23CE707: GROUND IMPROVEMENT TECHNIQUES

Topic: Introduction to Engineering Ground Modification

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- **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

- **Objective of Ground Improvement Techniques**

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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 adverse 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 use 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 fesible ground improvements 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 have 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.

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Topic: Identifying your soil type

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Identifying your soil type

Soils can be identified in to 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.

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.

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Topic: Insitu laboratory test for problematic Soils

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- **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.

- 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

- 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 maximize 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.

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.

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Topic: Determine the Plastic Limit of Soil

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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 425µm 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 shear strength. 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 425µm

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 425µm IS Sieve is mixed thoroughly with distilled water in the evaporating dish and left for 24hrs. for soaking.

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Topic: Liquid Limit of Soil

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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 appratus required to do this test :-

i) A set of fine IS Sieves of sizes – 2mm, 600µm, 425µm, 212µm and 75µm

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

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 60oC. 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^{o}C.

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 120oC 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.

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Topic: Measurement of soil density

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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(Ww). 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 (Wd).

iv) The pouring cylinder, filled to the constant weight (W1) should be so placed that the base of the cylinder covers the hole concentrically. The shutter should then be opened and sand allowed to runout 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 (W4).

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 dolley

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 (W1).

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 (W2).

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)

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 16 hrs.

ii) The mould of 1000cc capacity with base plate attached, should be weighed to the nearest 1g (W1). 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 (W2).

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Topic: Soil susceptible to crushing during compaction

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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.

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 of 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.

Insitu reinforcement is achieved by nails and anchors.

CE3208PE: GROUND IMPROVEMENT TECHNIQUES

Topic: Mechanical Modification

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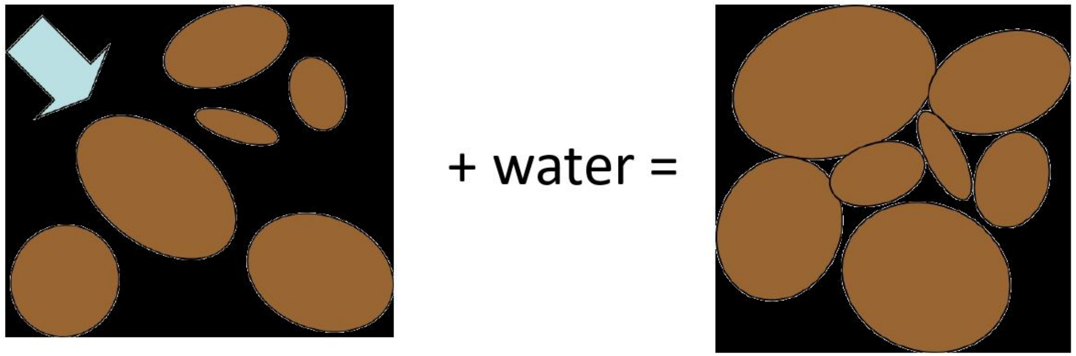
compaction

- A simple ground improvement technique, where the soil is densified through external compactive effort.
- By these compaction the improvement of soil properties and increasing the stability of the soil.
- Many types of compacting equipment are available now a days for compacting different types of soils.
- This is accomplished by applying static or dynamic loads to the soil.

Compaction image



Advantages of compaction

- Increases shear strength
- Reduces compressibility
- Reduces permeability
- Reduces settlement of foundation
- Increases slope stability.

Choice of method

- Type of soil
- Type and degree of improvement required
- Cost
- Available equipment
- Time
- Damage to adjacent structures
- durability

Factors affecting compaction in the field

- Compactive effort
- Moisture content
- Soil type
- Layer thickness
- Contact pressure
- Number of rollers passes
- Speed of rolling

CE3208PE: GROUND IMPROVEMENT TECHNIQUES

Topic: Mechanical Modification

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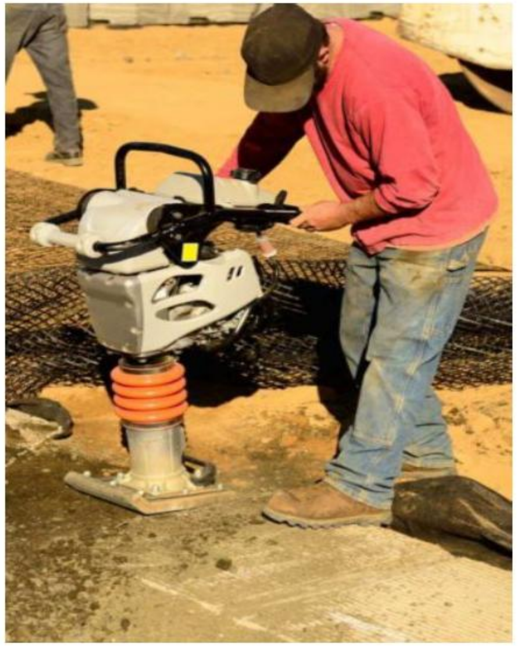
Types of action

- The maximum compaction is done by
  - ➢ Ramming
  - ➢ Vibration
  - ➢ Static roller

Rammers

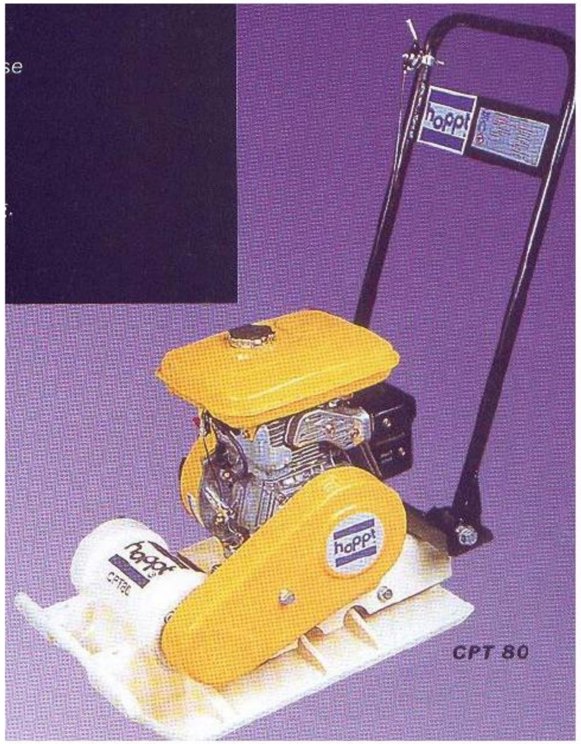
- This compaction equipment is light weight and easy to handle and these rammers are mainly
- Rammers are most suitable for cohesive and semi-cohesive soils.
- Its base dimensions are 15 cm x 15 cm or 20 cm x 20 cm or more
- Frequency ranges of blows are 500-750 per minute.
- Maximum 220mm thickness of layers can be compacted by using these rammers.
- The weight of the rammer is about 30 kg to 1 tonne.

- Rammer compacts surface through impact and vibration.
- Rammers are used at the difficult area where other types of equipment are not able to operate.



Vibrating plate compactors

- The weight of this compactor is 100kg to 2 tonnes and the plate areas between 0.16 sq.cm to 1.6 sq.cm.
- Used for compacting small areas.
- They usually travel about 0.7 km/h.
- These are used for small areas like parking slots etc.



Vibratory compaction equipment

... vibratory compactor as per the requirement.

2.4.2 Vibratory Compaction Equipments

Vibratory compactors may be categorized into the following groups (Sharma, 1988):

(*i*) Tandom vibratory compactors
(*ii*) Towed vibratory compactors
(*iii*) Towed sheeps-foot or Tamping-foot vibratory compactors
(*iv*) Self-propelled vibratory compactors
(*v*) Hand-guided vibratory compactors.

Tandom Vibratory Compactors: Two types of Tandom vibratory compactors are available, *viz.*, single-drum vibrating or double-drum vibrating. In the compactors with double-drum vibrating system two tandom wheels are provided with separate controlled vibrators in the front and rear rolls. Comparing single and double-drum vibratory compactors, the output of double-drum vibratory compactor is to be 80% more than the single-drum vibratory compactor. The double-drum vibratory type has an option to operate the single-drum or the double-drum.

Towed Vibratory Compactors: This type of compactor is especially used for compacting cohesive soils, fine and coarse grained mixed soil and rocky materials. The heavy type towed vibratory compactor is used in earth dam and embankment constructions. Because of the large amplitude, it shows more impact motion and therefore preferred for compacting cohesive soils, fine grained soils and mixed fine or coarse grained soils.

Towed Sheeps-Foot or Tamping-foot Vibratory Compactors: Towed sheeps-foot or tamping-foot vibratory compactor is useful in highly cohesive soils and soft rocks. The kneading and crushing effect of the feet improves the compaction performance. The compactors are provided

Vibratory compaction equipment

with sheeps-foot or tamping-foot vibratory equipment. Tamping-foot are larger than the sheeps-foot and hence has a more contact area.

Self-Propelled Vibratory Compactors: These compactors are available with a weight of 8 to 10 tons dead weight. In one type large vibratory steel roll in front and two rubber tyres at the rear. The rubber tyres may be smooth or with treads. The smooth one can be used for bituminous work and the treads one for earth compaction work.

In the other type, vibratory steel roll is in the front and two static steel rolls at the rear for multi purpose work.

Hand-Guided Vibratory Compactors: Compactors of this type have duplex or double vibratory compactors with dual roll vibration and dual roll drive. These vibrators are small in size and thereby enable cross country mobility and excellent gradeability. They have provision for dual roll drive. These are especially used for compacting trenches, slopes, packing lots, small repair jobs and sports grounds, *etc*.

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Topic: Mechanical Modification

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Rollers

- Sheep-foot roller
- Smooth drum roller
- Pneumatic-tire roller
- vibratory rollers

Compaction methods

- Laboratory procedure
- Shallow surface compaction
- Deep compaction techniques

other names

- Kneading
- Tamping
- Vibrating
- impact

Laboratory procedure

Parameter	Standard Proctor	Modified Proctor
Volume of mold (m^3)	9.44×10^{-4}	9.44×10^{-4}
Mass of hammer (kg)	2.5	4.54
Height of fall (mm)	305	457
Number of layers	3	5
Number of blows	25	25

Shallow surface compaction

Sheep foot roller

- It is also called tamping foot roller
- Suitable for predominantly clayey soils, not for coarse grained soils.
- Tamping and kneading action
- Protruding studs /feet that penetrate into soil
- Contact pressure: 1500-7000 kPa.
- Usual roller speed 3-6km/hr
- Width of drum is 1.22 m to 1.98 m and Dia of drum is 1.02 m to 1.83 m.
- Weight of empty roller is 1.6 to 7 tonns
- The number of passes necessary for this type of roller to obtain the required densities must be determined for each type of soil encountered.

- Advantages over smooth wheeled rollers
  - –More suitable for cohesive sols
  - –Kneading action
  - –Increased blending(mixing things together)
  - –simplification of adding water or drying as needed.
  - –Effective in breaking down rock pieces
- Disadvantages:
  - –Slow operation
  - –Lower compacted density
  - –Large entrapped air (voids present in the soil due to insufficient compaction)

Sheep foot roller

CE3208PE: GROUND IMPROVEMENT TECHNIQUES

Topic: Mechanical Modification

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Smooth drum roller

- Used primarily for granular soils.
- Probably its most effective use in subgrade work is in the final finish of a surface.
- 3-6km/hr speed
- Large contact area hence less pressure(300-400kPa)
- These rollers have one large steel drum in front and two steel drums on the rear. The gross weight of these rollers is in the range of 8-10 tonne.
- The other type of smooth wheel roller is called Tandem Roller, which weighs between 6-8 tonne.
- About 8 passes are adequate for compacting 20 cm layer.

Smooth drum roller

Advantages of Single Drum Roller

- The single drum roller has its unique advantages. Since it's smaller than the double drum roller, its sleek shape can guarantee that it can work in narrow and tight area, which the double drum roller can't do.
- The single drum roller is perfect for preparation work before paving road. Using a single drum roller, we can easily compact and flatten the ground of sidewalk or driveway. Therefore, single drum vibratory roller is very good at highway paving and setting foundations for some buildings.
- The front of single drum roller is heavier, The drum needs to be giant and weighs much to compact the ground. Besides, due to the back tires, the roller will have better quality than double drum one.

Double Drum Roller

- The biggest difference between single drum vibratory roller and double drum vibratory roller is that it has two drums instead of tires behind.
- A double drum roller can flatten ground in front of and behind the roller at the same time, while the single drum one can only compact on the front at one time.

Advantages of Double Drum Roller

- The most significant advantage of double drum roller is efficiency. After all when you are operating the roller, two drums will work on the same time.
- It’s double area when compared with single drum roller. That will certainly improve working efficiency and economize manpower.
- Because of better power and efficiency, double drum roller can work greatly on asphalt.
- The machine can flatten ground of highway with fast speed and high accuracy.

Pneumatic tyred roller

- Suitable for both cohesive and cohesion less soils
- Pneumatic tyred rollers are used in both earthwork and bituminous work
- they can compact the layers with uniform pressure throughout the width.
- Front and rear wheels not in alignment for better efficiency
- Speed 6-12 km/hr
- Smoother finish
- Lift thickness: 15-30 cm based on roller weight
- Heavier in weight hence lesser no; of passes required

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Pneumatic tyred roller

Advantages

- They provide a more uniform degree of compaction than steel wheel rollers.
- They provide a tighter, denser surface thus decreasing permeability of the layer.
- They provide increased density that many times cannot be obtained with steel wheeled rollers.

Disadvantages

- The individual tire arrangement may cause deformations in the mat that are difficult or impossible to remove with further rolling. Thus, they should not be used for finish rolling.
- If the HMA(Hot mix asphalt) binder contains a rubber modifier, HMA pickup (mix sticking to the tires) may be so severe as to warrant discontinuing use of the roller.

Pneumatic tyred roller

Grid rollers

- Intermediate between smooth wheeled and sheepfoot rollers
- Wheels made of steel bars forming a grid with square holes
- Less kneading action but high contact pressure
- More suitable for coarse grained soils.
- operate at speeds between 5 and 24 kmph.

Grid rollers

Vibratory rollers

- Latest specifications of earthwork invariably recommend vibratory rollers. These rollers are helpful from several considerations like:-
- (i) Higher compaction level can be achieved with maximum work
- (ii) Compaction can be done up to greater depths
- Vibratory rollers are similar to smooth wheel rollers with the modification that the drum or drums are made to vibrate by employing rotating or reciprocating mass

Vibratory rollers

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Impact roller

- The latest compaction equipment are high-energy impact rollers, which use shaped (e.g., triangular ellipsoids or hexagonal).
- The high energy imparted by these systems allows them to achieve compaction at a faster rate and to greater depths.
- A comparison of different types of compaction equipment based on vertical settlement with number of passes is shown at upper left, demonstrating the superior effectiveness, both in terms of number of passes, and influence depth of high-energy equipment.
- 1.5 m thick square with rounded edges.
- Provides deeper 2-3m compaction.

Impact roller

Table 1.1 : Typical characteristics of impact and vibratory equipment for shallow compaction*

Types no. and name		Typical characteristics				
		Mass, t	Max. working speed, km/h	Vibrating frequency, Hz	Depth of lift, m	Number of passes
1	Vibrating hammer	0.3 – 0.1	-	7 – 10	0.2 – 0.4	2 – 4
2	Light vibrating plate	0.06 – 0.8	1	10 - 80	0.15 – 0.5	2 – 4
3	Light vibrating roller	0.6 – 2	2 - 4	25 -70	0.3 – 0.5	4 – 6
4	Heavy towed vibrating roller	6 – 15	8 – 10	25 -30	0.3 – 1.5	4 – 6
5	Heavy self-propelled vibrating roller	6 -15	6 – 13	25 -40	0.3 – 0.5	4 – 6
6	Impact roller	7	10 -14	-	0.5 - 3	Up to 30

TABLE 3.2A Applicability of Compaction Equipment

Equipment	Most-suitable soils	Typical applications	Least-suitable soils
Smooth wheel rollers, static or vibrating	Well-graded sand-gravel mixtures, crushed rock, asphalt	Running surface, base courses, subgrades for roads and runways	Uniform sands
Rubber-tired rollers	Coarse-grained soils with some fines	Road and airfield subgrade and base course proof-rolling	Coarse uniform cohesionless soils, and rock
Grid rollers	Weathered rock, well-graded coarse soils	Subgrade, subbase	Clays, silty clays, uniformly graded materials
Sheepsfoot rollers:			
Static	Fine-grained soils with more than 20% fines	Dams, embankments, subgrades for airfields, highways	Clean coarse-grained soils, soils with cobbles, stones
Vibrating	As above, but also sand-gravel mixtures	Subgrade layers	
Vibrating plate (light)	Coarse-grained soils, 4 to 8% fines	Small patches	Cohesive soils
Tampers, rammers	All types	Difficult-access areas	
Impact rollers	Wide range of moist and saturated soils	Subgrade earthworks (except surface)	Dry, cohesionless soils

Hausmann, M. R., "Engineering Principles of Ground Modification", p 27, McGraw-Hill Co., 1990. Reproduced by permission of McGraw-Hill Companies.

Deep compaction

Vibroflotataion Techniques

- Vibroflotation is a ground improvement technique used at a considerable depth that by using a powered electrically or hydraulically probe, it strengthens the soil.
- Vibroflotation can be obtained by using three different techniques:
- Vibro Compaction method- This method allows granular soils to be compacted. This method is only used to compact sandy soils.
- Vibro Replacement or displacement method- The technique is used to replace poor or inadequate soil material by flushing out the soil with air or water and replacing it with granular soil. This can be used in various soil types such as clay and sandy soils.

Vibroflotation

Suitable for granular soils and cohesive soils

Practiced in several forms:

- vibro–compaction
- stone columns
- vibro-replacement

Vibroflot (vibrating unit)

Length = 2 – 3 m

Diameter = 0.3 – 0.5 m

Mass = 2 tonnes

(lowered into the ground and vibrated)

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Vibroflotation

Suitable for granular soils and cohesive soils
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- stone columns
- vibro-replacement

Vibroflot (vibrating unit)
Length = 2 – 3 m
Diameter = 0.3 – 0.5 m
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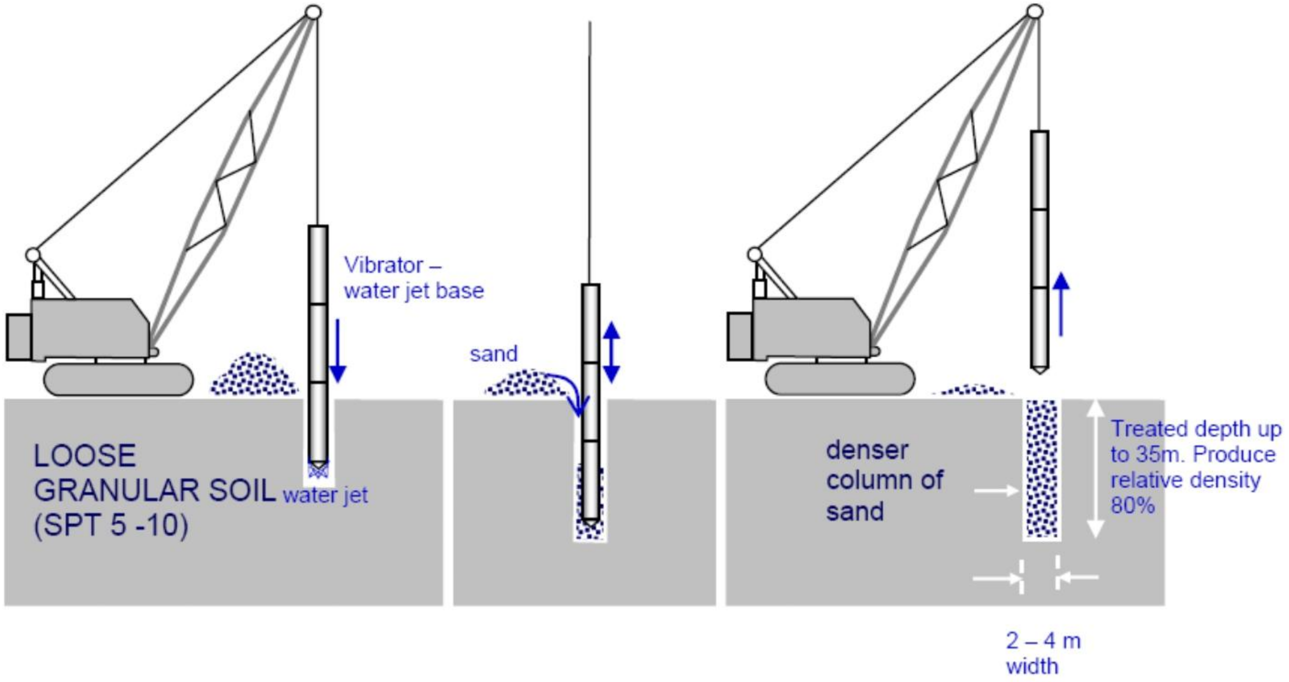


Figure 1.12 : Vibro compaction

Deep compaction techniques

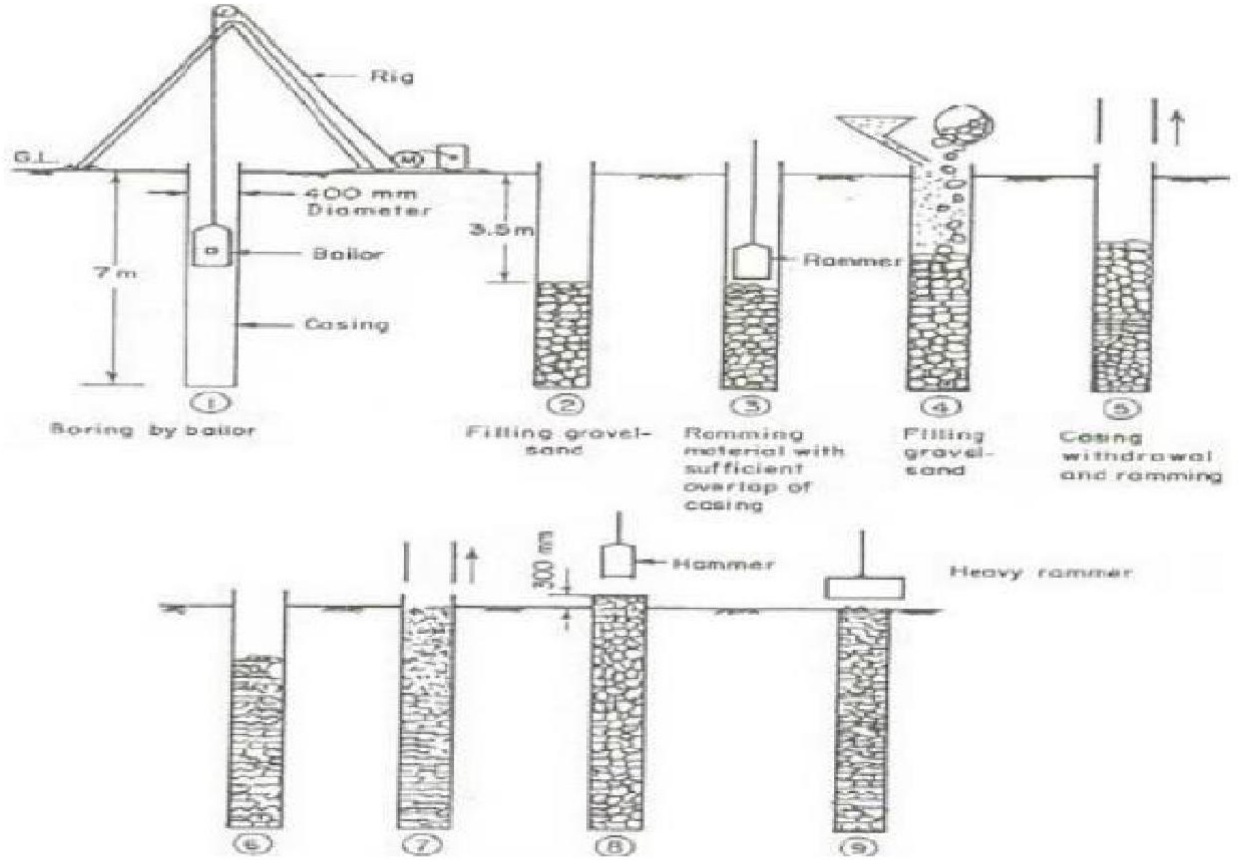
STONE COLUMNS

- Stone columns are a ground improvement technique to improve the load bearing capacity of the soil
- The stone column consists of crushed coarse aggregates of various sizes.
- Applicable to wide range of soils and Stone columns are best suited to cohesive soils.

Methods of installation

- Methods of installation Cased Borehole method/ Rammed stone column
- Vibration Methods - Vibrofloatation / Vibrocomposer

Cased Borehole Method/ Rammed stone column



Cased Borehole Method/ Rammed stone column

- Proposed by Datye and Nagaraju (1977) and developed by Nayke(1982)
- Uses a bored piling rig to dig the borehole and granular fill is placed and compacted in stages

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Cased Borehole Method/ Rammed stone column

- Rammer weighing 15 to 20 kN falling through height of 1 to 1.5 m for compacting stone aggregates.
- It is economical than vibrator compaction.
- In this method the bore hole is made by spiral auger and the bore hole is cleaned by using specially made tools.
- 2-75 mm size stone aggregate and 20-25% of sand is used.
- The aggregate and sand layers are placed alternatively with layer thickness of 300 to 500 mm respectively.

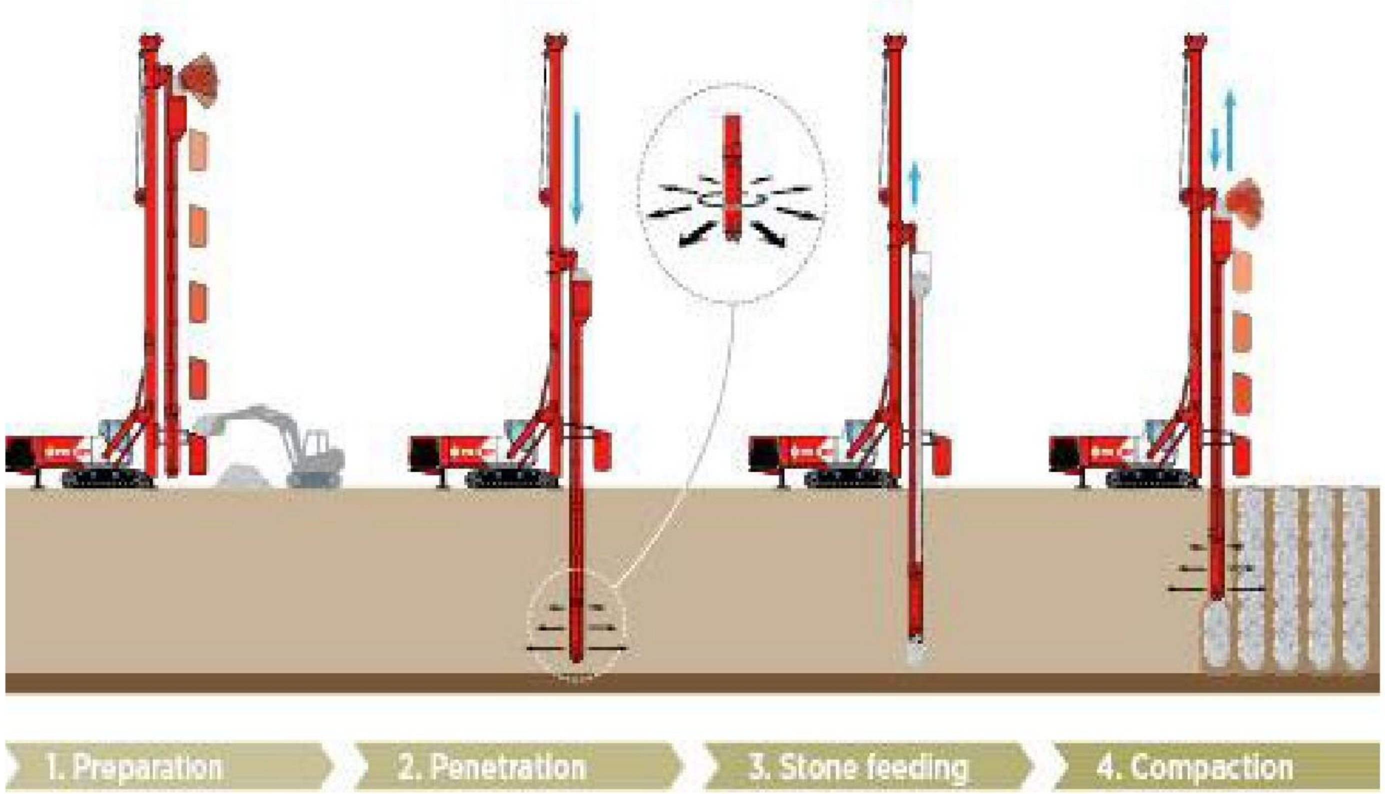
Rammed stone column- procedure

1. Cased borehole
2. Granular materal (2-75mm) backfilled upto 2-3m from surface
3. Each layer compacted using rammer (15-20kN from height 1-1.5m
4. Casing withdrawn in stages

Vibro-floatation

- Formation of stone columns using a vibroflot is quite suitable techniques for improvement of cohesive soils.
- The vibroflot is allowed to sink in to the ground due to its own weight, associated by water or air as a flushing medium up to required depth.
- Water is used as a jetting fluid for fully saturated soils while compressed air is used for partially saturated soils.
- It simultaneously releases water from the lower jets which remove the soft soil directly under the vibrofloat nose forming a hole.

Vibro-floatation



APPLICATION OF STONE COLUMNS

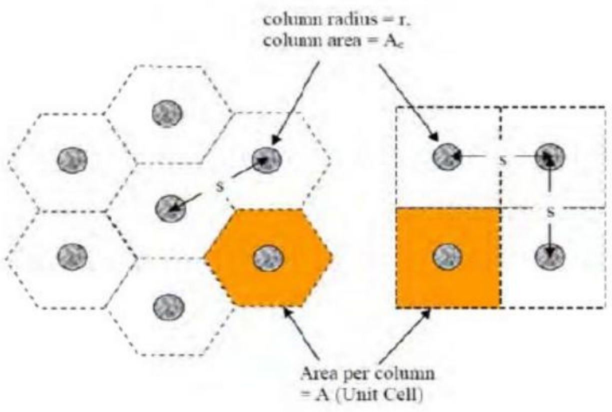
- Stone column acts as vertical drains and thus speeding up the process of consolidation.
- replaces the soft soil by a stronger material.
- Initial compaction of soil during the process of installation thereby increasing the unit weight.

Design Parameters

- Vibro-Displacement/Replacement Methods
  - Top/Bottom Feed methods
- Square or Rectangular Pattern:
  - Typical Spacing (S): 1.5 - 3.5m c/c
  - Triangular pattern: $D_e = 1.05\ S$
  - Rectangular pattern: $D_e = 1.13\ S$
- 0.6 -1.0 m Diameter Depending on the Material
- Length up to 20 m (Depends on the Strata)
- Crushed Rock Size: 20 - 75 mm
- Design loads: 20 – 50 tons

DESIGN CONSIDERATIONS

- *Stone Column Diameter*: The variation in pile diameter installed by vibroflot (diameter 300 to 500 mm) varies between 0.6m(stiff clays) and 1.1 m(very soft cohesive soils)
- *Pattern of arrangement* :



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- *Spacing:* the column spacing may broadly ranges from 2 to 3 m depending upon the site conditions, loading pattern, column
- *Replacement ratio: To quantify the amount of soil replaced by the stone, the term replacement ratio, as is used.* $a_s = 0.907 (D/S)^2$
- where the constant 0.907 is a function of the pattern used which, in this case, is the commonly employed equilateral triangular pattern.
- *Stress Concentration factor:* The stress concentration factor, n, due to externally applied load σ, is defined as the ratio of average stress in the stone column σ_s ,to the stress σ_g, in the soil within the unit cell,

$$n=\sigma_s / \sigma_g$$

The value of n generally lies between 2.5 and 5 at the ground surface

- *Stress*: By assuming a triaxial state of stress in the stone column and both the column and the surrounding soil at failure, the ultimate vertical stress $\sigma 1$, which the stone column can take, may be determined from the following equation:

$$\sigma 1/\ \sigma 3 = (1+\sin \varphi s)\ /(1-\sin \varphi s)$$

where $\sigma 3$ = lateral confining stress mobilized by the surrounding soil to resist the bulging of the stone column;

φs = angle of internal friction of the stone column

$\sigma 1/\ \sigma 3$ =coefficient of passive earth pressure of the stone column.

- *Settlement:* *Consolidation settlement of the composite (treated) soil S, is given by:*

$$S = mv\sigma gH$$

where

mv = Coefficient of volume change

σg = Vertical stress in surrounding ground

H = Thickness of treated soil

- <u>Aggregate:</u> Crushed stone or gravel which is chemically inert, devoid of organic matter, hard etc are used for constructing the aggregate column. Well graded stones of 75mm to 2mm may be used.

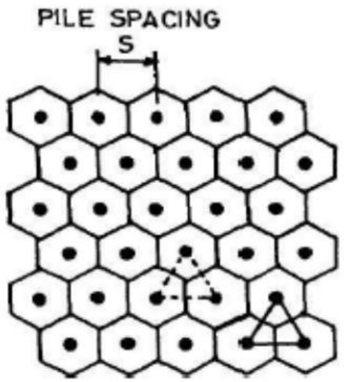

Fig. 7 Triangular pattern of arrangement

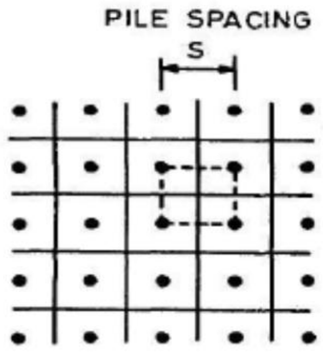

Fig. 8 Square pattern of arrangement

Disadvantages of stone columns

- Severe cracks could be seen in structures close by the stone column site due to the vibrations of 30-50Hz.

Deep dynamic compaction

- pounding the ground by a heavy weight
- Suitable for granular soils, land fills

Deep dynamic compaction

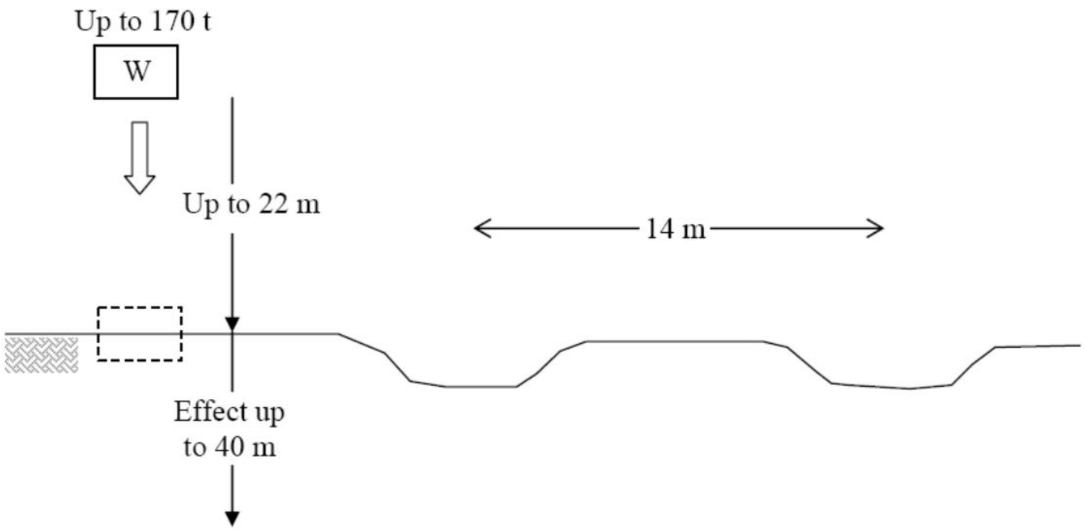

Figure 1.10 : Ground profile after tamping

Advantages of Dynamic compaction

- Compacts large areas of loose granular fills.
- Reduces the volume of landfill waste.
- Increases in situ density and the voids are collapsed.
- Increased bearing capacity.

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Topic: Mechanical Modification

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Disadvantages

- The impact of the weight in dynamic compaction sends waves of vibration through the ground. These vibrations could cause disturbance and possible damage of surrounding structures.
- Another disadvantage experienced when using dynamic compaction has occurred with combination soil profiles

In-place densification of granular soils

Blasting or by Explosives

- The range of soil grain sizes suitable for compacting by blasting method is the same as for Vibroflotation.
- In this method, the compaction is achieved by successive detonations of small explosive charges in saturated soils.
- Relative densities of 70 to 80 % upto a depth of 20 to 25 m can be achieved.

Blasting or by Explosives

- Explosive charges (60 % dynamite, 30% special gelatin dynamite, and ammonite are most commonly used) are placed at about 2/3 times the thickness of the stratum to be densified.
- The spacings of the charges vary from 3 to 8 m.
- Three to five successive detonations of several spaced charges are usually required to achieve the desired compaction.
- The shock waves due to blasting cause liquefaction of the saturated sand, followed by densification.
- Practically no compaction is achieved in the top 1 m and so this zone usually needs recompaction by rollers.

Blasting or by Explosives

The relation for the weight of charge and the sphere of influence for compaction can be given by:

$$\boxed{W = CR^3}$$

Where W = Weight of charge

R = Sphere of influence

C = Constant (0.0025 for 60 % dynamite)

- If blasting is used in dry or partially saturated soils, preflooding is desirable.

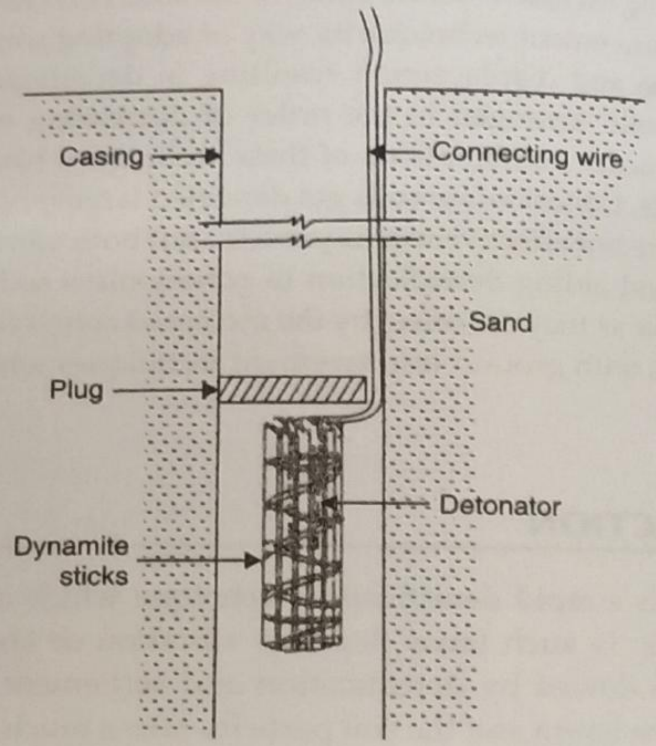

FIGURE 5.1. **Installation of Explosives.**
(*Source: Mitchell, 1970*)

Procedure of the blasting for ground improvement

- Series of boreholes are drilled and Pipe of 7.5 to 10 cm is driven to the required depth
- The detonator and the dynamic sticks are both enclosed and lowered through casings
- Casing is withdrawn and a wad of paper or wood is placed against the charge of Explosive (To protect it from misfire)

- Blasting is more effective in loose sands that contain less than 20% silt and less than 5% clay
- The blasting is done in stages. Repeated shots are more effective than a single larger one.
- The top surface up to 1m gets disturbed and needs surface compaction. Although blasting is quite economical, it's limited by several considerations as it produces strong vibrations that may damage nearby structures or produce significant ground movements.

Compaction quality control measurements

- Moisture control measurements
- In situ density measurements
- Nuclear moisture density methods
- Hilf’s method

CE3208PE: GROUND IMPROVEMENT TECHNIQUES

Topic: Hydraulic Modifications

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Hydraulic modifications

- pore water is forced out of the soil via (by means of) drains.
- - 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 (electro kinetic stabilization) is required.
- Hydraulic Modification can be termed as dewatering. Dewatering means modifying ground by lowering the water table, redirecting seepage or simply reducing its water content.

PURPOSES FOR DEWATERING

- To provide suitable working surface of the bottom of the excavation.
- Lowering the water table can also be utilized to increase the effective weight of the soil and consolidate the soil layers.

Vertical drains can be classified in to two types

- 1)sand drains
- 2)prefabricated sand drains(wick drains)

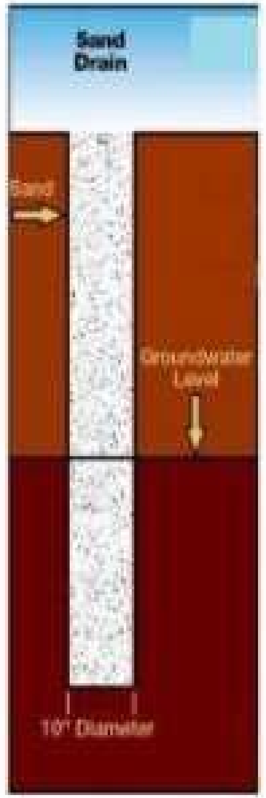
SAND DRAINS

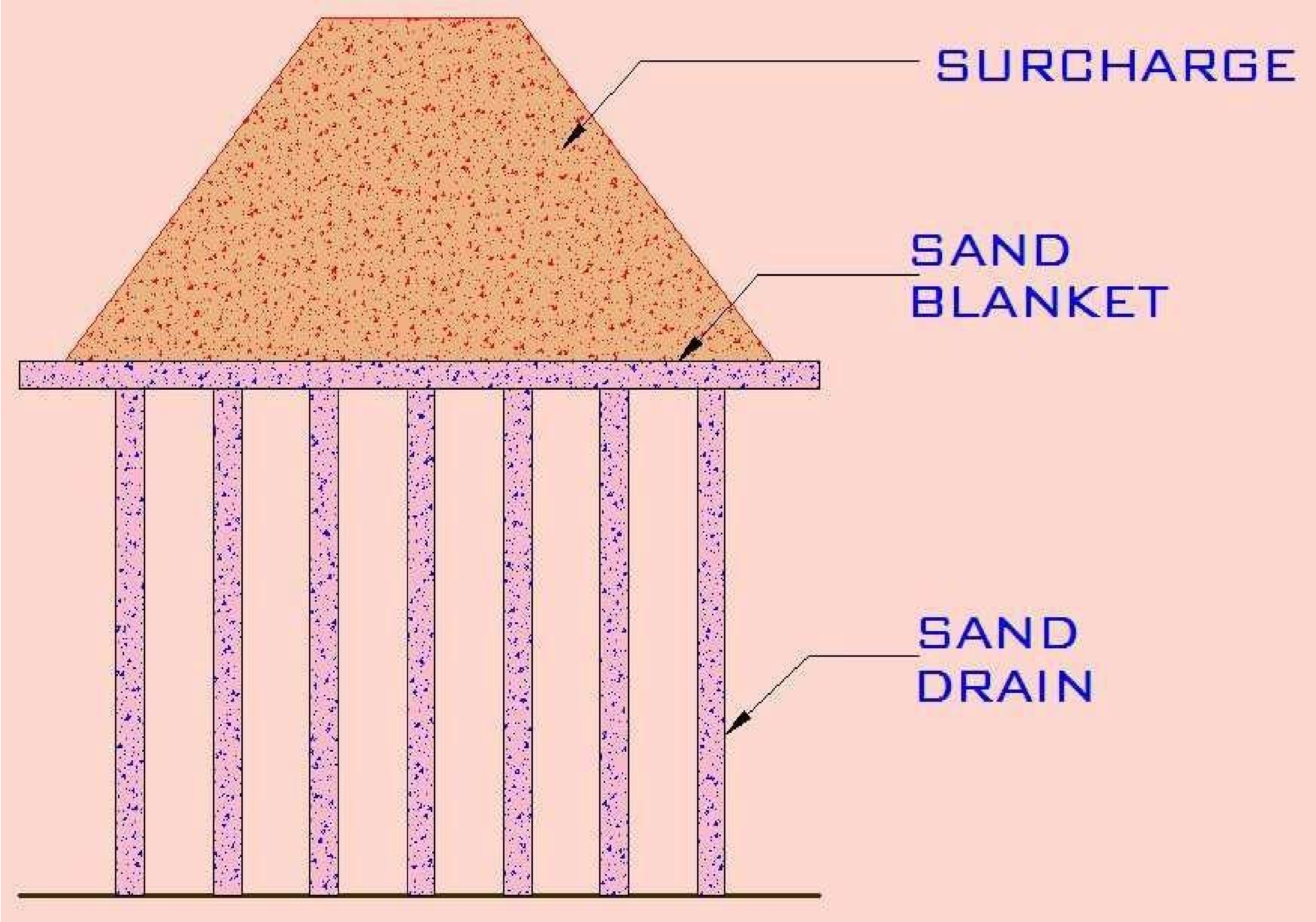
- The sand drain system uses to reinforce good to poor soils, including soft to stiff clay and silt, loose to dense sand, organic silt and peat.
- Sand drains are used to reinforce and stiffen compressible foundation soils and increase the time-rate of settlement by expulsion of pore water pressure.
- A circular casing or hollow steel mandrel, of about 25-cm internal diameter and 6-m height, is driven vertically into the soft soil up to the required depth

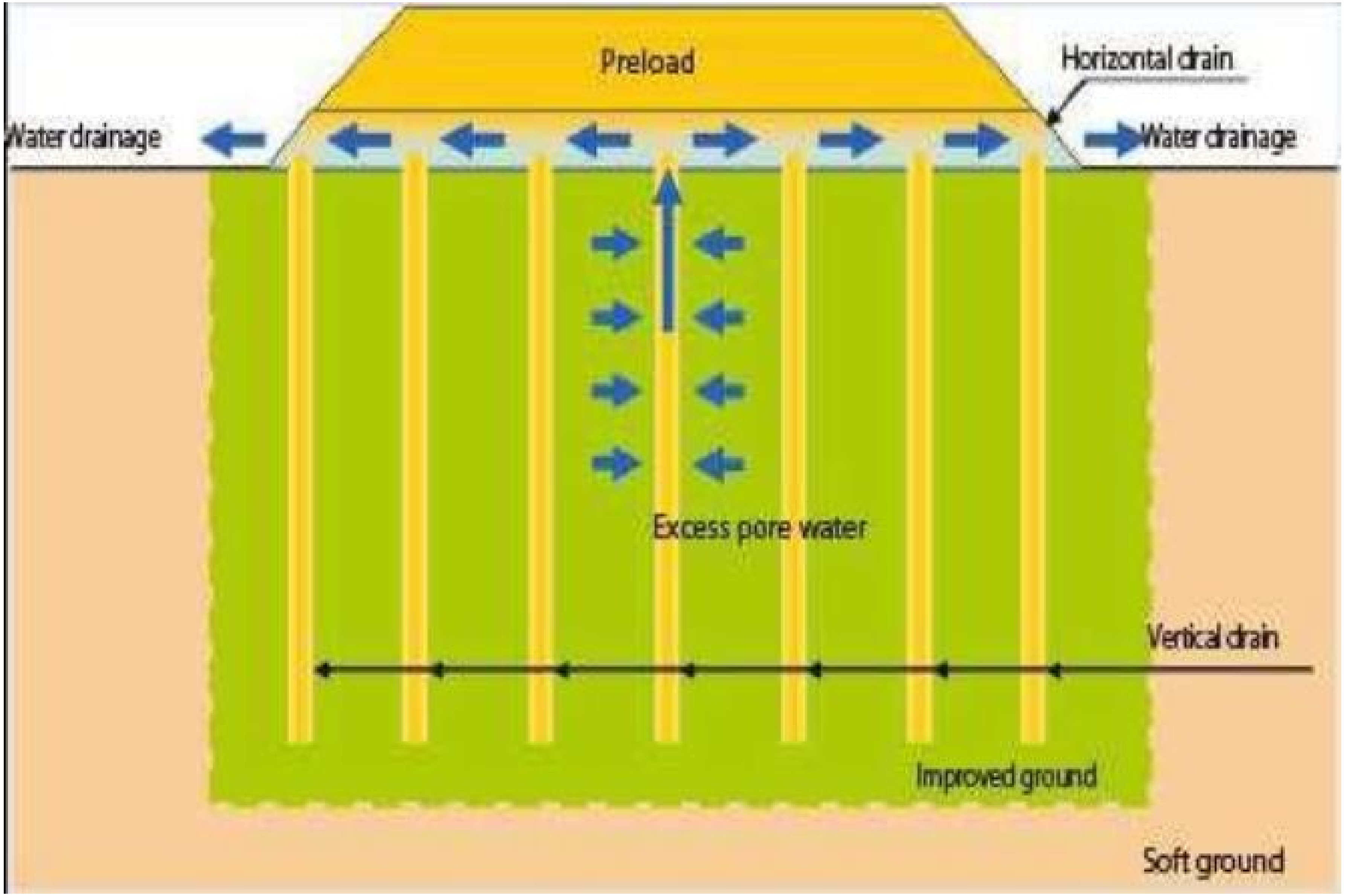
SAND DRAINS

A sand drain is a simple process, employing a column of at least 10 inches in width augered into ground to be surcharged & consolidated.

The column is then filled with sand and connected to a free-draining blanket of granular soil.




SURCHARGE
SAND
BLANKET
SAND
DRAIN



Preload
Horizontal drain
Water drainage
Water drainage
Excess pore water
Vertical drain
Improved ground
Soft ground

Three different techniques for installation of sand drains

- Mandrel drive
- Hollow stem continuous flight auger
- Jetted hollow or closed end pipe

Mandrel drive

- In this method a closed end pipe (mandrel) is driven to the bottom of the soil to be consolidated, it is filled with sand which is placed under approximately 100 Ib/in2 of air pressure and then it is gradually lifted out of ground. The closed end, being a hinged valve, opens and the sand under pressure rushes out.
- The pipe continues to be lifted until it reaches the ground surface.
- The entire process is then repeated for next sand drain.
- The cycle takes 2 to 10 minute, depending upon local conditions.

Hollow stem continuous flight auger

- Here a continuous flight auger of the diameter as the intended sand drains is rotated into the soil to the specified depth. Since the auger is formed around a hollow pipe, sand under pressure can be introduced into it.
- Auger is back rotated out of the hole; the sand drain is left behind and forms the sand drain.
- Cycle time for this installation method is 5 to 20 minutes.

Jetted hollow or closed end pipe

- The driving in to the soil of either hollow or either closed end hinged pipes via water jetting is also used for sand drain installation.
- After pipe placement, the sand is introduced under pressure as the pipe withdrawn.
- Cycle time is 5 to 20 minutes.

Process of construction of sand drains:

- The driven casing is withdrawn after the sand has been filled. A sand blanket is placed over the top of the sand drains to connect all the sand drains.
- To accelerate the drainage, a surcharge load is placed on the sand blanket. The surcharge is usually in the form of dumped soil.

Mechanism of consolidation:

- The pore water pressure is increased by the applied surcharge load in the embankment.
- The drainage occur in the vertical and horizontal directions. The horizontal drainage occur because of sand drains.
- The sand drains accelerate the process of dissipation of excess pore water created by the surcharge.

Spacing of Sand drains :

- The drains are generally laid either in a square pattern or a triangular pattern.
- The typical design parameter for sand drain may vary as below :

a) Spacing of sand drains, S = (2 ~ 5) m

b) Depth of sand drains = (3 ~ 35) m

c) Radius of sand drains well = (0.2 ~ 0.3) m

d) Thickness of sand blanket = (0.6 ~ 1) m

Application Of Sand Drains:

- Airport Runways
- Golf Courses
- Mine Tailings Consolidation
- Tailing Ponds
- Swampland/Wetland Development
- Building Foundations
- Retaining Walls
- Parking Lots
- Landfills

ADVANTAGES

- Provision of sand drains allows drainage of pore water in radial direction in addition to the drainage in vertical direction.
- With faster consolidation
- The long-term stability of the structure is also increased

- DISADVANTAGES

- Requires frequent maintenance.
- Time taking process about an years based on soil type.
- sand drains may have discontinuities if the mandril is withdrawn too fast

Wick drains

- sand drains people were using in the olden days. Now we are using pre-fabricated vertical drains.
- It is composed of a polypropylene strip with drainage channels wrapped in a geotextile filter fabric
- In this drain, you have a drain inside, which has drainage channels; so, the moment you apply the load, water comes here, and then goes to the drainage channels.

- wick drains are prefabricated vertical drains installed to accelerate the consolidation of compressible soils.
- The drain consists of a geotextile filter-wrapped plastic strip with extruded channels that allow water to drain from soft soil as it consolidates under an applied surcharge load.
- The geotextile filter prevents soil particles from entering the channels and clogging the drain.
- The time required for the consolidation to occur depends on the permeability of the soft strata, the existence of sand layers in the strata, the weight of the surcharge, and the spacing of the wicks.

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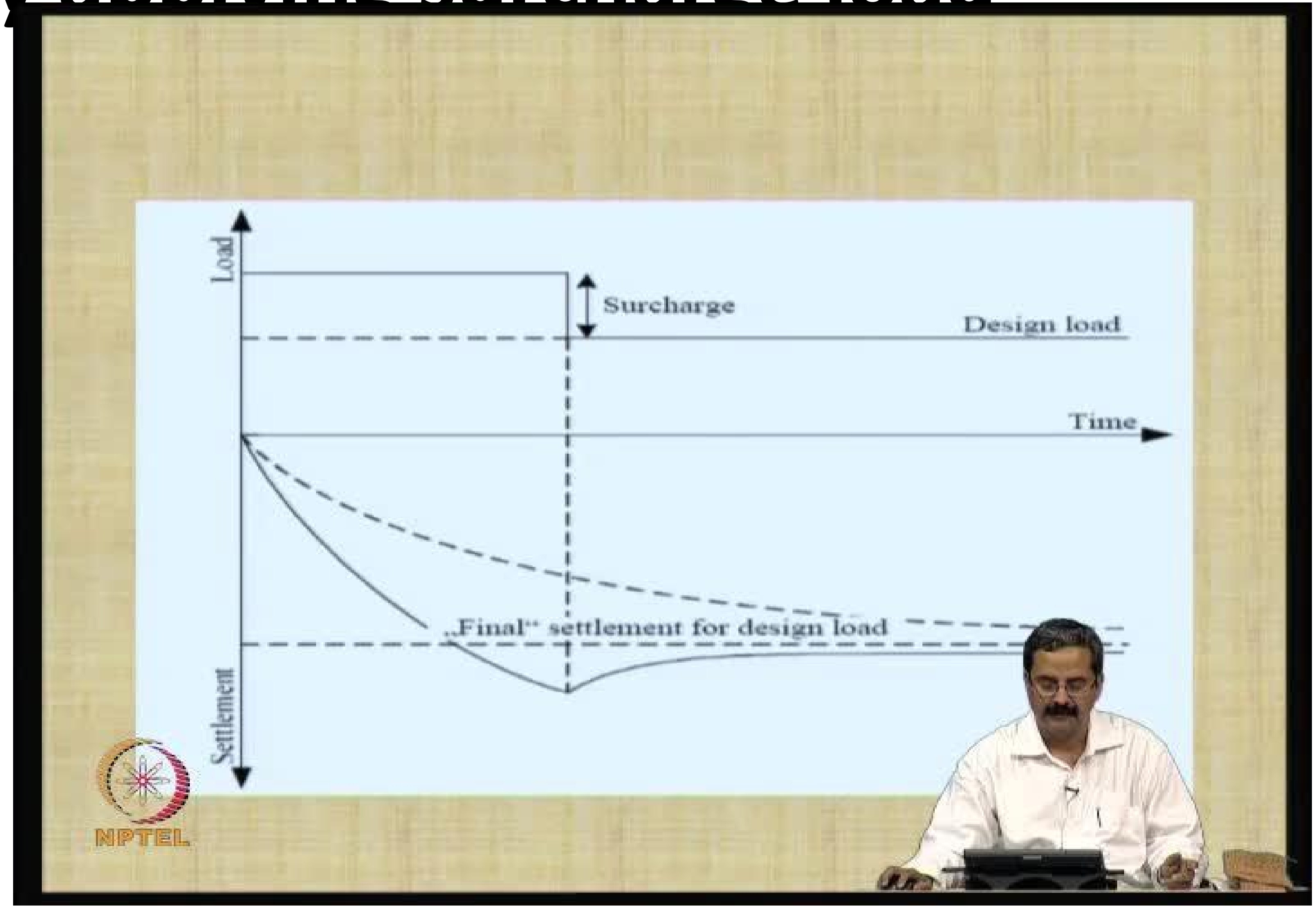
Prof. B V S Viswanadham, Department of Civil Engineering, IIT Bombay

Applications

- Wick drains can be applied to any site that requires consolidation, including sites for:
- Roadway embankments
- Bridge approaches and overpasses
- Storage tanks
- Dams
- residential buildings
- Railway embankments
- Mining wastes and tailings

By applying surcharge load



Installation procedure of wick drains

- Before installation can begin, the working surface must be prepared to ensure a stable working platform.
- Since wick drain sites are typically soft, a sand or gravel blanket may be needed to provide support for the equipment.
- The sand and gravel will also act as a drainage blanket to direct water away from the treatment area.
- Drains can be installed up to 140 feet deep from a track-mounted excavator

- The installation force is typically provided by vibratory hammers, static force methods, or a combination of these methods depending on the soil conditions.
- Generally PVD is installed by using a MANDREL mounted on a installation machine.
- MANDREL is a metallic hollow tube either rectangular or cylindrical contains the PVD.
- A disposable metallic shoe is connected at the end of the mandrel so that PVD can be easily inserted within the soil.
- After inserting the PVD the mandrel is extracted while the PVD remains at its position within the ground.

Wick drain material

- The wick drain material is a 4-in. wide x 0.25-in. (100 mm x 0.64 mm) thick plastic band shaped conduit.
- It is composed of a polypropylene strip with drainage channels wrapped in a geotextile filter fabric.

Figure 5. Example of wick drain material rolls.

Spacing

- Layout usually consists of triangular or square grid patterns.
- Typical spacing ranges from 2.5 to 8 feet on center.

PVD Installation Sequence

- Position Rig at Drain Location
- Place Anchor on Drain End
- Penetrate Mandrel to Desired Depth
- Withdraw Mandrel
- Cut Drain Material Above Drainage Blanket

INSTALLATION METHODS OF VERTICAL DRAINS

GROUP DESCRIPTION	PARTICULAR METHODS	REMARKS
DISPLACEMNT METHODS	Driving Vibration Pull Down(static Force) Washing Combinations Of Above	A mandrel with or without a disposal shoe is used in each case

Continued…

GROUP DESCRIPTION	PARTICULAR METHODS	REMARKS
DRILLING METHODS	Rotary drill, with or without a casing Rotary anger, including continuous standard and hollow fight augers Percussive(shell and auger) methods, with or without casing Hand auger	A mandrel with or without a disposal shoe is used in each case.

Continued…

GROUP DESCRIPTION	PARTICULAR METHODS	REMARKS
WASHING METHODS	Rotary wash jet Washed open ended case Weighted wash jet head on flexible hose	Methods in which sand is washed in via the jet pipe are not suitable for prefabricated drains

Ground Improvement S

Depth of PVD	10.00 m to 18.00 m below OGL
Spacing of PVD (Triangular)	1.00 m c/c below stacker reclaimers 1.50 m c/c in other area
Consolidation Period	For 1.00 m spacing: 65 days For 1.50 m spacing:
Thickness of Sand Mat	300 mm
Horizontal Drainage System	Geotextile pipes filled by boulders / gravels; PVD laid horizontally
Machinery Used	Hydraulic Stitchers

Advantages

- There is no risk of PVDs breaking installation, while sand drains may have discontinuities if the mandril is withdrawn too fast.
- There is no risk of shear failure of PVDs during settlement, while sand drains are vulnerable to shear failure during settlement.
- PVDs have discharge capacities, typically 30 X 10-6 to 90 X 10-6 m3/s, while a 0.35 m diameter sand drain has a discharge capacity of 20 X 10-6 m3/s

- When installed with a properly designed mandril, smear effects are much less for PVDs than for large diameter sand drains. The zone of smear is directly proportional to the diameter of mandril used for installation.
- PVDs are factory produced materials and are quality controlled, whereas sand drains are subject to the quality variance of naturally occuring sands.

Disadvantages

- If the compression layer is overlain by dense fills or sands, very stiff clay or other obstructions, drain installation could require predrilling, jetting, and/or use of a vibratory hammer, or may not even be feasible under such conditions, general pre-excavation can be performed if appropriate.
- Cost is more.

Example:

During construction of a highway bridge, the average permanent load on the clay layer is expected to increase by about 115 kN/m3. The average effective overburden pressure at the middle of the clay layer is 210 kN/m3. Here, $H_c = 10m, C_c = 0.81, e_o = 2.7$ and $C_v = 1.08 m^2$/month. The clay is normally consolidated. Determine

a. The total primary consolidation settlement of the bridge without precompression.

b. The surcharge, $\Delta\sigma'_{(f)}$, needed to eliminate the entire primary consolidation settlement in nine months by precompression.

Solution

Part a

The total primary consolidation settlement may be calculated from Eq(1):

$$S_{c(p)} = \frac{C_c H_c}{1 + e_o} \log \frac{\sigma'_o + \Delta\sigma'_{(p)}}{\sigma'_o}$$

$$= \frac{(0.81)(10)}{1 + 2.7} \log \left[\frac{210 + 115}{115}\right]$$

= 0.4152m = 415.2mm

Part b We have,

$$T_v = \frac{C_v t_2}{H^2}$$

C_v = 1.08 m^2/month.

H = 6m (two way drainage)

t_2 = 9 months.

Hence,

$$T_v = \frac{(1.08)(9)}{6^2} = 0.27$$

According to Figure 3, for T_v = 0.27, the value of U is 40%.

we have,

$\Delta\sigma'_{(p)} = 115\ kN/m^2$

and $\Delta\sigma'_o = 210 kN/m^2$

so

$$\frac{\Delta\sigma'_{(P)}}{\sigma'_o} = \frac{115}{210} = 0.548$$

According to Figure 2, for U=40% and $\Delta\sigma'_{(p)}/\sigma'_o = 0.548$,
$\Delta\sigma_{(f)}/\sigma'_{(p)} = 2.5$; $\Delta\sigma'_{(f)} = (2.5)(115) = 287.5 kN/m^2$

Assuming a bulk density of 20 kN/m^3 for fill material and a height of 5m gives a pre-load of 100 kN/m^2. The required surcharge is higher than pre-load and hence consolidation by sand drains/PVDs is required.

Vaccum consolidation

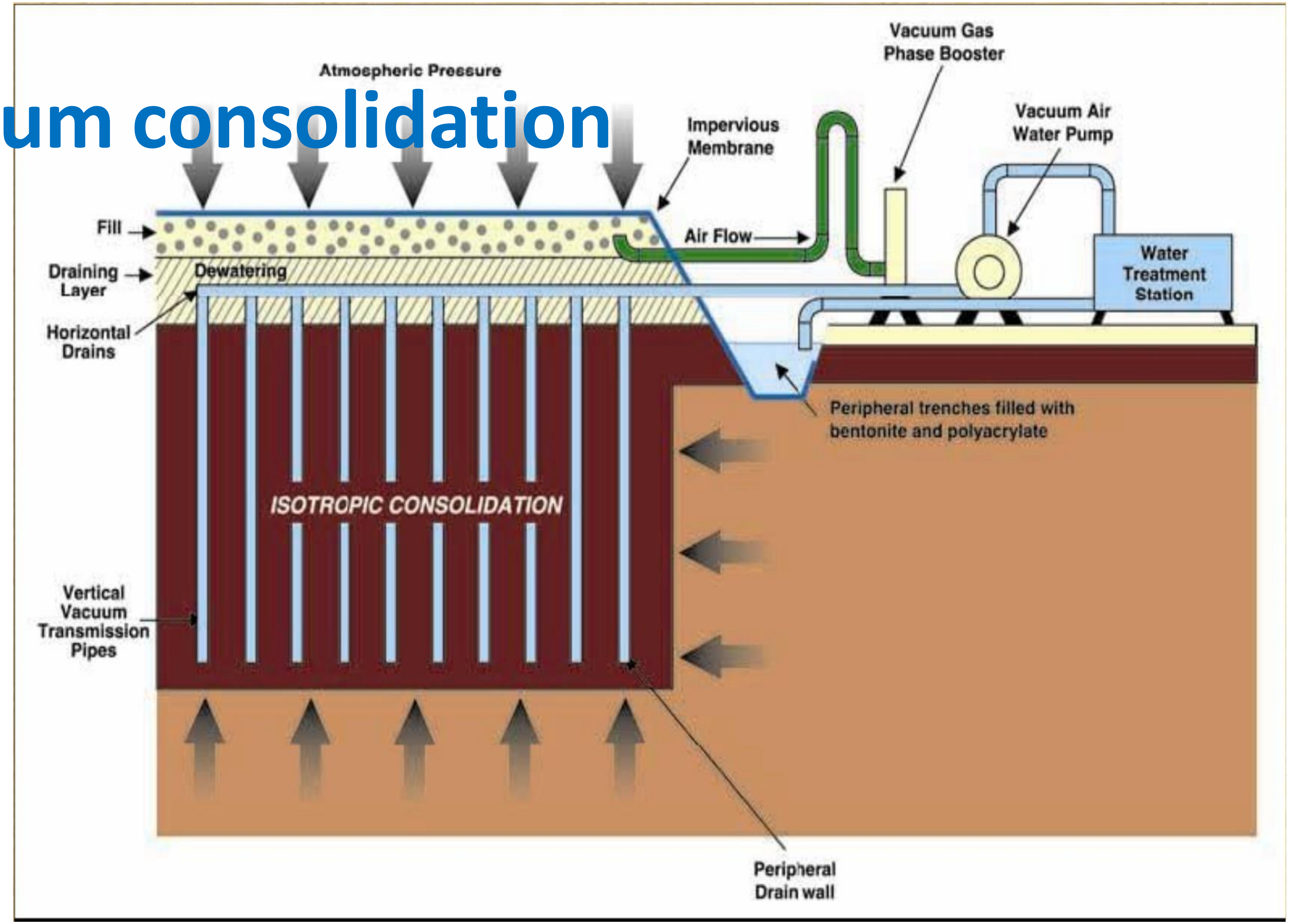
- Vacuum consolidation was first proposed in the early 1950s by Kjellman (1952), the developer of the prefabricated vertical “wick” drain. In the 1960s, isolated studies of vacuum induced or assisted consolidation continued for the next two decades (Holtz 1975). However, vacuum consolidation was not seriously investigated as an alternative to conventional surcharging until recently due to the low cost of placing and removing surcharge fills and the difficulties involved in applying and maintaining the vacuum.

- The steadily increasing direct and indirect costs of placing and removing surcharge fill the vacuum- consolidation an economically viable method as a replacement for or supplement to surcharge fill.
- Vacuum Consolidation is an effective means for accelerating the improvement of saturated soft soils.
- The soil site is covered with an airtight membrane and a vacuum is created underneath it by using a dual Venturi and vacuum pump.
- The technology can provide an equivalent pre-loading of about 4.5 m high as compared with a conventional surcharging fill.

- Instead of increasing the effective stress in the soil mass by increasing the total stress as in conventional mechanical surcharging, vacuum-assisted consolidation preloads the soil by reducing the pore pressure while maintaining a constant total stress.

- The effectiveness can be increased when applied with combination of a surcharge fill. Field experience indicates a substantial cost and time savings by this technology compared to conventional surcharging.

Vaccum consolidation



The current main application of vacuum assisted consolidation include:

- Replacement of standard pre-loading techniques, eliminating the risk of pre-loading induced foundation failures.
- Combining VCP with water pre-loading in scare fill areas. The method has been used to build large development projects on thick compressible soil.
- Combining VCP with surcharge pre-loading to increase foundation stability and thereby optimize pre-loading stage sequence and reduce project time.

DEWATERING

DEWATERING

- Dewatering is the term for the control of groundwater by pumping. On construction sites it may be known as ‘**construction dewatering’.** The method is also used on mine sites – ‘**mine dewatering**’
- The process of dewatering can be defined as – pumping from wells or sumps to temporarily lower groundwater levels, to allow excavations to be made in dry and stable conditions below natural groundwater level

Purpose of Dewatering

- dry excavation
- work efficiently
- To decrease seepage and pore water pressure
- Improve characteristics of foundation materials
- Increase stability of slopes
- Prevent frost heaving in pavements

Factors Controlling Selection

- Nature and Permeability of Ground
- Geological conditions of soil
- Extent of area to be Dewatered
- Depth of Water table below ground level
- Amount by which it has to be lowered
- Proposed methods of excavation and ground support
- Proximity of existing structure

HOW IT IS DONE?

Collection of water → Pumping → Filtering and removing silt and impurities → Discharge at proper location

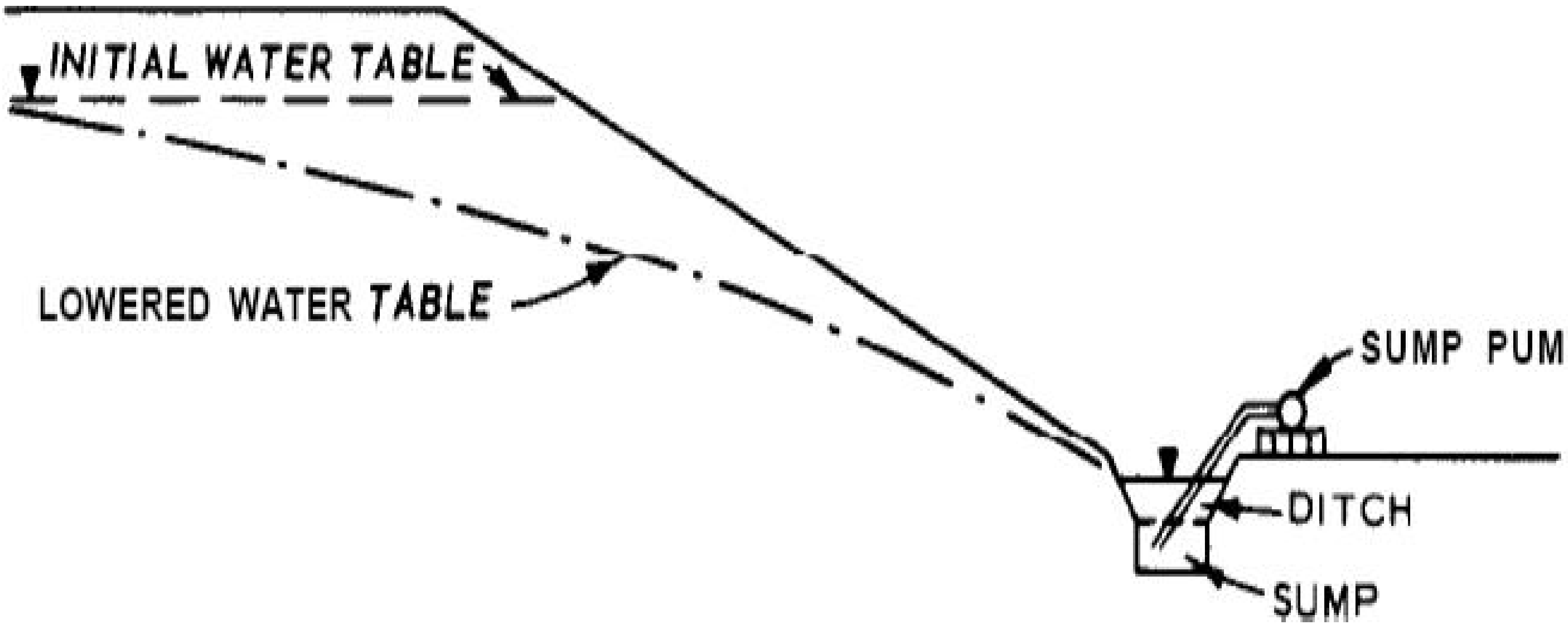
Methods of Dewatering

- Open sumps and ditches
- Well point systems
- Deep well drainage
- Vacuum Dewatering Systems
- Electro Osmosis

Open sumps and ditches

- 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. Sumps provide localized, very shallow dewatering (less than 3 feet) and consist of pumping from perforated drums or casings in a gravel-filled backhoe pit. Sumps work best in fine grained soils, or very coarse, boulder deposits.
- 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.

Open sumps and ditches



Open sumps and ditches

Advantages	Disadvantages
1. Widely used method. 2. Most economical method for installation and maintenance. 3. Can be applied for most soil and rock conditions. 4. Most appropriate method in situation where boulders or massive obstructions are met within the ground. Greatest depth to which the water table can be lowered by this method is about 8 m below the pump.	1. Ground water flows towards the excavation with high head or a steep slope and hence there is a risk of collapse of sides. 2. In open or timbered excavations there is risk of instability of the base due to upward.

Well point systems

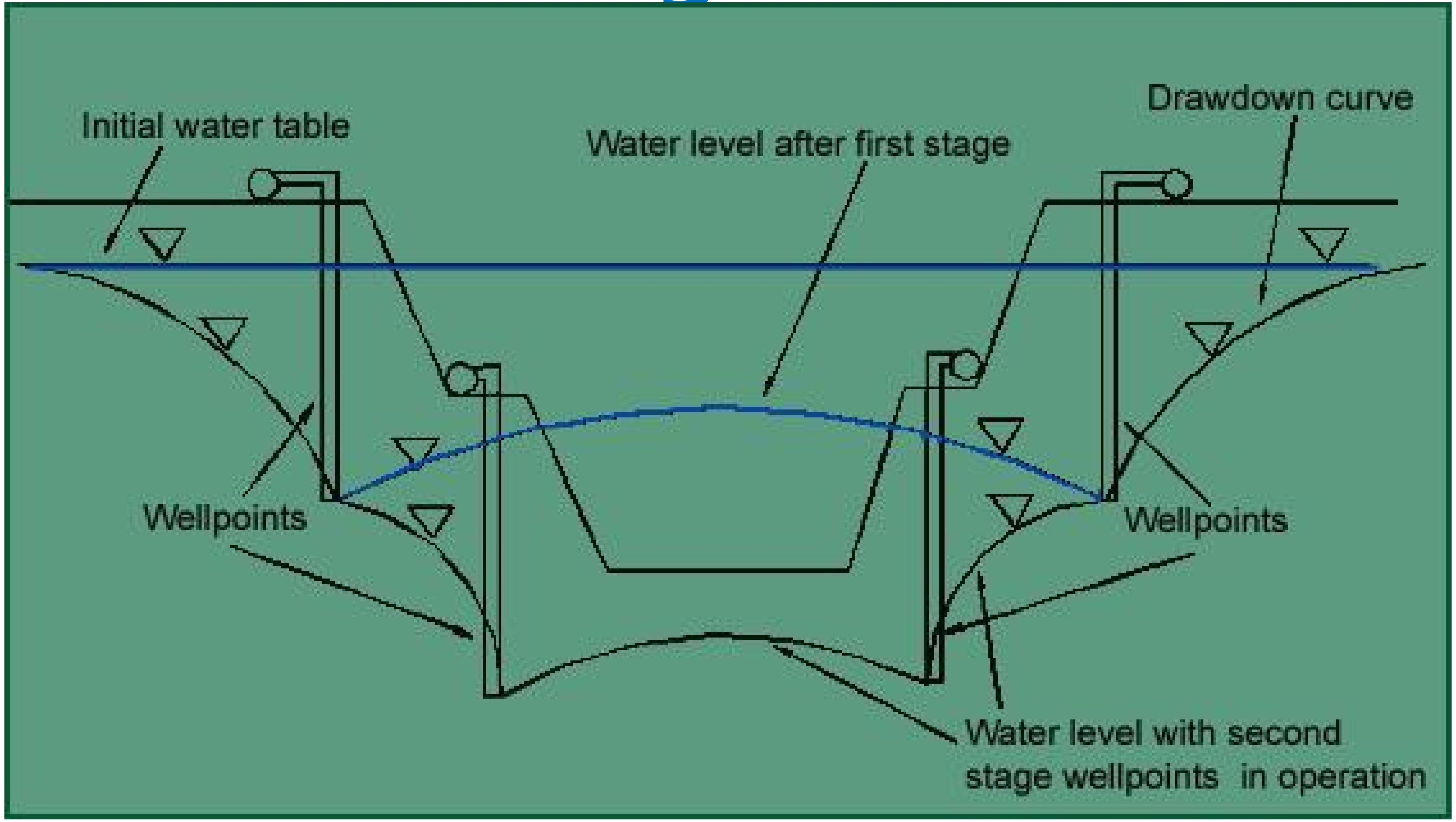
- Wells are systematically drilled around the construction area and submersible pumps placed into these wells.
- Wells are large-diameter (greater than 6 inches) holes, drilled relatively deep (greater than10 feet), and contain slotted casings and down hole pumps
- This practice appears to work effectively for many projects, especially those building projects that require excavations for deep basements.
- For dewatering deeper excavations, the well points must be installed in two or more stages

1. Single stage unit
2. Double stage unit

Setup and Procedure of working:

- A well-point is 5.0-7.5 cm diameter metal or plastic pipe 60 cm – 120 cm long which is perforated and covered with a screen.
- The lower end of the pipe has a driving head with water holes for jetting as shown in fig. Well-points are connected to 5.0-7.5 cm diameter pipes known as riser pipes and are inserted into the ground by driving or jetting.
- The upper ends of the riser pipes lead to a header pipe which, in turn, connected to a pump. The ground water is drawn by the pump into the wellpoints through the header pipe and discharged as shown in fig.
- The well-points are usually installed with 0.75m – 3m spacing

Double stage unit



Well point systems

Well point systems

Advantages	disadvantages
1. Effective in sandy soils 2. Provide drawdown up to 5-6 meters in sand and 4 meters in silty soil. 1. Relatively cheap and flexible 2. Installation is very rapid. 3. Water is filtered and carries little or no soil particles. 4. There is less danger of subsidence of the surrounding ground than with open-sump pumping	1. Not effective beyond 4-6 meters of drawdown 2. Might require stages of well installation.

DEEP WELL

- Deep well drainage system consists of deep wells and submersible or turbine pumps which can be installed outside the zone of construction operations and the water table lowered to the desire level.
- Deep wells are usually spaced from 8-80 meters depending upon the level to which water table must be lowered, permeability of the sand stratum, source of seepage and amount of submergence available.
- Deep wells may be combined with the well point system on certain field conditions for lowering the ground water tables

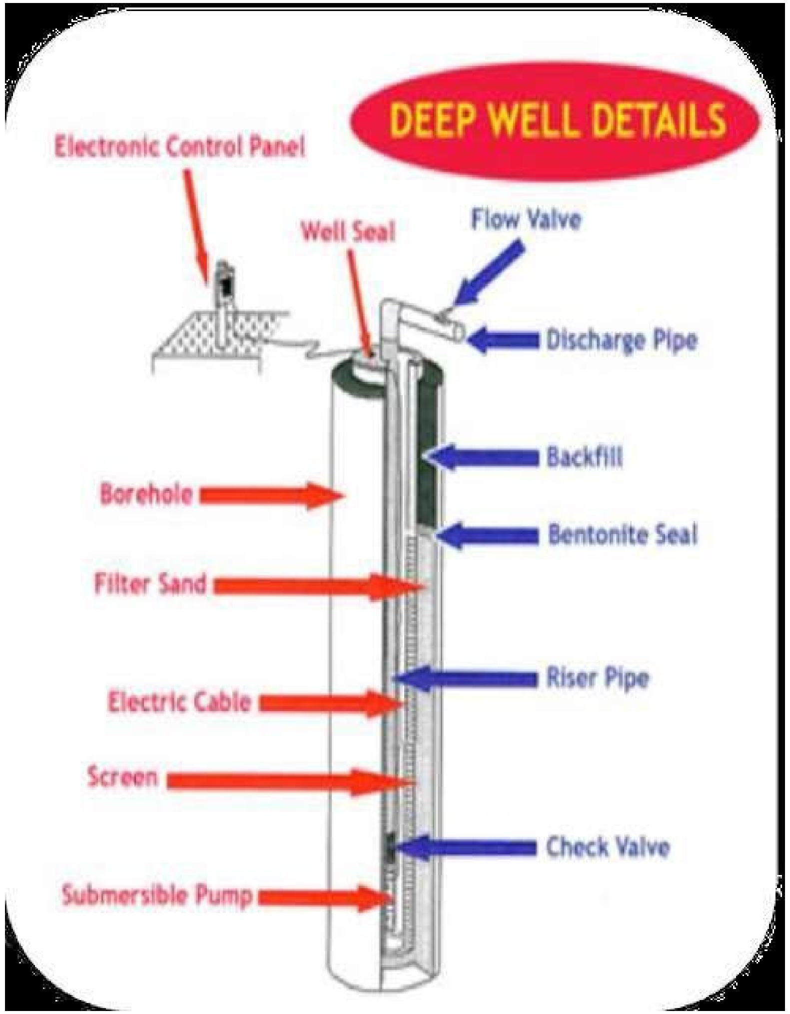
SPACING OF DEEP WELL POINT SYSTEM

- Normally, individual wells are spaced at an approximate distance of 15 m (50 feet) apart.
- However, depending upon soil conditions and the dewatering plan the spacing may need to be just a few meters apart.

DEWATERING CAPACITY OF DEEP WELL POINT SYSTEM

- Individual well capacities are from 2100 to 3000 gallons per minute and with total systems the capacities can be as high as 60,000 gallons per minute.
- Deep well pumps can lift water 30 m (100 feet) or more in a single stage and the variation of the typical deep well system is a pressure within an aquifer.
- Deep well points require no pump as the water is forced to the surface by its own pressure. To boost the water flow a vacuum pump is frequently used.

Deep well point system



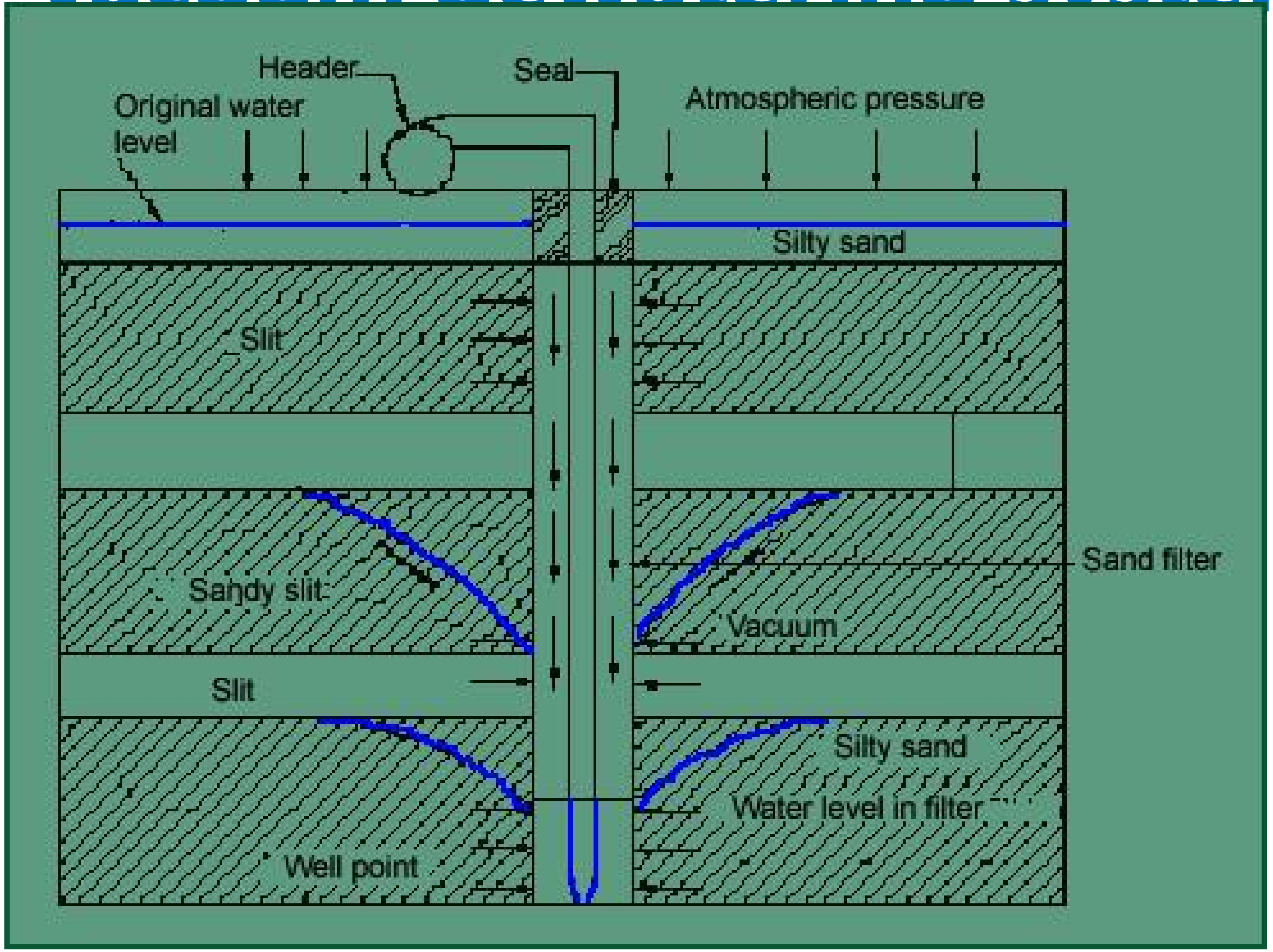
Deep well point system

advantages	Disadvantages
1. No limits on drawdown 2. Fewer wells required than well system	1. Expensive to install

Vacuum dewatering systems

- Gravity methods, such as well points and deep wells are not much effective in the fine-grained soils. Such soils can be dewatered satisfactorily by applying a vacuum to the piping system.
- A vacuum dewatering system requires that the well-point screens, and rise a pipe be surrounded with filter sand extending to within a few metres of the ground surface.
- This method is most suitable in layered or stratified soils.

Vacuum dewatering systems



Design steps for dewatering systems

- Design of a dewatering system requires the determination of the number, size, spacing, and penetration of wells or well points and the rate at which water must be removed from the pervious strata to achieve the required groundwater lowering or pressure relief. The size and capacity of pumps and collectors also depend on the required discharge and drawdown.
- The essential steps involved in the designing of the dewatering system are given below:

1. **Subsoil investigation**
2. **Source And Water Table Details**
3. **Distance of well points**

4.Effective Wall Radius

- The effective wall radius is decided based on the installation of the wells with or without filter. If a well is installed without gravel or a sand filter the effective radius can be taken as one half the outer diameter of the well screen. If a filter is used, the well radius is taken as one half the outside diameter of the filter

5.Discharge computations

The discharge Q of the well is then calculated using the formula given below:

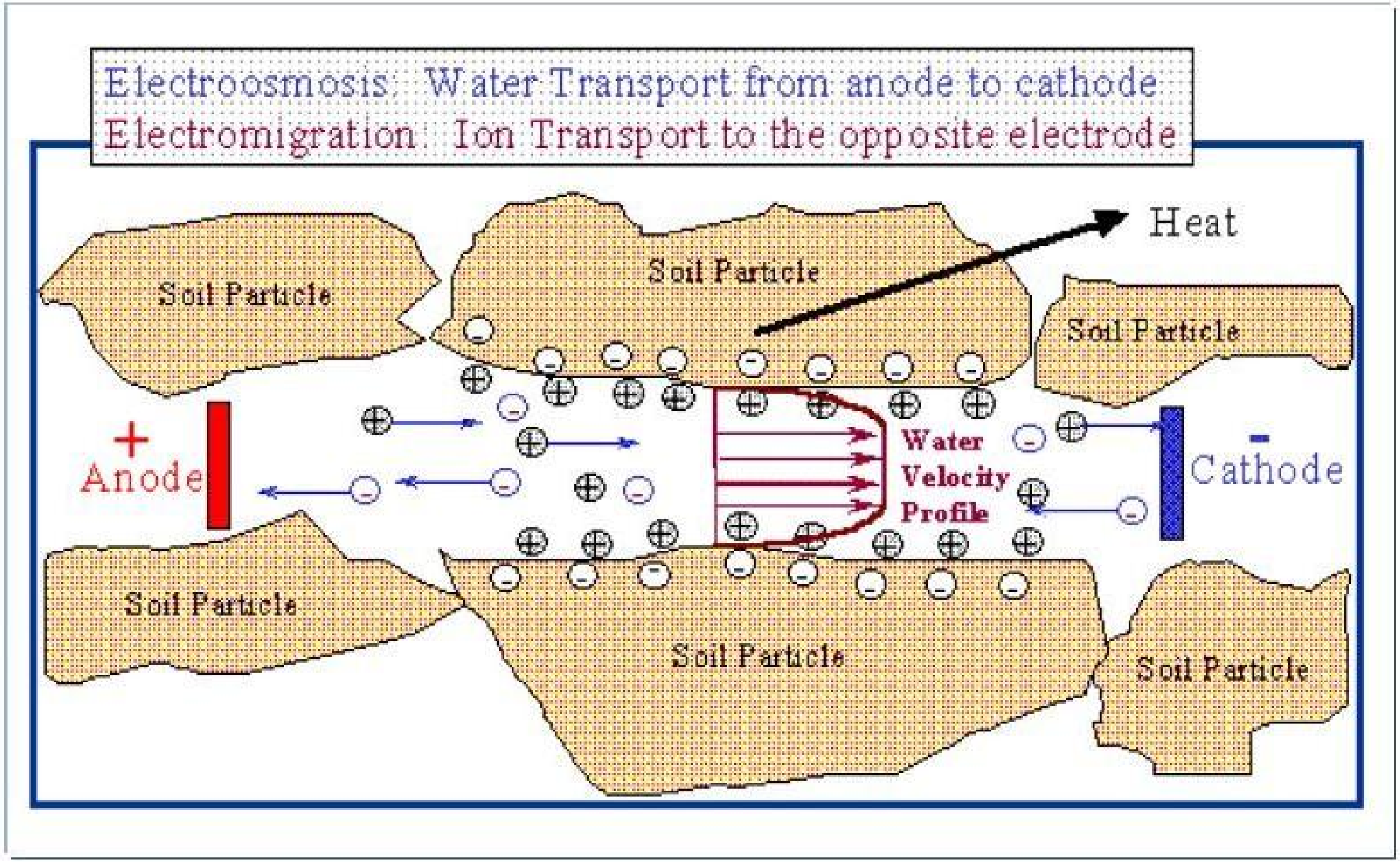
$$Q = \pi k \frac{H^2 - h^2}{2.3 \log_{10}\left(\frac{R}{r}\right)}$$

where Q is the discharge, k is the permeability, H is the depth of strata, h is the height of water in the well, r is the radius of well, R is the radius of influence.

Electro osmosis

- Dewatering Technique is done through the use of cathodes and anodes with passage of Electrical current.
- Electro-osmosis is defined as “the movement of water through a porous media by applying a direct current (DC) field”.
- It is the only effective method of dewatering in deep clay soils, silty clays, silts and some peats.

Electro osmosis



Mechanism of Electro-osmosis

- When electrodes are placed across a clay mass and a direct current is applied, water in the clay pore space is transported to the cathodically charged electrode by electro-osmosis.
- Electro-osmotic transport 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.
- The macroscopic effect is a reduction of water content at the anode and an increase in water content of the clay at the cathode.

Effectiveness of Electro-osmosis

- First, electro-osmosis provides uniform pore water movement in most types of soil.
- The entire soil mass between the electrodes is basically treated equally

Disadvantages

- Installation and running costs are usually high.