

GROUND IMPROVEMENT TECHNIQUE

UNIT-2

DENSIFICATION METHODS IN GRANULAR SOIL

The **method** of densifying **in-situ** sandy **soils** using deep vibration (vibro) was first developed in Germany over 60 years ago. Since then the technique has been extended to improve a wide range of **soil** types for structures of up to 30 storeys in height.

Need for densification of granular soils

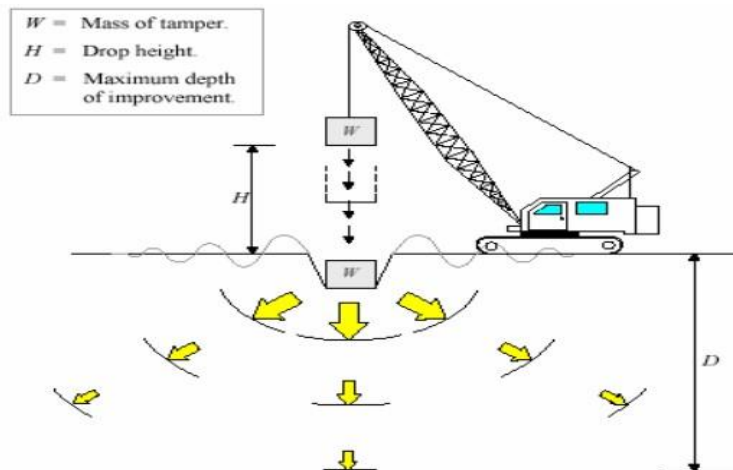
- ✚ The reclamation of new land with hydraulic fill results in a loose profile of granular soil mass. This loose granular soil will contribute to high elastic immediate settlement as well as liquefaction upon dynamic forces.
- ✚ In addition, the bearing capacity of a granular foundation is mainly dependent upon shear characteristics such as the friction angle of the soil. The compressibility is in turn dependent upon the elastic modulus of the soil.
- ✚ To increase the friction and the elastic modulus of granular soil, it has to be improved by a densification method. If reclamation is carried out by landfill operation, granular soil mass can be densified by roller compaction with a certain lift and a specified moisture.
- ✚ However, for existing land or land reclaimed by hydraulic filling, such method may not be feasible and hence one has to rely on deep compaction methods.
- ✚ Before carrying out deep compaction, the first thing that needs to be done is to ensure that the type of soil is densifiable with the deep compaction method. Generally, granular soil with less than 10% of fine can be densified with this method.
- ✚ **There are a few methods of deep compaction. Among these,**
(i) dynamic compaction, (ii) vibroflotation, and (iii) compaction piles are the methods most commonly used in densification of granular soils.
- ✚ Before carrying out the deep compaction works, the extent of densification required must first be decided. This required degree of densification is based on the bearing capacity and tolerable settlement of the soil.

Dynamic compaction

- ✚ Technique involves repeatedly dropping a large weight from a crane
- ✚ Weight may range from 6 to 172 tons

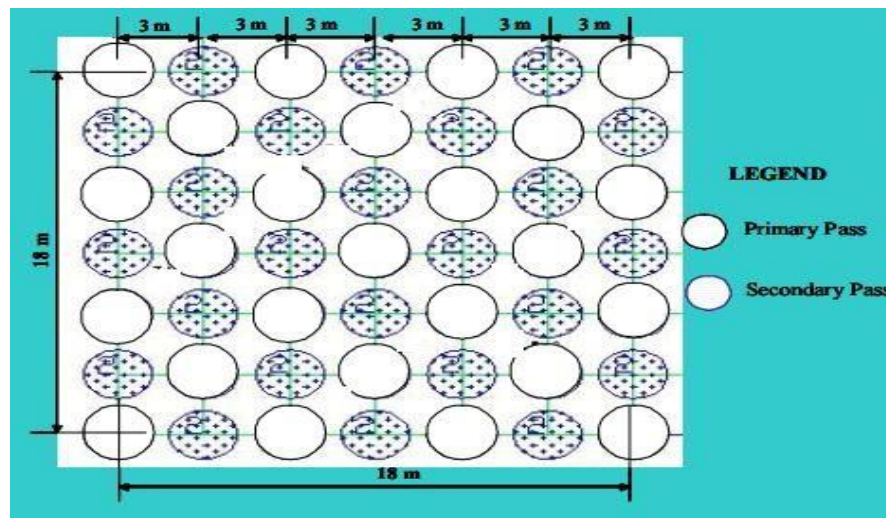
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- ✚ Drop height typically varies from 10 m to 40 m
- ✚ Degree of densification achieved is a function of the energy input (weight and drop height)



as well as the saturation level, fines content and permeability of the material

- ✚ Done systematically in a rectangular or triangular pattern in phases
- ✚ Each phase can have no of passes; primary, secondary, tertiary, etc.



- Spacing between impact points depend upon:
 - Depth of compressible layer
 - Permeability of soil
 - Location of ground water level
- ✚ Deeper layers are compacted at wider grid spacing
- ✚ upper layers are compacted with closer grid spacing
- ✚ Deep craters are formed by tamping
- ✚ Craters may be filled with sand after each pass

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- ✚ Heave around craters is generally small



Types Of Dynamic Compaction

Dynamic Compaction:

It is the compaction of unsaturated or highly permeable saturated granular materials by heavy tamping. The response to tamping is immediate

- ✚ Dynamic consolidation
- ✚ Dynamic replacement
- ✚ Rotational dynamic compaction
- ✚ Rapid impact dynamic compaction

Dynamic consolidation

The improvement by heavy tamping of saturated cohesive materials in which the response to tamping is largely time dependent. Excess pore water pressures are generated as a result of tamping and dissipate over several hours or days after tamping.

Dynamic replacement

The formation by heavy tamping of large pillars of imported granular soil within the body of soft saturated soil to be improved. The original soil is highly compressed and consolidated between the pillars and the excess pore pressure generated requires several hours to dissipate. The pillars are

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used both for soil reinforcement and drainage

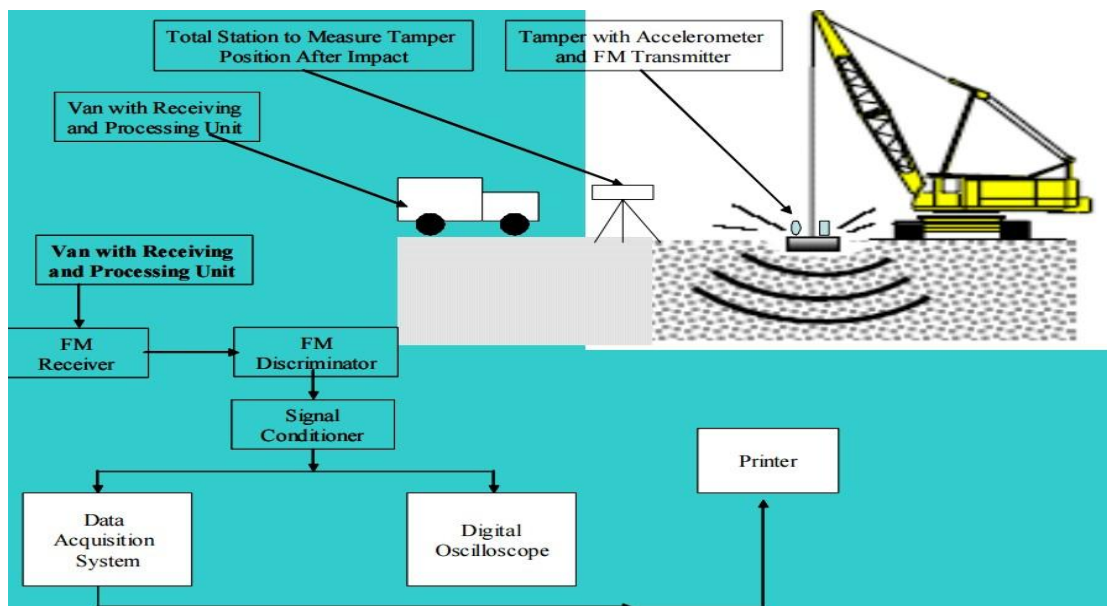
Rotational dynamic compaction

A new dynamic compaction technique which makes use of the free fall energy as well as rotational energy of the tamper called Rotational Dynamic Compaction (RDC). The technique increases depth of improvement in granular soils. Comparative study showed that the cone penetration resistance was generally larger than conventional dynamic compaction and the tamper penetration in rotational dynamic compaction was twice as large as that of conventional dynamic compaction

Rapid impact dynamic compaction

Rapid Impact Compaction (RIC) is a ground improvement technique that densifies shallow, loose granular soils, using a hydraulic hammer which repeatedly strikes an impact plate. The energy is transferred to the underlying loose granular soils and rearranges the particles into a denser configuration. The impact locations are typically located on a grid pattern, the spacing of which is determined by the subsurface conditions and foundation loading and geometry. Treated granular soils and fills have increased density, friction angle and stiffness. The technique has been used to increase bearing capacity, and decrease settlement for planned structures.

The Step Wise Layout Of Monitoring And Control In Dynamic Compaction Test

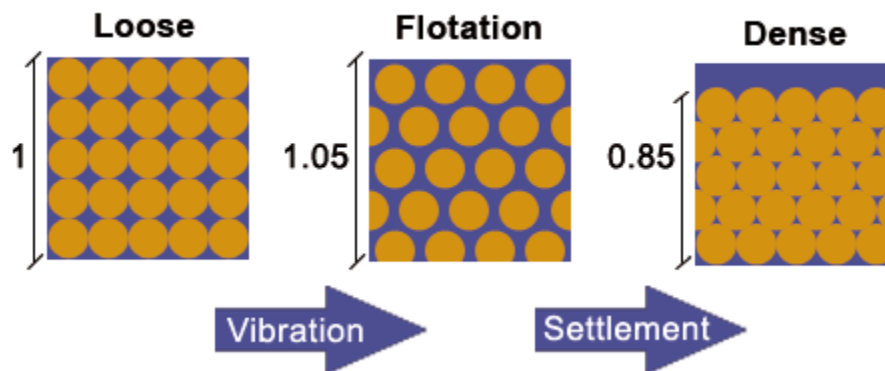


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vibro compaction method of densification

- ✚ Compaction of granular soils by depth vibrators is known as Vibro Compaction.
- ✚ The method is also known as “Vibroflotation”.
- ✚ Natural deposits as well as artificially reclaimed sands can be compacted to a depth of up to 70 m.
- ✚ The intensity of compaction can be varied to meet bearing capacity criteria.
- ✚ Other improvement effects such as reduction of both total and differential settlements are achieved.
- ✚ The risk of liquefaction in a earthquake prone area is also drastically reduced.

The following diagrams illustrate the compaction process:



The principle of sand compaction (Vibroflotation):

The compaction process consists of a flotation of the soil particles as a result of vibration, which then allows for a rearrangement of the particles into a denser state.

Effects of Compaction

The sand and gravel particles rearrange into a denser state.

The ratio of horizontal to vertical effective stress is increased significantly.

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The permeability of the soil is reduced 2 to 10 fold, depending on many factors.

The friction angle typically increases by up to 8 degrees.

Enforced settlements of the compacted soil mass are in the range of 2 % to 15 %, typically 5 %

The stiffness modulus can be increased 2 to 4 fold.

Test Pattern

On large projects the optimal compaction grid spacing has to be determined by test grids.

The compaction effect in the test grids should be as close as possible to the treatment in the later production areas.

In order to achieve this it is advisable to arrange the test grids close to each other.

Advantages

- ✚ The treatment is localized, which allows a customized and optimized treatment of the various soil layers, including at depth
- ✚ Possible treatment to a great depth (> 20 m)
- ✚ The treatment by vibro compaction is only effective starting from 1 to 2 meters in depth because of the lack of vertical confinement at the surface.

Applications

The most common applications are as follows :

- ✚ Vibro compaction is commonly used for anti-liquefaction treatment of soils. Vibration compactable grounds correspond in fact quite nicely to the grain size distribution spectra of soils with a strong liquefiable potential
- ✚ Treatment of hydraulic backfill and platforms reclaimed from the sea by dredging
- ✚ Treatment of river or sea banks behind and/or inside caissons or walls
- ✚ In-situ compaction of foundation shafts made of backfill materials

Densification By Compaction Piles

- ✚ Pile driving is one of the most effecting methods for compacting loose sand gravel.

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- ✚ The method is also effective in silty soils above the ground water table because of displacement caused by the pile driving.
- ✚ Compaction piles are therefore be used in fine grained soils than can vibroflotation or vibro compaction.
- ✚ The best effect is usually obtained below the ground water table where the soil is saturated.
- ✚ The compaction is partly caused by the vibrations from driving the piles and partly by the displacement of soil caused by piles.
- ✚ The diameter of the compacted zone around each pile is $7D$ to $12D$, where D is the diameter of the pile.
- ✚ The size of the compacted zone increases in general with the increasing initial relative density of the soil.
- ✚ The soil is also compacted below the piles down to the depth that corresponds to about one pile diameter. The maximum economic depth is about 20m.
- ✚ It is usually possible to compact the soil to a relative density of 75 to 80 percent.
- ✚ The method is economical for relatively small areas compared with other soil improvement methods.
- ✚ The increase in relative density of soil can be estimated from total volume of inserted piles and from the settlement of the ground surface observed during installation.
- ✚ Building settlements can be estimated as if the structures were supported on dense sand. The reduction of settlement by the compaction piles is generally large because the piles increase the horizontal pressures in the ground and thus the confinement.
- ✚ The relative improvement is less when the initial relative density of the soil is high.

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DENSIFICATION METHODS IN COHESIVE SOILS

In-Situ Densification Methods in Cohesive Soils

The conditions improved when unsuitable soils are encountered

If unsuitable soil conditions are encountered at the site of a proposed structure, one of the following four procedures may be adopted to insure satisfactory performance of the structure.

- ✚ By pass the unsuitable soils by means of deep foundations extending to a suitable bearing material
- ✚ Redesign the structure and its foundation for support by the poor soil. This procedure may not be feasible or economical.
- ✚ Remove the poor material and either treat it to improve and replace it or substitute for it with a suitable material
- ✚ Treat the soil in place to improve its properties

On the basis of mechanism by which they improve the engineering properties of soil, the most common of these can be divided into the following major categories. These are:

- ✚ Densification techniques
- ✚ Reinforcement techniques
- ✚ Stabilization techniques
- ✚ Miscellaneous methods

Apart from the methods listed above there are some other simple methods like removal and replacement of soil.

Classification Of Ground Improvement Techniques

Mechanical Modification:

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.

Hydraulic Modification:

- ✚ Free pore water is forced out of soil via drains or wells.
- ✚ Course grained soils; it is achieved by lowering the ground water level through pumping from boreholes, or trenches.
- ✚ In fine grained soils the long term application of external loads (preloading) or electrical forces (electrometric stabilization)

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Physical and chemical modification:

- ✚ Stabilization by physical mixing adhesives with surface layers or columns of soil.
- ✚ Adhesive includes natural soils industrial byproducts or waste. Materials or cementations or other chemicals which react with each other and/or 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.

Modification by inclusions and confinement:

- ✚ Reinforcement by 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

Various Methods Of Ground Improvement Suitable For Cohesion Less Soils

Following methods of ground treatment can be adopted for cohesion less soils.

- ✚ Vibratory surface compaction and Deep Vibro-compaction
- ✚ Removal and replacement of soft cohesive deposits of limited thickness
- ✚ Preloading of existing soft/loose fill
- ✚ Preloading with vertical drains.
- ✚ Dynamic Replacement.
- ✚ Stone Column
- ✚ Piled Embankments in areas having soft soil to large depths
- ✚ Viaduct for high embankments on ground having very deep soft soils with organic deposits.

Vibratory surface and Deep Vibro-compaction

Surface Vibratory compaction is used for densification of loose cohesion less soils using vibratory roller.

Deep Vibro-compaction can be done for the loose sandy deposits having less than 15% of fines for depths up to 10 m. Compaction is carried out by inserting the probe up to the design depth of improvement and allowing the soil around the probe to get compacted for certain time interval. Then the probe is raised by about 0.5m to compact the soil around the vibrator and the process is repeated.

Preloading

Preloading of soil is merely applying an external loading for a long duration to cause desirable changes in the soil.

Conventionally preloading is usually carried out before construction of any structure. However, this can be installed even under semi-finished condition and even after completion such as in case of liquid storage tanks.

If the thickness of fill placed for preloading is greater than that required for the final ground surface elevation, the excess fill is termed as surcharge fill.

Methods of preloading

- ✚ Heaping of fill materials
- ✚ Embankment loading
- ✚ Using the final structure as vehicle for load application

Applications of preloading in civil works

- ✚ Road embankments
- ✚ Bridge abutments and box culverts
- ✚ Warehouses
- ✚ Gravity quay walls
- ✚ Housing complexes
- ✚ Runways
- ✚ Canals
- ✚ Industries

Advantages of preloading

- ✚ Cost involved is comparatively less and varies between 10 to 20% without using vertical drains and 20 to 40% with the use of vertical drains.
- ✚ Especially attractive when the fill material, after completion of preloading is

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subsequently used in the same project as fill material, after completion of preload.

- ✚ Cost of monitoring equipment's is cheap and the time needed for installation is only two to three weeks.
- ✚ Provide uniform improved properties of the ground

Preloading With Vertical Drains For A Building Site

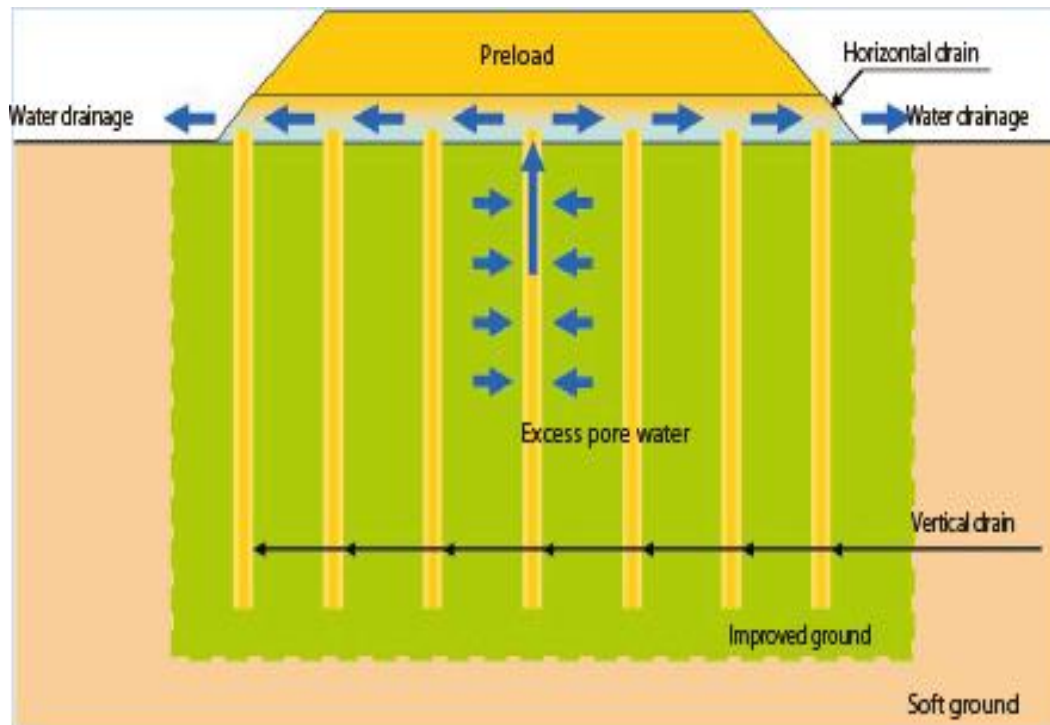
Vertical Drains

- ✚ This method is suitable for deep deposit of soft clay. The natural moisture content in this stratum can be brought down substantially by installing vertical drains with a preloading.
- ✚ The presence of vertical drains reduces the drainage path of water in the pores of soil and thereby reduces the time required for consolidation.
- ✚ The spacing of drains depends on the speed at which required improvement is to be achieved. In earlier days, such vertical drains were installed by driving a close ended steel pipe of 100-200 mm diameter up to the full thickness of such soft clay deposit.
- ✚ The pipe is then filled with sand and withdrawn in stages to form a vertical sand drain. The pipe is generally reused for installing other drains.
- ✚ In the recent past, there has been number of different materials developed to replace the sand drains. These are basically flexible plastic sections having thickness varying from 5 to 10 mm and width from 100 to 150 mm.
- ✚ The section has channels to permit flow of water. The perimeter of the section is covered with a layer of geo-textile to prevent the entry of soil particles into the channel.
- ✚ The advantage of such drain is that it results in minimum remoulding of surrounding soil during installation. The process of installation is also very fast.
- ✚ The machine is mounted on a crane and typical drain up to 10 m depth can be installed in a period varying from 1-2 minutes including the time for shifting the machine to the new location.
- ✚ The percentage consolidation which can be achieved by such vertical drains can be theoretically predicted from the design charts developed based on theory of three

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dimensional consolidations. Typically, a deposit which requires a period of over ten years for 95% consolidation can complete the same consolidation within a short period of 3 to 6 months when vertical Drains are installed. After the drains are installed, the magnitude of preload to be placed depends on the required shear strength of the layer after improvement.

- Depending on the time available for improvement, the degree of consolidation is worked out and the effective over burden pressure (p) is computed. From plasticity index of the soil, the ratio S_u / p is determined. This ratio normally remains constant and therefore with increase in value of p is determined. This ratio normally remains constant and therefore with increases in value of p the shear strength after treatment

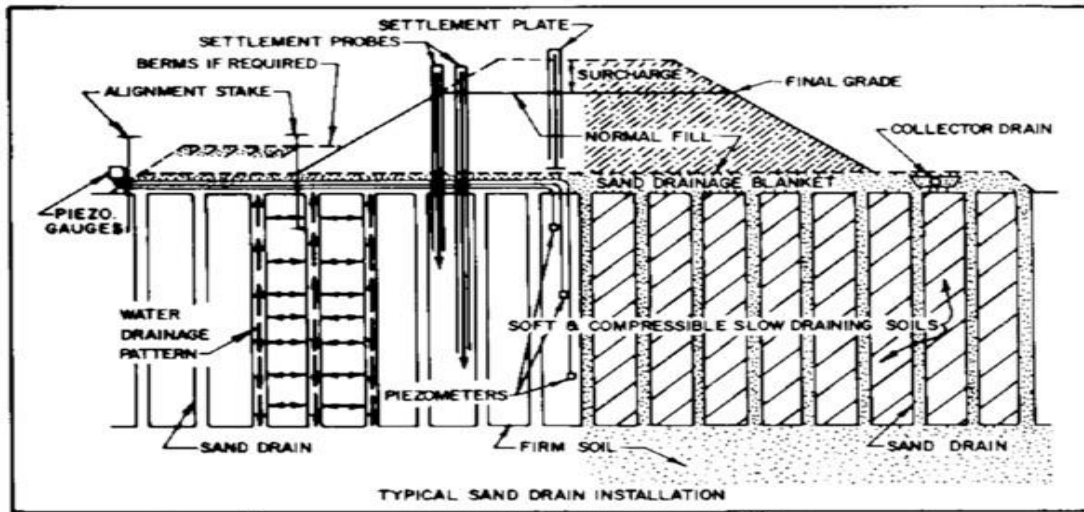


increases.

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Sand Drains

The theory and method of sand drains is shown below.



- ✚ A sand drain is basically a hole drilled in a cohesive soil and filled with sand.
- ✚ Since the sand has larger particle size, its permeability is much higher, thus water will flow through it much more easily.
- ✚ As shown above, an array (it's actually a two-dimensional array) of sand drains is installed, and a load is applied on top of the drains.
- ✚ The load shown above is an embankment, such as is used on a highway, and an additional, or surcharge, load is used to speed up the drainage process.
- ✚ The excess water is collected at the top and directed away from the jobsite.
- ✚ The tricky part comes in getting the sand drains in the ground. The obvious solution is to simply drill the holes and fill them with sand, but if the soil is soft (which is frequently the case,) the holes will collapse.

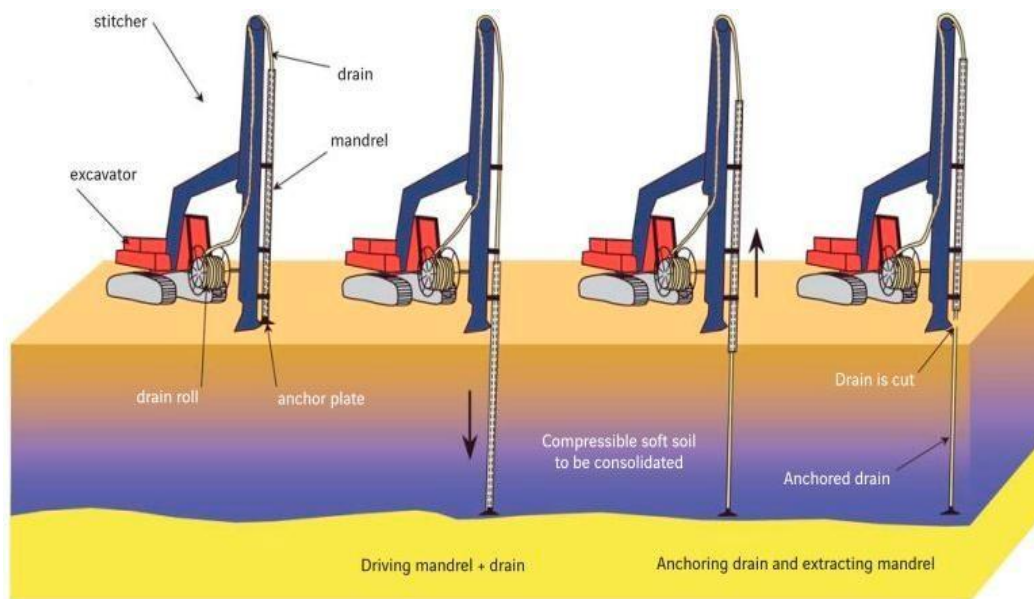
Sand Wicks

- ✚ A cursory examination of the procedure for sand drains shows that the procedure is fairly involved. It invites simplification, at least for some applications. A popular simplification is that of wick drains.
- ✚ A wick drain is just what the name implies: a geosynthetic "rope," usually about 100 mm wide and 5mm thick, which acts as a high-permeability conduit for water to flow out of

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the soil and to the surface, in the same manner as takes places with sand drains. As is the case with sand drains, they are installed as an array, generally in 3 metre spacings.

- ✚ Candle makers have the luxury of melting the medium into which their wicks are places. Since things aren't so simple for the contractor, he or she has to use a mandrel to insert the wicks.
- ✚ The simplest way to do this is to push the mandrel/wick combination into the ground, but some soils are too stiff for this, so the mandrel is frequently vibrated.
- ✚ Vulcan vibratory hammers have been used in some cases to install wick drains. Since many drains are installed, this is a fairly demanding application for a vibratory hammer, but it is another example of the versatility of vibratory pile drivers



Mechanism of stabilization using Stone Columns

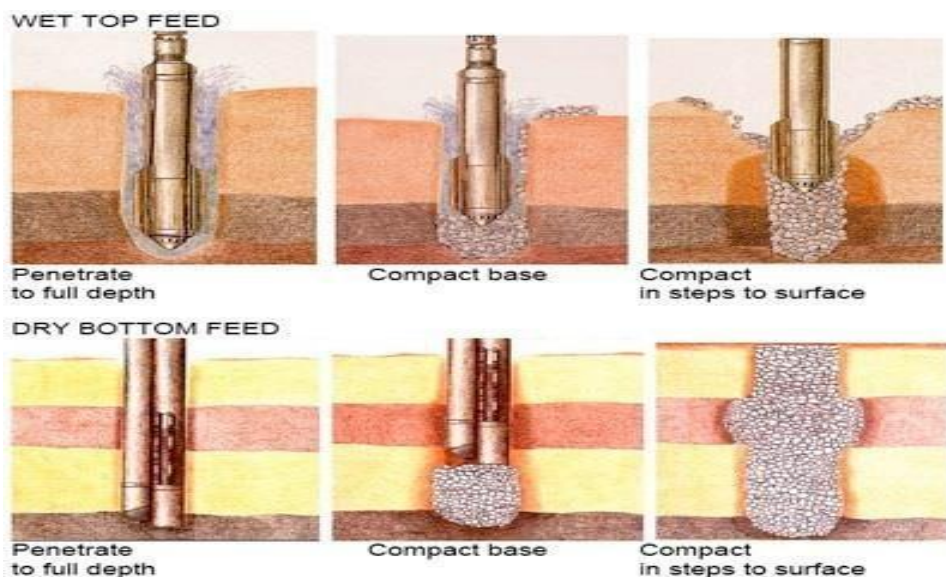
- ✚ Any soil type that does not respond to vibration alone is a candidate for stone columns. These soils include silty and clayey sands, silts, clays, and some layered soils where damping of vibrations occurs.
- ✚ Often very fine sands will not respond well to vibration, because of their low permeability, but can be improved with stone columns.
- ✚ Soils with appreciable silt or clay content do not respond to deep vibratory compaction.

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- ✚ To improve these cohesive soil types to allow building and other heavy construction, it is necessary to create stiff reinforcing elements in the soil mass.
- ✚ The stone column technique, also known as vibro-replacement or vibro displacement, is a ground improvement process where vertical columns of compacted aggregate are formed through the soils to be improved.
- ✚ These columns result in considerable vertical load carrying capacity and improved shear resistance in the soil mass.

Installation Procedure of Stone Columns

- ✚ Stone columns are installed with specialized vibratory probes, generally having a horizontal mode of vibration.
- ✚ Column diameters of 2 to 5 feet can be achieved, depending upon soil conditions and design requirements.
- ✚ The vibrator first penetrates to the required depth by vibration and air or water jetting or by vibration alone.
- ✚ Gravel is then added at the tip of the vibrator and progressive raising and Repenetration of the vibrator results in the gravel being pushed into the surrounding soil.
- ✚ The soil-column matrix results in an overall mass having a high shear strength and a low compressibility.



Installation Procedure of Stone Columns

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Advantages:

- ✚ Stone Columns are designed to reduce settlements of compressible soil layers in order to be able to build most structures with shallow footings and slab-on-grades on very soft soil;
- ✚ When applicable, their draining characteristics result in an increase in the time rate of consolidation settlement in soft cohesive soil;
- ✚ Because they are made of compacted granular material, no curing period is necessary and no cut-off to the shallow footing grades are required as the excavation of the footing can immediately follow the installation of the stone columns down to the required elevation; High production rates;
- ✚ Stone Columns are also well-adapted to the mitigation of liquefaction potential thanks to the combined effect/advantage of their draining potential and the increase of shear strength and stiffness of the improved soils.

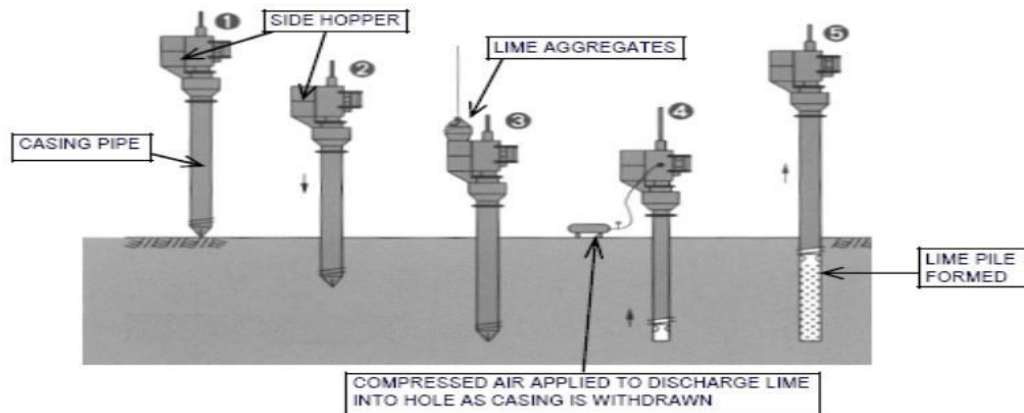
Mechanism of stabilization using Lime Columns

Stabilization using lime is an established practice to improve the characteristics of fine grained soils.

- ✚ The addition of lime affects the shear strength, compressibility, and the permeability of soft clays. These beneficial changes occur due to the diffusion of lime.
- ✚ Soil-lime reaction
- ✚ Cation-exchange Flocculation
- ✚ Aggregation (time and temperature dependent)
- ✚ In this technique it was assumed that the improved soil column in the bore was acting as a pile to support the superstructure. Later it was found that lime can diffuse in to the surrounding soil and can stabilize a greater volume of soil.

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- ✚ This method produces both a consolidation and strength gain effect on the treated soil, without additional loading, via lateral expansion of the lime columns as they absorb water from the soft soil



Effect of lime columns on the adjacent soil

a) Consolidation / dewatering effect

Quick lime, CaO , absorbs water from the surrounding ground, causing the lime to swell and forms slaked lime (Ca(OH)_2) as per the following chemical reaction $\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + 15.6 \text{ Kcal/mol}$

b) Ion exchange effect

As the surface of fine particles of clay is negatively charged, calcium ions (Ca^{++}) from the slaked lime are absorbed by the surface of clay particles. As a result, clay particles are bonded with each other and the weak clay is improved with a resultant increase in shear strength.

c) Pozzolanic effect

Calcium ions continue to react with SiO_2 and Al_2O_3 in the clay for a long time forming compounds that cause the clay strength to be improved. This reaction is termed a pozzolanic reaction. The lime piles themselves have considerable strength and therefore act to reinforce the soil as well as alter its properties.

Among all the three effects only consolidation/dewatering effect is the main process by which the strength and stiffness of the soil mass is improved in the shorter term. Other two effects ion

exchange effect and pozzolanic effect are ignored.

Mechanism of stabilization using Thermal methods

Methods based on temperature control are classified as:

1. Heat treatment method.
2. Ground freezing method.

Temperature control method (Heat treatment) depend on

- ✚ Thermal conductivity of the soil
- ✚ Heat capacity of the soil
- ✚ Heat of fusion
- ✚ Heat of vaporization
- ✚ Methods of heating soil in-situ
- ✚ Ground surface heating
- ✚ Heating through boreholes
- ✚ Use of thermally stabilized building blocks
- ✚ Thermal piles

Geothermal piles are an innovative system of building foundations for use in combination with ground-source energy technology. Conventional ground-loops are installed in building piles, through which water or another fluid is pumped. The fluid and ground-transfer heat energy is then passed through a heat exchanger in the building to provide cooling or, more commonly, heating in the winter. The geothermal system is essentially the same as closed-loop borehole systems; however, since they are installed in the building foundations, the technology serves a dual purpose.

Ground freezing method

- ✚ Assembling freeze pipes.
- ✚ Installation of freeze pipes.
- ✚ Application of freeze with electronically controlled refrigeration plant.
- ✚ Frost development on freeze pipe headers.
- ✚ Excavation following completion of freeze wall.
- ✚ Construction of concrete liner. Once completed, refrigeration can be shut down.

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IMPORTANT QUESTIONS

1. Discuss the principles of ground improvement in cohesion less soils.
2. Discuss the effectiveness of both vibro flotation and compaction piles for compacting the granular soils.
3. (a) With neat sketches explain in-situ densification methods in cohesive soils.
(b) Discuss how the stress history of a soil deposit affects its suitability for preloading with vertical drains.
4. (a) Compare vibratory probe compaction and dynamic compaction.
(b) Explain the vibrocompaction method for cohesionless soils.
5. (a) Explain with a neat sketch sand drain to accelerate the drainage of impervious soils.
(b) What are the advantages of using wick geo drains?
6. Discuss the need of ground improvement and write the principles of ground improvement in cohesionless soils.
(b) Briefly explain about methods of impact at ground surface and at depth used in densification of granular soil deposits
7. (a) Write short notes on densification of cohesive soils by Lime columns.
(b) Discuss the important formulae used in the improvement of soft clay deposits using stone columns.
8. (a) Explain briefly with a neat sketch the vibro compaction method of densifying deep granular deposits.
(b) Explain the impact at ground surface method to densify granular soils.
9. (a) Explain in detail the in-situ densification of cohesive soils by using pre-loading with vertical drains.
(b) What is a sand drain? How is it constructed and is useful in densifying cohesive soil deposits?
10. Explain various insitu densification methods for cohesive soils.

