UNIT17 COMPACTION AND STABILIZATION TECHNIQUES

Structure

17.1 INTRODUCTION

In a wide class of construction, soils are used extensively. They may be used as dams and levees to resist the passage of water and hold a body of water or suppart pavement for highways and airports or even to support any structure built on ground. Some soils may be suitable for use in their natural state, while others must be excavated, processed and compacted in order to serve their purposes.

When earth is placed in a fill and compacted under modern construction methods, it will often have a smaller volume than in its original condition. The decrease in volume is due to the fact that the density of soil has increased. The increase in density can be felt from the difficulty frequently encountered in driving a wooden peg into a fill after the earth has been thoroughly compacted by sheep's foot tamping rollers, pneumatic tires or other compacting equipment.

Different methods are available by which density of a soil can be increased whether in laboratory or in the field. Two terms are associated with these processes. Consolidation is the term used for the gradual expulsion of water from the pores of a saturated cohesive soil under the action of continuously acting static load over a period of time. The increase in the density occurs as a result of decrease in void ratio by expulsion of water from the pores. Some of the examples of consolidation are as under.

- When a clay strata gets compressed under the pressure of a structure built on it.
- When a fill gets compressed under its own weight.

Another term which is used in connection with increase in density of soil is compaction. The term compaction is used to refer to the more or less rapid reduction in voids deliberately produced by mechanical means during the construction process in the field or during the preparation of a sample in the laboratory. Usually no water is expelled from the voids during compaction. Some of the examples of compaction are :

- Reduction of voids or increase of density produced during the construction of and earthen dam.
- Reduction in voids produced in a layer of subgrade by a roller during construction.

Many soils may have differential expansion or shrinkage when they are subjected to changes in their moisture content. They also rut and move under a moving wheel load. If pavements are to be constructed on such soils, it is usually necessary to stabilize them to reduce the volume changes and strengthen them to the point where they can carry the imposed load, even when they are saturated. Stabilization is a process or treatment carried out on soil to render it more stable.

Objectives

The purpose of compaction or stabilization is to improve the properties of the soil used either as a subgrade material for roads or in the fills of dams or simply as a foundation material for supporting any structure on ground. The following properties that are improved due to compaction or stabilization.

i) shear strength, and

ii) low premeability and water absorption.

After reading this unit, you should be able to :

* discuss various types, methods and some interesting features of soil stabilization,
* list the types and methods of compaction, and
* understand the various types and description of various modern compacting equipments.

17.2 SOIL STABILIZATION

Stabilization of soil as mentioned earlier refers to any treatment of the soil which renders it more stable. In engineering construction, stabilization refers to addition and mixing an admixture known to be stabilizing agent with soil before compaction is carried out, so as to altering the chemical make up of soil resulting in more stable material.

Stabilization may be applied in place to a soil in its natural position or as it is placed in a fill. Also, stabilization may be applied in a plant and then transported to the job site for placement and compaction.

17.2.1 Methods of Soil Stabilization

Methods of soil stabilization includes the follwing operations :

a) Blending and mixing heterogeneous soils to produce more homogeneous soils.

b) Incorporating lime or lime-fly ash into soils that are 73 high in clay content.

c) Blending asphalt with the soil.

d) Incorporating Portland cement (with or without fly ash) into soils that are largely granular in nature.

e) Incorporating various salts into soil.

f) Incorporating certain chemicals into the soil.

g) Compacting the soils after they are processed.

Blending and Mixing Soils

If the soils found to be heterogeneous in their original states for example in the borrow pit itself, should be mixed thoroughly before being used in the fill. This can be accomplished during excavation itself by using equipment such as a power shovel or a deep-cutting belt loader to exacavate through several layers in one operation. After these materials is placed on fill, further blending can be carried out by several passes with a disk harrow.

Stabilization of Soils with Lime

Clays and silty clays having plasticity indexes greater than about 10 cause lot of problems if they are not stabilized properly. They become very soft when water is introduced in them. Stabilization with lime followd by compaction improves behaviour of such soils to a considerable extent. Lime in its hydrated form rapidly exchanges cataion leading to flocculation and agglomeration, provided it is intimately mixed with the soil. The clay type soil will then behave more like a silt type soil than clay type soil. This transformation starts within a hour of mixing and significant changes are realised within a very few days depending upon the plasticity index of the soil and the amount of lime used. The observed effect in the field is one of the drying action.

Along with this rapid soil improvement another type of slow improvement is also observed in lime stabilizated. This is due to pozzolanic reaction. In this reaction, the lime chemically combines with silicon-di-oxide and Aluminia Oxide of the soil farming cementicious material which then hydrates to form hard mass by binding soil particles together. However the hydrated product in this case is somewhat different from the product formed due to reaction of portland cement and water. This process is very slow and hence slow strength again with time experienced with lime stabilization of clay provides flexibilities in manipulation of the soil. Lime can be initially added and the soil mixed and compacted to achieve initial drying and flocculation. Several days to several weeks later the soil can be remixed and compacted to form a dense stabilized layer that will continue to gain strength for many years. Runways and Taxiways constructed in Texas in 1943 using 2 percent lime to reduce the plasticity of caliche gravel have been giving excellent service ever since.

Lime-fly Ash Stabilization

Lime-fly ash stabilization though not new but only recently being used in a big way, as fly ash which is a waste by-product from the stack in a coal-fire power plant is produced in a phenomenal quantity throughout many parts of the world. As fly ash is produced from burning of coal, its properties also depend primarily on properties of coal being used. As properties of coal can vary over a wide range (sub-bituminous or lignite to bituminous or anthracite) the fly ash can be a highly variable product and its engineering usefulness can range from superior to extremely poor. Suitable quality of fly ash can be highly pozzolanic as it contains necessary silicates and aluminates and can replace a portion of lime otherwise would be necessary to only lime stabilization of a clay-type soil. As lime is costlier than fly ash, lime-fly ash stabilization is gradually replacing lime stabilization. The major drawback to the use of lime-fly ash is that two stabilizing agents are being used instead of only one, which means more manipulation of the soil and more chances for error.

Asphalt-soil Stabilization

Asphalts in the form of emulsion or a cutback if mixed in the amount of 6 to 8 percent with granular soil, will improve the properties of soil and make it more durable and stable. In some cases to have better effect, soils are first stabilized with 10 to 15 percent of fines of size below No 200-mesh to fill the inerstices in the soil and then mixing this blend with asphalt.

Two things are to be noted. Firstly while asphalt is added, moisture content of the soil must be low. Secondly volatile oil should be allowed to evaporate from betumen before finishing and rolling the material. Soils treated in this manner may be used as finished surfaces for low-traffic density secondary roads or they may serve as base courses for high-type pavements.

Cement-soil Stabilization

Portland cement can be used to stabilize and strengthen certain type of soils. Granular soils are very effective for cement stabilization. Soils with higher amount of clay-sized particles are difficult to manipulate and mix thoroughly with the cement before the cement sets. The plasticity index (PI) of the stabilizing soil should preferably be below 10. The quantity of cement in the soil should be around 5 to 7 percent by weight of the soil.

Method of soil stabilization with portland cement is as follow : The required quantity of portland cement is spread over the soil uniformly which is to be stabilized, followed by mixing it into the soil, preferably with a pulverizer-type machine, to the specified depth, followed by fine grading and compaction. If the moisture content of the soil is low, it will be necessary to sprinkle the surface with water during the process of operation.

The compaction should be carried out within 30 minutes after it is mixed using tamping or pneumatic-tired rollers and finally rolling with smooth-wheeled rollers. Sometimes it may be necessary to apply a seating coat on the surface with asphalt or such like things. This is to be done to maintain the moisture level in the mix constant.

17.3 SOIL COMPACTION

The compaction of soil at optimum moisture content is the most widely used method of improving soil strength when it is used as a subgrade under a pavement structure or used as a foundation for other structures. The usefulness of proper compaction, which far outweighs its costs, need no elaboration. Generally a uniform layer or lift of 20 to 30 cm of soil is compacted in one go by means of several passes of heavy mechanized compaction equipment. Greater the densification of soil, increased are the benefits to be derived.

17.3.1 Measurement of Compaction

Compaction of soil is measured in terms of the dry density of the soil, which is the weight of soil solids per unit volume of the soil bulk. The dry density may be expressed as the weight of solids in gm /cm^3 or kg /m^3. If γ_t is the bulk density and w is the moisture content, the dry density γ_d may be expressed as

$$\gamma_d = \frac{\gamma_t}{1 + w} \qquad (17.1)$$

17.3.2 Factors that Affect Compaction

The factors that affect compaction are moisture content of soil and compactive effort. While moisture content means the amount of moisture present in the soil, compacting effort is defined as the amount of energy given to soil for compaction. Against a constant moisture content, any increase in compacting effort will result in closer packing of soil particles and hence increase in dry density. Further against a constant compactive effort there is only one moisture content which gives the maximum dry density. The moisture content that gives maximum dry density is called the optimum moisture content (OMC) (See Figure 17.1). If the compactive effort is increased the maximum dry density also increases but the optimum moisture content decreases.

When the soil compacted properly its shear strength increases, permeability and settlement decreases. The importance of improvement of these qualities of soil can be well appreciated if we take an example of earthen dam. The improvement of shear strength of soil will make the dam more stable with lesser width (hence lesser material involved). The decrease in the permeability will decrease the seepage loss of stored water. Improvement in density will lead to lesser settlement of dam.

All above leads to the conclusion that if all the desired qualities of the material are to be achieved, suitable procedures should be adopted in the field to compact the earth fill in layers at the appropriate water content with requisite compactive effort. The compactive effort to the soil in the field during construction is imparted by mechanical rollers. Rollers of different types and sizes are used in practice according to requirements. Whether the soil in the field has attained the required maximum density can be watched by carrying ou appropriate laboratory tests on the soil.

17.3.3 Laboratory Tests

The laboratory tests that are normally used for determining the optimum moisture content and maximum dry density of a given soil are Standart procto test and Modified proctor test. These tests are carried out to determine moisture density curve against different compactive effort (Figure 17.1).

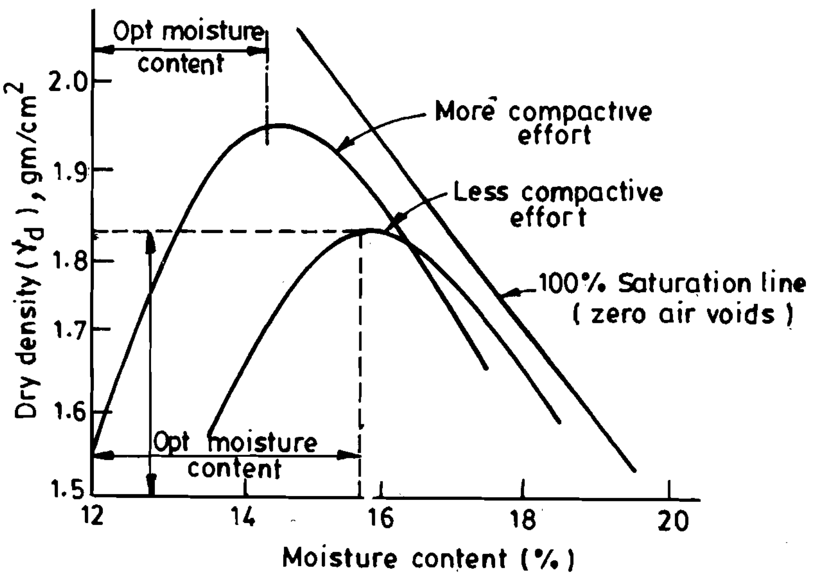


Figure 17.1 : Moisture Density Curve

The behaviour of soil at different-moisture content which is depicted in Figure 17.1 may be explained in the following few lines. At low moisture content, the soil is stiff and hence difficult to compress. Thus, it will have high air contents (can be seen in Figure 17.1 that left part of the curve is far away from 100% saturation line). As the moisture content increases, the water acts as lubricant, causing the soil to soften and become more workable. This results in higher densities and lower air contents (rise in the curve and approaching more nearer to saturation line in Figure 17.1). As the air content becomes less, the water and air in combination tend to keep the particles apart and prevent any appreciable decrease in the air content. The total voids, however, continue to increase with moisture content and hence the dry density of the soil falls. The saturation line shown in Figure 17.1 relates dry density with moisture content for soils having no air voids. All Moisture content-dry density curve approaches this saturation line but can never reach since it is never possible to expel by compaction all the air entrapped in the voids of the soil.

The shear strength of a soil increases with the amount of compaction applied. The more the soil is compacted, greater is the value of cohesion and the angle of shearing resistance. Comparing the shear strength with the moisture content against a constant compactive effort, it may be observed that the greatest shear strength is achieved at a moisture content lower than the optimum for maximum dry density. Figure 17.2 shows the same phenomenon for a sandy clay soil.

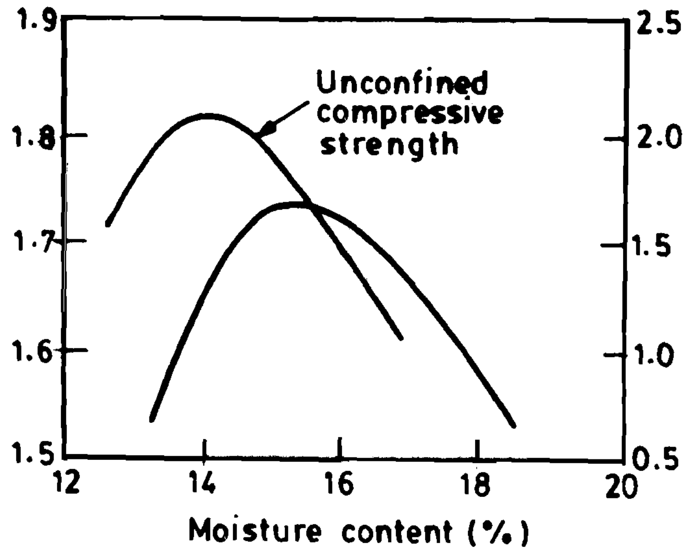


Figure 17.2: Moisture-density and Shear Strength Moisture Curve – a Comparison

The moisture density relationship in case of cohesionless soil is different. A typical such relationship for cohesionless sand is shown in Figure 17.3. From the curve it can be seen that at low water content small films of water around the grains keep the particles apart and can decrease the density up to a particular water content (Point B in Figure 17.3).

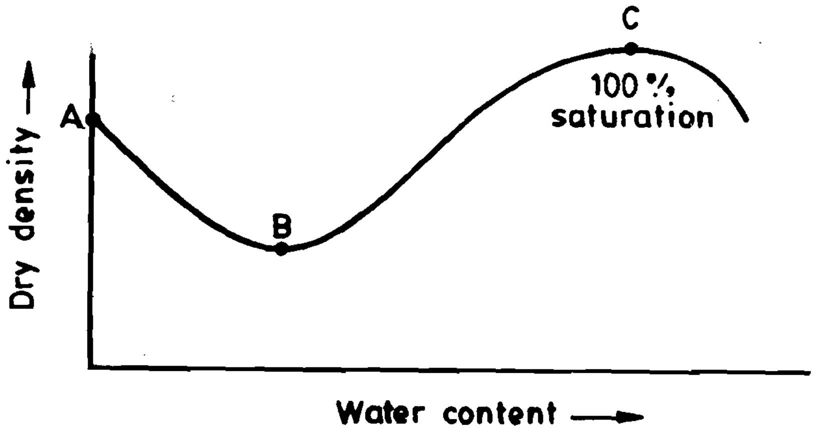


Figure 17.3 : Typical Moisture Density Curve for Cohesionless Soil

However, with increase in moisture content the surface tension reduces and the particles come closer indicating an increase in dry density (upto point C). The apparent cohesion gets reduced as the water content increases beyond B and ultimately destroyed at point C.

Compactive effort has much less effort on cohesionless soils (they are free draining) than on cohesive soils. In freely draining cohesionless soils, the degree of compaction is sometimes expressed in terms of relative density or void ratio.

17.3.4 Type of Compacting Equipments

Following are the basic modes by which energy is imparted to the soil to attain compaction.

- Kneading action
- Static weight
- Vibration
- Impact
- Explosives

Various types of compacting equipments are available which includes following equipments also

- Tamping rollers
- Smooth-wheel rollers
- Pneumatic-tired rollers
- Vibrating rollers, including tamping, smooth-wheel and pneumatic
- Self-propelled vibrating plates and/or shoes
- Manually propelled vibrating plates
- Manually propelled compactors
- Vibratory compactors for deep sand

Table 17.1 below indicates the type of equipment to be used for a particular soil and the amount of compaction can be achieved there in. However in some situations it may be desirable to use more than one type of equipment to attain the desired results and to effect the greatest economy.

Table 17.1 : Types of Equipments for Soil Compaction

Types of Compaction	Soil best suited for	Maximum effect in loose lift (inches)	Density gained in lift	Maximum weight (tons)
Sheep's foot	Clay, silty clay, gravel with clay binder	7 to 12	Nearly uniform	20
Steel tanden two-axle	Sandy silts, most granular material with some clay binder	4 to 8	Average*	16
Steel tanden three-axle	Same as above	4 to 8	Average*	20
Steel three wheel	Granular or granular plastic material	4 to 8	Average* to uniform	20
Pneumatic small-tire	Sandy silts, sandy clays, gravelly sand and clays with few fines	4 to 8	Average* to uniform	12
Penumatic large-tire	All types	9 to 24	uniform	50
Vibratory	Sand, silty sand, silty gravels	3 to 6	uniform	30
Combinations	All	3 to 6	uniform	20

*Density may decrease with depth.

Tamping Rollers : Tamping rollers consists of hollow steel drum on whose outer surface a number of projecting steel feet of varying length and cross-section are welded. This drum may be towed to a tractor or self propelled. These projections which are welded to the drum are known as sheep's-feet. A unit may consist of one or several drums mounted on one or more horizontal axles. The required pressure under the feet of the projections can be developed by adding water or sand into the drum.

During the movement of the tamping rollers, the sheeps-feet penetrate into the soil causing kneading action. After several passes, the penetration of the feet decreases untill the roller is said to walk out of the fill.

These are very effective in compacting clays and mixture of sand and clay. However, they are not effective granular soils like sand and gravel. Figure 17.4 and Figure 17.5 below show a typical sheep's-foot roller and a self-propelled tamping roller.

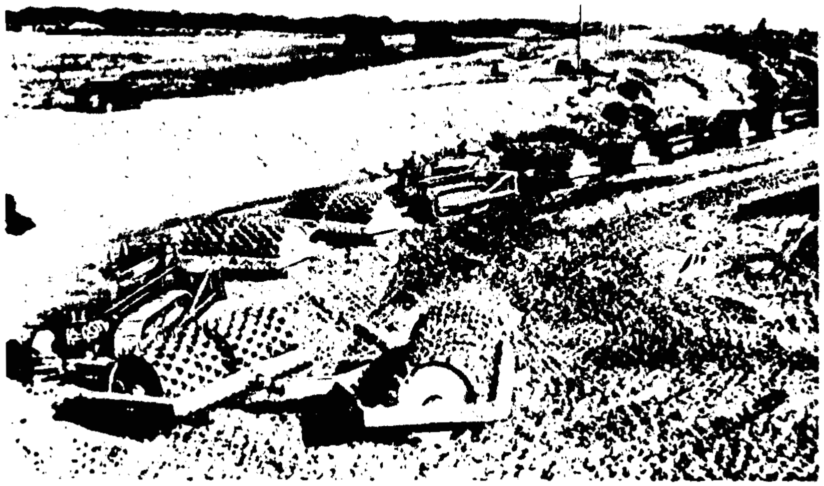


Figure 17.4 : Tractor Pulled Sheep's-foot Rollers

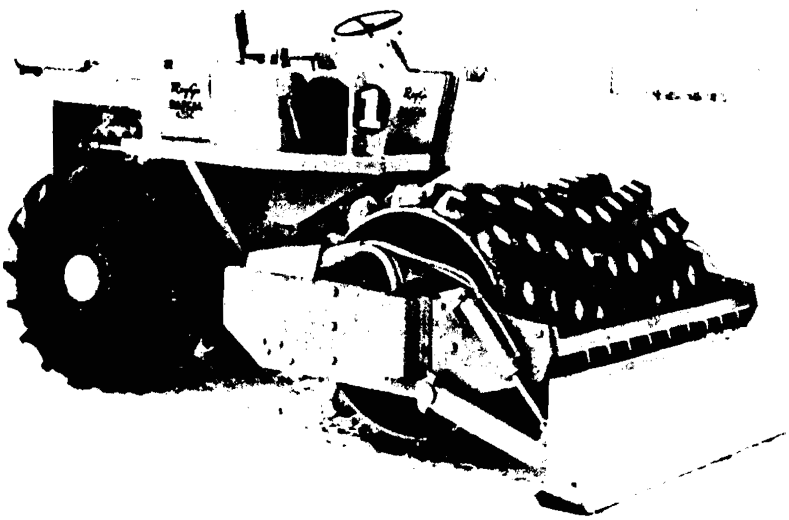


Figure 17.5: Self-propelled Tamping Roller and Dozeres.

Smooth-wheel Rollers : These are dual-drum self propelled type. The front drum is for steering and the rear wheel is powered for driving. They are classified by weight. The weight of the drum can be varied by ballasting with water or sand. Smooth wheel rollers are not effective in compacting cohesive soils as these rollers form a crust over the surface, which may prevent adequate compaction in the lower portions of a lift. These rollers, of course, very effective in compacting granular soils such as sand, gravel and crushed stone. They can be used in cohesive soil provided the soil has already been compacted to a considerable extent by tamping rollers. Figure 17.6 shows a typical smooth wheel roller.

Pneumatic-tired Rollers : These rollers can be small-tired or large tired. In both cases they have two tandom axles with four to nine tires on each axle. The rear wheels are placed in such a way that they curve the space between front wheels. Front and rear wheels 73 together cover the whole width of the roller at the same time sufficient kneading action is developed so that efficient compaction can be achieved. The wheels may be mounted in

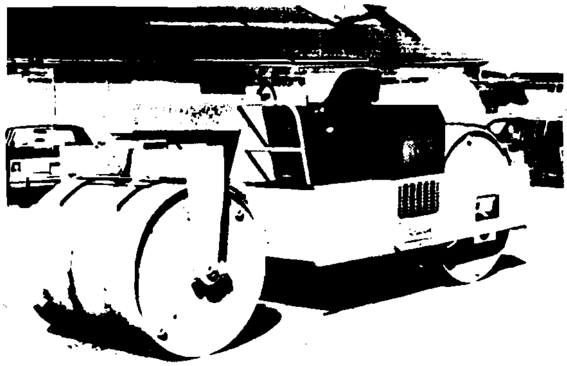


Figure 17.6 : Smooth-wheel Roller, Diesel Powered

a manner that will give them a wobbly-wheel effect to increase the kneading action of the soil. Usually the weight of the roller may be varied by adding extra weight. These rollers may be self propelled on towed.

Vibrating Compactors : Combination of pressure and vibration is very effective in certain types of soil like sand, gravel and relatively large stones. Vibration makes these soil particles to come closer and pressure causes remaining compaction. Several types of vibrating compactors which can be used to densify such soils are

- Vibrating sheep's-foot rollers
- Vibrating steel-drum rollers
- Vibrating pneumatic tired rollers
- Vibrating plates or shoes

Vibrating sheep's-foot, steel-drum and pneumatic tired rollers are run by different engines placed on the rollers or run by hydraulic drives which rotate horizontal shafts on which one or more eccentric weights are mounted. Vibrations may vary from 1000 to 5000 per min. Vibration may be adjusted to match with the natural frequency of the soil to achieve best compaction.

Vibrating plate compactors are self propelled and used for consolidating soils and asphalt in locations where large units are not practical. These gasoline or diesel-powered units are rated by centrifugal force, exciter revolutions per minute, depth of vibration penetration (lift), feet per minute travel and area of coverage per hour. Figure 17.7 illustrates a typical manually operated vibratory plate compactor.

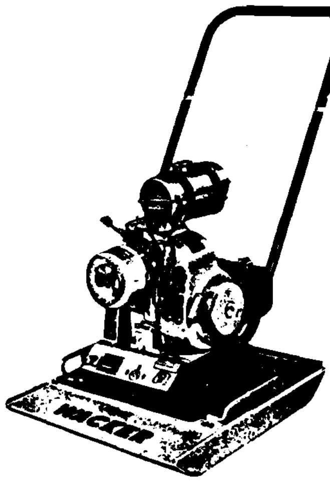


Figure 17.7 : Self-propedded Vibro-plate

17.3.5 Deep Vibration

Compressibility of loose granular materials can be reduced and thus resulting in improvement of bearing capacity of soil can be achieved by deep vibration. In many cases costly raft and piled foundation could be avoided and instead strip foundation could be adoted by using deep vibration which resulted in achieving a degree of uniformity in the density of foundation material. Fill materials consisting of brick rubble, broken concrete, tiles arising out of clearance of old houses or loose soils or other miscellaneous materials can be given effective compaction by means of close-spaced insertions of a heavy high-frequency vibration unit along the line of the proposed foundation. Under such vibration, the foundation materials are induced to attain a closer state of packing and voids formed by arching of the fill are broken down. Additional granular material may be fed into the depression formed around the vibration. By means of repeated insertions and withdrawals of the unit the granular material is compacted into any remaining voids, thus forming a strip of dense granular fill upon which the new foundations can be constructed without risk of appreciable differential settlement.

Two principal methods are used for deep compaction. In the vibroflotatioon process, a heavy vibratory unit is jetted down into the soil (Figure 17.8 shows vibratory unit and Figure 17.9 (a) shows jetting down process). On reaching the desired depth, the 22 kW rotating vibrating machine within the unit is set in motion and the direction of jetting is reversed to carry the soil particles downward. The vibrator which has an amplitude of 20 mm, compacts the soil to a radius of about 1.2 to 1.5 m around the unit and sand is shovelled into fill the cone shaped depression which appears at the surface [Figure17.9 (b)] The unit is withdrawn in 0.25 m stages, vibration being applied at each stage and ground surface made up as required. The unit is put down again about 2 or 2.5 m away and the process repeated until the whole area to be treated is covered by overlapping cylinders of compacted soil. The units can be jetted to a depth of about 10 m.

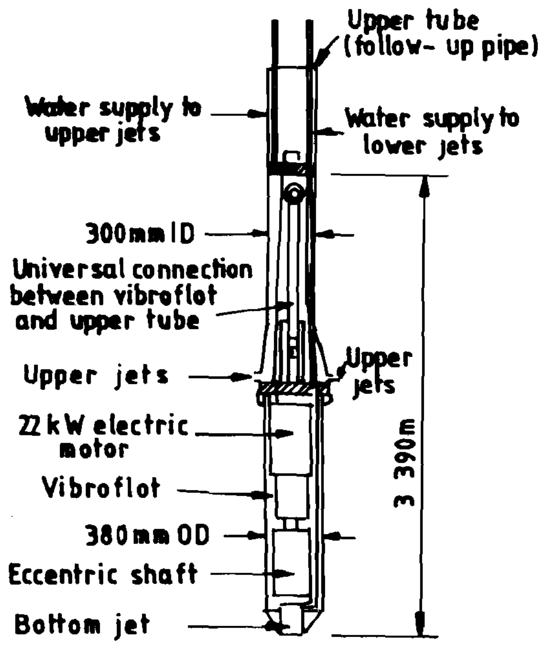


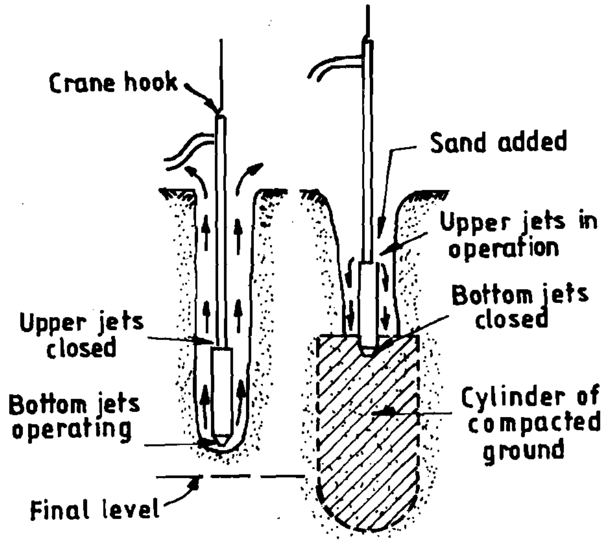
Figure 17.8 : Diagram of Vibroflot

The vibroflot is most effective in clean sands or gravels or granular fills, but it operate in silty or clayey sands containing upto 25 per cent of silt or 5 per cent of clay.

In the vibro-replacement process use of a large vibrating tube is made. It has a large dead weight and can be vibrated with high frequency. Combination of large dead weight and high frequency vibration makes it possible to penetrate into the ground. No water is used in case of vibro-replacement but the procedure remains same like vibroflotation.

Both the procedure enables to introduce some strong materials into soft silts or clays so as to increase the load carrying capacity of foundation. The method of vibro-flotation or vibro-replacement forms columns of clean graded stone or blastfurnace slag at close spacing over the entire foundation area. The stone columns act in several ways. These columns not only act as bearing piles but also form zones of granular material having a higher shear strength then surrounding soil, thus increasing the capacity of the soil to resist general shear failure.

An example of the successful use of vibroflotation process is the consolidation of the ground beneath the foundation of a 20-storey building at Lagos in Nigeria. Foundation soil originally consisted of loose sand extending to a depth of 6 m, followed by denser sand to 12 m underlain by a considerable depth of soft to stiff clays alternating with mainly compact sands. It was calculated that settlement of a raft foundation with a loading of 183 kN/m^2 would have been above 200 mm. Vibroflotation was done on a grid of 19 m over the entire foundation area. Measurements of settlement of the 20 storey building were made up to a period of a year after completing the main structure. The maximum settlement was found to be about 25 mm only.



(a) Jetting down Vibroflot (b) Withdrawal of Vibroflot

Figure 17.9 : Operation of Vibroflot

17.3.6 Densification of Soils by Explosive Vibration

Localized spontaneous liquefaction occurs when sudden explosive vibration is given to loose, saturated granular soil. The weight of the soil above is transfered temporarily to liquid and soil particles realign themselves in a newer pattern which is much denser and compact than original. The moment soil particles are forced or loosend from original state, even a small compactive effort can become more effective to reorient them in a compact mass. The process is not reversible and the new density is permanent.

The best result is obtained either when the soil is completely saturated or dry. When the water content is brought down from full saturation, the water remains as retained or absorbed water around each particle of soil. This absorbed water around each particle causes capillary tension making densification difficult. This effect is more pronounced if the soil is finer. The capillary tension can be removed by ponding or flooding the area, then allowing adequate time for the water to seep downward to meet existing water level.

In explosive vibration it is observed that top 0.6 to 1 m of soil is not as densified as deeper layers of soil. This is because a small amount of superimposed load is advantageous in reorienting the soil particles. For compacting this top soil layer (0.6 to 1 m) conventional mechanical vibrating equipment is to be used.

The current charge exploded in a area will cause further settling of soil particles than the previous charge, but each successive charge produces a smaller effect until no appreciable or useful settling can be obtained. It is seen that first quarter of charges causes approximately 60 percent densification, the second quarter, causes 25 percent more, the third quarter 10 percent more and the last quarter 5 percent more. This condition must be considered while deciding the spacing of the hole, to ensure that a sufficient number of overlapping effect, is applied to each location.

Densification of soil by means of explosive is totally different from regular blasting as energy of explosion in densification must be contained fully within the soil. There cannot be any debris from explosion of charge.

The approximate sizes and depths of changes can be determined from emperical formulae aided with experience and field tests conducted at site. However, the amount of change will depend in the following factors :

a) Type of soil

b) Depth of strata

c) Desired amount of densification

d) Spacing of hole, and overlapping effect of charges

e) Present ground water level

f) Distance of existing structure

g) Explosive type

Generally, horizontal spacing of hole, may vary from 3 to 8 m. Spacing closer than 3 m in saturated soil, should be avoided because of possible propagation of sensitive explosions of adjacent charges.

SAQ 1

a) Mention various types of compacting equipments ?

b) Describe action of smooth-wheel rollers ? Under what conditions they are most effective.

c) Mention different types of soil where vibrating compactions are most useful.

d) Under what circumstances deep vibration is most effective.

e) What are the principle methods that are used for deep vibration ?

17.4 SUMMARY

The purpose of compaction is to improve the qualities of soil used either as a subgrade material or as a fill or for foundation of any structure. With the advent of modern compacting equipments it is now possible to improve the qualities of soil to a great extent.

Many soils are subjected to differential expansion and shrinkage when they undergo changes, in moisture content. Many soils also move and rut when they are subjected to load. Such soil require stabilization. In this chapter you are exposed to various methods of soil compaction and stabilization.

17.5 KEY WORDS

Base : The layer of material in a roadway or airport runway section on which the pavement is placed.

Binder : Fine aggregate or other material, which fill voids or hold coarse aggregate together.

Borrowpit : An excavation from which fill material is excavated.

Clay : A soil composed of particles less than about 5μ m in size.

Cohesion	:	The quality of some soil particles, to be attracted to like particles, manifested in a tendency to stick together as in clay.
Lift	:	A layer of soil placed in top of soil previously placed in an embankment.
Liquid Limit	:	The water content expressed as a percent of the weight of water of the dry weight of the soil, at which the soil passes from a plastic to a liquid state.
OMC	:	The percent of moisture, by weight, all which the greatest density of a soil can be obtained by compaction.
Plasticity Index	:	The numerical difference between a soils liquid limit and its plastic limit.
Plestic limit	:	The lowest water content, expressed as percent of the ratio of the weight of moisture to the dry weight of soil, at which the soil remains in a plastic state.
Stabilize	:	To make the soil more firm, increase in its strength and stiffness, and decrease its sensivity to volume changes, with change, in moisture content.

17.6 ANSWERS TO SAQs

Check your answers of all SAQs from respective text portion.