Techniques of Ground Improvement and Its Applications

Ms.J.Divya [1] , **Mr.P. BIKKU** [2], Mrs. M.Durga [3], Mrs.V.Srujana [4]
Department of Civil Engineering, Samskruti College of Engineering and Technology

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ABSTRACT: It is due to rapid growth of population, fast urbanization and more development of infrastructures like buildings, highways , railways and other structures in recent past years has resulted in reduction of availability of good quality of land. Therefore engineers have no choice left except to use soft and weak soils around by improving their strength by means of suitable modern ground improvement techniques for construction activities. At present the available ground improvement techniques are replacement of soil, vertical drains, stone columns, vibro compaction , dynamic compaction, soil reinforcement, vibro piers, in-situ densification, pre-loadings, grouting and stabilization using admixtures. The aim of these techniques are to increase the bearing capacity of soil and reduce the settlement. Ground improvement by reinforcing the soil is achieved by using fibers of steel, glass ,various polymers in the form of strips or grids and geosynthetics. Geosynthetics may be permeable or impermeable in nature depending on composition and its structure. The geosynthetics material can be used to perform different roles in different applications. It can be used as reinforcement, separation, filtration, protection , containment and confinement of soil to increase its bearing capacity. Depending upon the requirement and site condition a Geocell reinforcement may also be used. This paper presents a thorough study on various available modern ground improvement techniques and their applications in civil engineering in present scenario. On the basis of long term performance results of various ground improvement techniques and its analysis, an efficient design can be developed and a suitable method of ground improvement technique may be adopted for a particular application.

KEYWORDS: Geosynthetics, vertical drains, stone columns, vibro-compaction, dynamic compaction, soil reinforcement.

I. INTRODUCTION

The social, economic, cultural and industrial growth of any country depends heavily on its transportation system. The only mode which could give maximum service to one and all is transportation by highways and railways. As a result of development of infrastructures like buildings, highways, railways and other structures in recent past years has resulted in scarcity of good quality of land for construction projects. Therefore the engineers are bound to adopt inferior and weak soil for construction. In present scenario the role of ground improvement techniques has become an important and crucial task for various construction projects. By ground improvement techniques the strength of the soil increases, its compressibility reduces and the performance under applied loading enhances. The expansive and collapsible soils are challenges to engineers due to their peculiar behavior of high swelling and shrinkage action. The construction of foundation on sanitary landfills, soft soils, organic soils and karst deposits are troublesome. It is to better to replace or bypass such type of soil strata by adopting suitable design of foundation and if not possible the ground improvement is the best solution for a such construction project site. This paper presents thorough study on various available modern ground improvement techniques and their applications in civil engineering in present scenario.

II. GROUND IMPROVEMENT TECHNIQUES

2.1. Mechanical Stabilization: The prime purpose of this technique is to increase soil density by applying mechanical force in the form of static, vibratory rollers and plate vibrators as the case may be to achieve proper compaction. Compaction of the soil can be done easily if the soil fill material is well graded. Well graded soil being characterized by high uniformity coefficient $C_u > 15$ and coefficient of curvature Cc between 1 and 3 can be compacted to greater density by rollers , tampers and other mechanical means. The optimum moisture content (OMC) should be determined and compaction should be done at or near the optimum moisture content for cohesive soils to achieve max dry density (MDD) with sheep foot rollers. However in case of cohesionless soils the compaction can be best achieved by vibrations. The various methods are listed below-

2.1.1 Vibro-flotation
2.1.2 Heavy weight compaction
2.1.3 Sand compaction piles
2.1.4 Stone columns
2.1.5 Blending
2.1.6 Blast Densification

2.1.1. Vibro-flotation: This technique can be effectively used for deposits of sands. In this method compaction is achieved by vibration and flooding the soil around it with water. This technique was invented around 1930 in Germany for treatment of sandy soils. The equipment required for vibro-flotation is shown in Fig-1. It contains a vibro-float with a water sump, a crane, a front end loader, power supply etc. The vibro-float consists of a cylindrical penetrator tube about 0.38 meters in diameter and about 2.0 meter in length with an eccentric rotating weight inside the cylinder which is responsible for developing a horizontal vibratory motion. The weight can develop a horizontal centrifugal force of magnitude of about 100 KN at a speed of 1800 rpm.

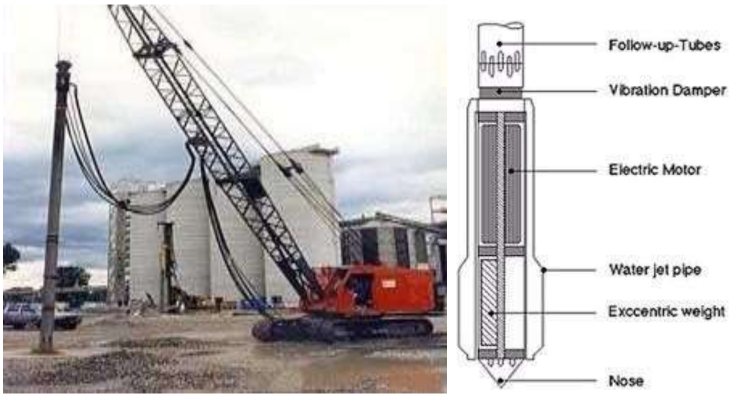
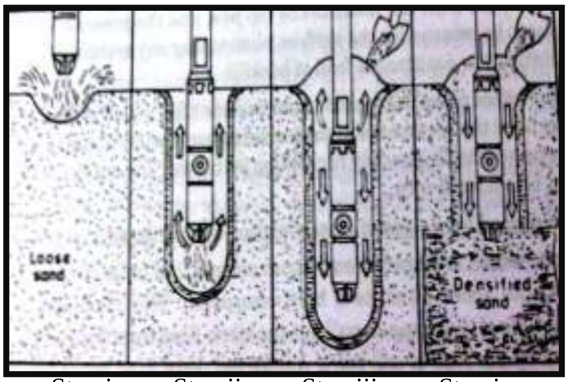


Fig-1 Vibro-flotation equipments arrangement & Vibro-float

A typical vibro-float as shown in Fig-1,consists of two parts, the lower part is horizontally vibrating unit which is connected with upper part, a follow up pipe of adjustable length to suit compaction depth. The water pump provides water to sink the vibro-float into the ground by jetting action, as the vibro-float is lowered from the crane. Vibro-flotation, sometimes also mentioned as vibro-compaction. Vibro-flotation may be defined as a process of rearrangement of soil grains into a denser state by use of powerful depth vibration. It creates a stable foundation soils by densifying loose sand. The loose sand grains are rearranged into a much compact state by combined action of vibration and water saturation by jetting. Each compaction sequence as shown in Fig-2, involves four basic steps, as mentioned below-

i. The vibro-float probe is suspended from the crane, and is positioned over the ground at the spot to be compacted. Its lower jet is then fully opened.
ii. Water is pumped in faster than it can drain away into the subsoil. This creates a momentary “quick” condition beneath the jet, which permits the vibro-float to sink of its own weight and vibrations.
iii. Water is switched from the lower to the top jets, and pressure is reduced enough to allow water to be returned to the surface, eliminating any arching of the backfill material and facilitating the continuous feed of backfill.
iv. Compaction takes place during 0.3 m per minute lifts, which return the vibro-float to the surface,up from the bottom of soil deposit being compacted. Thus raising the vibrator step by step and simultaneously backfilling with sand, the entire deposit of sand can be compacted into a hard core.



Step i Step ii Step iii Step iv

Fig-2 Steps involved in Vibro-flotation process

The depth up to which a vibro-float can cause compaction is about 30 meters. The maximum compaction depth depends on the capacity of the crane to pull out vibro-float from the ground , soil type and backfill material. The suitability of the backfill material depends upon the gradation. Brown in 1976 has developed a rating system to judge the suitability of the backfill material. The rating is based on suitability number, which is defined as-

Suitability Number $= 1.7\sqrt{\left(\frac{3}{D50^2} + \frac{1}{D20^2} + \frac{1}{D10^2}\right)}$ ----------- (1)

Where D_{10},D_{20} and D_{50} are the particle corresponding to 10,20 and 50% finer respectively.

On the basis of suitability number the quality of backfill material can be described as excellent, good and bad, as shown in table -1 below-

Table-1 Backfill Evaluation Criteria

S. No.	Suitability Number	Rating of the quality of the backfill material
1	0-10	Excellent
2	10-20	Good
3	20-30	Fair
4	30-50	Poor
5	>50	Unsuitable

Very loose sand below the water table can be best compacted by this method. Relative density up to 85% can be achieved. However with increase in silt and clay content in the soil layer the depth of compaction reduces. It is only due to finer particles and organics damping out vibrations, sticks the sand particles together or filling the voids between the particles, thereby restricting the movement of particles necessary for densification. Clay layers present in in-situ soil also reduce the zone of compaction. In soft cohesive soils the vibro-flotation technique is used with gravel as backfill material.

Applications-

- Reduction of foundation settlement
- Permit construction on granular fills.
- Reduction of risk of liquefaction due to seismic activity.

2.1.2. Heavy weight compaction: In this method loose soils are compacted by repeated dropping of heavy weight on the ground surface, so as to cause compaction of soil up to sufficient depths. This method is very simple, can be used for both cohesionless and cohesive soils as well. This method is also known as deep dynamic compaction or deep dynamic consolidation method.

Fig-3 Deep dynamic compaction

A crane is used to lift a heavy concrete or steel block weighing up to 500 KN and up to a height of 40 to 50 meters, from this height it is allowed to fall freely on to the ground surface. As a result of impact of falling weight on ground will cause a deep pit on the surface as shown in Fig-3. This process of falling weight is then repeated either at the same location or over other parts of the area to be compacted turn by turn, as to cover entire area. Top soil is then levelled and compacted in the same manner by using some lighter weight. The depth up to which compaction is caused by fall of heavy weight can be calculated by the Leonardo equation as shown below-

$$D = \sqrt{Wh}/6.26 \quad \text{-----} \quad (2)$$

Where W= Weight of falling weight in KN , h= height of fall in meters

Applications:

- can be used for both cohesionless and cohesive soils

2.1.3. Sand compaction piles: For construction of sand compaction pile a hollow steel pile with bottom closed by a collapsible plate, is driven up to the required depth through the loose fill, The hollow pipe is then filled with sand and the pipe is withdrawn while the air pressure is directed against the inside sand from the top. The bottom plate which is of collapsible type in nature, opens during the withdrawal, and sand from pipe backfills the hollow space created earlier during driving of the pile. The in-situ soil is densified while the pipe is being withdrawn and the sand backfill prevents the soil surrounding the compaction pipe from collapsing as the pipe is withdrawn.

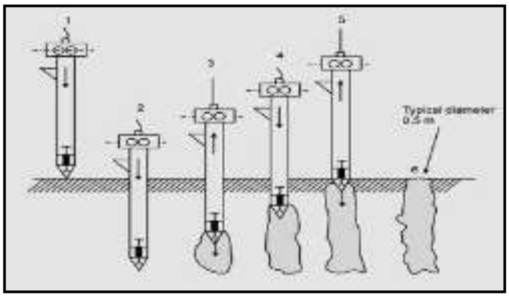
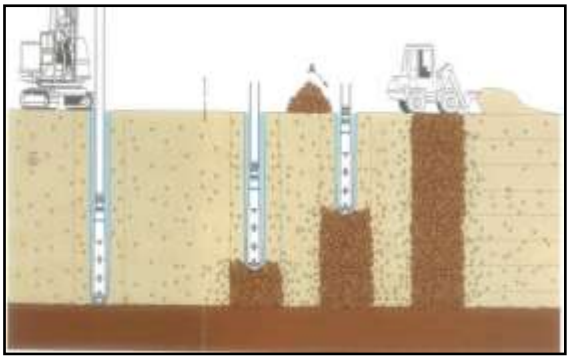


Fig-4 Formation of sand compaction piles

The maximum limit of fines that can be present is 15% passing 0.075mm sieve and 3% passing 0.005 mm sieve. The spacing between sand compaction piles will depend upon the site conditions of the fill to be compacted. The steps of formation of sand compaction piles are shown in Fig-4.

2.1.4. Stone columns: The method used for formation of sand compaction pile or the vibro-float can be used to construct stone columns. The hollow steel compaction piles are here filled with stones instead of sand, and the technique of constructing the stone columns remains the same as that for sand piles. Similarly in vibro-flotation technique gravel may be used as the backfill material. Here the steps of stone column construction by vibro-float is shown in Fig-5. The size of stones to be used in stone columns may vary from 6 to 40 mm. The spacing of the stone columns may vary from 1 to 3 meter over the entire fill area.



1- Penetration 2- Replacement 3- Finishing
Fig-5 Formation of stone columns

It is usually assumed that entire foundation load is carried by installed stone columns with no contribution from intermediate ground. Bowels in 1988 given a relationship for finding out allowable bearing capacity of a stone column as shown below-

allowable bearing capacity, $qa = \frac{Kp}{Fs}(4c + \sigma\bar{r})$ -- (3)

Where q_a = Allowable bearing capacity of stone column
Kp = Tan² [45°+$\bar{\phi}$/2]
$\bar{\phi}$ = Drained angle of internal friction of stone
C = Either the drained cohesion (for large areas) or undrained shear strength (C_u)
$\bar{\sigma}r$ = effective radial stress as measured by pressure meter
Fs = Factor of safety of 1.5 to 2.0
The total allowable load (Qa) on each stone column of an average cross-sectional area A, is then given as qa x A. The stone column should extend through soft clay to firm strata to control settlements.

Applications-

- Particular application in soft inorganic cohesive soils and are generally inserted on a volume displacement basis.
- Can be used in loose sand deposits to increase density.
- Reduction of foundation settlement
- Improve bearing capacity/reduce footing size requirements
- Reduction of the risk of liquefaction due to seismic activity
- Slope stabilization
- Permit construction on fills
- Permit shallow footing construction

2.1.5. Blending: Sometimes soil deposits show skip grading i.e. the particle size distribution (PSD) curve possesses a horizontal portion , reflecting deficiency of particles of some particular size. The particles of missing sizes will have to be added to reduce their void ratio. This addition of missing size of particles is known as blending and is often used in highway projects. Similarly cohesionless soils (uniformly graded) are usually mixed with cohesive soils , as to enable them to be compacted easily with conventional road rollers. This is also known as blending. The main objective of the blending is to reduce the void ratio. In the field it is achieved by obtaining particle size distribution (PSD) curve with high coefficient of uniformity (Cu) after blending.

Fuller's Law of blending: It states that the granular soil mass attains a very high density after compaction, if the distribution of particle size as follows-

Percentage of particle passing any sieve , $P = (D/Dmax)½$ -- (4)
Where D_{max} = size of largest particle
D = Opening of a particular size

Applications-

- In highway projects for soil sub-grade

2.1.6. Blast Densification: It is a ground improvement technique used for loose cohesionless soil to densify the same. It increases the density of loose granular soil irrespective of its position above or below the ground water table. Due to impact of explosive waves soil temporarily gets liquefied and excess pore water pressure gets dissipated causing rearrangement in soil grains to achieve higher relative density. It is suitable to treat soil up to 40 meters depth. At greater depth more charge is required for similar action. Relation between excess pore pressure and settlement is shown below-

$$Nh = \sqrt[3]{W}/R \text{ -- (5)}$$

Nh = Hopkin's number
W = Weight of explosives, equivalent kilogram of TNT
R = Radial distance from point of explosion in meter
If $0.09 < N_h < 0.15$, liquefaction does not occur and equation can be used to estimate safe distance from explosion. The basic principle of this method states that soil is compacted due to shock waves and vibration generated by blasting. This method is also called explosive compaction. It is economical and can treat large depths at low cost. The soil types treated by this method range from silt tailings to gravel cobbles and boulders.

Applications-

- In mining sectors
- Ease of treating large depths

2.2. Stabilization by Pre-loading Method: The deposits of oft fine grained silts and clays , organic soils, loose silts, and sandy soils and even rubbish can be stabilized by pre-loading method. In this method a load is placed on the area having the weak compressible or loose surface strata , usually after spreading a blanket layer of sand over the site as shown in Fig- 6&7. This blanket layer acts as a drainage layer of high permeability as well as a levelling course. The surcharge load over the blanket layer increases the stress in the soil layer below it, thereby increasing the neutral stress (pore water pressure). The increase in the neutral stress initiates the consolidation process. And with the passage of time the neutral stress gets dissipated with expulsion of water. This causes a corresponding increase in the effective stress between the soil particles. This increase in effective stress changes the alignment of soil solids and consequently decreases the void ratio. Thus there occurs a volume change and increase in shear strength of the deposit. The weak compressible soil layer hence becomes stronger and a good bearing strata.

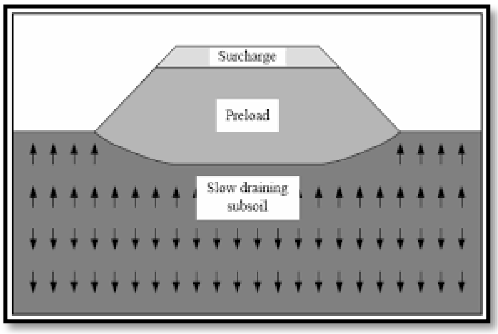


Fig-6 Pre-loading Method

Pre-loading is generally accomplished by applying dead load in the form of an earth fill or construction material or both, placed over the site which is overlain by a blanket sand layer before placement of dead load as shown in Fig-7.

The amount of dead load should also be controlled, as not to cause shear failure of the soil under that load itself. However with the dissipation of neutral stress, the pre-load can be increased. The rate of dissipation of neutral stress can be determined from one dimensional consolidation theory or by inserting a piezometers in the compressible layer.

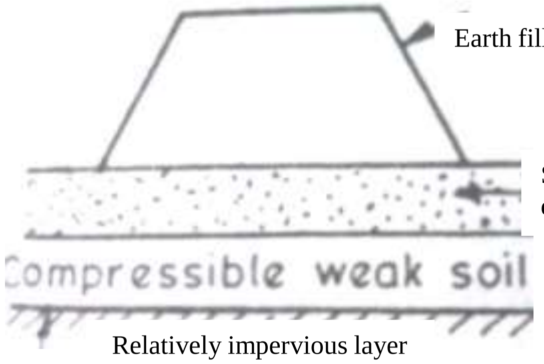


Fig-7 Improvement of compressible layer by Pre-loading

When a layer undergoes consolidation there is an increase in effective stress level and such a consolidated layer is said to have a pre-consolidation load equal to the effective stress attained due to consolidation. Generally a predetermined magnitude of surcharge load is placed to make the final effective stress at every point in compressible layer greater than or equal to effective stress likely to be induced by the foundation load. Thus the material will undergo little or no settlement due to the foundation load in the post construction period.

Applications-

- This method is most effective for soft cohesive soil.
- Reduced post construction settlement
- Reduction in secondary compression
- Densification
- Improvement in bearing capacity

2.3. Stabilization by Sand Drain Method: A thick compressible layer requires a long time to consolidate because water particles have to travel a long distance to reach the drainage layer. Reducing the length of travel path will result in hastening the consolidation in such layers. This is achieved by installing sand drains. Sand drains also called vertical drains , are vertical columns of sand or other materials of high permeability inserted through the compressible layers at sufficiently closed spacing. The spacing should be such that the longest horizontal travel path of water particles is a fraction of the longest vertical travel path. The presence of drains reduces the travel path for the water particles and hastens the consolidation process. The related equation is shown below-

Time factor for consolidation due to vertical drains, $Tv = Cv.t \backslash d^2$ --(6)

Where Cv = Coefficient of consolidation for vertical drainage , d = drainage path

Since the horizontal permeability of layered deposits is often much more than vertical permeability, the coefficient of consolidation for radial flow primarily involved in flow to sand drains is usually higher than that for vertical flow in one dimensional consolidation. This results in quick dissipation of neutral stress to achieve consolidation at a faster rate.

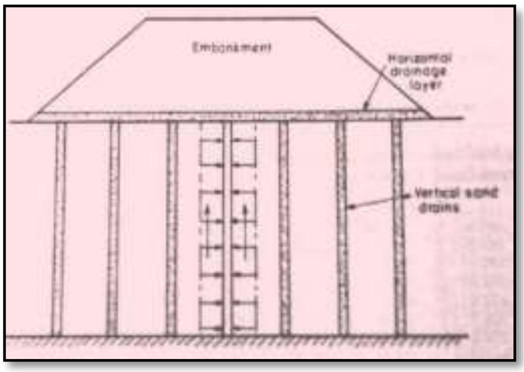


Fig-8 Installation of sand drains through a compressible soil layer

The geometry of a typical sand drain is shown in Fig-8. The water from the zone of influence of each well, the square and hexagonal area as shown in Fig-9, collects into the well and also flows vertically towards the free draining boundary resulting in a combination of radial and vertical flows.

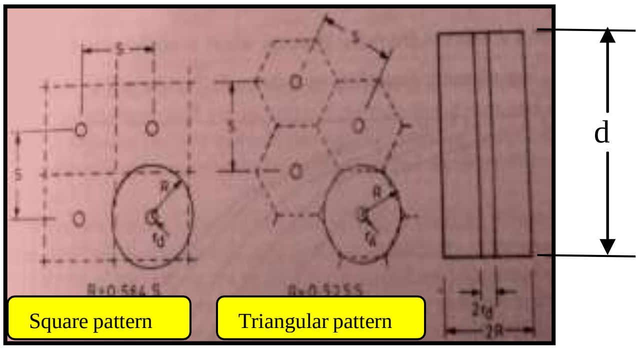


Fig-9 Spacing of sand drains

During the installation of sand drains, the zone around the periphery of the well gets distributed and the horizontal permeability in the distributed zone gets reduced. This effect, called smear, impedes the flow towards the well. Leonardo has suggested that by taking the diameter of the well equal to half the actually installed diameter, the effect of the smear can be accounted for.

Applications-

- Sand drains are normally used in conjunction with pre-loading
- In recent fills sand drains may be installed to relieve the excess hydrostatic pressure without surcharge loading.

2.4. Physical and Chemical Modification Techniques: Soil improvement by this method is achieved by mixing of adhesives and suitable chemicals in the surface layer or columns of soils as the case may be. The adhesive may be in the form of natural soils , waste materials , industrial by-products or other chemicals which react with each other and the soil. When the adhesives are injected under pressure through a pipe or boreholes into the voids of ground or in between the structure, the process is termed as grouting. In thermal method of soil stabilization soil is heated or freezed to achieve modification in properties of soil. Methods which are in practice are listed below-

2.4.1. Grouting
2.4.2. Electro-osmosis
2.4.3. Soil cement
2.4.4. Heating
2.4.5. Freezing
2.4.6. Vitrification

2.4.1. Grouting: This method is frequently used for ground improvement for underground and foundation construction. Now-a-days it has become very common practice. The process consists of sealing pores or cavities in soil or hard strata with a liquid form material to decrease permeability and improve the shear strength by virtue of increase in cohesion after it has set. For gravely layers cement base grout mixes are generally used. In some cases chemical or organic grout mixes are also used. The development of ultrafine grout mixes in recent times has extended the performance of hydraulic base grout for soil treatment. Ultrafine grout mix can be used to treat sandy gravel soil. The classification of grout mix are shown below-

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

The use of various grout mixes are very much dependent on the nature of soil and gradation of soil. Grouting Method steps are shown in Fig-10. The grouting may be further categorized, as follows-

- Penetration grouting
- Displacement grouting
- Compaction grouting
- Grouting of Voids
- Jet grouting

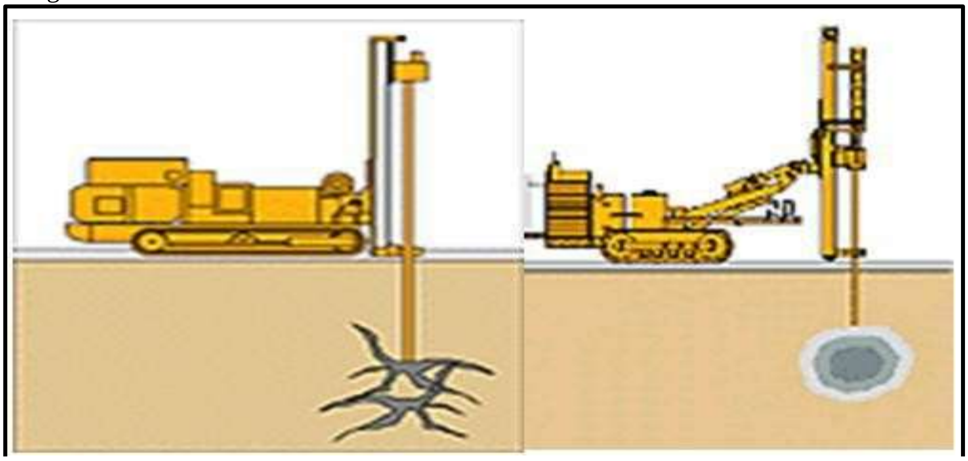


Fig-10 Grouting Method

Mitchell and Katti in 1981 has evaluated that the ability of grouting based on N value, where n is defined as -
N= (D_{15})soil / (D_{65})Grout.
If N > 24, Grouting is considered feasible.
If N < 11, Grouting is considered not feasible.
In 2003 use of chemical grouting for the repair of underwater road tunnel in Montreal, Canada was carried out by Palardy et al. and in 2007 a field trial of use of colloidal silica grouting for improvement of liquefaction by Gallagher et al. was carried out.

Jet Grouting: Jet grouting is a general term used by grouting contractors to describe various construction techniques used for ground modification or ground improvement. Grouting contractors use ultra high-pressure fluids or binders that are injected into the soils at high velocities. These binders break up the soil structure completely and mix the soil particles in-situ to create a homogeneous mass, which in turn solidifies. This ground modification/ground improvement of the soil plays an important role in the fields of foundation stability, particularly in the treatment of load bearing soils under new and existing buildings; in the in-depth impermeabilization of water bearing soils; in tunnel construction; and to mitigate the movement of impacted soils and groundwater. Teesta Dam in India is the example.

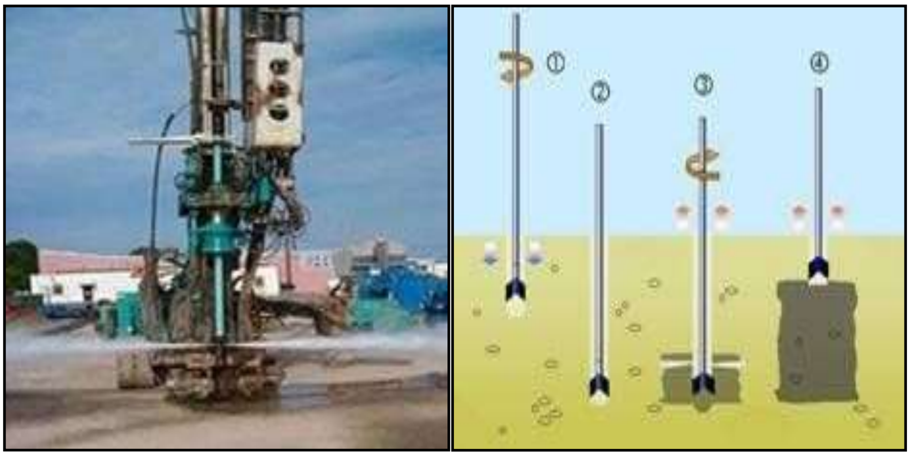


Fig -11 Jet grouting

The steps and arrangement of jet grouting process are shown in Fig-11. When grouting material is injected under pressure and it mixes with the soil particles in-situ to create a homogeneous mass, which in turn solidifies as shown in Fig-11.

2.4.2. Electro-osmosis: It is defined as the addition of chemicals like sodium silicate or calcium chloride at the anode resulting in electro chemical hardening. These chemicals seep into the ground flowing in the direction of cathode while anode works as grout injection pipe.

2.4.3. Soil cement: Cement and other admixtures like fly ash ,blast furnace slag has been used in many geotechnical and highway projects to stabilize the soil. These includes-
These applications include

- Shallow depth stabilization- sub-grade, sub-base and base course of highways and embankment material.
- Treatment of deep soils like soft soils and peaty soils.

Studies reveals that addition of small quantity of cement can increase degree of strength and stiffness and the process has been used in stabilization of highways and embankments. In large scale applications depending upon the strength requirement based on nature of soil the quantity required are huge and a large scale machinery are required in the process of improvement of deep soils. The following benefits can be achieved by this process-

- Increased strength and stiffness and better volume stability
- Increased durability

Factors which influence the improvement of soil are-

- Cement content, water content combined into water/ cement(w/c) ratio.
- Method of compaction.
- Time elapsed between mixing and compaction.
- Length of curing.
- Temperature and humidity.
- Specimen size and boundary effects

2.4.4. Heating: Studies have shown that due to heating, permanent change in soil properties are observed and the material becomes hard and durable. Settlements of clay under a given applied load increases with increase in temperature. The engineering properties of clay changes when it is heated to about 400°C. Heating breaks the soil particle down to form crystal products.

Fig-12 Stabilization by Heating Method

The arrangement of stabilization by heating method is shown in Fig-12. Electrical current is used to heat the soil and modify the physical characteristics of the soil. Depends on the nature of soil temperature can be varied between 300°C to 1000°C. However the safety of adjacent structures should be ensured while heating.

Applications-

- Immobilization of radioactive or contaminated soil.
- Densification and stabilization

2.4.5. Freezing: This method is based on conversion of in-situ pore water by use of refrigeration. This ice then acts as a cement or glue, bonding together adjacent particle or blocks of rocks to increase their combined strength resulting in an impervious structure.

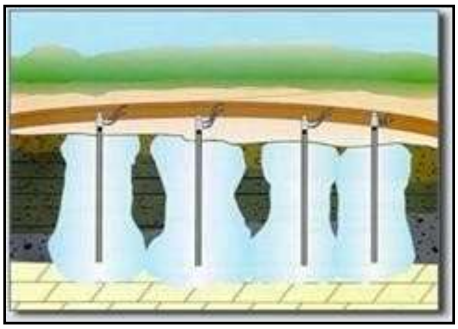


Fig-13 Stabilization by Freezing Method

The Steps of stabilization by freezing method is shown in Fig-13. The concerns about freezing method of soil stabilization are as shown below-

- Thermal analysis
- Thermal properties of ground
- Energy requirement
- Freezing rate
- Nature and geometry of refrigeration system

Water expands about 10% by volume ,which does not itself impose any serious stresses and strains on the soil unless the water is confined within a restricted volume.

Applications-

- Temporary underpinning
- Temporary support for an excavation
- Prevention of groundwater flow into excavated area
- Temporary slope stabilization

2.4.6. Vitrification: This method is based on the principle of melting and refreezing of soil to form a glassy solid that entraps inorganic contaminations thereby isolating it from the environment. To melt the soil high temperature is required. The soils which are contaminated with both organic chemicals and metals can be treated by vitrification method positively. 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 (1100-1450°C) cause rapid volatilization and reaction of organic contamination.

2.5. Modification by Addition and Confinement Techniques:

Using reinforcement in the form of fibers, strips, meshes and fabric the soil can be modified. These items are responsible for inducing tensile strength in the soil mass. By use of nails and anchors in-situ reinforcement can be provided. 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

2.5.1. 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 wallop, 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.

2.5.2. 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.

2.5.3. 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.

2.5.4. 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:

- Facultative anaerobic bacteria
- Micro-aerophilic bacteria
- Anaerobic fermenting bacteria
- Anaerobic respiring bacteria
- 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.

2.6. 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.
(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.

2.6.1. Soil Nailing: This ground reinforcement process uses steel tendons which are drilled and grouted into the soil to create a composite mass. A shotcrete facing is typically applied. Soil Nailing is an in situ technique for reinforcing, stabilizing and retaining excavations and deep cuts.

Fig-14 Soil Nailing

Procedure of soil nailing for soil slope is shown in Fig-14. Soil nailing is not practical in-

- Soft, plastic clays
- Organics/Peat
- Fills (rubble, cinder, ash, etc.)

This method was first implemented in 1972 for a railroad widening project near Versailles in France. This method is cost-effective and less time consuming as compared to other conventional support methods.

2.6.2. 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 fibers 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 stabilized earth wall is an example of this method which widely used now days.

2.6.3. Micro Piles: Micro-piles are small diameter piles (up to 300 mm), with the capability of sustaining high loads (compressive loads of over 5000 KN).The drilling equipment and methods allows micro- piles to be drilled through virtually every ground conditions, natural and artificial, with minimal vibration, disturbances and noise, at any angle below horizontal. The equipment can be further adapted to operate in locations with low headroom and severely restricted access.

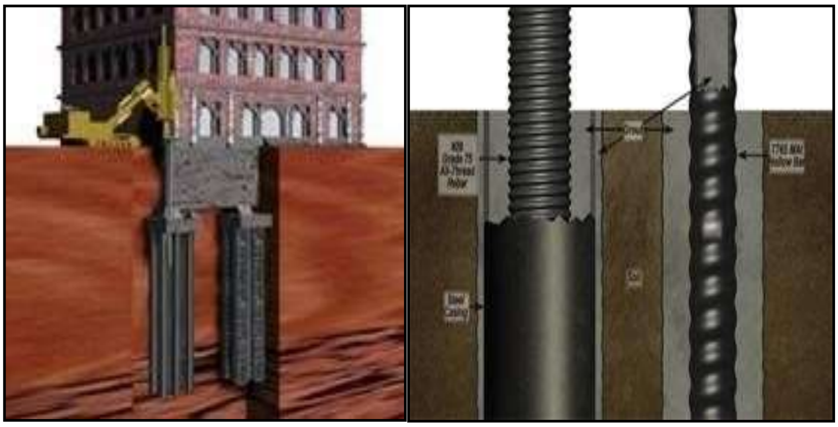


Fig-15 Micro-piles

The arrangement and typical construction sequences of Micro-piles are shown in Fig-15. The micro-piles which are used in present scenario are small diameter cast-in-situ piles. A typical micro-pile construction involves drilling of pile shaft to the required depth, placing the steel reinforcement, initial grouting by tremie and placing the additional grout under pressure where applicable.

Applications-

- For Structural Support and stability
- Foundation for new structures
- Repair / Replacement of existing foundations
- Arresting / Prevention of movement
- Embankment, slope and landslide stabilization
- Soil strengthening and protection

2.7. Combination of above Methods:

The soil improvement is achieved by combination of 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.

III. LATEST TRENDS IN GROUND IMPROVEMENT

The improvement in ground properties can be done by certain methods. By using Vibro-flotation the density of the soil can be increased by virtue of powerful depth vibrators. By use of vacuum pump the properties soft soil can be improved by consolidation. The pore water can be removed from the soil over a passage of time by pre-loading technique. By passing electric current in the ground results in heating of soil particles to form a crystalline product. The pore water is converted into ice by freezing action of ground which will result in increase their combined strength of ground and will make them impervious. Bearing capacity of the soil is increased by Vibro-replacement stone columns whereas the soil is displaced by Vibro-displacement method. Water flows through fine grained soils by virtue of Electro-osmosis which is responsible for Electro kinetics stabilization of soil. In sloping walls, dams etc. the reinforced soil is used. The reinforced soil mass is created by stabilizing earth structure mechanically. The Geosynthetics, geogrids are also used for this purpose. The shear strength of the in-situ soil is increased by soil nailing and restrains its displacement. The structural support to the existing foundation can be given by repair and replacement using micro-piles. To increase its rigidity grouting is done under pressure by using pumpable materials. The technique of jet grouting is advance and is speedy too as compared to general grouting.

IV. CONCLUSION

From the study it can be concluded that the Ground Improvement Techniques is a technically viable and cost effective solution for soils which are weak in strength and treatment is to be done in order to make them suitable for construction. The use of various techniques have been tested and its use has been proven in the recent past years for a variety of projects like highways, ports, runways, industrial structures, railways, dams, slope stabilization, excavations, tunnelling and other infrastructure facilities. These method of soil stabilization have been used world-wide for variety of soils like loose sand, silts, clays and weak rocks. A suitable and cost effective technique for ground improvement can be designed, keeping in view the following points-

- Nature and type of soil
- Intensity of loading and
- Intended performance

In addition to above, before selecting any ground improvement technique it is important to evaluate the cost of each particular method and expected soil improvement, available equipments, which are the decisive factors for the selection of appropriate method. There are so many methods available for ground improvement but still a method which suits for routine application , perhaps not available. For future development the following possibility should be explored-

1. Best incorporation sustainability consideration in suitable ground improvement method selection on the basis of green construction and life cycle cost analysis.
2. Development of codes and legislation.
3. Study on adverse environmental impacts due the effect of adding things to the ground.
4. Development of a data bank with the description of incidents, variability of soil and material properties and accidents for a more deep understanding of ground improvement.
5. Development of improved and more reliable method of ground improvement with adequate quality control.

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