses of each machine.

Vibro-compaction is successful in loose sand soils typically with an original SPT value of 5 to 10 near the surface and not applicable to clays. Relative density of up to 85% can be achieved.

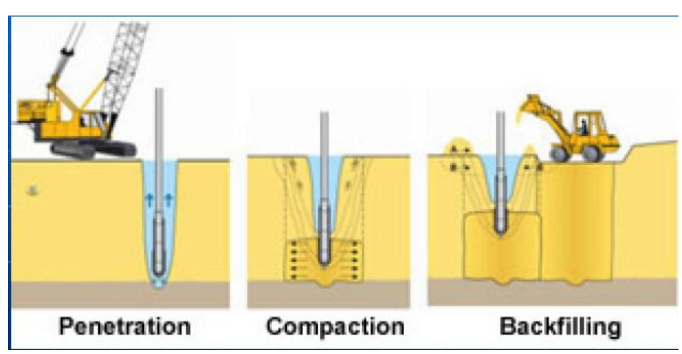

Fig.2 Process Of Vibro Compaction

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C. Development of Compaction Grouting

Compaction grouting is a ground treatment technique that involves injection of a thick-consistency soil-cement grout under pressure into the soil mass, consolidating, and thereby increases density of surrounding soils in-situ. The injected grout mass occupies void space created by pressure-densification. Pump pressure, as transmitted through low-mobility grout, produces compaction by displacing soil at depth until resisted by the weight of overlying soils. Compaction Grouting When injected into very dense soils or bedrock, compaction grout remains somewhat confined, since the surrounding material is quite dense. However when injected into under-consolidated or poorly-compacted soils, grout is able to "push" these materials aside. When grouting treatment is applied on a grid pattern, the result is improved compaction of displaced soils and greater uniformity of the treated soil mass. As a secondary benefit, the resulting grout columns add strength in the vertical axis, as typical grout compressive strengths exceed those of the surrounding soils. Compaction grouting applications include densification of foundation soils, raising and relieving of structures and foundation elements, mitigation of liquefaction potential, augmentation of pile capacity and pile repair, and densification of utility trench backfill soils.

The method has also been used to support deep excavation into soft ground for a case in Shanghai (Liu et al 2005). A few more examples are given by Welsh and Burke (2000). An alternative compaction grouting technique has also been proposed by Naudts and Van Impe (2000) in which geo-textile bags are used. In adopting this method, regular sleeve pipes are installed to the required depth. Geo-textile bags are strapped straddling all or some of the sleeves. The geo-textile bags are inflated via a double packer with balanced, stable, low viscosity cement based suspension grout with high resistance against pressure filtration. Several bags (on different pipes) are inflated at the same time. The inflation process is done in stages to allow the water to slowly (pressure) filtrate through the geo-textile bags. During each grouting stage the pressure is systematically increased. The spacing between the grout pipes has to be such that the soils are subjected to vertical stresses in excess of those they will eventually be subjected to. The volume reduction of the surrounding soils under the grouting pressure, as well as the influence radius of the compaction grouting can be mathematically estimated with the method described by Naudts and Van Impe (2000). This in turn dictates the spacing between the grout pipes.

For projects in which the densification of soil is the main issue, the alternative compaction grouting method can result in a more controlled and predictable compaction system.

D. Soil Modification by Pre-fabricated Vertical Drains

This method increases the bearing capacity and reduces the compressibility of weak ground and it is achieved by placing temporary surcharge on the ground. Surcharge generally more than the expected bearing capacity. It is most effective for soft cohesive ground. The process may be speed up by vertical sand drains/prefabricated vertical drains. These drains are installed in order to accelerate settlement and gain in strength of soft cohesive soil. Vertical drains accelerate primary consolidation only. As significant water movement is associated with it. Secondary consolidation causes only very small amount of water to drain from soil; Secondary settlement is not speeded up by vertical drains. Only relatively impermeable type of soil is benefited from vertical drains. Soils which are more permeable will consolidate under surcharge. Vertical drains are effective where a clay deposit contain many horizontal sand or silt lenses.

Fig.3 Compaction Grouting

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E. Soil Modification by blast densification

Blast-densification is a ground improvement technique for densifying loose, relatively clean, cohesion less soils. It increases the density of loose granular deposits, above or below the water table.

The explosive wave temporarily liquefies the soil, causing the soil particles to rearrange to a higher relative density as excess pore pressure dissipates. It has been used to treat soils to depths of up to 40m. As depth increases, the size of the charge necessary to destroy the soil structure and liquefy the soil increases. Excess pore pressure and settlement due to explosion are related to the ratio $Nh = W^{1/3}/R$,where Nh= Hopkin's number, W= weight of explosives, equivalent kilograms of TNT and R= radial distance from point of explosion, m. If Nh is less and in the range of 0.09 to 0.15, liquefaction does not occur and the equation can be used to estimate safe distance from explosion. Example Nh = 0.12 and W= 10kg Radial distance from point of explosion, R = 17.95m The use of blasting for the densification of granular soil has been developed for many years. The principle of the method is to generate settlement of granular soil ground or fill by causing the soil to liquefy or be compacted using the shock waves and vibration generated by blasting. This method was used in the past mainly for mitigation of liquefaction in hydraulically placed sand fill. Therefore, the method has also been called explosive compaction. The development and application of this method up to the early 80s were summarised by Mitchell (1981). Explosive compaction has the advantage of low cost and ease of treating large depths. However, the method has not been widely accepted mainly because it is still based on experience rather than theory. Some field studies (Charlie et al 1992; Gandhi et al. 1998; Gohl et al. 1998; 2000) have been carried out in order to understand better the blasting process. Theoretical analyses and numerical modelling using cavity expansion theories and blasting mechanics have also been done (Henrch 1979; Wu 1995; Van Court and Mitchell 1995; Gohl et al. 1998) to improve the design and analysis. In recent years, explosive compaction has also been applied to the mining sector to shake down tailings ponds for tailings consisting of essentially non-plastic silt and sand-size particles. In this way, the volume of the existing tailings is reduced, which increases the storage capacity of the tailings impoundment and minimizes the need to raise the crest elevation of the tailings containment dike. The soil types treated by the explosive compaction method range from silt tailings to gravel cobbles and boulders.

III. HYDRAULIC MODIFICATION

The modification of soil properties are achieved by forcing the free pore water out of soil via drains or wells. In case of course grained soils it is achieved by lowering the ground water level through pumping from boreholes, or trenches and for fine grained soils the long term application of external loads (preloading) or electrical forces (electrometric stabilization). Some of the hydraulic modification method is:-

a. Preloading using fill
b. Preloading using fill with vertical drain
c. Vacuum preloading with vertical drains
d. Combined fill and vacuum preloading

A. Preloading using fill

Preloading is a process to apply surcharge load on to the ground prior to the placement of structure or external loads to consolidate the soil until most of the primary settlement has occurred so as to increase the bearing capacity and reduce the compressibility of weak ground.

The temporary surcharge applied on the ground is generally more than the expected bearing capacity. It is more effective for soft cohesive ground.

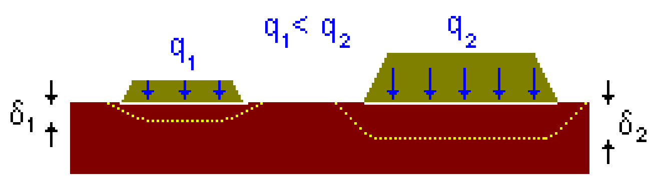

Fig.4 Preloading Using Fill

B. Preloading using fill with vertical drain

The method is the same as described earlier, except that vertical drains are used to provide radial drainage and accelerate the rate of consolidation by reducing the drainage paths thus accelerate the process of settlement in order to and gain in strength of soft cohesive soil. Vertical drains accelerate primary consolidation only. As significant water movement is associated with it. Secondary consolidation causes only very small amount of water to drain from soil. Secondary settlement is not speeded up by vertical drains.

The method of preloading using fill has been used for many years in the past and has been considered one of the mature soil improvement methods. Major progress in this method has been made since PVDs were introduced as part of the preloading techniques.

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As a result of numerous research and field studies, the PVD technique has been established in a systematic way from analysis to construction. The past developments have been summarised in many publications, for example, Holtz et al (1991), Bo et al. (2003), Moseley and Kirsch (2004) and Raison (2004). Many case histories have also been published, e.g., Hansbo (2005) and Moh and Lin (2005). However, there are several new developments on PVDs that are still worth mentioning. The first is the development of design codes or design guides. These include the Code of Practice for Installation of Prefabricated Drains and the Quality Inspection Standard for Prefabricated Drains developed in China (JTJ/T256-96 1996, JTJ/T257-96 1996) and the European Standard on Execution of Special Geotechnical Works —Vertical Drainage (pr EN 15237, 2005). Second is the emergence of the new types of drains, such as electric vertical drain with a metal foil embedded 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 integrated drain offers a higher tensile strength and discharge capacity than the ordinary drain of the same materials and same dimensions. There are also PVDs for geoenvironmental use. For example, PVDs have been used to help in providing a vapour extraction system (Schaefer et al. 1997).For environmental usage, the PVD materials may need to be specially designed to resist acid corrosion (Chu et al. 2005).

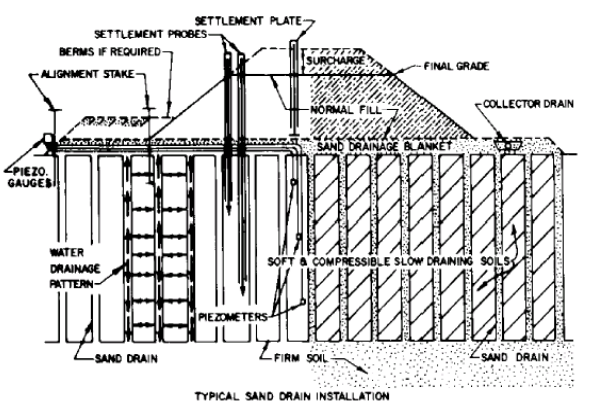

Fig.5 Vertical Drains

The vacuum preloading method has evolved into a mature and efficient technique for the treatment of soft clay.

This method has been successfully used for many soil improvement or land reclamation projects all over the world (Holtz 1975; Chen and Bao 1983; Cognon 1991; Bergado et al. 1998; Chu et al. 2000;Yee et al. 2004; Indraratna et al. 2005).With the merging of new materials and new technologies, this method has been further improved in recent years. The first large scale application of vacuum preloading was probably made in the early 80s in China for the development of the Tianjin Harbour (Chen and Bao 1983). The vacuum preloading was required because clay slurry was used for reclamation due to a shortage of granular fill materials there. In adopting this technique, sand drains (in the past) and prefabricated vertical drains (PVDs) were used to distribute the vacuum pressure and discharge pore water. In theory, a vacuum load of 90 kPa can be applied. However, in practice, the real vacuum pressure applied is normally lower than this. An overview of the principles and techniques of the Tianjin method and their applications have also been given by Chu and Yan (2005). Thousands of hectares of land have been reclaimed in Tianjin using this method (Chen and Bao 1983; Yan and Chu 2005). A number of case histories have been published (Chen and Bao 1983; Choa 1989; Tang and Shang 2000; Chu et al. 2000; Yan and Chu 2003; 2005). This method has been widely usedin other parts of China and other countries.

D. Vacuum preloading with vertical drains

This method is a combination of what have been described in B & C when a surcharge more than the vacuum pressure is required. The method is applicable to ground consists of mainly saturated soils having low permeability. The method can be used when there is a stability problem with fill surcharge. This method can also be used to extract polluted ground pore water if required. When surcharge higher than the maximum value that the vacuum pressure can provide a combined vacuum and fill surcharge can be applied. In this case, the fill surcharge is applied after the ground has been consolidated to gain adequate strength. As the fill surcharge generates excessive pore-water pressure higher than the hydrostatic or initial in-situ pore-water pressure, the vacuum pressure applied may expedite the dissipation of excess pore-water pressure and make the combined fill and vacuum preloading method more effective than using vacuum or fill surcharge alone for the same amount of total surcharge.

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IV. Physical And Chemical Modification

In this method soil improvement is achieved by physical mixing of adhesives with surface layers or columns of soil. The adhesive includes natural soils industrial by products or waste materials or cementations or other chemicals which react with each other and the ground. When adhesives are injected via boreholes under pressure into voids within the ground or between it and a structure the process is called grouting. Soil stabilization by heating and by freezing the ground is considered thermal methods of modifications. Some of the physical and chemical modification methods are:-

a. Grouting
b. Electro-osmosis
c. Soil Cement
d. Heating
e. Freezing
f. Vitrification

A. Grouting

Grouting technology has become a common ground improvement method used frequently for underground and foundation constructions. The process of grouting consists filling pores or cavities in soil or rock with a liquid form material to decrease the permeability and improve the shear strength by increasing the cohesion when it is set. Cement base grout mixes are commonly used for gravely layers or fissure rock treatment. But the suspension grain size may be too big to penetrate sand or silty-sand layers. In this case, chemical or organic grout mixes are also used. In recent years, the availability of ultrafine grout mixes has extended the performance of hydraulic base grout for soil treatment. Sandy gravel soil treated using ultrafine cement mix. The grout mix can be classified into four types:

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 operational limits of different grout mix are dependent on the type of soils and the particle size distribution of the soil. The grouting may be categorised as:

a. Penetration grouting
b. Displacement grouting
c. Compaction grouting
d. Grouting of Voids
e. Jet grouting

The grout-ability of soil with particulate grouting has been evaluated based on the N value, (Mitchell and Katti 1981) where N is defined as N = (D15)Soil / (D65)Grout. Grouting is considered feasible if N > 24 and not feasible if N < 11. Another alternative is to use Nc = (D10)Soil / (D95)Grout. Grouting is considered feasible if Nc > 11 and not feasible if N < 6 (Karol 2003).Many case histories of particulate grouting have been reported in the literature (e.g., Littlejohn 2004a; Schmall et al.07). A field evaluation of three different permeation grouts, namely sodium silicate, microfine powder, and microfine cement in a medium-dense, silty sand outwash deposit has been carried out by Brachman et al. (2004). It was found from this study that the sodium silicate grout zone was uniformly permeated and had a massive structure. The microfine powder grout appeared to permeate the outwash sand but did not harden in the ground. The specific formulation of the microfine cement grout resulted in only discrete veins of grouted sand. Cross-hole seismic velocity tests were conducted in this project. The average shear wave velocities measured through the grout zone were approximately 480 m/s in sodium silicate, 340 to 420 m/s in microfine cement or microfine powder. The shear wave velocity for the ungrouted sand was around 230 m/s (Brachman et al. 2004). A number of case histories of applications of chemical grouting have been given by Karol (2003) and Powers et al. (2007). Chemical grouting has been used for some major hydraulic or dam constructions in China including the three Gorges Dam and other projects (Tao et al. 2006). Many studies have been carried out recently on the properties of grouted soil. However, there are relatively fewer case histories published. Examples include the use of chemical grouting for the repair of an underwater road tunnel in Montréal, Canada by Palardy et al. (2003) and a field trial of the use of colloidal silica grouting for mitigation of liquefaction (Gallagher et al. 2007).

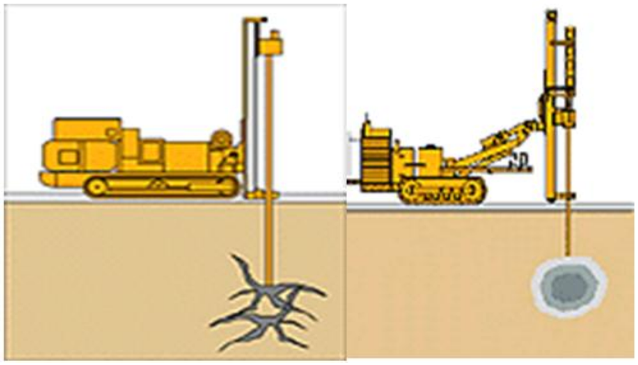

Fig.6 Grouting Methods

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B. Electro-osmosis

It is a term used for process of electro chemical hardening during electro osmosis by adding chemicals, such as sodium silicate or calcium chloride at the Anode. Under the influence of, the electric field, these chemicals permeate the ground, flowing in the direction of Cathode, while the Anode becomes a grout injection pipe.

C. Soil Cement

Stabilization using cement and other admixtures such as fly ash, blast furnace slag has been adopted in many geotechnical and highway engineering projects. These applications include a)Shallow depth applications in the case of improvement of subgrade, sub-base and base course of highways and embankment material and b) stabilization of deep soil deposits such as soft soils and peaty soils.

Addition of small quantities of cement proved to be beneficial and the degree of strength/ stiffness required is the basis for design and has been used in the stabilization of highways and embankments.

In large scale applications, depending on the strength and stiffness required based on the type of soil, the quantities required are huge and need large scale machinery and special procedures are required in stabilization of deep soils which are weak (Eg: peaty soils).

Benefits 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

Comprehensive reviews and descriptions of the various methods of deep mixing and applications have been given by Terashi (2003), Topolnicki (2004), Larsson (2005), Essler and Kitazume (2008) and Arulrajah et al. (2009). Standards such as BS EN 14679 (2005) for deep mixing have been established. The recent developments have mainly taken place in the optimisation of the process and the optimisation of tools for mass production.

D. Heating

Heating causes permanent changes in soil properties and renders the material hard and durable. Laboratory studies have shown that an increase in temperature increases settlements of clays under a given applied stress. Heat treatment of a clay soil to about 400°C results in pronounced changes in engineering properties. Heating is energy intensive and to stabilize one m^3 of soil 50 to 100 liters of fuel oil are required. It is not recommended now a day except in places where it is already available as inherent energy in waste products and in landfills. However use of geothermal piles as heating systems is prevalent in places like UK. The idea of preconsolidation of clay using a combined vacuum and heating method in cold region has been attempted by Marques and Leroueil (2005) in Quebec. Another field trial was carried out recently by Pothiraksanon et al. (2008) in which hot water was circulated into the PVDs to elevate the ground temperature. However, these methods are still in the experimental stage and there are no large scale field applications yet. Another application of heating method is the so-called heat exchange pile which has been discussed in detail by Brandl (2006) and Laloui et al. (2005). Some other methods of using heat for soil improvement purposes have been described in Van Impe (1989).

E. Freezing

The effectiveness of freezing depends on the presence of water to create ice, cementing the particles and increasing the strength of the ground to the equivalent of soft or medium rock. If the ground is saturated or nearly so it will be rendered impermeable. If the moisture does not fill the pores, it may be necessary to add water. The strength achieved depends on freeze temperature, moisture content and the nature of the soil. Freezing can be particularly effective in stabilizing silts, which are too fine for injection of any ordinary grouts. On freezing, water expands in volume by about 9% which does not itself impose any serious stresses and strains on the soil unless the water is confined within a restricted volume. After the initial freezing has been completed and the frozen barrier is in place, the required refrigeration capacity is significantly reduced to maintain the frozen barrier because freezing can be imposed uniformly on a wide range of soil types in a single operation, it may offer greater security in mixed ground than treatment by injection of various grouts. Applications of the method are:

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a. Temporary underpinning of adjacent structure and support during permanent underpinning
b. Shaft sinking through water-bearing ground
c. Shaft construction totally within non-cohesive saturated ground
d. Tunnelling through a full face of granular soil
e. Tunnelling through mixed ground
f. Soil stabilisation
g. Once the freezing process has begun, monitoring is required to ensure formation of the barrier wall and also to verify when freezing is complete.
h. During the drilling process, temperature-monitoring pipes are installed to measure the ground temperature.

F. Vitrification

Vitrification involves the melting and refreezing of soil to createa glass-like solid that entraps inorganic contamination thereby isolating it from the environment. The high temperatures required to melt soil also destroy organic contamination. Vitrification is thus capable of treating soil that is contaminated with both organic chemicals and metals. Six vitrification technologies have been studied thus far under the U.S. Environmental Protection Agency's Superfund Innovative Technology Evaluation (SITE) Program. Vitrification has been viewed as a potentially useful way to treat soil contaminated with both organic chemicals and metals. The high temperatures required to melt soil (2012-2642°F, 1100-1450°C) cause rapid volatilization and reaction of organic contamination.

V. Modification By Inclusion And Confinement

In this method modification of soil properties are achieved using reinforcement by means of fibers, strips bars meshes and fabrics imparts tensile strength to a constructed soil mass. In-situ reinforcement is achieved by nails and anchors. Stable earth retaining structure can also be formed by confining soil with concrete, steel, or fabric elements and Geocell. There has been a large increase in the use of admixtures for ground improvement for both cohesive and non-cohesive soil in recently years. Sand compaction piles, stone columns, dynamic replacement, semi-rigid and rigid inclusions, geotextile confined columns. A brief description of each technique under this method is presented in following paragraph

A. Vibro replacement or stone columns

Vibro Replacement is a technique of constructing stone columns through fill material and weak soils to improve their load bearing and settlement characteristics.

Unlike clean granular soils, fine grained soils (such as clays and silts) do not densify effectively under vibrations. Hence, it is necessary to form stone columns to reinforce and improve fill materials for weak cohesive and mixed soils.In the method a hole jetted into soft, fine-grained soil and back filled with densely compacted gravel or sand to form columns.

A variation of the stone column method is the vibro concrete column which is installed using dry bottom feed vibro equipment with stone aggregate replaced with a high slump concrete mix. One application of the vibro concrete column for a highway embankment over soft clay is described by Serridge and Synacy (2007). Another technique similar to the stone columns is the rammed aggregate pier method. This method also installs columns using crushed stone. However, the construction process is different. Instead of being horizontally vibrated into place, the stone is densely compacted by vertical ramming in about 0.3 m layers in the rammed pier method.

A patented bevelled tamper rams each layer of aggregate using static down force and vertical impact ramming energy, resulting in superior strength and stiffness. The tamper densifies aggregate vertically and forces aggregate laterally into the loose matrix soil. This results in matrix soil improvement and excellent coupling with the surrounding soils, thereby delivering reduction of liquefaction potential and highly reliable settlement control. The rammed aggregate piers can be used to reinforce a variety of soils, including loose sands, silts, and mixed soil layers including clays, uncontrolled fill and soils below the ground water table.

B. Dynamic replacement

In this method aggregates are driven into soil by high energy dynamic impact to form columns. The backfill can be sand, gravel stones or demolition debris. The method improves the strength of saturated cohesive soils and soft organic soils, when dynamic compaction is not effective due to the high fines content of the in-situ soils.

Case histories of soil improvement projects using the dynamic replacement method have been presented by Lo et al. (1990), Wong and Lacazedieu (2004), Ong et al. (2007) and Godlewski et al. (2007). The DR method was also adopted for the KAUST (King Abdullah University of Science and Technology) project for the treatment of Sabkas soil. DR columns with an average diameter of 2.5 m were installed on a square grid of 3.80 m x 3.80 m into the top loose sand to very soft Sabkas soil of up to 9 m.

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C. Sand compaction piles (SCP)

SCP is a special type of dynamic replacement which can be used for both clayey and sandy ground. The method was originated in Japan and has been widely used in Japan and other Asian countries. The method deserves special mentioning as the construction processes involved in sand compaction piles can be different from that for vibro compaction or stone columns. In forming sand compaction piles, sand is fed into the ground through a casing pipe and is compacted by either vibration, dynamic impact or static excitation to form columns. Sand compaction piles can be used for the treatment of both sandy and clayey ground. This is different from vibro compaction. The main purposes of using SCPs for sandy ground are to prevent liquefaction and reduce settlement.

D. Geotextile confined columns (GCC)

The GCC technique consists of driving or vibrating a 80 cm diameter steel casing into the bearing soil followed by placing a seamless cylindrical closed bottom geotextile “sock”, with tensile strength ranging from 200 to 400 kN/m. This is followed by filling it with sand to form a sand column. The basic principle of this technique is to relieve the load on soft soil without altering the soil structure substantially. The Sand is fed into a closed bottom geotextile lined cylindrical hole to form a column.

E. Rigid inclusions (or composite foundation)

In this technique piles, rigid or semi-rigid bodies or columns which are either premade or formed in-situ to strengthen soft ground. Rigid inclusions refer to the use of semi-rigid or rigid integrated columns or bodies in soft ground to improve the ground performance globally so as to decrease settlement and increase the bearing capacity of the ground. In the broad sense, stone columns, SCPs and GCCs are types of rigid inclusions. However, they are treated separately because the materials used for those columns (sand, granular or stones) are disintegrated and the columns formed are not able to stand without the lateral support of soil.

The method of rigid inclusion is similar to the use of piles. However, the strength and stiffness of rigid inclusions are usually much smaller than piles mainly for economical reasons.

F. Geosynthetic reinforced column or pile supported embankment

The method is used for road or rail constructions over soft ground, geosynthetic-reinforced columns/pile supported embankment or the so-called piled embankment system, has often been used. In this system, piles or columns are used together with a load transfer platform to support embankment on soft soil. The piles may be either concrete piles, stone columns, GCC, or any types of the rigid inclusions discussed above to enhance the stability and reduce the settlement of embankments.

G. Microbial methods

In this technique the microbial materials are used to modify soil to increase its strength or reduce its permeability. The principle of microbial treatment is to use microorganisms to produce bonding and cementation in soil so as to increase the shear strength and reduce the permeability of soil or rock. Suitable microorganisms for the purpose are:

a. Facultative anaerobic bacteria
b. Micro-aerophilic bacteria
c. Anaerobic fermenting bacteria
d. Anaerobic respiring bacteria
e. Obligate aerobic bacteria

It is relatively new idea, in geotechnical engineering in general but it has been identified as a “high priority” research area and cited as “a critical research thrust and the opportunity for the future”

H. Other methods

Unconventional methods, such as formation of sand pile using blasting and the use of bamboo, timber and other natural products.

(a) Sand pile formation by blasting is a method of forming sand piles using hidden explosions with elongated blasting charges was also used in Europe (Dembicki et al. 2006). In adopting this method, an additional layer of sand fill is first placed on the soft soil to be treated. Elongated explosive charges are installed, blast and then backfill.

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(b) The natural products such as bamboo and timber may also be used in countries where these products are abundant, it can be more economical to use these natural products for soil improvement. Some case histories have been presented by Rahardjo (2005) and Irsyam et al. (2008). The applications include slope repair and stabilization, as piles for embankment, and for road construction.

I. Reinforcement

This method improves the soil response by interaction between soil and inclusion. The improving period depends on the life of inclusion. In this technique there is no change in the state of soil. It is a widely used technique as it can be done for many types of soils. Sometimes fibres may also be used to provide tensile strength, redistribution of stresses and / of confinement, thereby increasing the stability of a soil mass, reducing earth pressures, or decreasing deformation or susceptibility to cracking. Geosynthetics or mechanically stabilised earth wall is an example of this method which widely used now a days .

VI. Combination Of The Above

By this method soil improvement is achieved by combination of improvement techniques discussed above to achieve composite improvement in the desired properties. The example of the method are geosynthetic encased stone column, combination of deep Soil Mixing (DSM) columns and reinforced concrete bored piles (Shao et al. 2005) and combination of mini piles and jet grout columns.

VII. Conclusions

This paper has attempted to offer a review of the recent development in of ground improvement techniques which are widely used in the field of geotechnical engineering and will play a major role in the field and earthwork construction projects of many types in the years ahead. As described many technologies are now available, some that are very old and some that are still developing and emerging, but perhaps not yet quite ready for routine application. Some of the further research area among the key problems is:-

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

It is anticipated that with continued research and field experience in addressing challenges such as above, the sub-discipline of ground improvement will continue its development and importance as a critical component of successful geotechnical engineering and construction.

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REFERENCES

[1] Hausmann,M(1990),"Engineering principles of Ground modification", Mc Graw-Hill Publications.

[2] Binquet,J.& Lee, K.L. (1975), "Bearing capacity test on reinforced earth slabs", Journal of Geotechnical Engineering Division, ASCE, 101(12), 1241-1255.

[3] Guido, V.A., Chang, D.K. & Sweeney, M.A. (1986), "Comparison of geogrid and geotextile reinforced earth slabs",Canadian Geotechnical Journal (23), 435-440.

[4] Varaksin, S.(1981), "Recent development in soil improvement techniques and their practical applications", Solcompact Sols/Soils, Techniques Louis Menard, 15, rue des Sablons, Paris, 38/39-1981.

[5] Liu, J. (2003), "Compensation grouting to reduce settlement of buildings during an adjacent deep excavation", Proc. 3rd Int. Conf. on Grouting and Ground Treatment, Geotechnical Special Publication120, ASCE, New Orleans, Louisiana, 2: 837-844.

[6] Welsh, J.P., & Burke, G.K. (2000), "Advances in grouting technology", Proceedings of GeoEng 2000. Melbourne.

[7] Van Impe, W. F. (1989)," Soil improvement techniques and theirEvolution", Taylor & Francis.

[8] Charlie, W.A., Jacobs, P.J., & Doehring, D.O. (1992), "Blasting-induced liquefaction of an alluvial sand deposit" Geotechnical Testing Journal, ASTM, 15(1): 14-23.

[9] Bo, M.W., Chu, J., Low, B.K. & Choa, V. (2003), "Soil Improvement Prefabricated Vertical Drain Technique", Thomson Learning.

[10] Mitchell, J.K., & Katti R.K. (1981), "Soil Improvement" - State of the Art Report. 10th ICSMFE, Stockholm, 4: 509-565.

[11] Karol, R.H. (2003), "Chemical Grouting and Soil Stabilization", 3rd: CRC Press.

[12] Rahardjo, P. P. (2005), "The Use of bamboo & bakau piles for soil improvements and application of pile raft system for the construction of embankment on peats and soft soils", Chapter 31,Ground Improvement - Case Histories, B. Indraratna & J. Chu (Eds.), Elsevier, 899-922.

[13] Hausmann, M R (1984), "Engineering principles of Ground Modification".

[14] Schafer et al (1997), "Ground Improvement, Ground Reinforcement, and Ground Treatment- Developments".

[15] Warner, J.(2004), "Practical Handbook of Grouting, Soil, Rock, and Structures", John Wiley and Sons.

[16] Chu, J., Varaksin, S., Klotz, U. and Menge, P. (2009), State of the Art Report- Construction Processes",17th Intl. Conf. on Soil Mech. and Geotech. Engrg.: TC17 meeting ground improvement, Alexandria, Egypt, 7 October 2009, 130.

[17] Hamidi, B., Nikraz, H. and Varaksin, S. (2009), "A Review on Impact Oriented Ground Improvement Techniques", Australian Geomechanics J., 44(2): 17–24.

[18] Menard, L. and Broise, Y. (1975), "Theoretical and Practical Aspects of Dynamic Compaction", Geotechnique, 25(3): 3–18.

[19] D. Leshchinsky (2011),"Some issues in geosynthetic reinforced walls and slopes", Geotechnical Engineering journal of the SEAGS & AGSSEA, Vol. 42 No.1

[20] G. Madhavi Latha et al (2007), "Effects of reinforcement form on the behavior of geosynthetic reinforced sand" Geotextiles and geomembranes 25, 23-32.