

# LECTURE NOTES ON

## GROUND IMPROVEMENT TECHNIQUES

Department of Civil Engineering



**MALLA REDDY ENGINEERING COLLEGE (AUTONOMOUS)**

**Maisammaguda, Dhulapally -**

**500 100,Hyderabad**

## **SYLLABUS:**

### **MODULE I: Dewatering and Grouting**

Dewatering Methods of de-watering- sumps and interceptor ditches- single, multi stage well points - vacuum well points- Horizontal wells-foundation drains-blanket drains- criteria for selection of fill material around drains –Electro-osmosis. Grouting Objectives of grouting- grouts and their properties- grouting methods ascending, descending and stage grouting- hydraulic fracturing in soils and rocks post, grout test.

### **MODULE II:**

**In – Situ Densification Methods in Granular Soils** Vibration at the ground surface, Impact at the Ground Surface, Vibration at depth, Impact at depth.

**In – Situ Densification Methods in Cohesive Soils** Preloading or dewatering, Vertical drains – Sand Drains, Sand wick geodrains – Stone and lime columns – thermal methods.

### **MODULE III: Geosynthetics and Geoenvironmental Application**

A: Geosynthetics Description, properties, functions and applications of geosynthetics

B: Geoenvironmental Application of Geosynthetics Geomembranes for landfills and ponds, Geosynthetic clay liner, Designing with GCL;s, Filtration, Erosion control, slope protection.

MODULE IV: Reinforced Earth Principles Components of reinforced earth – factors governing design of reinforced earth walls – design principles of reinforced earth walls.

### **MODULE V: Stabilization**

Methods of stabilization-mechanical-cement- lime-bituminous chemical stabilization with calcium chloride, sodium silicate and gypsum. Expansive soils: Problems of expansive soils – tests for identification – methods of determination of swell pressure. Improvement of expansive soils – Foundation techniques in expansive soils – under reamed piles.

## UNIT-1

### **Introduction to Engineering Ground Modification.**

**The Need for Engineered Ground Improvement:** As more and more land becomes subject to urban or industrial development, good construction sites and borrow areas are difficult to find and the soil improvement alternatives becomes the best option, technically and economically.

Where a project encounters difficult foundation conditions, possible alternative solutions are:

1. Avoid the particular site. Relocate a planned highway or development site.
2. Design the planned structure accordingly. Some of the many possible approaches are to:
  - Use a raft foundation supported by piles,
  - Design a very stiff structure which is not damaged by settlement,
  - Or choose a very flexible construction which accommodates differential movement or allows for compensation.
3. Remove and replace unsuitable soils. Removing organic topsoil, which is soft, compressible, and volumetrically unstable.

This is a standard precaution in road or foundation construction.

4. Attempt to modify the existing ground

### **Objective of Ground Improvement Techniques**

The most common traditional objectives include improvement of the soil and ground for use as a foundation or construction material.

The typical Engineering objectives have been:

- 1) Increasing shear strength, durability, stiffness. And stability:
- 2) Mitigating undesirable properties (eg. Shrink/ swell potential, compressibility, liquefability
- 3) Modifying permeability, the rate of fluid to flow through a medium; and
- 4) Improving efficiency and productivity by using methods that save time and expense,

The engineer must take a determination on how best to achieve the desired goals required by providing a workable solution for each project encountered. Ground improvement methods have provided a diverse choice of approaches to solving these challenges.

### **Factors affecting choice of improvement method**

1. **Soil type** : this is one of the most important parameters that will control what approach or materials will be applicable to only certain types of soil types and grain sizes
2. **Area** , depth and location of treatment required- many ground improvement methods have depth limitations that render them unsuitable for applications for deeper soil horizons.
3. **Desired/required soil properties**- obviously, different methods are used to achieve different engineering properties, and certain methods will provide various levels of uniformity to improved sites.
4. **Availability of materials**- Depending on the location of the project and materials required for each feasible ground improvement approach.
5. **Availability of skills**, local experience, and local preferences- While the engineer may possess the knowledge and understanding of a preferred method.
6. **Environmental concerns**- With a better understanding and a greater awareness of effects on the natural environment, more attention has been placed on methods that assure less environmental impacts.
7. **Economics**- when all else has been considered, the final decision on choice of improvement method will often come down to the ultimate cost of a proposed method, or cost will be the deciding factor in choosing between two or more otherwise suitable methods.

### **Identifying your soil type**

**Soils can be identified into their general types by the way they feel and respond to handling...**

Pick up a handful and squeeze it together. Sand feels gritty and the grains do not stick together when squeezed. Loam feels velvety or flour-like when dry and forms a weak ball shape when wet which crumbles apart when dry. Clay feels sticky, but goes smooth when rubbed. Chalk will have large lumps in it and be hard to mould.

### **How to work with your soil**

The most important thing is to identify your soil type and work with it, remember the golden rule All soil types have their good points and can be improved. Even the best loam soils will benefit from additional organic matter.

### **Heavy, Clay soil**

This holds water, but also bakes dry in the summer. However, clay is very good at holding nutrients and moisture and very fertile as long as you can break it down with the addition of organic matter and grit. This will enable the roots of plants to get through to the nutrients more easily and of course make planting less back breaking for you. Try and avoid walking on the soil too much as this will compact it to a hard pan.

### **Sandy soil**

It loses water very quickly being particularly free-draining. However, you can improve both of these factors with the addition of organic matter and soil improver and of course, many plants thrive in a free-draining soil. It also warms up quickly in the spring.

### **Chalky**

This is alkaline so will not suit plants that require ericaceous soil. Some soils contain large clumps of chalk; others are a mixture of chalk and clay. It is normally free draining, but may be low in nutrients so as with the other soils the addition of organic matter will help with both the structure and nutritional content of the soil.

### **Normal**

It retains moisture without impeding drainage, captures nutrients and allows oxygen to circulate. It normally contains equal quantities of sand, clay, silt, and organic matter.

### **Loam, Sand & Silt Soil Identification**



Soil type affects drainage.

Many plants are quite picky about the type of soil in which they live. Therefore, identifying your garden's kind of soil will help you know whether particular plants will do well in your garden without soil amendment or with soil amendment, or if you should just skip using those plants altogether.

### **Sandy Soil**

Most people associate sandy textures with those they feel between their toes at the beach, and the feeling is similar in sandy soil. Its particles are the largest of all the soil particle types, ranging from 0.05 to 0.10 millimeters at the small end and 1 to 2 millimeters at the large end. That factor gives wet or dry sandy soil a grainy texture when you rub it between your fingers, and it makes the soil light and crumbly even when you try to stick it together in your hand. Sandy soil drains very quickly.

## **Silt Soil**

Many people think of loam as the intermediate between sand and clay, but midsized soil particles are referred to as silt. Silt soil is fine and feels almost floury to the touch when dry. When wet, it becomes a smooth mud that you can form easily into balls or other shapes in your hand. When silt soil is very wet, it blends seamlessly with water to form fine, runny puddles of mud. Silt particles are very small, between 0.002 and 0.05 millimeters, which results in their very smooth texture. Silty soil drains well but not as quickly as sand.

## **Clay Soil**

Clay particles are the finest of all the soil particles, measuring fewer than 0.002 millimeters in size. They stick together readily and form a sticky or gluey texture when they are wet or dry. When you gather clay soil into your hand, you can readily shape it into whatever form you want. It will form a ball that doesn't break when squeezed, or a thin, flexible ribbon when pressed between your thumb and forefinger.

## **Loam Soil**

Loam is not its own particle type but a designation for soils containing certain combinations of other particles. The way the other particles combine in the soil makes the loam. For instance, a soil that is 30 percent clay, 50 percent sand and 20 percent silt is a sandy clay loam, with the soil types before "loam" listed in the order their particles are most dominant in the loam. The labels "clay loam," "silt loam" and "sand loam" are used to refer to soils that are composed predominantly of those ingredients.

## **In situ laboratory test for problematic Soils**

### **In Situ and Laboratory Testing**

ESG's (Environmental, Social and Governance) geotechnical division offers a wide range of in situ and laboratory-based testing methods for the measurement of soil and rock stiffness parameters. In recent years the importance of soil and rock stiffness parameters in geotechnical engineering design has been increasingly recognized, driven in part by the requirements of EC-7 for calculating serviceability limit state conditions.

## Specialist in situ testing

We provide a number of specialist in situ tests for the measurement of soil stiffness, either as a standalone service or part of a wider site investigation, backed up by proven technical and analytical expertise:

- Borehole and surface seismic methods, such as down hole, cross hole, surface refraction and multichannel analysis of surface waves (MASW)
- Seismic cone penetration testing (SCPT), a version of the down hole method where a seismic receiver is incorporated with conventional cone penetration testing (CPT)
- Pressure meter testing using pre-bored high pressure dilatometer (HPD), self-boring pressuremeter (SBP) and driven pressure meter (DPM) to carry out load displacement tests in boreholes

The adoption of EC-7, which advocates the direct measurement of geotechnical parameters by in situ testing techniques, has seen a significant increase in the demand for SBP and HPD testing methods.

Following a major period of investment, ESG's in situ team now offers combined magnetometer/piezcone resources and upgraded down hole magnetometer analysis, as well as the capability for site clearance with the potential risk of Unexploded Ordnance. In addition, our main cone penetration test rigs have undergone a program of detailed refurbishment to ensure they provide the best possible results.

## **Advanced laboratory testing**

Alongside in situ testing, we also provide extensive sample analysis in our UKAS accredited computer-based laboratories:

- Resonant column and simple shear apparatus, which provide soil stiffness and damping parameters over a range of strain amplitudes
- Triaxial tests with local strain and mid-height pore water pressure measurement to obtain strength and stiffness properties, while significantly reducing the influences of sample



bedding, end effects and allowing a much greater degree of precision of stress and strain measurement, together with automated control of all stages of testing

- Bender elements, either stand-alone or combined with other tests, to measure elastic wave travel times for calculation of wave velocities and stiffness

### **In situ sampling methods**

ESG offers a range of sampling methods to maximise undisturbed sample recovery in a variety of soil and rock ground conditions suitable for advanced testing methods, including:

- Thin-walled open drive tube samples (UT100)
- Thin-walled pushed samples (Shelby) and hydraulically-pushed piston samples
- Block samples
- Wireline rotary cored samples

### **Various Lab Test on Soil**

Soil inspection or say geotechnical inspection is very important in understanding the physical properties of soil and the rocks beneath. This is required to ascertain the type of foundation required for the proposed construction. Various tests are done to explore the sub surface and surface characteristics of soil. Some of these are given below. Just click on the link to go to the details of that particular test.

**1) Water Content** – There are two tests which can be done to determine the water content of soil. These are

a) [Calcium Carbide Method](#)

### **Determining Water Content In Soil – Calcium Carbide Method**

This test is done to determine the water content in soil by calcium carbide method as per IS: 2720 (Part II) – 1973. It is a method for rapid determination of water content from the gas pressure developed by the reaction of calcium carbide with the free water of the soil. From the calibrated scale of the pressure gauge the percentage of water on total mass of wet soil is obtained and the same is converted to water content on dry mass of soil.

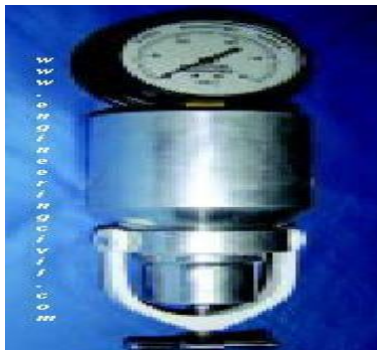
Apparatus required :-

i) Metallic pressure vessel, with a clamp for sealing the cup, alongwith a gauge calibrated in percentage water content

- ii) Counterpoised balance, for weighing the sample
- iii) Scoop, for measuring the absorbent (Calcium Carbide)
- iv) Steel balls – 3 steel balls of about 12.5mm dia. and 1 steel ball of 25mm dia.
- v) One bottle of the absorbent (Calcium Carbide)

### **PREPARATION OF SAMPLE**

Sand – No special preparation. Coarse powders may be ground and pulverized. Cohesive and plastic soil – Soil is tested with addition of steel ball in the pressure vessels. The test requires about 6g of sample.



### **Procedure to determine Water Content in Soil by Calcium Carbide Method**

- i) Set up the balance, place the sample in the pan till the mark on the balance arm matches with the index mark.
- ii) Check that the cup and the body are clean.
- iii) Hold the body horizontally and gently deposit the leveled, scoop-full of the absorbent (Calcium Carbide) inside the chamber.
- iv) Transfer the weighed soil from the pan to the cup.
- v) Hold cup and chamber horizontally, bringing them together without disturbing the sample and the absorbent.
- vi) Clamp the cup tightly into place. If the sample is bulky, reverse the above placement, that is, put the sample in the chamber and the absorbent in the cup.

vii) In case of clayey soils, place all the 4 steel balls (3 smaller and 1 bigger) in the body along with the absorbent.

viii) Shake the unit up and down vigorously in this position for about 15 seconds.

ix) Hold the unit horizontally, rotating it for 10 seconds, so that the balls roll around the inner circumference of the body.

x) Rest for 20 seconds.

xi) Repeat the above cycle until the pressure gauge reading is constant and note the reading. Usually it takes 4 to 8 minutes to achieve constant reading. This is the water content (m) obtained on wet mass basis.

xii) Finally, release the pressure slowly by opening the clamp screw and taking the cup out, empty the contents and clean the instrument with a brush.

#### b) Oven Drying Method

#### **Determining Water Content in Soil – Oven Drying Method**

This test is done to determine the water content in soil by oven drying method as per IS: 2720 (Part II) – 1973. The water content (w) of a soil sample is equal to the mass of water divided by the mass of solids.

Apparatus required:-

- i) Thermostatically controlled oven maintained at a temperature of  $110 \pm 5^{\circ}\text{C}$
- ii) Weighing balance, with an accuracy of 0.04% of the weight of the soil taken
- iii) Air-tight container made of non-corrodible material with lidTongs

#### **PREPARATION OF SAMPLE**

The soil specimen should be representative of the soil mass. The quantity of the specimen taken would depend upon the gradation and the maximum size of particles as under:

#### **Procedure to determine Water Content in Soil By Oven Drying Method**

- i) Clean the container, dry it and weigh it with the lid (Weight 'W<sub>1</sub>').
- ii) Take the required quantity of the wet soil specimen in the container and weigh it with the lid (Weight 'W<sub>2</sub>').

iii) Place the container, with its lid removed, in the oven till its weight becomes constant (Normally for 24hrs.).

iv) When the soil has dried, remove the container from the oven, using tongs.

v) Find the weight 'W<sub>3</sub>' of the container with the lid and the dry soil sample.

## **2) Free Swell Index Of Soil**

To determine the free swell index of soil as per IS: 2720 (Part XL) – 1977. Free swell or differential free swell, also termed as free swell index, is the increase in volume of soil without any external constraint when subjected to submergence in water. The apparatus used:

i) IS Sieve of size 425µm?

ii) Oven

iii) Balance, with an accuracy of 0.01g

iv) Graduated glass cylinder- 2 nos., each of 100ml capacity

v) Take two specimens of 10g each of pulverized soil passing through 425µm IS Sieve and oven-dry.ii) Pour each soil specimen into a graduated glass cylinder of 100ml capacity.iii) Pour distilled water in one and kerosene oil in the other cylinder upto 100ml mark.

iv) Remove entrapped air by gently shaking or stirring with a glass rod.

v) Allow the suspension to attain the state of equilibrium (for not less than 24hours).

vi) Final volume of soil in each of the cylinder should be read out.

## **3) Plastic Limit Of Soil**

### **Determine the Plastic Limit of Soil**

This test is done to determine the plastic limit of soil as per IS: 2720 (Part 5) – 1985. The plastic limit of fine-grained soil is the water content of the soil below which it ceases to be plastic. It begins to crumble when rolled into threads of 3mm dia. The apparatus used:

- i) Porcelain evaporating dish about 120mm dia.
- ii) Spatula
- iii) Container to determine moisture content
- iv) Balance, with an accuracy of 0.01g
- v) Oven
- vi) Ground glass plate – 20cm x 15cm
- vii) Rod – 3mm dia. and about 10cm long

## PREPARATION OF SAMPLE

Take out 30g of air-dried soil from a thoroughly mixed sample of the soil passing through 425 $\mu$ m IS Sieve. Mix the soil with distilled water in an evaporating dish and leave the soil mass for nurturing. This period may be up to 24hrs.

### Procedure to determine The Plastic Limit of Soil

- i) Take about 8g of the soil and roll it with fingers on a glass plate. The rate of rolling should be between 80 to 90 strokes per minute to form a 3mm dia.
- ii) If the dia. of the threads can be reduced to less than 3mm, without any cracks appearing, it means that the water content is more than its plastic limit. Knead the soil to reduce the water content and roll it into a thread again.
- iii) Repeat the process of alternate rolling and kneading until the thread crumbles.
- iv) Collect and keep the pieces of crumbled soil thread in the container used to determine the moisture content.
- v) Repeat the process at least twice more with fresh samples of plastic soil each time.

### 4) Liquid Limit Of Soil

This test is done to determine the liquid limit of soil as per IS: 2720 (Part 5) – 1985. The liquid limit of fine-grained soil is the water content at which soil behaves practically like a liquid, but has small shearstrength. Its flow closes the groove in just 25 blows in Casagrande’s liquid limit device. The apparatus used :-

- i) Casagrande’s liquid limit device

- ii) Grooving tools of both standard and ASTM types
- iii) Oven
- iv) Evaporating dish
- v) Spatula
- vi) IS Sieve of size 425 $\mu$ m
- vii) Weighing balance, with 0.01g accuracy
- viii) Wash bottle
- ix) Air-tight and non-corrodible container for determination of moisture content

### **PREPARATION OF SAMPLE**

- i) Air-dry the soil sample and break the clods. Remove the organic matter like tree roots, pieces of bark, etc.
- ii) About 100g of the specimen passing through 425 $\mu$ m IS Sieve is mixed thoroughly with distilled water in the evaporating dish and left for 24hrs. for soaking.



6)

### **Procedure to Determine The Liquid Limit of Soil**

- i) Place a portion of the paste in the cup of the liquid limit device.
- ii) Level the mix so as to have a maximum depth of 1cm.
- iii) Draw the grooving tool through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup.
- iv) For normal fine grained soil: The Casagrande's tool is used to cut a groove 2mm wide at the bottom, 11mm wide at the top and 8mm deep.
- v) For sandy soil: The ASTM tool is used to cut a groove 2mm wide at the bottom, 13.6mm wide at the top and 10mm deep.
- vi) After the soil pat has been cut by a proper grooving tool, the handle is rotated at the rate of about 2 revolutions per second and the no. of blows counted, till the two parts of the soil sample come into contact for about 10mm length.
- vii) Take about 10g of soil near the closed groove and determine its water content
- viii) The soil of the cup is transferred to the dish containing the soil paste and mixed thoroughly after adding a little more water. Repeat the test.
- ix) By altering the water content of the soil and repeating the foregoing operations, obtain at least 5 readings in the range of 15 to 35 blows. Don't mix dry soil to change its consistency.
- x) Liquid limit is determined by plotting a 'flow curve' on a semi-log graph, with no. of blows as abscissa (log scale) and the water content as ordinate and drawing the best straight line through the plotted points.

## 5) **Particle Size Distribution Of Soil**

### **Determine Particle Size Distribution of Soil**

This test is done to determine the particle size distribution of soil as per IS: 2720 (Part 4) – 1985.

The apparatus required to do this test :-

- i) A set of fine IS Sieves of sizes – 2mm, 600 $\mu$ m, 425 $\mu$ m, 212 $\mu$ m and 75 $\mu$ m
- ii) A set of coarse IS Sieves of sizes – 20mm, 10mm and 4.75mm
- iii) Weighing balance, with an accuracy of 0.1% of the weight of sample
- iv) Oven
- v) Mechanical shaker
- vi) Mortar with rubber pestle Brushes
- viii) Trays

## PREPARATION OF SAMPLE

- i) Soil sample, as received from the field, should be dried in air or in the sun. In wet weather, the drying apparatus may be used in which case the temperature of the sample should not exceed 60°C. The clod may be broken with wooden mallet to hasten drying. Tree roots and pieces of bark should be removed from the sample.
- ii) The big clods may be broken with the help of wooden mallet. Care should be taken not to break the individual soil particles.
- iii) A representative soil sample of required quantity as given below is taken and dried in the oven at 105 to 120°C.

Maximum size of material present in substantial quantities (mm)	Weight to be taken for test (kg)
75	60
40	25
25	13
19	6.5
12.5	3.5
10	1.5
6.5	0.75
4.75	0.4

### Procedure to determine Particle Size Distribution Of Soil

- i) The dried sample is taken in a tray, soaked in water and mixed with either 2g of sodium hexametaphosphate or 1g of sodium hydroxide and 1g of sodium carbonate per litre of water, which is added as a dispersive agent. The soaking of soil is continued for 10 to 12hrs.
- ii) The sample is washed through 4.75mm IS Sieve with water till substantially clean water comes out. Retained sample on 4.75mm IS Sieve should be oven-dried for 24hrs. This dried sample is sieved through 20mm and 10mm IS Sieves.
- iii) The portion passing through 4.75mm IS Sieve should be oven-dried for 24hrs. This oven-dried material is riffled and about 200g taken.



iv) This sample of about 200g is washed through 75µm IS Sieve with half litre distilled water, till substantially clear water comes out.

v) The material retained on 75µm IS Sieve is collected and dried in oven at a temperature of 105 to 120°C for 24hrs. The dried soil sample is sieved through 2mm, 600µm, 425µm

and 212µm IS Sieves. Soil retained on each sieve is weighed.

vi) If the soil passing 75µm is 10% or more, hydrometer method is used to analyse soil particle size.

## **6) The Specific Gravity Of Soil**

### **Determine the Specific Gravity of Soil**

This test is done to determine the specific gravity of fine-grained soil by density bottle method as per IS: 2720 (Part III/Sec 1) – 1980. Specific gravity is the ratio of the weight in air of a given volume

of a material at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature.

The apparatus used:

i) Two density bottles of approximately 50ml capacity along with stoppers

ii) Constant temperature water bath (27.0 + 0.2°C)

iii) Vacuumdesiccators

iv) Oven, capable of maintaining a temperature of 105 to 110°C

v) Weighing balance, with an accuracy of 0.001g

vi) Spatula

## **PREPARATION OF SAMPLE**

The soil sample (50g) should if necessary be ground to pass through a 2mm IS Sieve. A 5 to 10g sub-sample should be obtained by riffing and oven-dried at a temperature of 105 to 110°C.

### **Procedure to Determine the Specific Gravity of Fine-Grained Soil**

- i) The density bottle along with the stopper, should be dried at a temperature of 105 to 110°C, cooled in the desiccator and weighed to the nearest 0.001g ( $W_1$ ).
- ii) The sub-sample, which had been oven-dried should be transferred to the density bottle directly from the desiccator in which it was cooled. The bottles and contents together with the stopper should be weighed to the nearest 0.001g ( $W_2$ ).
- iii) Cover the soil with air-free distilled water from the glass wash bottle and leave for a period of 2 to 3hrs. for soaking. Add water to fill the bottle to about half.
- iv) Entrapped air can be removed by heating the density bottle on a water bath or a sand bath.
- v) Keep the bottle without the stopper in a vacuum desiccator for about 1 to 2hrs. until there is no further loss of air.
- vi) Gently stir the soil in the density bottle with a clean glass rod, carefully wash off the adhering particles from the rod with some drops of distilled water and see that no more soil particles are lost.
- vii) Repeat the process till no more air bubbles are observed in the soil-water mixture.
- viii) Observe the constant temperature in the bottle and record.
- ix) Insert the stopper in the density bottle, wipe and weigh ( $W_3$ ).
- x) Now empty the bottle, clean thoroughly and fill the density bottle with distilled water at the same temperature. Insert the stopper in the bottle, wipe dry from the outside and weigh ( $W_4$ ).
- xi) Take at least two such observations for the same soil.

### **7) The In-Situ Dry Density Of Soil By Sand Replacement Method**

## **Determine the In-Situ Dry Density of Soil by Sand Replacement Method**

This test is done to determine the in-situ dry density of soil by sand replacement method as per IS: 2720 (Part XXVIII) – 1974. The apparatus needed is

- i) Sand-pouring cylinder conforming to IS: 2720 (Part XXVIII) -1974
- ii) Cylindrical calibrating container conforming to IS: 2720 (Part XXVIII) – 1974
- iii) Soil cutting and excavating tools such as a scraper tool, bent spoon
- iv) Glass plate – 450mm square and 9mm thick or larger
- v) Metal containers to collect excavated soil
- vi) Metal tray – 300mm square and 40mm deep with a 100mm hole in the centre
- vii) Balance, with an accuracy of 1g

## **Procedure to Determine The In-Situ Dry Density Of Soil By Sand Replacement Method**

### **A. Calibration of apparatus**

- a) **The method given below should be followed for the determination of the weight of sand in the cone of the pouring cylinder:**
  - b) The pouring cylinder should be filled so that the level of the sand in the cylinder is within about 10mm of the top. Its total initial weight ( $W_1$ ) should be maintained constant throughout the tests for which the calibration is used. A volume of sand equivalent to that of the excavated hole in the soil (or equal to that of the calibrating container) should be allowed to runout of the cylinder under gravity. The shutter of the pouring cylinder should then be closed and the cylinder placed on a plain surface, such as a glass plate.
  - ii) The shutter of the pouring cylinder should be opened and sand allowed to runout. When no further movement of sand takes place in the cylinder, the shutter should be closed and the cylinder removed carefully.
  - iii) The sand that had filled the cone of the pouring cylinder (that is, the sand that is left on the plain surface) should be collected and weighed to the nearest gram.
  - iv) These measurements should be repeated at least thrice and the mean weight ( $W_2$ ) taken.

**b) The method described below should be followed for the determination of the bulk density of the sand (  $Y_s$  ):**

- i) The internal volume ( $V$ ) in ml of the calibrating container should be determined from the weight of water contained in the container when filled to the brim. The volume may also be calculated from the measured internal dimensions of the container.
- ii) The pouring cylinder should be placed concentrically on the top of the calibrating container after being filled to the constant weight ( $W_1$ ). The shutter of the pouring cylinder should be closed during the operation. The shutter should be opened and sand allowed to run out. When no further movement of sand takes place in the cylinder, the shutter should be closed. The pouring cylinder should be removed and weighed to the nearest gram.
- iii) These measurements should be repeated at least thrice and the mean weight ( $W_3$ ) taken.

**B. Measurement of soil density**

The following method should be followed for the measurement of soil density:

- i) A flat area, approximately 450sq.mm of the soil to be tested should be exposed and trimmed down to a level surface, preferably with the aid of the scraper tool.
- ii) The metal tray with a central hole should be laid on the prepared surface of the soil with the hole over the portion of the soil to be tested. The hole in the soil should then be excavated using the hole in the tray as a pattern, to the depth of the layer to be tested upto a maximum of 150mm. The excavated soil should be carefully collected, leaving no loose material in the hole and weighed to the nearest gram( $W_w$ ). The metal tray should be removed before the pouring cylinder is placed in position over the excavated hole.
- iii) The water content ( $w$ ) of the excavated soil should be determined as discussed in earlier posts. Alternatively, the whole of the excavated soil should be dried and weighed ( $W_d$ ).
- iv) The pouring cylinder, filled to the constant weight ( $W_1$ ) should be so placed that the base of the cylinder covers the hole concentrically. The shutter should then be opened and sand allowed to run out into the hole. The pouring cylinder and the surrounding area should not be vibrated

during this period. When no further movement of sand takes place, the shutter should be closed. The cylinder should be removed and weighed to the nearest gram ( $W_4$ ).

## **8 )The In-Situ Dry Density Of Soil By Core Cutter Method**

### **Determine The In-Situ Dry Density Of Soil By Core Cutter Method**

This test is done to determine the in-situ dry density of soil by core cutter method as per IS: 2720 (Part XXIX) – 1975. The apparatus needed for this test is

- i) Cylindrical core cutter
- ii) Steel dolly
- iii) Steel rammer
- iv) Balance, with an accuracy of 1g
- v) Straightedge
- vi) Square metal tray – 300mm x 300mm x 40mm
- vii) Trowel

### **Procedure Determine The In-Situ Dry Density Of Soil By Core Cutter Method**

- i) The internal volume ( $V$ ) of the core cutter in cc should be calculated from its dimensions which should be measured to the nearest 0.25mm.
- ii) The core cutter should be weighed to the nearest gram ( $W_1$ ).



- iii) A small area, approximately 30cm square of the soil layer to be tested should be exposed and levelled. The steel dolly should be placed on top of the cutter and the latter should be rammed down vertically into the soil layer until only about 15mm of the dolly protrudes above the surface, care being taken not to rock the cutter. The cutter should then be dug out of the

surrounding soil, care being taken to allow some soil to project from the lower end of the cutter. The ends of the soil core should then be trimmed flat in level with the ends of the cutter by means of the straightedge.

iv) The cutter containing the soil core should be weighed to the nearest gram ( $W_2$ ).

v) The soil core should be removed from the cutter and a representative sample should be placed in an air-tight container and its water content ( $w$ )

### **9) The Maximum Dry Density And The Optimum Moisture Content Of Soil**

**Apart from these some Soil Compaction Tests are also done. See this for details**

Determine The Maximum Dry Density And The Optimum Moisture Content Of Soil

This test is done to determine the maximum dry density and the optimum moisture content of soil using heavy compaction as per IS: 2720 (Part 8) – 1983. The apparatus used is

i) Cylindrical metal mould – it should be either of 100mm dia. and 1000cc volume or 150mm dia. and 2250cc volume and should conform to IS: 10074 – 1982.

ii) Balances – one of 10kg capacity, sensitive to 1g and the other of 200g capacity, sensitive to 0.01g

iii) Oven – thermostatically controlled with an interior of noncorroding material to maintain temperature between 105 and 110°C

iv) Steel straightedge – 30cm long

v) IS Sieves of sizes – 4.75mm, 19mm and 37.5mm

### **PREPARATION OF SAMPLE**

A representative portion of air-dried soil material, large enough to provide about 6kg of material passing through a 19mm IS Sieve (for soils not susceptible to crushing during compaction) or about 15kg of material passing through a 19mm IS Sieve (for soils susceptible to crushing during compaction), should be taken. This portion should be sieved through a 19mm IS Sieve and the coarse fraction rejected after its proportion of the total sample has been recorded. Aggregations of particles should be broken down so that if the sample was sieved through a 4.75mm IS Sieve, only separated individual particles would be retained.

## **Procedure To Determine The Maximum Dry Density And The Optimum Moisture Content Of Soil**

A) Soil not susceptible to crushing during compaction –

i) A 5kg sample of air-dried soil passing through the 19mm IS Sieve should be taken. The sample should be mixed thoroughly with a suitable amount of water depending on the soil type (for sandy and gravelly soil – 3 to 5% and for cohesive soil – 12 to 16% below the plastic limit). The soil sample should be stored in a sealed container for a minimum period of 16hrs.

ii) The mould of 1000cc capacity with base plate attached, should be weighed to the nearest 1g ( $W_1$ ). The mould should be placed on a solid base, such as a concrete floor or plinth and the moist soil should be compacted into the mould, with the extension attached, in five layers of approximately equal mass, each layer being given 25 blows from the 4.9kg rammer dropped from a height of 450mm above the soil. The blows should be distributed uniformly over the surface of each layer. The amount of soil used should be sufficient to fill the mould, leaving not more than about 6mm to be struck off when the extension is removed. The extension should be removed and the compacted soil should be levelled off carefully to the top of the mould by means of the straight edge. The mould and soil should then be weighed to the nearest gram ( $W_2$ ).

iii) The compacted soil specimen should be removed from the mould and placed onto the mixing tray. The water content ( $w$ ) of a representative sample of the specimen should be determined.

iv) The remaining soil specimen should be broken up, rubbed through 19mm IS Sieve and then mixed with the remaining original sample. Suitable increments of water should be added successively and mixed into the sample, and the above operations i.e. ii) to iv) should be repeated for each increment of water added. The total number of determinations made should be at least five and the moisture contents should be such that the optimum moisture content at which the maximum dry density occurs, lies within that range.

B) Soil susceptible to crushing during compaction –

Five or more 2.5kg samples of air-dried soil passing through the 19mm IS Sieve, should be taken. The samples should each be mixed thoroughly with different amounts of water and stored in a sealed container as mentioned in Part A)

C) Compaction in large size mould –

For compacting soil containing coarse material upto 37.5 mm sizes, the 2250cc mould should be used. A sample weighing about 30kg and passing through the 37.5mm IS Sieve is used for the test. Soil is compacted in five layers, each layer being given 55 blows of the 4.9kg rammer. The rest of the procedure is same as above.

### Classification of Ground Modification Techniques

Four groups of ground improvement Techniques are distinguished:

1. Mechanical modification
2. Hydraulic modification
3. Physical and chemical modification
4. Modification by inclusion and Confinement.

#### **1. Mechanical modification**

Soil density is increased by the application of

Short-term external mechanical forces, including Compaction of surface layers by:

- Static,
- Vibratory,
- Impact rollers,
- Plate vibrators.

Deep compaction by heavy tamping at the surface or vibration at depth.

#### **2. Hydraulic modification**

Free –pore water is forced out of the soil via (by means of) drains or wells.

- In coarse grained soils, this 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 (electrokinetic stabilization) is required.

### **3. Physical and chemical modification**

Additives include:- natural soils- industrial by-products or waste materials (fly ash, slag),- Cementations and other chemicals (lime, cement) which react with each other and the ground.

When additives are injected via boreholes under pressure into the voids within the ground or between it and a structure, the process is called GROUTING. Rigs with multiple injectors deliver the stabilizing fluid into the soil. The fluid will prefer to travel into cracks and fissures.

Soil stabilization by heating the ground and by freezing the ground are THERMAL METHODS OF MODIFICATION.

- Heating evaporates water and causes permanent changes in the mineral structure of soils.
- Freezing solidifies part or all of the water and bonds individual particles together.

### **4. Modification by inclusion and Confinement Reinforcement by:**

- Fibers,
- Strips
- Bars,
- Meshes and
- Fabrics.

In situ reinforcement is achieved by nails and anchors.

Suitability, Feasibility, Desirability

The choice of a method of ground improvement depends on many factors including:

- Type and degree of improvement required
- Type of soil, geological structure,
- Seepage conditions,

Cost (the size of the project may be Decisive),

- Availability of equipment and materials and the quantity of work required,

Construction time available,

- Possible damage to adjacent structures or Pollution of ground water resources,
- Durability of the materials involved,
- Toxicity or corrosiveness of any chemical

Additives (government regulations may Restrict the choice of additives),

Reversibility or irreversibility of the process,

- Reusability of components,
- Reliability of methods of analysis and design,
- Feasibility of construction control and performance measurements.

The feasibility of a particular method is strongly Related to the type of problem in hand:

- a foundation,
- An embankment on soft ground,
- An unstable slope,
- An excavation,
- An earth-retaining structure,
- A leaking dam or reservoir.

Traditional Objectives and Emerging Trends  
The aim of improving soils as foundation or  
Construction materials:

1. Increase strength, reduce compressibility
2. Reduce distortion under stress (increase Stress-strain modulus)
3. Reduce compressibility
4. Control shrinking and swelling (improve volume stability)
5. Control permeability, reduce water pressure, redirect seepage
6. Prevent detrimental physical or chemical Changes due to environmental conditions (Freezing/thawing, wetting/drying) \
7. Reduce susceptibility to liquefaction
8. Reduce natural variability of borrow Materials or foundation soils.

## **Environmental Geotechnics**

Examples of desirable ground modification activities within the framework of environmental geotechnics are:

- Constructive use and if necessary modification of waste materials,
- Prevention of subsidence due to mining
- Preservation of quality and flow patterns of ground water.

### **Containment and Constructive use of Waste Materials**

- Ground modification techniques are also increasingly being applied in the rehabilitation of hazardous-waste disposal areas.
- Of increasing concern to environmentally conscious engineers is the constructive use of high-energy waste materials such as slag and fly ash. Part of this concern arises from the estimated increase in ash production in the years to come. In the United States, it has been predicted that by next century coal burning will produce 200 million tons of ash per year. Fly ash could be used as:
  - Structural fill on its own or
  - In combination with lime or cementAs a stabilizing agent for road bases.

## Deep Compaction Techniques

Densification of deep soil deposits is achieved by the following techniques:

- a. **Precompression**
- b. **Explosion**
- c. **Heavy tamping**
- d. **Vibration**
- e. **Compaction grouting**

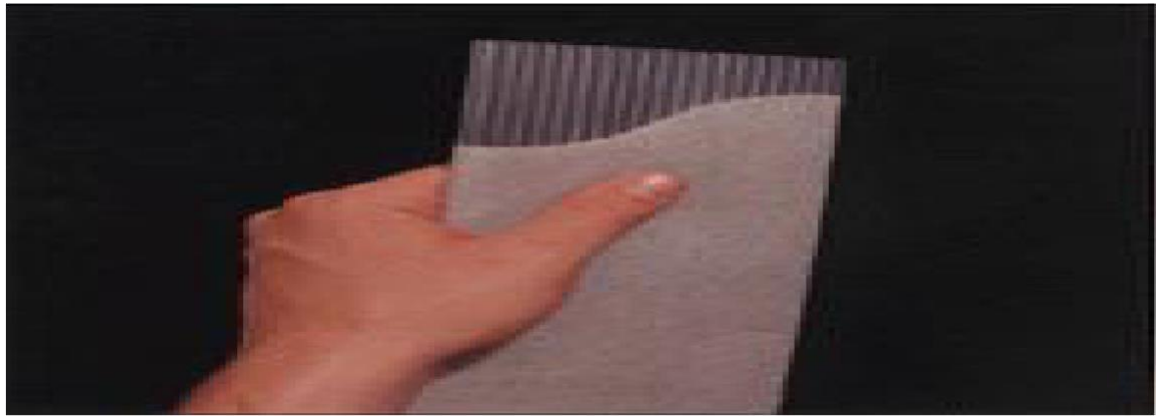
a. Precompression

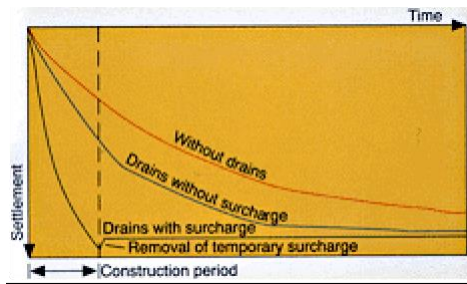
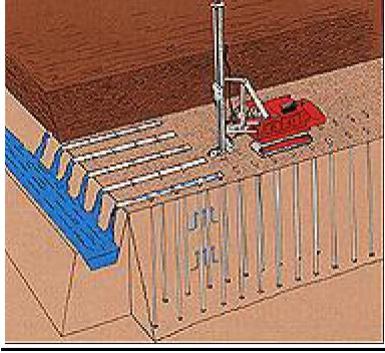
**A site is loaded by means of a surcharge or by lowering the groundwater level, causing the ground to consolidate.**

**Usually reserved for cohesive soils.**

**Consolidation of these soils is a long-term process, unless the existing longest drainage paths are shortened by the installation of:**

- **Sand columns**
- **Paper wicks or**
- **Geocomposite drains.**





## b. Explosion

Explosives are detonated (exploded) on the surface, or more likely, in an array of boreholes, causing a loose soil structure to collapse which leads to a denser arrangement of the particles. The final density may not be achieved immediately, as the dissipation of excess pore pressures generated may take some time.

Explosives can be employed to modify:

- Sands
- Loose rock and
- Special soils such as loess which is characterized by relatively high porosity.

In saturated soils temporary high pore pressures are set up, causing liquefaction. These excess semi-dynamic pore pressures are essential for effective densification resulting from subsequent consolidation. Installation of vertical drains may assist the explosion-induced consolidation process. Care must be taken that structures adjacent to the blasting site are not affected.

## **Deep Compaction Techniques**

Deep soil compaction as a method of ground improvement and to stabilization of wastes and slopes with danger of liquefaction, determining the modulus of deformation and shear strength parameters of loose rock.

For the stabilization of dumps with the construction of hidden dams and for building ground improvement, for instance for traffic lines over dumps, nearly all applied compaction methods have the aim to reduce the pore volume in the loose rock. With these methods, a homogenization of the compacted loose rock will be obtained too. The compaction methods of weight compaction by falling weight, compaction by vibration and compaction by blasting have been introduced, and their applications and efficiencies have been shown. For the estimation of the effective depth of the compaction and for a safe planning of the bearing layer, respectively, the necessary material parameters have to be determined for each deep compaction method. Proposals for the determination of these parameters have been made within this paper. In connection with the stabilization of flow-slide-prone dump slopes, as well as for the improvement of dump areas for the use as building ground, it is necessary to assess the deformation behavior and the bearing capacity. To assess the resulting building ground improvement, deformation indexes (assessment of the flow-prone layer) and strength indexes (assessment of the bearing capacity) have to be determined with soil mechanical tests. Surface Mining, 1995;51(1):39-47] improved a direct procedure, the so-called plate-loading test. With this improved procedure, it is possible to produce profiles of deformation parameters and shear-strength parameters of the loose rock. On this basis the settlement behavior and the bearing behavior of the ground can be described. The PDV-BS cone-penetration test and the pressiometer test are compared and the reliability of the soil mechanical indexes is assessed critically. The PDV-BS can be used as a calibration test for cone penetration tests as well as for the calibration of pressiometer tests. With the application of a PDV-BS and a pressiometer test in combination in a testing field, the anisotropy properties of the loose rock can be proved.

## **BLASTING GROUND IMPROVEMENT TECHNIQUES**

Rock blasting is the controlled use of explosives and other methods such as gas pressure blasting pyrotechnics or plasma processes, to excavate, break down or remove rock. It is

practiced most often in mining, quarrying and civil engineering such as dam or road construction. Except in mining, the result of rock blasting is often known as a rock cut.

The use of explosives in mining goes back to the year 1627,<sup>[1]</sup> when gunpowder was first used in place of mechanical tools in the Hungarian (now Slovakian) town of Banská Štiavnica. The innovation spread quickly throughout Europe and the Americas.

Rock blasting currently utilizes many different varieties of explosives with different compositions and performance properties. High velocity explosives are used for relatively hard rock in order to shatter and break the rock, while low velocity explosives are used in soft rocks to generate more gas pressure and a greater heaving effect. For instance, an early 20th-century blasting manual compared the effects of black powder to that of a wedge, and dynamite to that of a hammer.<sup>[2]</sup> The most commonly used explosives in mining today are ANFO based blends due to lower cost than dynamite.

In 1990, 2.1 million tonnes (2.32 million short tons) of commercial explosives were consumed in the USA, representing an estimated expenditure of 3.5 to 4 billion 1993 dollars on blasting. Australia had the highest explosives consumption that year at 500 million tonnes (551 million short tons), with Scandinavian countries another leader in rock blasting (Persson et al. 1994:1).

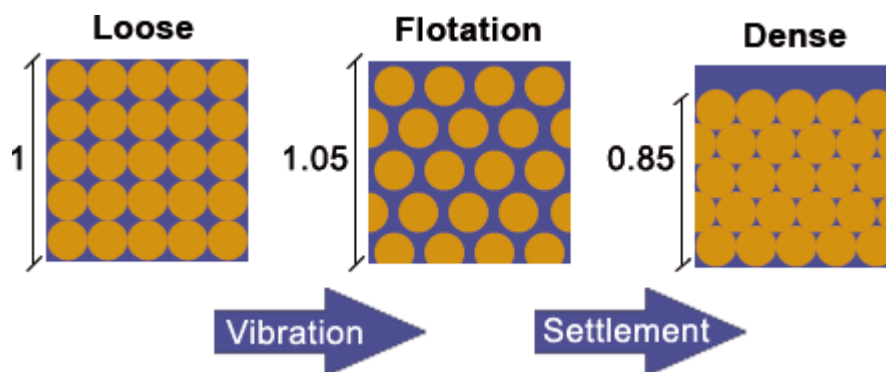
During operation, blasting mats may be used to contain the blast, suppress dust and noise, for fly rock prevention and sometimes to direct the blast.<sup>[3][4]</sup>

The potential of nuclear explosives for rock blasting and earth-moving was tested by the United States and Soviet Union in the 1960s and 70s as the focus of two research projects, Operation Plowshare and Nuclear Explosions for the National Economy respectively. Their potential was never used beyond mere experimentation, due to ensuing issues of radioactivity and public opposition, and was ended alongside the general end of atmospheric testing of nuclear explosives.



## VIBROCOMPACTION

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 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.



- 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.

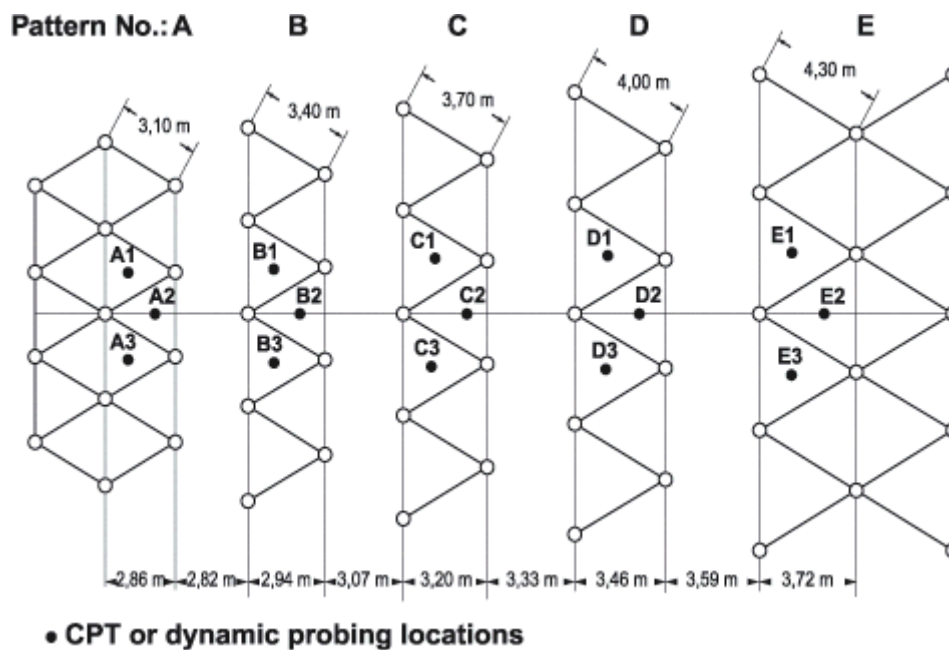
### Test Pattern

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.

The distance between grid A (3.10 m) and grid B (3.40 m) should be



### DYNAMIC TAMPING

A tamping machine or ballast tamper is a machine used to pack (or tamp) the track ballast under railway tracks to make the tracks more durable. Prior to the introduction of mechanical tampers, this task was done by manual labour with the help of beaters. As well as being faster, more accurate, more efficient and less labour-intensive, tamping machines are essential for the use of concrete sleepers since they are too heavy (usually over 250 kg (551 lb)) to be packed into the ballast by hand.

Early machines only lifted the track and packed the ballast. More modern machines, sometimes known as a tamper-liner or tamping and lining machine, also correct the alignment of the rails to make them parallel and level, in order to achieve a more comfortable ride for passengers and freight and to reduce the mechanical strain applied to the rails by passing trains. This is done by finding places where the sleepers have sunk from the weight of the passing trains or frost action, causing the track to sag. The tamper lifts each sleeper and the rails up, and packs ballast underneath. When the sleeper is laid down again, the sagged rails now sit at the proper level. In cases where frost action has caused adjacent rails to rise higher, ballast tampers can raise rails above their original level to make the line level again. "Lining" rails doesn't involve ballast tamping, it merely ensures the rails are perfectly parallel and straight as possible. Combining tamping and lining into a single machine saves time and money, as only one machine needs to be run over the track to perform both functions.

## **COMPACTION PILES**

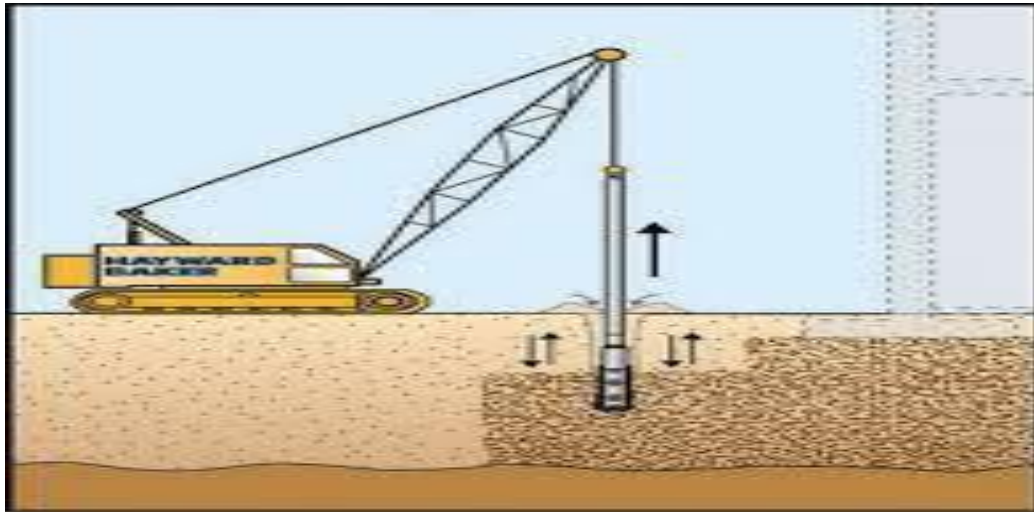
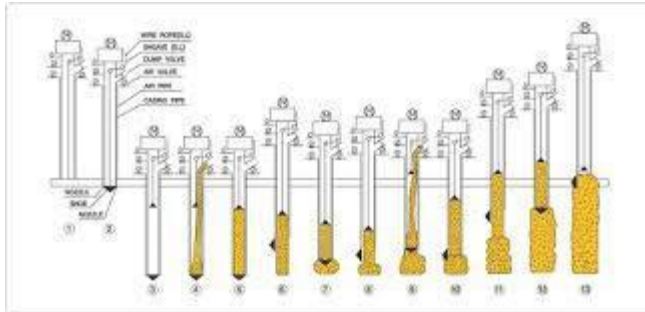
Sand compaction piling (SCP) is a cost-effective method of ground improvement which is commonly used to improve soft seabed soils prior to land reclamation works. This method involves driving closely-spaced sand columns into the soft seabed to form a grid of sand columns, which imparts higher strength and stiffness to the improved ground. The installation of these sand compaction piles often involves a large amount of cavity expansion displacement of the soft clay around the sand piles, which in turn, leads to significant changes in the strength and stiffness of the soft clay around the sand piles. In practice and research, the properties of the soft clay are taken to be those of the in-situ soil.

**The improvement in the strength of the softy clay is around 25% to 50%.**

The results of these experiments allow the changes in total stress and pore pressure due to the installation of sand compaction piles to be quantified. Comparison of the measured changes in lateral stress and pore pressure with conventional plane strain cavity expansion theory shows that the latter gives a reasonably good estimate at large depth for the entire installation process. However, deviation from plane strain cavity expansion theory was noted at shallow depths. To account for the effect of the ground surface, a semi-empirical plane stress cavity expansion theory was proposed for the shallow zones. The establishment of the two limits formed by the plane strain and plane stress theories allows semi-empirical relations to be fitted to the data. These findings also indicated that, in order to mobilize significant set-up of stress in the improved ground, there must be substantial further cavity expansion during the sand injection stage of SCP. The cumulative total stress and pore pressure increment at a given location due to the installation of multiple piles in a grid is also reasonably estimated by superimposing the increments due to the installation of each pile. The measured and computed undrained shear strength after the dissipation of the excess pore pressure is also higher in the clays enclosed within the SCPs. The quantum of improvement in the strength of the soft clay due to the cavity expansion displacement is typically of the order of 25% to 50%.

Tests were also conducted to quantify the relative performance of different methods of installing sand piles. The results of this comparative study show that the effects of cavity expansion displacement in the soft clay do lead to a significant improvement in the strength and stiffness of the soft clay. The sequence of installation also affects the resulting properties of the soft clay, although this is second-order compared to the effect of installation method.

Some of the results of this study have been published in international journals and conferences. The significance of the published results was recently highlighted by a detailed citation of the team's research by Professor Osamu Kusakabe in a keynote address in the International Conference on Physical Modelling in Geotechnics, in Newfoundland, Canada.



## **UNIT-3**

Dewatering or construction dewatering are terms used to describe the action of removing groundwater or surface water from a construction site. Normally dewatering process is done by pumping or evaporation and is usually done before excavation for footings or to lower water table that might be causing problems during excavations. Dewatering can also be known as the process of removing water from soil by wet classification.

### **NEED OF DEWATERING**

- To provide suitable working surface of the bottom of the excavation.
- To stabilize the banks of the excavation thus avoiding the hazards of slides and sloughing.
- To prevent disturbance of the soil at the bottom of excavation caused by boils or piping. Such disturbances may reduce the bearing power of the soil.
- Lowering the water table can also be utilized to increase the effective weight of the soil and consolidate the soil layers. Reducing lateral loads on sheeting and bracing is another way of use.

### **VARIOUS METHODS OF DEWATERING**

- Surface water control like ditches, training walls, embankments. Simple methods of diverting surface water, open excavations.
- Simple pumping equipment. Gravity drainage. Relatively impermeable soils. Open excavations especially on sloping sites. Simple pumping equipment.
- Sump pumping
- Wellpoint systems with suction pumps.
- Shallow (bored) wells with pumps.
- Deep (bored) wells with pumps.
- Eductor system
- Drainage galleries. Removal of large quantities of water for dam abutments, cut-offs, landslides etc. Large quantities of water can be drained into gallery (small diameter tunnel) and disposed of by conventional large – scale pumps.

- Electro-osmosis. Used in low permeability soils (silts, silty clays, some peats) when no other method is suitable. Direct current electricity is applied from anodes (steel rods) to cathodes (well-points, i.e. small diameter filter wells)

## **ADVANTAGES AND DISADVANTAGES**

### **ADVANTAGES**

- Reduces the amount of sediment leaving the site
- Allows for a more in-depth site assessment – additional necessary erosion control measures may be identified

### **DISADVANTAGES**

- Must abide by multiple government laws and standards and obtain appropriate permits
- Requires frequent maintenance
- May be costly

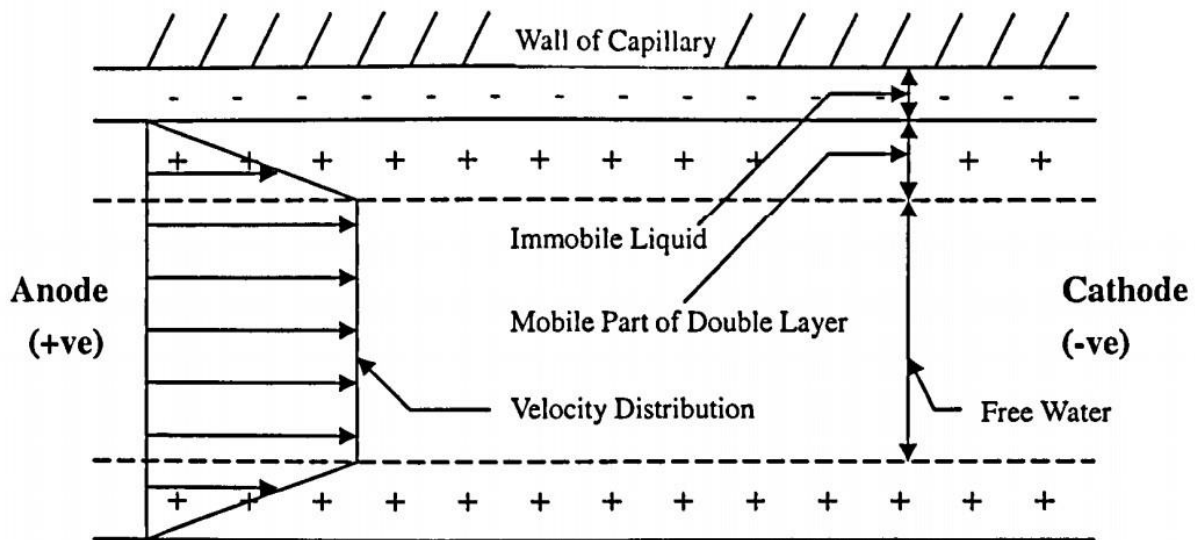
### **Sumps and sump pumping:**

A sump is merely a hole in the ground from which water is being pumped for the purpose of removing water from the adjoining area (Fig 9.1). They are used with ditches leading to them in large excavations. Up to maximum of 8m below pump installation level; for greater depths a submersible pump is required. Shallow slopes may be required for unsupported excavations in silts and fine sands. Gravels and coarse sands are more suitable. Fines may be easily removed from ground and soils containing large percent of fines are not suitable. If there are existing foundations in the vicinity pumping may cause settlement of these foundations. Subsidence of adjacent ground and sloughing of the lower part of a slope (sloped pits) may occur. The sump should be preferably lined with a filter material which has grain size gradations in compatible with the filter rules. For prolonged pumping the sump should be prepared by first driving sheeting around the sump area for the full depth of the sump and installing a cage inside the sump made of wire mesh with internal strutting or a perforating pipe filling the filter material in the space outside the cage and at the bottom of the cage and withdrawing the sheeting. Two simple

The essential feature of this method is a sump below the ground level of the excavation at one or more corners or sides..a small ditch is cut around the bottom of the excavation , falling towards the sump. It is the most widely used and economical of all methods of ground water lowering. This method is also more appropriate in situations where boulders or other massive obstructions are met with the ground. There is also a disadvantage that the groundwater flows towards the excavation with a high head or a steep slope and hence there is a risk of collapse of the sides.

### Dewatering by electro – osmosis

When an external electro motive force is applied across a soil liquid interface the movable diffuse double layer is displaced tangentially with respect to the fixed layer .this is electro osmosis. As the surface of fine grained soil particles causes negative charge, the positive ions in solution are attracted towards the soil particles and concentrate near the surfaces. Upon application of the electro motive force between two electrodes in a soil medium the positive ions adjacent to the soil particles and the water molecules attached to the ions are attracted to the cathode and are repelled by the anode. The free water in the interior of the void spaces is carried along to the cathode by viscous flow. By making the cathode a well, water can be collected in the well and then pumped out.



## INTRODUCTION

Electro osmotic consolidation means the consolidation of soft clays by the application of electric current. It was studied and applied for the first time by Casagrande. It is inherent that fine grained clay particles with large interfacial surface will consolidate and generate significant settlement when loaded. The settlement creates problem in the foundation engineering. Electro osmosis was originally developed as a means of dewatering fine grained soils for the consolidation and strengthening of soft saturated clayey soils. Electro osmotic dewatering essentially involves applying a small electric potential across the sediment layer. It is the process where in positively charged ions move from anode to cathode. ie. Water moves from anode to cathode where it can be collected and pumped out of soil Electro osmotic flow depends on soil nature, water content, pH and on ionic type concentration in the pore water. **ELECTRO OSMOTIC CONSOLIDATION** Due to the applied electric potential the electrolysis of water occurs at the electrodes  $2\text{H}_2\text{O} \rightarrow \text{O}_2 (\text{g}) + 4\text{H}^+ + 4\text{e}^-$  oxidation (anode)  $4\text{H}_2\text{O} + 4\text{e}^- \rightarrow 2\text{H}_2 (\text{g}) + 4\text{OH}^-$  reduction (cathode) The clay particles have a  $\delta$ oeve charge. These  $\delta$ oeve charge produce an electro static surface property known as the double layer which creates a net abundance of cations

Due to the applied electric potential the electrolysis of water occurs at the electrodes  $2\text{H}_2\text{O} \rightarrow \text{O}_2 (\text{g}) + 4\text{H}^+ + 4\text{e}^-$  oxidation (anode)  $4\text{H}_2\text{O} + 4\text{e}^- \rightarrow 2\text{H}_2 (\text{g}) + 4\text{OH}^-$  reduction (cathode) The clay particles have a  $\delta$ oeve charge. These  $\delta$ oeve charge produce an electro static surface property known as the double layer which creates a net abundance of cations.

in pore space. Electro osmotic transfer of water through a clay is a result of diffuse double layer cations in the clay pores being attracted to a negatively charged electrode or cathode. When electrodes are placed across a saturated clay mass and direct current is applied ,water in the clay pore space is transported towards cathode by electro osmosis. In addition frictional drag is created by the motion of ions as they move through the clay pores helping to transport additional water. The flow generated by the electric gradient is called electro osmotic flow.

**EVALUATION OF ELECTRO OSMOTIC CONSOLIDATION** Determination of parameters Electrical operation systems for field application Materials Spacing between electrodes Cost of electrodes and installation cost.



## **DESIGN OF SUB-SURFACE DRAINAGE SYSTEMS**

Sub-surface drainage is the removal of excess groundwater below the soil surface.

It aims at increasing the rate at which water will drain from the soil, and so lowering the water table, thus increasing the depth of drier soil above the water table.

Sub-surface drainage can be done by open ditches or buried drains.

### **Sub-Surface Drainage Using Ditches**

Ditches have lower initial cost than buried drains;

There is ease of inspection and ditches are applicable in some organic soils where drains are unsuitable.

Ditches, however, reduce the land available for cropping and require more maintenance than drains due to weed growth and erosion.

### **Sub-Surface Drains Using Buried**

Drains Sub-Surface Drainage Using Buried Drains Buried drains refer to any type of buried conduits having open joints or perforations, which collect and convey drainage water.

They can be fabricated from clay, concrete, corrugated plastic tubes or any other suitable material. The drains can be arranged in a parallel, herringbone, double main or random fashion.

Sub-Surface Drainage Designs The Major Considerations in Sub-surface Drainage Design Include: Drainage Coefficient; Drain Depth and Spacing; Drain Diameters and Gradient;

Drainage Filters. Drainage Coefficient This is the rate of water removal used in drainage design to obtain the desired protection of crops from excess surface or sub-surface water and can be expressed in mm/day , m/day etc.

Drainage is different in Rain-Fed Areas and Irrigated Areas

## **GEOSYNTHESIS**

Geosynthetics are artificial fibres used in conjunction with soil or rock as an integral part of a man made project

They are mainly grouped into two categories

- a. Geotextiles – permeable
- b. Geomembrane – impermeable

## **VARIOUS TYPES OF GEOSYNTHESIS**

- Geonets
- Geomats
- Geosynthetic clay liners
- Geofilm
- Geocells
- Geocomposites
- Geotextiles
- Geogrids
- Geomembranes

### **How does the use of a geosynthetic as a filter differ from that of Drainage**

Filtration applications are highway underdrain systems, retaining wall drainage, landfill leachate collection systems, as silt fences and curtains, and as flexible forms for bags, tubes and container

o Drainage applications for these different geosynthetics are retaining walls, sport fields, dams, canals, reservoirs, and capillary breaks.

### **Preloading and vertical drains**

In times of urbanization, growth of population and associated developments, construction activities are more and more focused on soils which were considered unsuitable in the past decades. These soft soil deposits have a low bearing capacity and exhibit large settlements when subjected to loading. It is therefore inevitable to treat soft soil deposits prior to construction activities in order to prevent differential settlements and subsequently potential damages to structures. Different ground improvement techniques are available today. Every technique should

lead to an increase of soil shear strength, a reduction of soil compressibility and a reduction of soil permeability. The choice of ground improvement technique depends on geological formation of the soil, soil characteristics, cost, availability of backfill material and experience in the past. According to Bergado et al. (1996) they can be divided broadly into two categories. The first category includes techniques which require foreign materials and utilisation of reinforcements. They are based on stiffening columns either by the use of a granular fill (stone columns), by piling elements which are not reaching a still soil stratum (creep piles) or by in situ mixing of the soil with chemical agents (deep stabilisation). The second category includes methods which are strengthening the soil by dewatering, i.e. preloading techniques often combined with vertical drains. This report will focus on preloading techniques and utilisation of vertical drains. Preloading is the application of surcharge load on the site prior to construction of the permanent structure, until most of the primary settlement has occurred. Since compressible soils are usually characterized by very low permeability, the time needed for the desired consolidation can be very long, even with very high surcharge load. Therefore, the application of preloading alone may not be feasible with tight construction schedules and hence, a system of vertical drains is often introduced to achieve accelerated radial drainage and consolidation by reducing the length of the drainage paths.

## UNIT- 4

### **Physical and Chemical Modification**

Chemical admixtures are the ingredients in concrete other than portland cement, water, and aggregate that are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations.

Successful use of admixtures depends on the use of appropriate methods of batching and concreting. Most admixtures are supplied in ready-to-use liquid form and are added to the concrete at the plant or at the jobsite. Certain admixtures, such as pigments, expansive agents, and pumping aids are used only in extremely small amounts and are usually batched by hand from premeasured containers.

Admixtures are classed according to function. There are five distinct classes of chemical admixtures: air-entraining, water-reducing, retarding, accelerating, and plasticizers (superplasticizers). All other varieties of admixtures fall into the specialty category whose functions include corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, workability enhancement, bonding, damp proofing, and coloring. Air-entraining admixtures, which are used to purposely place microscopic air bubbles into the concrete, are discussed more fully in Air-Entrained Concrete.

**Water-reducing admixtures** usually reduce the required water content for a concrete mixture by about 5 to 10 percent. Consequently, concrete containing a water-reducing admixture needs less water to reach a required slump than untreated concrete. The treated concrete can have a lower water-cement ratio. This usually indicates that a higher strength concrete can be produced without increasing the amount of cement. Recent advancements in admixture technology have led to the development of mid-range water reducers. These admixtures reduce water content by at least 8 percent and tend to be more stable over a wider range of temperatures. Mid-range water reducers provide more consistent setting times than standard water reducers.

**Retarding admixtures**, which slow the setting rate of concrete, are used to counteract the accelerating effect of hot weather on concrete setting. High temperatures often cause an increased rate of hardening which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete. Most retarders also function as water reducers and may entrain some air in concrete.

**Accelerating admixtures** increase the rate of early strength development, reduce the time required for proper curing and protection, and speed up the start of finishing operations. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather.

**Superplasticizers**, also known as plasticizers or high-range water reducers (HRWR), reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete. Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction. The effect of superplasticizers lasts only 30 to 60 minutes, depending on the brand and dosage rate, and is followed by a rapid loss in workability. As a result of the slump loss, superplasticizers are usually added to concrete at the jobsite.

**Corrosion-inhibiting admixtures** fall into the specialty admixture category and are used to slow corrosion of reinforcing steel in concrete. Corrosion inhibitors can be used as a defensive strategy for concrete structures, such as marine facilities, highway bridges, and parking garages, that will be exposed to high concentrations of chloride. Other specialty admixtures include shrinkage-reducing admixtures and alkali-silica reactivity inhibitors. The shrinkage reducers are used to control drying shrinkage and minimize cracking, while ASR inhibitors control durability problems associated with alkali-silica reactivity.

### **Shotcreting and Guniting Technology**

Shotcrete and guniting are important terminologies associated with the domain of civil construction. Shotcreting or guniting are techniques or processes that have proven to be of immense benefit in diverse subdomains of construction such as slope protection or stabilisation, pools, tunnels, fluid tanks, concrete repair works and many more. Many of us, including this

author, have not only studied about shotcreting or guniting but also have practical experience of varying degrees in this particular area.

Yet, when it comes to defining or differentiating between these two terms there would, in all probability, be lack of unanimity. Can't blame one though, as some of the established and experienced producers and companies involved in the application of shotcrete or gunitite themselves do not seem to converge on an identical interpretation of these terms. While some consider guniting as a type (class) of shotcreting some others still regard them as two completely different processes.

Confusion brewing up already ? Let's have a bit more of that. For American Shotcrete Association (ASA), apparently, the terms gunitite or guniting simply do not exist – technically. ASA only believes in the term shotcrete and according to it there exist only dry-mix shotcrete and wet-mix shotcrete. Take your pick.

Nevertheless, what everyone agrees on is that there are two processes involved when it comes to spraying concrete or mortar pneumatically through a spraying gun (nozzle) at high velocity onto a surface. One is called the dry-mix process while the other wet-mix process. Also, whoever uses the terms gunitite or guniting uses them to mean the dry-mix process only and never the wet-mix one.

The dry-mix process involves mixing cement and aggregates (fine or both fine & coarse aggregates) completely dry in a bin, rig etc and the pumping the same through a hose pneumatically (ie using compressed air by a compressor) under high pressure to a nozzle (the spray-gun). Water is introduced to the dry mix only at the nozzle (by means of a water feeding line) just before the mix blasts off the nozzle at a high velocity onto the surface being treated. On the other hand, the wet-mix process involves spraying of a pre-mixed or ready-mixed (wet) concrete or mortar under high pressure and at high velocity eliminating the need of adding any water in the nozzle or the spray-gun. Both processes have their unique advantages and requirements. But, the questions still remain as to what exactly is shotcrete and what is gunitite, are they the same or different, if different, what are the differences etc etc.

So, let's turn the heads into the ones who originally coined these terms, developed these techniques or set them in motion since and then see what shows up.

A little bit of study on the subject quickly reveals that it was the term "gunite" that came into existence first. The term was used to describe a then newly developed technique in US in which concrete was used to be sprayed under pressure through a spray-gun at high velocity onto a surfacing requiring such an application. Since the material was sprayed through a gun, the term gunite seems to have surfaced. All these happened at the dawn of the previous century.

Later, the term "shotcrete" came into being for the first time in the early 1930s when the American Railway Engineers Association (AREA) started using it to describe concrete (or mortar) nozzle-sprayed pneumatically at high velocity onto a surface either by dry-mix or by wet-mix process.

In the early 1950s the American Concrete Institute (ACI) too adopted the term "shotcrete" to describe the dry-mix spraying process erstwhile known as guniting. ACI classified the shotcreting process into two types, namely, the dry-mix process and the wet-mix process. They also accepted the term guniting for the dry-mix shotcreting process. In other words, according to ACI, guniting is a type of shotcreting only.

Contrary to that, some seem to regard "gunite" merely as a trademark only. Let's take an example. Xerox is a popular trademark while the process involved is photocopying and not xeroxing. Similarly, this section believes that while gunite can exist as a trademark or brand name the term guniting is meaningless and the technically correct term is shotcreting (dry-mix) only. Some others don't seem to agree however.

This author would prefer to have the following views and would suggest the same to others as well :- The process or technique that involves pumping of concrete or mortar under high pressure through a hose to a nozzle (spray-gun) and then spraying them at high velocity onto a surface either by dry-mix or by wet-mix process is called shotcreting. Usually, shotcrete is reinforced by

using steel or wire mesh, steel rebars, synthetic fibres etc. Since, the dry-mix shotcreting is also called as guniting by some (yet, not by all), better to stick to the terms dry-mix shotcreting & wet-mix shotcreting rather than guniting.

Nevertheless, if one is highly used to the terms guniting and guniting, or, if one is dealing with an entity that is hell bent on using the terms guniting and guniting, the same may be used to mean the dry-mix shotcreting method only. Also, it is to be noted that a mix sprayed under low pressure and at low velocity is usually not regarded as either guniting or shotcrete. One of the basic purpose of these processes is to achieve very high degree of compaction and thus high strength due to the high-velocity ejection from the spray-gun eliminating the need of any further compaction. This also eliminates the need of any formwork. The high velocity of the mix also ensures better adhesion with the receiving surface. The velocity is usually well over 100 m/s, say about 150 m/s, but can be even higher if situation demands.

Also, when it comes to guniting, usually, smaller sized coarse aggregates, say max. 10mm or so, are used. For the wet-mix process use of aggregates of max.size of 1 inch or so is not uncommon.

The dry-mix shotcreting process (aka guniting) seems to be the most widely used method worldwide due to certain unique advantages it has to offer as mentioned below:

1. It's extremely versatile. This process can be used to give virtually any shape to any element of a structure – curved, undulating, spheroidal and many more. This is a reason why this process is commonly adopted to add special features or shapes to swimming pools, spas, artificial caves & waterfalls etc. It is used in sculpting work as well. It's versatility makes it an excellent candidate for a large variety of work such as tunnel lining, refractory lining, slope protection, repair works besides making it suitable for diverse uses in structures like tanks, dams, reservoirs, canals, docks, bridges, pipelines etc.

2. Water content of the mix can be controlled instantly and at any time at the nozzle by the crew while spraying the mix onto a surface. This enables one – at any moment – to render the mix



only as much dry or wet as the situation demands by controlling the addition of water at the nozzle.

3. Dry-mix shotcrete (gunite) is quite economical, can be quickly prepared and applied unlike the wet-mix variety. It is quite suitable for overhead application where wet-mix shotcrete may not stick well and may sag or fall off.

4. If very thin linings or coatings are required to be applied on a surface or if the quantum of the work is small or in case of concrete repairs needing finer treatments such as filling up of cracks or small broken patches, damage etc, guniting would be a the choice rather than wet-mix shotcreting.

5. If the application job involves frequent stops of work for some reason or another guniting could be a much better choice over the wet-mix application.

Dry-mix process or guniting needs highly skilled crew. That's especially true for the nozzleman as he is the one who controls and monitors the water flow at the nozzle. This demands experience and skill.

Another issue with guniting is "rebound". While spraying the mix onto a surface some amount of the material is bound to bounce off the surface and fall on the ground. This occurrence is known as rebound and is unavoidable in guniting or even in wet-mix shotcreting as well. The rebound-quantity is a complete waste as reuse of the same would result in an inferior product. Lesser rebound not only minimises waste but also indicates a better quality mix and thus a better product. Experience and skill are necessary qualities in order to get the better of the rebound problem partially.

The wet-mix shotcreting process also finds a lots of use. In fact, if stronger linings or coatings are the need of the hour in a particular work, wet-mix shotcrete can be a better choice than gunite as it results in a stronger product. Except where special or curved features are necessary calling

for decorative or artistic finishes, wet-mix shotcreting can be applied virtually on all occasions as already mentioned earlier in this article where guniting can be implemented.

A better control over quality of the material is possible in case of the wet-mix process since all ingredients of the mix, including water, are pre-mixed before pumping the same to the spray gun. So, the mix can be precisely designed in accordance with the requirements like strength, durability etc. Also, rebound is much lesser for wet-mix shotcreting as compared to dry-mix shotcreting (guniting). For work involving large quantity of mix wet-mix shotcreting process is quite convenient, especially, if the work is continuous with no or very less stops.

At the end of the day, it's much more important to choose the right or more suitable process (dry-mix or wet-mix) for a particular work and ensure that the same is properly & skillfully implemented rather than bothering too much about whether to call it dry-mix shotcreting or guniting.

### **GROUTING.**

Grouting is defined as the process of injecting suitable fluid under pressure into the subsurface soil or rock to fill voids, cracks and fissures for the purpose of improving the soil.

The fluid may be colloidal solutions, cement suspensions, chemical solutions etc.

### **Application of Grouting**

1. Producing mass concrete structures and piles
2. Fixing ground anchors for sheet pile walls, concrete pile walls, retaining walls tunnels etc
3. Repairing a ground underneath a formation or cracks
4. Defects on building masonry or pavement
5. Fixing the tendons in prestressed post tensioned concrete
6. Filling the void between the lining and rock face in tunnel works
7. Seepage control in soil
8. Soil stabilization and solidification
9. Vibration control

### **Various types of grouting.**

Suspension grouts  
Solution Grouts  
Colloidal solution grouts

### **Different types of Grouting**

Compaction grouting  
Permeation grouting  
Hydraulic fracturing  
Jet grouting

### **Suspension grouts**

These are multi-phase systems capable of forming sub systems after being subjected to natural sieving processes, with chemical properties which must ensure that they do not militate against controlled properties of setting and strength. Water in association with cement, lime, soil, etc., constitute suspensions. Emulsion (asphalt or bitumen) with water is a two-phase system which is also included under suspension. Solution Grouts These are intimate one-phase system retaining an originally designed chemical balance until completion of the relevant reactions. Silicate derivatives, lignosulphite derivatives, phenoplast resins etc. come under this category. Colloidal solution grouts Solutions in which the solute is present in the colloidal state are known as colloidal solutions. Chemical grouts fall into this category.

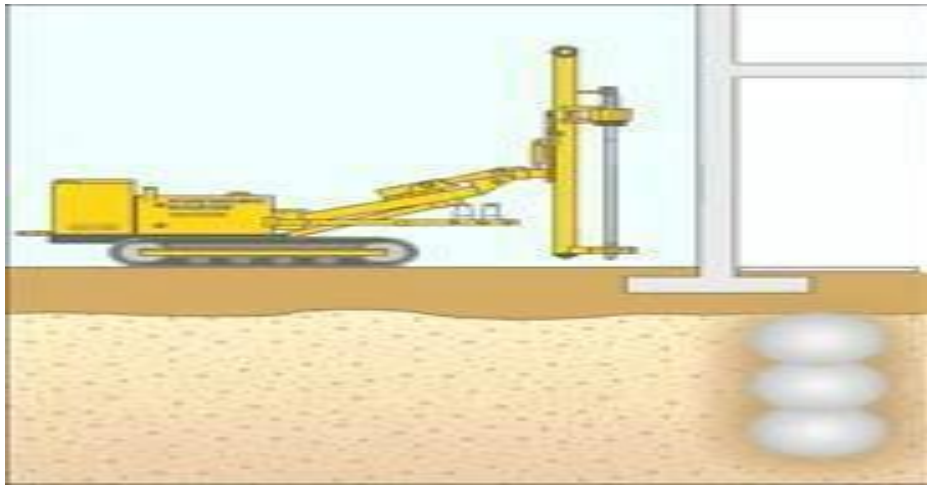
- i. Compaction grouting
  - ii. Permeation grouting
  - iii. Hydraulic fracturing
  - iv. Jet grouting
- o Compaction Grouting

The basic concept is of injecting an highly viscous grout with high internal friction, injected into a compactable soil, the grout acts as a radial-hydraulic jack and physically displaces the soil particles thus achieving controlled densification.

Minimum disturbance to • Grouting adjacent to the structure and unsupported slopes may be surrounding ground, ineffective.

- Minimum risk during

- Not suitable in construction. decomposable materials.
- Ground water not affected.
- Danger of filling
- Supports all portions of underground pipes with structures.
- grout. • Effectiveness questionable in saturated clays



### **Permeation grouting**

Grout is injected into the soil at low pressure and fills the voids without significantly changing the soil's structure and volume. Variety of binders are used with this technique, the choice of which is dictated mainly by the permeability of the soil.

#### **Merits:**

Solidifies the soil  
 Cost of grout increases as Adds to its cohesion permeability decreases  
 Reduces permeability  
 Cannot be adopted when permeability decreases below 10-6cm/s

#### **Demerits:**

Hydrofracturing uses high-mobility grout to split the ground and thereby create lifting or densification under structures or other facilities. This process is often undertaken as a reaction to movements while tunnel excavation is in progress. The main disadvantage of this method is that it is difficult to control

**Chemical stabilization.**

Chemical stabilization is achieved by the addition of proper percentages of cement, lime, fly ash, bitumen, or combinations of these materials to the soil. The selection of type and determination of the percentage of chemical to be used is dependent upon the soil classification and the degree of improvement in soil quality desired. Generally, smaller amounts of chemicals are required when it is simply desired to modify soil properties such as gradation, workability, and plasticity. When it is desired to improve the strength and durability significantly, larger quantities of additive are used.

## UNIT-5

### **EARTH REINFORCEMENT**

Concept of reinforcement - Types of reinforcement material - Applications of reinforced earth – use of Geotextiles for filtration, drainage and separation in road and other works Soil nails are more or less rigid bars driven into soil or pushed into boreholes which are filled with grout. Together with the insitu soil, they are intended to form a coherent.

Reinforced earth has been in use by man since ancient times with the fundamentals of the techniques being mentioned in the Bible The earliest remaining examples of soil reinforcement are the Agar-Quf Ziggurat and the Great wall of China The Romans, Gauls, Dutch and British have been documented using reinforced

Reinforced earth has been in use by man since ancient times with the fundamentals of the techniques being mentioned in the Bible The earliest remaining examples of soil reinforcement are the Agar-Quf Ziggurat and the Great wall of China The Romans, Gauls, Dutch and British have been documented using reinforced soil for various applications The modern concept of earth reinforcement was proposed by Casagrande He idealized the problems in the form of weak soil reinforced by high strength membranes laid horizontally in layers The modern form of earth reinforcement was introduced by Henry Vidal in the 1960s Vidals concept was for a composite material formed from flat reinforcing strips laid horizontally in a frictional soil The interaction between the soil and the reinforcing members was solely by friction generated by gravity This he described as “Reinforced Earth”, a term now generally being used to refer to all reinforced works.

#### **Applications of reinforced earth for ground improvement. Theory of Reinforcement**

Reinforced earth has been in use by man since ancient times with the fundamentals of the techniques being mentioned in the Bible The earliest remaining examples of soil reinforcement are the Agar-Quf Ziggurat and the Great wall of China The Romans, Gauls, Dutch and British have been documented using reinforced soil for various applications.

The modern concept of earth reinforcement was proposed by Casagrande. He idealized the problems in the form of weak soil reinforced by high strength membranes laid horizontally in layers. The modern form of earth reinforcement was introduced by Henry Vidal in the 1960s. Vidals concept was for a composite material formed from flat reinforcing strips laid horizontally in a frictional soil. The interaction between the soil and the reinforcing members was solely by

friction generated by gravity. This he described as “Reinforced Earth”, a term now generally being used to refer to all reinforced works.

### **Principle of Reinforced Earth**

It is analogous to reinforced concrete but direct comparison is not completely valid. The mode of action of reinforcement in soil is to carry tensile loads or anisotropic reduction of normal strain rate. Introduction of reinforcement into soil results in interaction between the two. The interaction between the soil and reinforcement can be in the form of either adhesion or friction. Failure can occur only if the adhesion or frictional force is overcome or the reinforcement itself ruptures. The reinforcement disrupts the uniform pattern of strain that would have developed if it did not exist.

### **REINFORCED EMBANKMENTS ON SOFT FOUNDATIONS**

The design and construction of embankments on soft foundation soils is a very challenging geotechnical problem. As noted by Leroueil and Rowe (2001), successful projects require a thorough subsurface investigation, properties determination, and settlement and stability analyses. If the settlements are too large or instability is likely, then some type of foundation soil improvement is warranted. Traditional soil improvement methods include preloading/surcharging with drains; lightweight fill; excavation and replacement; deep soil mixing, embankment piles, etc., as discussed by Holtz (1989) and Holtz et al. (2001a). Today, geosynthetic reinforcement must also be considered as a feasible treatment alternative. In some situations, the most economical final design may be some combination of a traditional

foundation treatment alternative together with geosynthetic reinforcement. Figure 2a shows the basic concept for using geosynthetic reinforcement. Note that the reinforcement will not reduce the magnitude of long-term consolidation or secondary settlement of the embankment.

## **REINFORCED STEEP SLOPES**

The first use of geosynthetics for the stabilization of steep slopes was for the reinstatement of failed slopes. Cost savings resulted because the slide debris could be reused in the repaired slope (together with geosynthetic reinforcement), rather than importing select materials to reconstruct the slope. Even if foundation conditions are satisfactory, costs of fill and right-of-way plus other considerations may require a steeper slope than is stable in compacted embankment soils without reinforcement. As shown in Fig.3, multiple layers of geogrids or geotextiles may be placed in a fill slope during construction or reconstruction to reinforce the soil and provide increased slope stability. Most steep slope reinforcement projects are for the construction of new embankments, alternatives to retaining walls, widening of existing embankments, and repair of failed slopes.

Another use of geosynthetics in slopes is for compaction aids (Fig. 3). In this application, narrow geosynthetic strips, 1 to 2 m wide, are placed at the edge of the fill slope to provide increased lateral confinement at the slope face, and therefore increased compacted density over that normally achieved. Even modest amounts of reinforcement in compacted slopes have been found to prevent sloughing and reduce slope erosion. In some cases, thick nonwoven geotextiles with in-plane drainage capabilities allow for rapid pore pressure dissipation in compacted cohesive fill soils.

## **GROUND ANCHORS**

An **earth anchor** is a device designed to support structures, most commonly used in geotechnical and construction applications. Also known as a **ground anchor**, **percussion driven earth anchor** or **mechanical anchor**, it may be impact driven into the ground or run in spirally, depending on its design and intended force-resistance characteristics.

Earth anchors are used in both temporary or permanent applications, including supporting retaining walls, guyed masts, and circus tents.



## Typical applications

---

Earth anchors are typically used in civil engineering and construction projects, and have a variety of applications, including:

- Retaining walls, as part of erosion control systems.<sup>[1]</sup>
- Structural support of temporary buildings and structures,<sup>[2]</sup> such as circus tents and outdoor stages.
- Tethering marine structures, such as floating docks and pipelines.
- Supporting guyed masts, such as radio transmission towers.
- Anchoring utility poles and similar structures.
- Drainage systems, for loadlocking and restraining capability to happen simultaneously
- Landscape, anchoring trees, often semi-mature transplants. .
- General security, as in anchoring small aircraft.
- Sporting activities, such as slacklining or abseiling.

A rock bolt is a long anchor bolt, for stabilizing rock excavations, which may be used in tunnels or rock cuts. It transfers load from the unstable exterior, to the confined (and much stronger) interior of the rock mass.

A rock bolt is a long anchor bolt, for stabilizing rock excavations, which may be used in tunnels or rock cuts. It transfers load from the unstable exterior, to the confined (and much stronger) interior of the rock mass. Rock bolts were first used in mining starting in the 1890s, with systematic use documented at the St Joseph Lead Mine in the US in the 1920s. Rock bolts were applied to civil tunneling support in the US and in Australia, starting in the late 40s. Rock bolts were used and further developed, starting in 1947, by Australian engineers who began experimenting with four metre long expanding anchor rock bolts while working on the Snowy Mountains Scheme.

As shown in the figure, rock bolts are almost always installed in a pattern, the design of which depends on the rock quality designation and the type of excavation.<sup>[2]</sup> Rock bolts are an essential component of the New Austrian Tunneling method. As with anchor bolts, there are many types of proprietary rock bolt designs, with either a mechanical or epoxy means of establishing the set. There are also fiberglass bolts which can be cut through again by subsequent excavation. Many

papers have been written on methods of rock bolt desi. Rock bolts work by 'knitting' the rock mass together sufficiently before it can move enough to loosen and fail by unravelling (piece by piece). As in the photo, rock bolts may be used to support wire mesh, but this is usually a small part of their function. Unlike common anchor bolts, rock bolts can become 'seized' throughout their length by small shears in the rock mass, so they are not fully dependent on their pull-out strength. This has become an item of controversy in the Big Dig project, which used the much lighter pull-out tests for rock bolts, rather than the proper tests for concrete anchor bolts. Rock bolts can also be used to prevent rockfall.

Soil nailing is a construction technique that can be used as a remedial measure to treat unstable natural soil slopes or as a construction technique that allows the safe over-steepening of new or existing soil slopes. The technique involves the insertion of relatively slender reinforcing elements into the slope – often general purpose reinforcing bars (rebar) although proprietary solid or hollow-system bars are also available. Solid bars are usually installed into pre-drilled holes and then grouted into place using a separate grout line, whereas hollow bars may be drilled and grouted simultaneously by the use of a sacrificial drill bit and by pumping grout down the hollow bar as drilling progresses. Kinetic methods of firing relatively short bars into soil slopes have also been developed. Bars installed using drilling techniques are usually fully grouted and installed at a slight downward inclination with bars installed at regularly spaced points across the slope face. A rigid facing (often pneumatically applied concrete, otherwise known as shotcrete) or isolated soil nail head plates may be used at the surface.<sup>[1]</sup> Alternatively a flexible reinforcing mesh may be held against the soil face beneath the head plates. Rabbit proof wire mesh and environmental erosion control fabrics and may be used in conjunction with flexible mesh facing where environmental conditions dictate.

Soil nail components may also be used to stabilize retaining walls or existing fill slopes (embankments and levees); this is normally undertaken as a remedial measure.

Since its first application using modern techniques in Versailles in 1972,<sup>[1]</sup> soil nailing is now a well-established technique around the world. One of the first national guideline publications for soil nailing was produced in Japan in 1987. The U.S. Federal Highway Administration issued guideline publications in 1996<sup>[3]</sup> and 2003.