GROUND IMPROVEMENT TECHNIQUES

14.1 INTRODUCTION

Prior to the advancements in the field of Geotechnical Engineering, the foundation engineer had no choice but to design the foundations to match the subsoil conditions at the proposed site. Now-a-days, he can modify the weak foundation soils, improve their strength and compressibility characteristics to suit the foundations of his choice. *The geotechnical process of improving the required characteristics of the soils is known as ground improvement.* The improvement attained through various processes is permanent and does not diminish with time due to the weathering effects. By these processes, the density (γ) and shear strength parameters (c & ϕ) are increased while compressibility, settlement and permeability are reduced, making the soil more weather resistant, stable and durable.

As stated in chapter-1, the two major uses of soils are:-

(i) Soil as a construction material is used in the construction of earthen structures such as dams, levees, embankments for roads and rail roads, sub bases and bases of roads etc.

(ii) Soil as a supporting material is used underneath the foundation of all Civil Engineering structures (e.g. buildings. bridges, roads, dams, etc.).

When the soil is used as a construction material, the improvement influence zone beneath the structure is limited to a relatively shallow depth (usually ≤ 1m) below the level at which the improvement is being carried out (e.g. in the construction of embankment for dams, road etc. The compaction effect is limited to a depth of about 0.3 to 0.5m below the surface being rolled). *The improvement process under this situation when the influence zone is limited to about a depth ≤ 1m is called as Surface Stabilization.* This technique is suitable for the construction of roads, dams, etc.

For foundations support, the in-situ soil deposits are improved to a relatively greater depth extending to at least 2 to 5 times the width of the footing below the base of the foundation. *The process of improving the in-situ soils for the support of the foundations is known as Ground Improvement.*

Numerous method of stabilization and ground improvement are available and the choice of a most suitable method in any particular case depends upon the form of improvement needed, and the type of soil to be improved. Most of the methods require special knowledge and experience, and it is beyond the scope of this chapter to describe in detail, each and every process. Only the broad outlines, fundamental principles, and factors affecting choice of each method are discussed in the

- Cost Considerations

Polyacrylamide, one of the more common soil palliatives, costs between \$4 and \$35 per pound; a pound can stabilize approximately 1 acre of land.

- **Physio-chemical stabilization**

A combination of both physical and chemical methods such as lime stabilization.

14.3 GROUND IMPROVEMENT METHODS

In-place soils supporting the foundations, may be improved by using any one or a combination of the following methods:

(i) Deep compaction

(ii) Soil replacement

(iii) Pre-loading

(iii) Drainage and *GWT* control (consolidation)

(iv) Injection grouting

(v) Soil freezing

(vi) Use of Geotextiles

Further details of the these methods are given below:

(i) Deep Compaction

Deep compaction of the in-situ foundation soils may be carried out by the following methods:

(a) Dynamic Compaction or consolidation

(b) Vibrocompaction (vibroflotation, a method patented by the vibroflotation Co.)

(c) Terra probe compaction.

(d) Compaction piles

(a) Dynamic Compaction

Dynamic compaction is simply an extension of the laboratory compaction method, where the soils are densified using high intensity impacts generated by 10 to 20 tonnes weight dropped freely from heights upto about 30 meters or less using heavy duty cranes. This method was developed in 1970s, in France by L. Menard. The shock waves generated by the impacts of the heavy weight, travel to considerable depths, rearranging the soil particles into a denser, more compact state. Soils have been treated to depths of 15 m using this technique and it is possible to treat the soils to greater depths using special equipment and heavier weights. This method improves the bearing capacity by improving the shear strength and reduces the compressibility.

- Advantages

The main advantages of the method are:

-Low cost; specially for free-draining, granular soils when the area to be treated is ≥ 5 hectares.

-Rapid treatment

-Suitable for large variety of soils

-Suitable in treating soils below water table

- **Disadvantages**

- Development of pore pressure in fine-grained soil reduces its applicability by making the process relatively expensive and time consuming.

- May not be suitable for fully developed sites as the strain waves generated by the shocks may affect the underground utilities and the adjoining structures. When working close to the structure, however, the intensity of vibrations can be reduced by using lighter weights, or lower height of fall. The observance of the following rule may make the operation safe:

$$D > \frac{\sqrt{WH}}{80} \qquad 14.2$$

Where,

$D =$ safe distance from the impact spot in meters

$W =$ weight of tamper in Newtons

$H =$ height of fall in meters

Experienced contractors have been reported to have treated the soils as close as 3 m from underground services and about 6 m from sound structures.

- When the *GWT* is about within 2m below the ground surface, the treatment may be complicated and for success of the treatment, the entire site level may need to be raised by imported materials. Alternatively *GWT* may be lowered prior to the application of the treatment.

- Environmental Pollution may occur by noise, vibrations, gusts of air, and permanent soil deformations.

- **Methodology**

For compaction of deeper zones, distribution of impacts and the sequence of the application are critical. The impacts are applied in increments, each complete coverage of the area being referred to as a phase. The early phases are known as high-energy phases, and used for compaction of deeper layers. The spacing between the impacts for the early phase are directly related to the depth of the compressible strata (generally equal to the depth of compressible layer). The phase of high energy impact is followed by a low energy phase called as *ironing phase*. This phase is designed to compact the layers near to the ground surface.

- **Control Testing**

To assess the degree of improvement achieved, the control tests must be carried out and process needs to be continuously monitored.

Control testing may be divided into three types:

(i) Production control.

(ii) Environmental control

(iii) Specification control.

- Production Control

It includes quality assurance aspects, such as logging the impacts, elevation survey of the working surface, and monitoring the changing soil characteristics during treatment using in-situ geotechnical testing methods. Most commonly used geotechnical tests are:

~ Pressuremeter (PMT)

~ Standard Penetration Test (SPT)

~ Cone Penetration Test (CPT)

~ Plate Load Test (PLT)

~ Pore Pressure Measurement using Piezometer

~ Surface Settlement Evaluation

~ Field Vane Shear Test

~ Dilatometer Testing.

- Environmental Control

It consists of measuring ground vibration levels and carrying out boundary surveys to minimize the effects of the tamping operations on the adjacent structures. It may include instrumentation designed to detect potential movement and deformations.

- Specification Controls

Specification controls are carried out after the treatment is completed to certify that the objectives of the treatment have been attained. Some times, in project specifications, certain special conditions are included as a criterion for final acceptance. For example, in a ground improvement project for residential apartments in Yambu, KSA, it was included that after improvement, the ground improvement Contractor has to demonstrate that a footing of 2m×2m under a contact pressure of 200 kPa shall not settle more than 25 mm in 7 days.

- Soil Improvement Depth

The depth of improvement depends upon the following factors:

- Tamper weight (*W*) and its height of fall (*H*).

- Surface area of the tamper and its shape.

- Impacts spacing and grid pattern (triangular or square etc.).

- Number of phases of the treatment.

- Total compactive energy.

- Time delay between the phases.
- Soil type; *GWT* position, and initial degree of consolidation of the deposit.

The maximum depth of influence is given by:

$$D_{max} = \alpha\sqrt{WH} \qquad 14.3$$

Where,

W = weight of tamper in Newtons

H = height of fall of the tamper in meters

α = a coefficient usually taken as 5×10^{-3} to 7×10^{-3} (dimension $\sqrt{m/N}$)

Improvement achieved by means of this treatment has been reported to increase with depth to a maximum value at a specified depth and then diminishes with depth until reaching a depth, D_{max}, below which the soil properties remains unaffected. The specified depth is approximately between 1/3 and 1/2 of the maximum depth (D_{max}).

Engineering Requirements

The degree of improvement achieved varies considerably depending upon the type of soil being treated. Table 14.1 presents the presumed allowable bearing pressure values attainable for different soils.

Table 14.1 Presumed allowable bearing pressures for soils treated by dynamic compaction

Soil type	Allowable bearing pressure (kPa)
Fine-grained alluvial, silty fills	100 - 150
Heterogeneous fills	100 - 200
Fine silty sand, hydraulic fills	200
Coarse sand, gravels	300
Well-graded gravel, rockfill	400 - 500

Source: Canadian Foundation Engineering Manual, 4th edition.

Dynamic compaction techniques may also be used for the construction of stone columns discussed under vibro-compaction.

(b) Vibroflotation

The idea of compacting deep loose deposits of sand using depth vibrators (usually known as vibro probes) was conceived in 1930's.

In the early 1960's, the use of more technically advanced vibro probes led to their use for improving even the fine-grained soils by replacing fines in the soil with coarse materials. This techniques is called as *vibro-replacement* or sometime as *stone column*, method.

The vibro-compaction method was patented by vibroflotation Foundation Co. and is generally called as vibroflotation method.

In this method a vibro probe of about 300 to 500 mm in diameter and approximately 2 to 5 m long, with water jets at the top and bottom is forced into the ground. An eccentric disc inside the probe develops a horizontal centrifugal force causing vibrations which helps in forcing the device into the ground. Bottom water jets operate during forcing. When the probe reaches the desired depth; the top jet is turned on and the probe is gradually withdrawn. Sand or gravel is added to the crater formed at the top from densification as the device is withdrawn.

The probe is inserted at about 1 to 3 or 5 m center to center depending upon the degree of compaction required, depth of treatment needed and the soil type. Close spacing is required for fine-grained soils compared with coarse-grained soils. Normally allowable bearing capacity of 200 - 400 kPa can be attained using this method. Vibro-compaction is suitable for soils with silt content upto 20% or clay content upto 10%, vibro-replacement can be used for sands and clays.

Fig. 14.1. represents the principles of vibro-compaction.

Quality assurance testing is similar to that of dynamic compaction process.

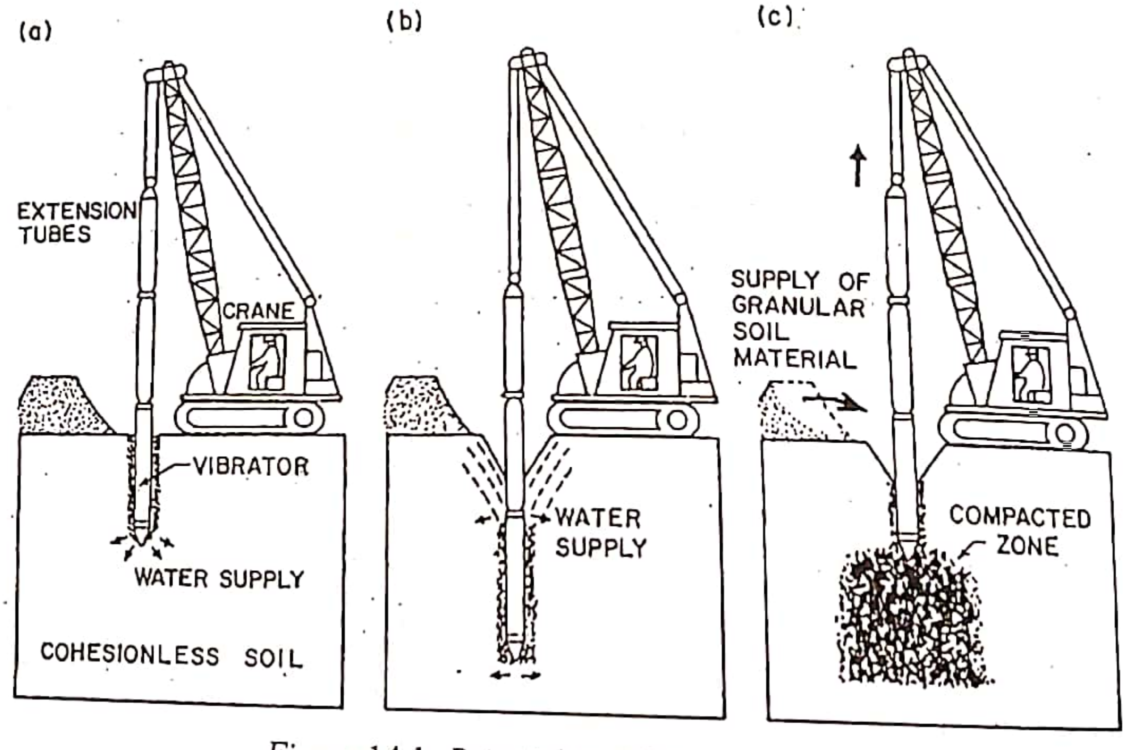

Figure 14.1 *Principles of Vibro-compaction*

(c) Terra Probe

This method of compaction by vibration is patented by the L.B. Foster Co. The method involves mounting a vibratory pile driver on a probe (pile) and vibrating it into and out of the soil to be treated. This method is effective for the soils which can be densified using vibroflotation. Depending upon the degree of compaction required, the probe is inserted at 1.5 to 5m center to center spacing.

(d) Compaction Piles

In this process, volume displacement piles are used for the compaction of sandy soils. A steel casing is driven into the ground. When the required depth is reached, sand is placed and compacted in the hole so formed, while at the same time the casing is gradually withdrawn. The effect of this process is twofold. The vibration and displacement caused by driving the casing compacts the surrounding soil, while the pile, itself consists of a column of densely packed material.

(ii) Soil Replacement

In this method, the unsuitable weak/soft soil and/or organic soil is removed and replaced by compacted engineering select fill. The best select materials are cohesionless, free draining, granlar soils (gravel, sand or their mixtures). This is the most reliable and economical when used above the ground water table and when select fill materials are available at or near the project site.

(iii) Pre-loading

The pre-loading technique was developed in 1940's and has been mainly used in connection with highways. Now-a-days, this techniques is used for a variety of projects including buildings, storage tanks, airfields, flood control structures etc. This technique may not yield favourable results for structures having heavy concentrated loads.

The treatment is very effective for normally consolidated alluvial soils having high moisture content, low shear strength and high compressibility. This treatment eliminates settlement that would otherwise occur after completion of construction. It also improves shear strength of the sub-soils by reducing the voids, increasing density and reducing moisture content.

- **Methodology**

  In this method, the weak soils are improved by applying pre-loading in advance of the proposed construction. The magnitude of the pre-loading pressure is kept slightly greater (usually 1.2 to 1.3 time the actual structural pressure) than the maximum anticipated pressure generated by the proposed structural load. Pre-load is applied by earth fills, water lowering, vacuum under impervious membranes and by ground water lowering or using any other suitable means of loading.

  On completion of settlement under the pre-load, the pre-load is removed and the structure is constructed. The time needed for pre-loading can be reduced by accelerating consolidation using vertical sand drains.

  The pre-loading area is generally greater than the area of the final structure so that the stresses induced at any depth in the foundation soils by the pre-load under the edge of the proposed structure are uniform and at least equal to or, preferably greater than the final stresses at that location. Possible future extension, may also be taken into account while fixing the limits of the pre-load area.

- **Quality Assurance Testing**

For the success of this method, quality assurance testing and continuous monitoring of the process is mandatory. The site should be instrumented to record settlement, pore pressure etc. at various stages of pre-loading and during construction of the proposed facility. Monitoring must continue for several years after completion of the facility. Sufficient strength and compressibility tests should be performed on samples taken, prior to the start of pre-loading, at various stages of loading, and on completion of the programme and the results are compared.

The instrumentation may include settlement gauges or plates installed at various depths, piezometers, inclinometers etc.

- **Merits and Demerits**

This method offers several advantages when the materials for generating pre-loading are available easily at low cost and when sufficient time for pre-loading is also available. The main merits are:

- Post-construction settlement is reduced in particular for soils of heterogeneous characteristics.
- The pre-load fill may be used for general grading of the site. This may reduce the cost of pre-loading considerably.
- The treatment is free of noise and vibrations and may be considered suitable when environmental restrictions are imposed.

The main demerits are:

- Risk of unexpected time delays may make the treatment costly.
- Disposal of pre-loading fill, if required, may increase the cost.
- Future extension of the project required to be considered in pre-loading programme, which may impose an undesirable initial investment.

(iv) Drainage and GWT Lowering

Ground water conditions are attained by drains and through lowering GWT. By changing GW conditions, effective stresses are changed and the consolidation process is accelerated.

Blanket drains and vertical sand drains are sometime installed to accelerate the consolidation process during pre-loading treatment (see Fig. 14.2)

Before lowering the GWT, the effect of settlement caused because of GWT lowering must be investigated on the adjacent structures.