GROUND IMPROVEMENT TECHNIQUES

UNIT-1

Introduction

Need for Engineering ground Improvement

When a project encounters difficult foundation conditions, possible alternate solutions are:

- Avoid the particular site
- Design the planned structure accordingly.

Use a soft foundation supported by piles, design a very stiff structure which is not damaged by settlements

- Remove and replace unsuitable soils.
- Attempt to modify the existing ground

Classification of Ground modification Techniques:

4 Groups of Ground Improvement techniques

Mechanical Modification: Soil density is increased by the application of mechanical force, including compaction of surface layers by static vibratory such as compact roller and plate vibrators.

Hydraulic Modification:

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

Physical and chemical modification:

Stabilization by physical mixing adhesives with surface layers or columns of soil .Adhesive includes natural soils industrial by-products or waste.

Materials or cementations or other chemicals which react with each other and/or the ground.

When adhesives are injected via boreholes under pressure into voids within the ground or between it and a structure the process is called grouting. Soil stabilization by heating and by freezing the ground is considered thermal methods of modifications

Modification by inclusions and confinement:

Reinforcement by fibers, strips bars meshes and fabrics imparts tensile strength to a constructed soil mass. In-situ reinforcement is achieved by nails and anchors. Stable earth retaining structure can also be formed by confining soil with concrete, Steel, or fabric elements.

Suitability, Feasibility and Desirability

The choice of a method of ground improvement for a particular object will depend on the following factors.

- Type and degree of improvement required
- Type of soil , geological structure, seepage conditions
- cost
- Availability of equipment and materials and the quality of work required
- Construction time available
- Possible damage to adjacent structures or pollution of ground water resources
- Durability of material involved (as related to the expected life of structure for a given environmental and stress conditions)
- Toxicity or corrosivity of any chemical additives.
- Reliability of method of analysis and design.
- Feasibility of construction control and performance measurements If soil is moist, freezing is applicable to all type of soil.

Dewatering

Dewatering involves controlling groundwater by pumping, to locally lower groundwater levels in the vicinity of the excavation.

The application of **sumps and ditches** within an excavation is one of the elementary method of dewatering employed in construction. The water entering these installed units can be pumped out.

The general procedure of dewatering with sumps and ditches is depicted in the figure-1.

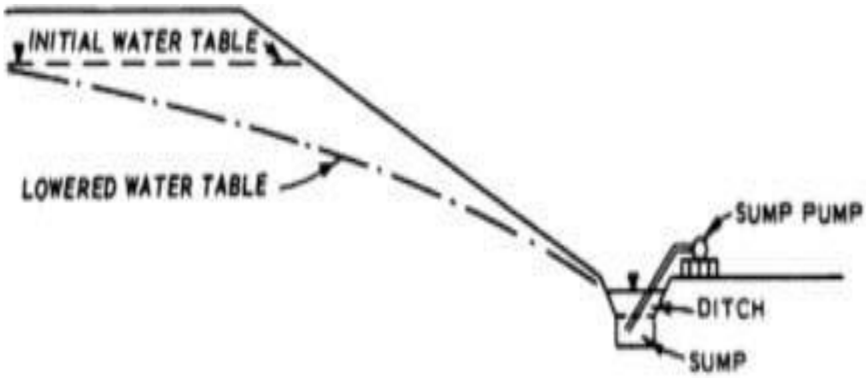


Fig.1. Dewatering Method by the Installation of Sumps and Ditches

The sump is located below the ground level of the excavation as shown in figure-1, at one or more corners or the sides. The procedure involves the cutting of a small ditch around the bottom of the excavation, that is falling towards the sump.

The sumps is the name given for the shallow pits that are dug along the periphery of the excavation or the drainage area, which is named as ditches. Under the action of gravity, the water from the slopes will flow to the sumps. The sumps collect the water and are later pumped out.

Significant amount of seepage can result in raveling or sloughing or softening of the slope in the lower part. The slump bottom may also be subjected to piping.

The above problems can be solved by the use of inverted filter that is of many layers. These have coarser material in successive layers from the bottom of the sump pit to the upward direction. This is a simple method used for dewatering shallow excavations that have coarse grained soils or the soils that have permeability that is greater than 10^{-3} cm/sec.

Suitability of Sumps and Ditches for Dewatering of Excavations

If the construction demands for lowering the water table or the ground water head of the area to a depth greater than 1 feet, the method of sumps and ditches is not suitable.

If sumps and ditches are employed for greater depth lowering, seepage will be prominent that will result in the instability of the excavation slopes. This wrong decision will also bring effects that are detrimental for the integrity of the foundation soils of the area.

In order to overcome the problems that arise due to minor raveling and to support the collection of seepage water, it is recommended to employ filter blankets or drains in the sump and ditch system installed.

Use of Sumps and Ditches in Cofferdams

In areas that are confined, the common method of excavation that is followed is the driving of a sheet pile that is either wood or steel, below the subgrade elevation. Then the bracing is installed and proceeds with the excavation of earth. Later the water that seeps into the cofferdam area is pumped out.

The use of sumps and ditches in the dewatering of sheet excavation face the limitation similar to that of open excavations. The formation of hydraulic heave at the bottom of the excavation which is found to be very dangerous can be reduced by the driving of sheeting into the impermeable strata that is underlying. This can help in the reduction of seepage into the bottom of the excavation.

Those excavation carried out below the water table can be effectively conducted with the help of sheeting and sump. This is merely dependent on the site conditions. The hydrostatic pressure and toe support are the two factors that is to be considered important while designing the sheeting and the bracing.

The construction process and the pumping out activities can be conducted smoothly by covering the bottom of the excavation by means of a inverted sand and gravel filter blanket.

Advantages of Sumps and Ditches

The advantages of Sumps and Ditches are:

1. The method is widely used. It is appropriate for small depth lowering.

2. This method is found to be most economical one among dewatering systems while considering the installation and the maintenance procedures

3. This method can be applied for most of the soil and rock conditions.
4. The site is mostly recommended where boulders or massive obstructions are met within the ground.
5. The greatest depth up to which the water table can be lowered by this method is 8m

Disadvantages of Open Sump and Ditches

The disadvantages of this method are:

1. In areas where there is high heads or steep slopes, the method is not demanded. This method will bring collapse of the slopes and cause dangerous problems
2. The use of sumps and ditches in open or timbered excavation will bring risk in the stability of the base.

The simplest form of dewatering is sump pumping, where groundwater is allowed to enter the excavation where it is then collected in a sump and pumped away by robust solids handling pumps. Sump pumping can be effective in many circumstances, but seepage into the excavation can create the risk of instability and other construction problems.

To prevent significant groundwater seepage into the excavation and to ensure stability of excavation side slopes and base it may be necessary to lower groundwater levels in advance of excavation. This is known as **'pre-drainage'.**

Pre-drainage methods include:

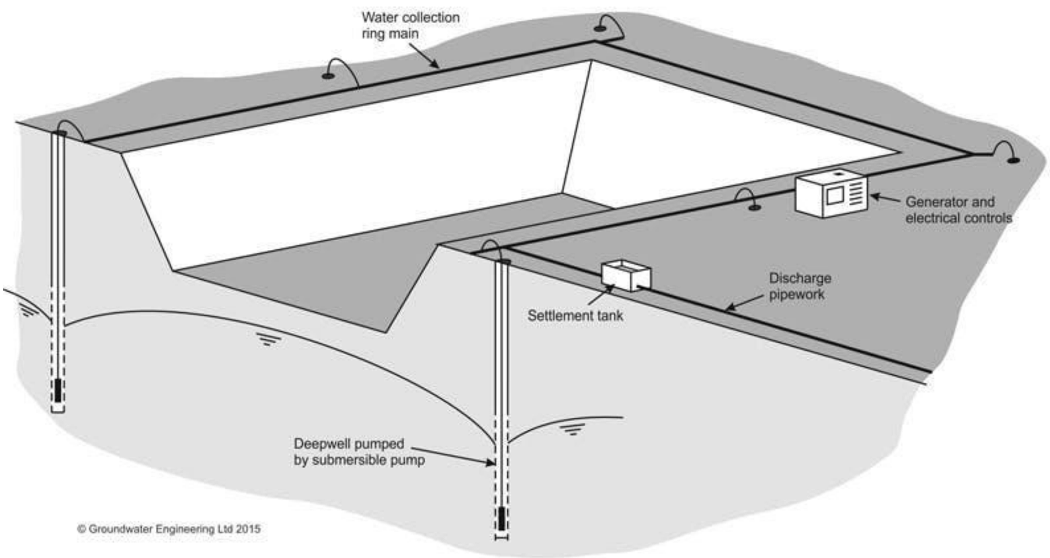
1. Deep wells
2. WellPoint's
3. Eductors
4. Vacuum wells
5. Horizontal wells

Other specialist dewatering techniques are also sometimes used:

1. Relief wells
2. Artificial recharge
3. Siphon drains

The selection of the dewatering technique or techniques at a particular site or country will depend on many factors. Groundwater Engineering's team has decades of experience in dewatering projects around the world, and we provide a complete design and installation service to control your groundwater problems.

DEEP WELLS



A deep well system consists of an array of bored wells pumped by submersible pumps. Pumping from each well lowers the groundwater level and creates a cone of depression or drawdown around itself. Several wells acting in combination can lower groundwater level over a wide area beneath an excavation. Because the technique does not operate on a suction principle, large drawdowns can be achieved, limited only by the depth of the wells, and the hydrogeological conditions.

The wells are generally sited just outside the area of proposed excavation, and are pumped by electric submersible pumps near the base of each well. Water collection pipes, power supply generators, electrical controls and monitoring systems are located at the surface.

This is shown in figure-1. Here the excavation can be pre*drained for the complete depth.

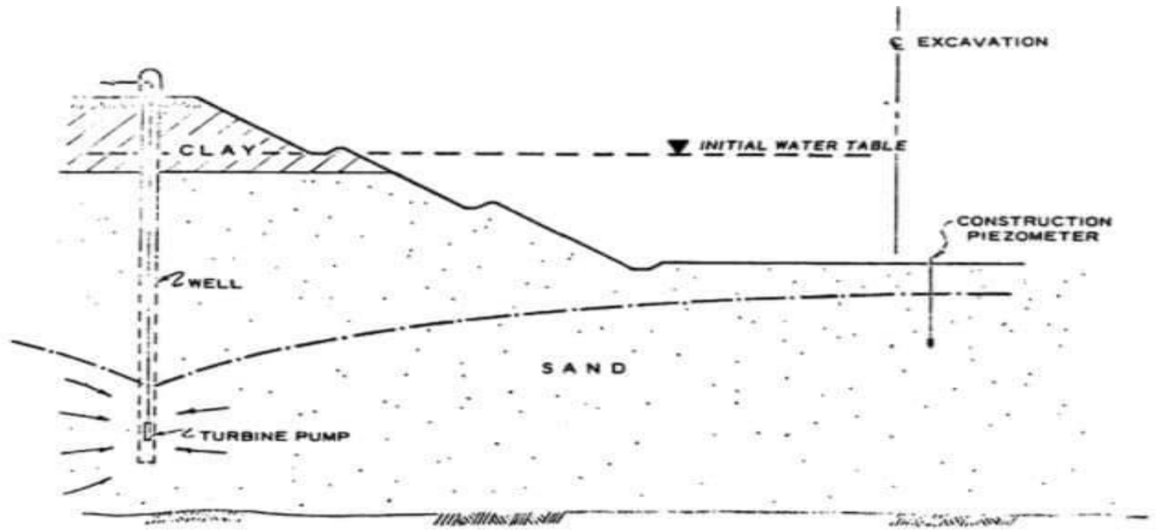


Fig.1: Deep Well Dewatering System

Working and Arrangement of Deep Well System

The deep wells arrangement for the purpose of dewatering is similar to that for commercial water wells. These systems will make use of a screen that have a diameter of 6 to 4 inches with lengths ranging up to 300 feet.

When such a system is installed, a filter is placed around the screen. This arrangement helps to prevent the infiltration of the foundation materials into the well. The installation of filter also helps to improve the yield.

In order to dewater small deep excavations, the deep well systems can be used in conjunction with the deep wells. This is applied for related works of tunnels, caissons sunk, shafts and the areas with fine grained sand or stratified soils that are pervious. In areas, there are rock layer below the ground table this method work best.

An increase in hydraulic gradient to the well because of the use of vacuum creates a vacuum within the surrounding. This phenomenon avoids seepage from the perched water into the excavation.

The installation of deep well system incorporating vacuum is shown in figure-2. This type requires adequate vacuum capacity to undergo the dewatering operation efficiently.

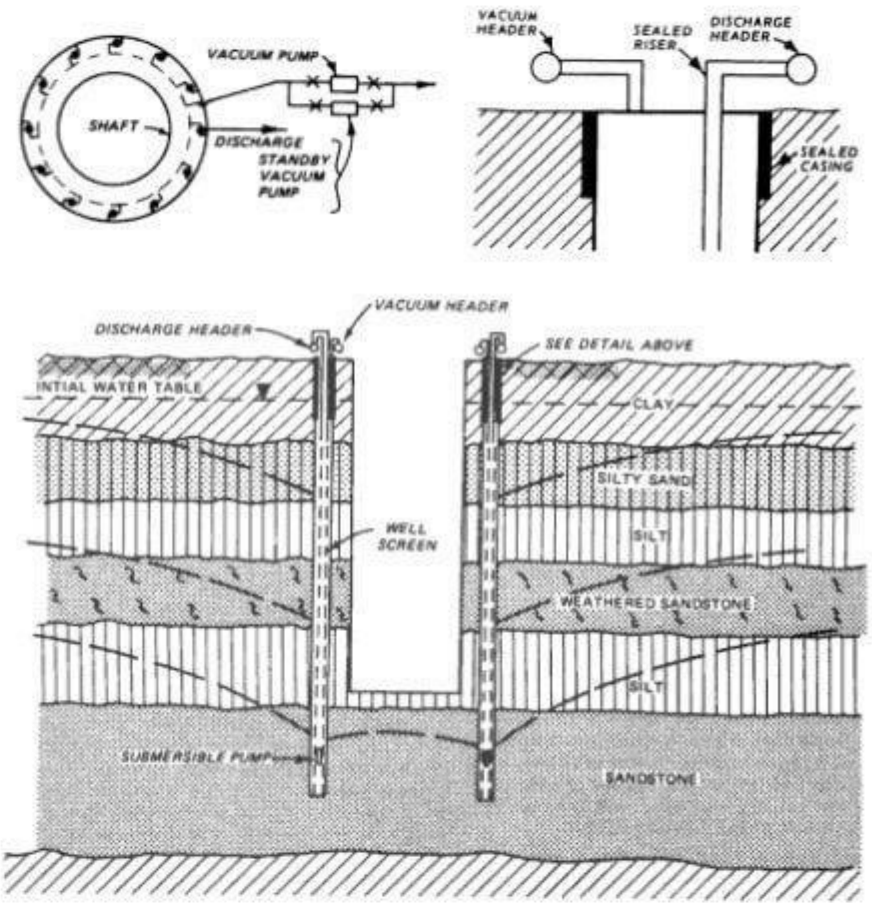


Fig.2. The use of deep well with vacuum systems to dewater a shaft over a stratified ground material.

To have sufficient wetted area of intake in the aquifer, adequate well depth have to be provided. This helps to produce yield and interactive drawdown. In most of the civil engineering applications, a depth of 60m with a typical depth value of 20m is used.

For a limited distance say 1 to 2m, the well might penetrate an impermeable layer lying below the pumped aquifer. This is to behave as sump for the fines. The pump must be placed such a level in the well so that the water circulation helps it to remain cool.

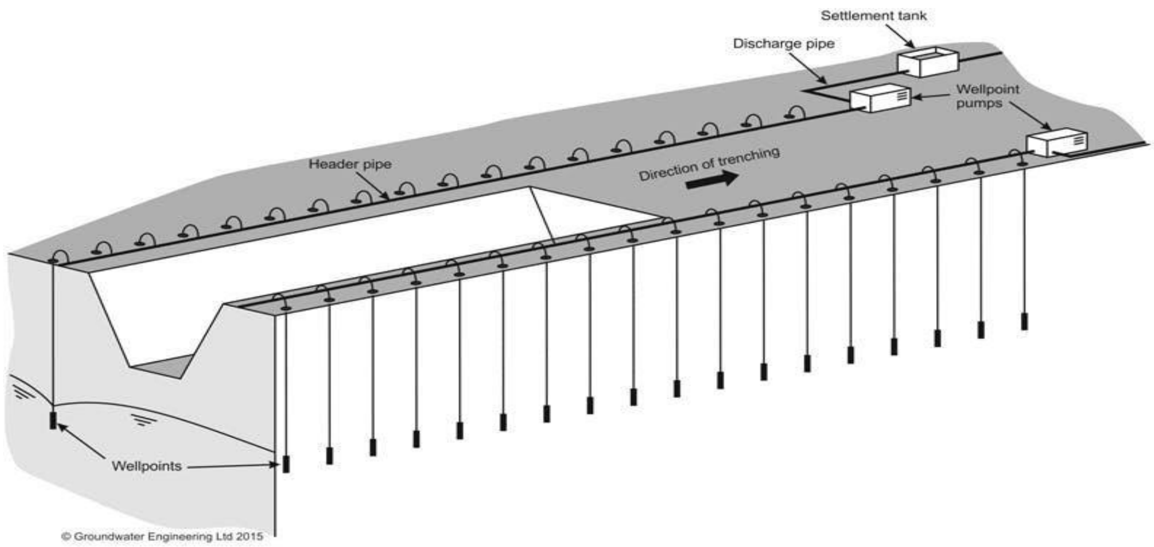
The site layout decides the spacing of the wells. But most commonly, the spacing used is 10 to 30m. The deepening of the well creates drawdown in areas. Sometimes these might be the areas where the wells cannot be sited.

Special care and precaution must be taken so that with increase in drawdown no kind of settlement is happening to the adjacent buildings.

Groundwater Engineering provides complete deep well dewatering solutions:

- Design of dewatering systems
- Well drilling and installation
- Pumping tests
- Equipment sales and rental
- Monitoring systems
- On-site operation and maintenance

WELLPOINTS



Wellpoint dewatering is widely used for excavations of shallow depths, especially for pipeline trench excavations. In appropriate ground conditions a wellpoint system can be installed speedily and made operational rapidly. A typical wellpoint system consists of a series of small diameters wells (known as wellpoints) connected via a header pipe, to the suction side of a suitable wellpoint pump. The pump creates a vacuum in the header pipe, drawing water up out of the ground. For long pipeline trenches, **horizontal wellpoints** may be installed by special trenching machines.

Wellpoints are typically installed in lines or rings around the excavation, and are pumped by diesel or electrically powered pumps, with associated header mains, water discharge pipes, power supply generators, electrical controls and monitoring systems.

There are two types of well point system, namely single stage well point system and multi-stage well point system. These systems are briefly described in the followings.

1. Single Stage Well Point system
2. Multistage Well Point system

Single Stage Well Point system – A well point consists of a pipe about 1 m long and 50 mm in diameter. It has perforations, which are covered with a screen to prevent clogging in. At the lower end, a jetting nozzle is provided. This nozzle also acts as a drive point. A ball valve provided near the lower end allows the water to flow only in downward direction during installation of the well point. A sketch of the well point is shown in Fig.1 below. A riser pipe having the same diameter as the well point connects the well point at its bottom end. The riser pipes are connected to a horizontal pipe, known as header pipe, at the ground level. The header pipe is connected to a pumping unit. The well points are spaced every 0.6 to 1.5 The well points are installed to the required depth by jetting water through riser pipes in the downward direction. Once installed pumping is started continuously till the excavation work is completed.

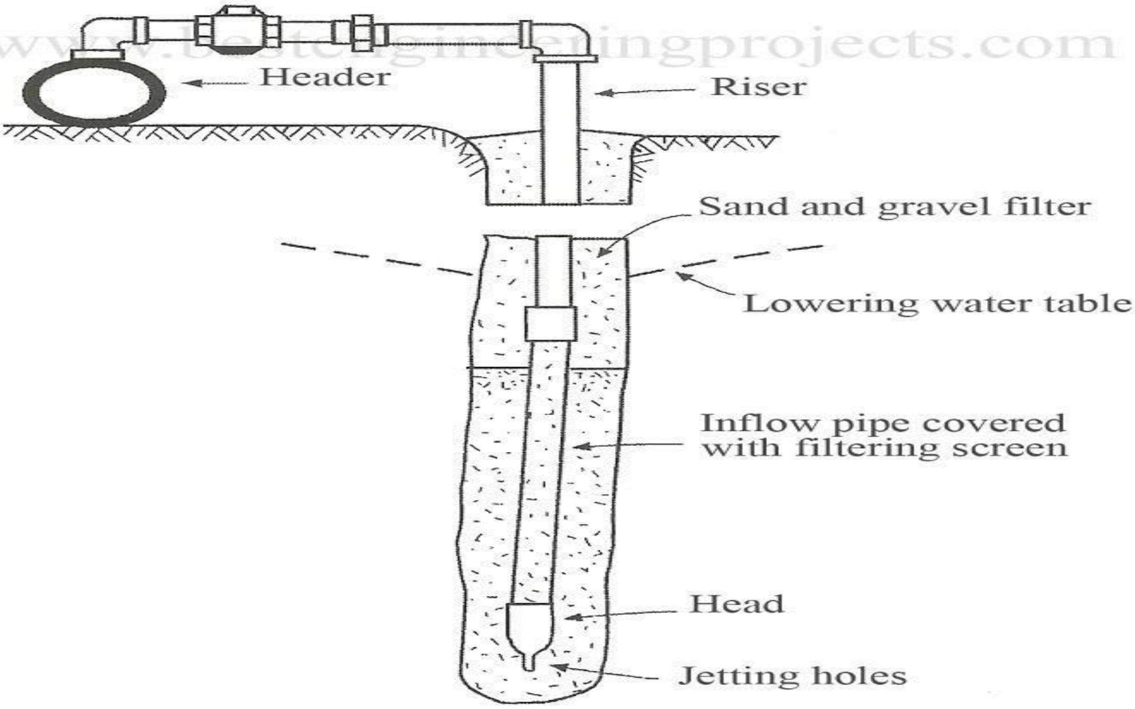


Fig 1 Single Stage Well Point

Single stage well point system is used when the depth of excavation is less than 4.5 m. They are effective in granular soils. By Single stage well point stage method the water table is lowered by about 4.5m. This method is suitable to soils having coefficient of permeability between 10^{-2} to 10^{-4} cm/sec.

Multistage Well Point system – These systems are used if excavation exceeds 4.5 m and there is a chance of slope failure. The set up of the system is shown in Fig.2.In this system the well points are installed in stages. In the first stage well points are installed to a depth of around 4.5 and put into action till the water table is lowered by about 4.5 m. Then the area is excavated up to this 4.5 m depth. After this second stages of well points are installed within the area, which is excavated already. The water table is further lowered by another 4.5 m.

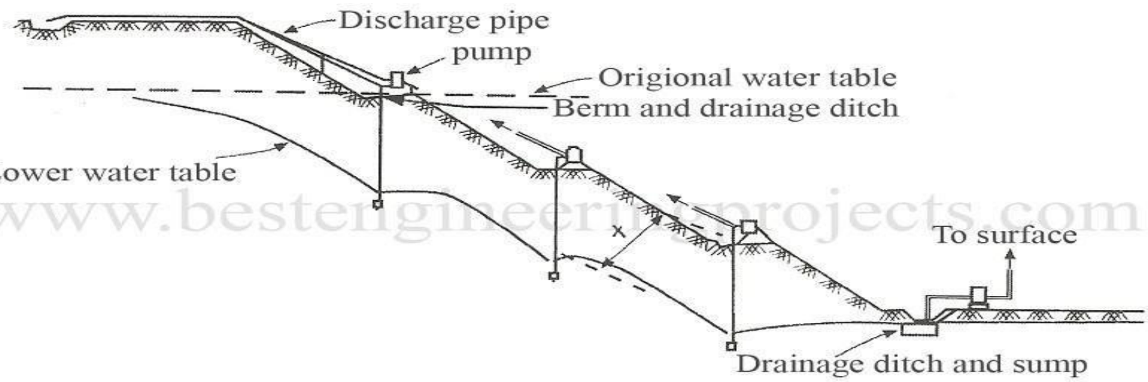


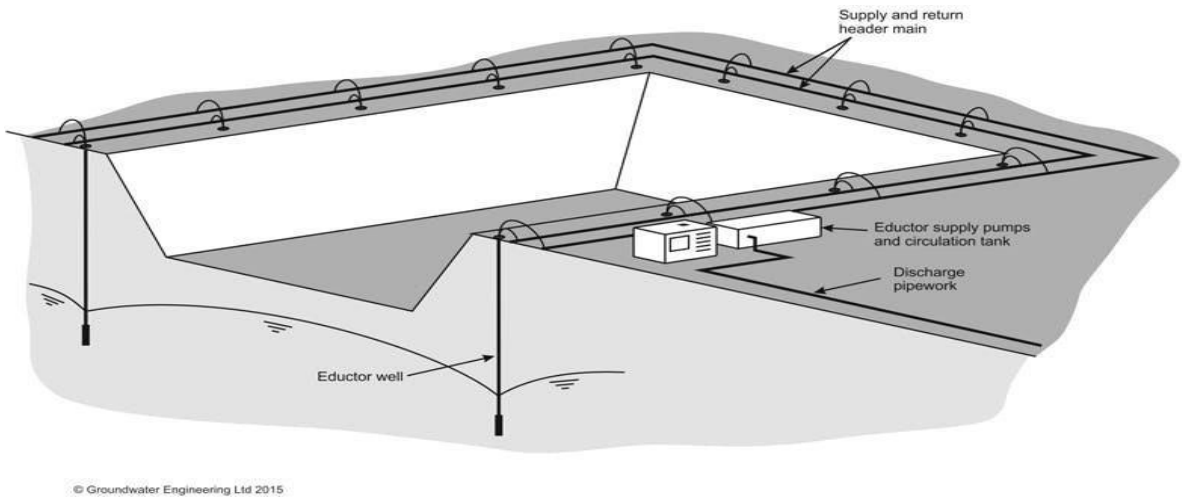
Fig 2 Multistage Well pump

In this way the excavation is carried out till the excavation reaches to about 15 m. By well point system method excavation greater than 15 m cannot be made.

Groundwater Engineering provides complete wellpoint dewatering solutions:

- Design of dewatering systems
- Wellpoint installation
- Equipment sales and rental
- Monitoring systems
- On-site operation and maintenance

EDUCTORS



The eductor system (also known as the ejector system) is specialist technique used to control pore water pressure in low permeability soils such as very silty sands, silts, or clays with permeable fabric. Eductors are typically used to help stabilise the side slopes and base of excavations in soils that would be difficult to dewater with wellpoints or deep wells.
Eductors have the advantage that they can allow vacuum-assisted drainage, to draw water out of poorly draining fine-grained soils. The system works by circulating high pressure water (from a tank and supply pumps at ground level) down the well to a small-diameter nozzle and venturi located in the eductor in each well. This generates a vacuum of up to 9.5 m of water at the level of the eductor. The vacuum draws groundwater into the well from where it is piped back to ground level via a return riser pipe and thence through the reservoir tank back to the supply pump for recirculation.

Groundwater Engineering provides complete eductor dewatering solutions:

- Design of dewatering systems
- Well drilling and installation
- Equipment sales and rental
- Monitoring systems
- On-site operation and maintenance

VACUUM WELLS

Vacuum wells are an adaptation of **deep well** systems. Each well in the system is pumped by a submersible pumps, but a vacuum is also applied to each well via a vacuum pump located at the surface. The application of a vacuum allows the wells to be more effective in reducing pore water pressures in poorly draining fine grained soils. In appropriate ground conditions vacuum wells can be a viable alternative to **eductors**.
Groundwater Engineering provides complete vacuum well dewatering solutions:

- Design of dewatering systems
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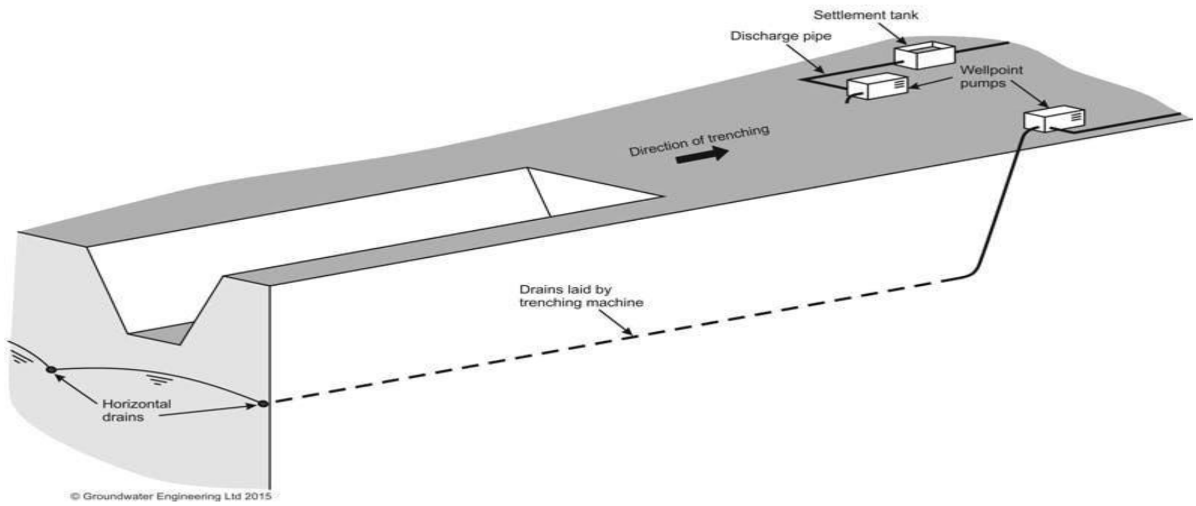
HORIZONTAL WELLS



Horizontal wells for dewatering are of two principal types:

- Horizontal drains installed by specialist trenching machines
- Horizontally directionally drilled (HDD) wells.

Horizontal drains installed by specialist trenching machines

This technique uses a horizontal flexible perforated pipe, pumped by a wellpoint pump, to lower groundwater levels. The perforated pipe is installed by a special trenching machine. One end of the pipe is unperforated and is brought to the surface and connected to a wellpoint suction pump. The method can be very effective for dewatering long pipeline excavations.

Horizontally directionally drilled (HDD) wells

HDD wells are used where groundwater must be abstracted from beneath inaccessible areas or from areas where the disruption associated with surface drilling is undesirable. Applications for HDD wells include:

- Installation of permanent dewatering systems beneath existing built up (urban) environments.
- Pumping for remediation of contaminated groundwater without the risks of cross-contamination associated with vertical drilling
- Dewatering for tunnel construction
- Recharge wells to re-inject water as part of artificial recharge schemes.

Groundwater Engineering provides complete horizontal well dewatering solutions:

- Design of dewatering systems

- Well drilling and installation
- Pumping tests

- Equipment sales and rental
- Monitoring systems
- On-site operation and maintenance

Drains:

A Drain consists of filter, conduit and disposal system. A filter is necessary for continued efficiency of the drain and to prevent seepage erosion. The collection of water is done in the drain conduits. Normally the size of the conduit is 5 to 10 times larger than its hydraulic dictate. The commercial pipes have perforations of diameter 8 to 9mm and are need of 12 to 15mm gravel filter.

Classification:

a. Open drains
b. Closed drains
c. Horizontal drains
d. Foundation drains
e. Blanket drains
f. Interceptor drains

Open drains

- Drainage systems may be open or closed (subsurface), depending on the drainage method.
- In the open system, open channels are used as the regulating network, whereas in the closed system, the regulating network is made up of closed collectors and has underground drains and small channels.
- In both systems, the main conducting and protective channels are open.
- Open drainage systems are used for the initial drainage of marshes and forests and sometimes also of hayfields and pastures.
- Their drawbacks include a reduction in land available for cultivation, interference with mechanized farming operations, and overgrowth with weeds and other types of interference in the channels.

Closed drains

Closed drainage systems are technically more advanced and long lasting.

They do not have the shortcomings of open systems, and they offer great potential for irrigation of drained lands during dry periods of the growing season.

For every 30m to 50m there must be openings to flush out the pipe. At 100m to 150m intervals, the manholes must be provided at changes in direction along straight sections.

Such systems are built for intensive use of drained lands.

The Criterion For Selecting Of Fill Material Around Drains

The criteria for **selecting** material as suitable for use as fill shall be based on achieving adequate strength, stiffness and permeability after compaction. These criteria shall take account of the purpose of the fill and the requirements of any structure to be placed on it.

- Suitable fill materials include most graded natural granular materials and certain waste products such as selected colliery waste and pulverized fuel ash. Some manufactured materials, such as light aggregate, can also be used in some circumstances. Some cohesive materials may be suitable but require particular care.

- The following aspects shall be considered when selecting a fill material:

- grading;
- resistance to crushing;
- compactibility;
- plasticity;
- organic content;
- chemical aggressivity;
- pollution effects;
- solubility;
- susceptibility to volume changes (swelling clays and collapsible materials);
- the effect of frost;
- resistance to weathering;
- the effect of excavation, transportation and placement;
- the possibility of cementation occurring after placement (e.g. blast furnace slags).

- If local materials are not suitable for use as fill in their natural state it may be necessary to adopt one of the following procedures:

- adjust the water content;
- mix with cement, lime or other materials; - crush, sieve or wash;
- Protect with appropriate material; - use drainage layers.

- When the selected material contains potentially aggressive or polluting chemicals, adequate provisions shall be adopted to prevent these attacking structures or services or polluting the groundwater. Such materials shall only be used in large amounts in permanently monitored locations.

Blanket Drains

- A drainage blanket is a very permeable layer of material. It can be used to remove water from beneath pavement structures when applied as a permeable base or can be used effectively to control groundwater from cut slopes and beneath fills.

- In slope stability applications drainage blankets improve slope stability by preventing a seepage surface from developing on the slope and by providing a buttressing effect.

- Drainage blankets are also used as an interface between embankment and soft foundations to provide drainage during foundation consolidation.

- Blanket drains often require a collection system and transverse pipe under drains may be needed to outlet the blanket.

Horizontal Drains

- Horizontal drains can be relatively inexpensive and effective in lowering groundwater levels and relieving stresses on slopes, side hill fills and behind retaining structures.

  Their principle use is in slope stabilization applications.

- A horizontal drain is a perforated or slotted pipe advanced into a slope with a special auger typically at 5 degrees above horizontal. The last 10 ft of pipe should be left imperforated to assure that water flows out.

- Filter material or filter fabric should be used if clogging is expected. This can greatly extend the life of the drain but is extremely difficult to install.

- Horizontal drains should be designed by the Geotechnical Section. They are commonly installed in fan-shaped arrays of several pipes emanating from a common point.

- Construction of horizontal drains can often be complicated depending on the drilling capabilities and techniques used. Soil conditions and moisture can affect stability of borings. Horizontal and vertical controls are essential to ensure that the drains are installed as intended.
- Regular maintenance and inspection of horizontal drain installations is critical to ensure effectiveness. Horizontal drains can clog from precipitation of metals, piping of fine particles and root penetration.

- Clogged drains can sometimes be cleaned with high pressure water systems. Drains installed in unstable soil slopes which continue to move after installation can fail.

Underdrains

- Deep underdrains can be used to lower groundwater levels in slopes and intercept seepage before it can reach the slope face.

- Interceptor drains are most effective when deep enough to intercept an impervious layer below the surface. Although interceptor drains as deep as 30 feet have been constructed in Colorado, construction techniques and worker safety should be considered before recommending an underdrain.

- Often other drainage methods will need to be considered when subsurface drainage is required at greater depths. If continued movement of the slope is possible, perforated pipe in an underdrain is likely to rupture and fail.

Interconnected Belled Caisson Drains

- Interconnected belled caisson drains are usually used to lower groundwater levels on unstable slopes where depths restrict the use of underdrains.

- A caisson drill rig is used to auger a line of large diameter holes. The bottom of each hole is belled such that each hole is interconnected.

- The belled caisson holes are filled with a coarse aggregate drainage material immediately after drilling. This is done one caisson at a time until the drain is complete.

- Vertical and horizontal control is essential to ensure that continuity and positive drainage is provided between adjacent bell sections.

Caisson drains are outlet with non-perforated pipe that is stubbed into the last caisson bell. The outlet pipe is typically larger in diameter than underdrain outlet pipe because of the large flow capacity of these drains. Interconnected belled caisson drains must be established in material which is firm enough to support them; usually shales. The use of this method is limited to those locations where this condition can be met.

Dewatering by electro osmosis

- When an external electro motive force is applied across a soild 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.

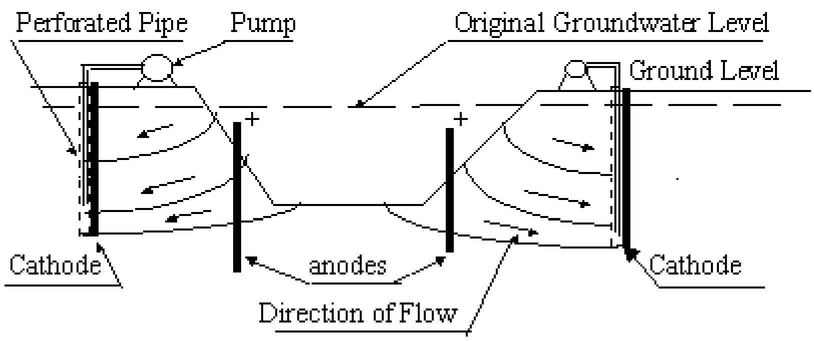


Fig. 8.8 Control of Groundwater by Electro-Osmosis Methods

SAFETY MEASURES

- Only persons wearing rubber boots should be admitted into the neighbourhood of the electrodes,

- While working between anode and cathode neither the electrode nor the wiring should be touched in such a manner that while one hand is on the electrode, the other gets into contact with the ground or with the other electrode.

- Where the excavation is carried out by machinery special attention has to be paid by the operator to avoid the occurrence of short circuits.

GROUTING

Grout is a fluid form of concrete used to fill gaps. **Grout** is generally a mixture of water, cement, and sand, and is employed in pressure **grouting**, embedding rebar in masonry walls, connecting sections of pre-cast concrete, filling voids, and sealing joints such as those between tiles.

Grouting is a high-cost treatment method and should be used where there is adequate confinement to handle the injection pressures. The typical applications include control of groundwater during construction, filling voids to prevent larger amounts of settlement, soil strengthening, stabilization of loose sands, foundation underpinning, filling voids in calcareous formations and strengthening soils for protection during excavation. Selection of the most suitable method for stabilization will depend on the type of soil, degree of improvement and depth and extent of treatment required. Another factor to consider is whether the treatment is required for a new or existing structure.

Grouting especially with some chemical grouts may present risks to the public health and environment that must be considered. Considerations for utilizing a treatment method include energy use, maintenance costs, requirements for excavation and adequate treatment performance. Environmental risks include mismanagement of surface and groundwater drainage and incomplete treatment. Leachates and migration of contaminants can contaminate subsoil, groundwater, water wells and nearby surface water unless properly managed. There are several ground barrier methods used to control seepage, which include slurry-trench cutoff walls and grout curtains.

The advantages of grouting include:

a. Can be performed on almost any ground condition
b. It doesn't induce vibration and can be controlled to avoid structural damages
c. Improvements to ground formations can be measured
d. Very useful for confined spaces and low headroom applications
e. Used for slab jacking to lift or level distorted foundations
f. Can be installed adjacent to existing walls.
g. Can be used to control seepage, groundwater flows and hazardous waste plumes

The primary **Objectives of grouting** ground formations are to:

a) Increase the strength and bearing capacity or the soil stability,

b) Reduce seepage and control groundwater during construction,

c) Form groundwater barriers and d) rehabilitate or reinforce structures.

The Different Investigation Methods Carried Out Before Grouting:

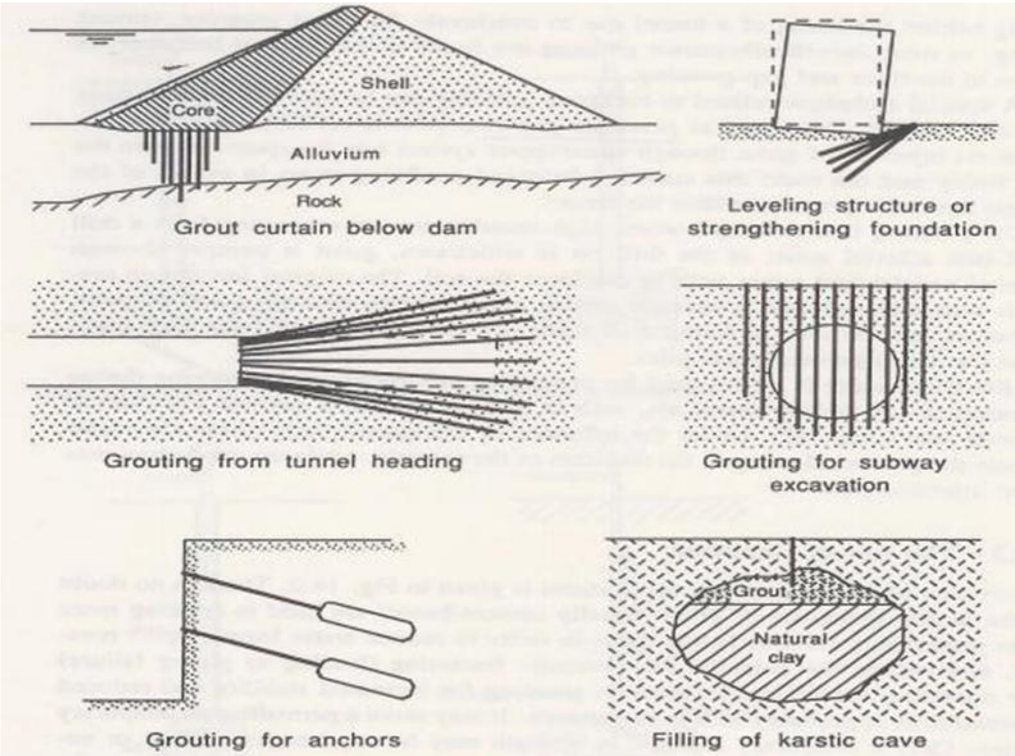
- Drilling and direct inspection to accurately locate and determine local conditions.
- Taking coring samples for laboratory tests.
- Drilling with drilling data recording to locate fissured zones, voids and the interface between structure and surrounding ground
- Borehole logging with BHTV Scanner examination (optical/seismic)
- Non-destructive geophysical investigations (seismic resistivity)
- Water testing (constant head or falling head tests conducted in borehole)
- Underground flow & temperature measurements

- Pumping test to assessment of initial hydraulic conditions.

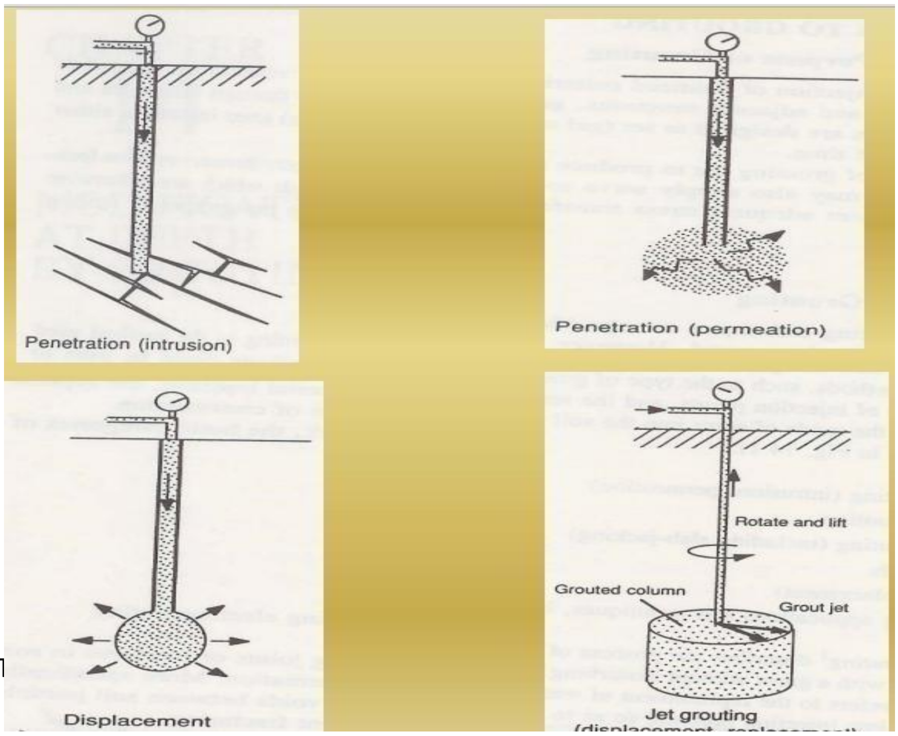
The Applications Of Grouting

Grouting May Be Used In The Following Applications:

- Filling Voids To Prevent Excessive Settlement
- To Increase Allowable Pressure Of The Soil Both For New Structures And / Or Additions To Existing Structures.
- Control Of Groundwater Flow
- Prevention of Loose - Loose to Medium Sand Densification under Adjacent Structures (i.e. both for Vertical and Lateral Movements) Due To Adjacent Excavations, Pile Driving Etc. Ground Movement Control during Tunnelling Operations.
- Soil Strengthening To Reduce Lateral Support Requirement.
- Soil Strengthening To Increase Lateral and Vertical Resistance of Piles.
- Stabilization of Loose Sands against Liquefaction.
- Foundation Underpinning.
- Slope Stabilization.
- Volume Change Control Of Expansive Soils Through Pressure Injection Of Lime Slurry (Only For Some Expansive Soils Not All)



The Systematic Representation Of Different Methods Of Grouting:



Different Grouting Materials

Grout Materials:

1. **Suspensions:** Small particles of solids are distributed in a liquid dispersion medium.

Example: cement and clay in water

2. **Emulsions:** A two phase system containing minute (colloidal) droplets of liquid in a disperse phase.

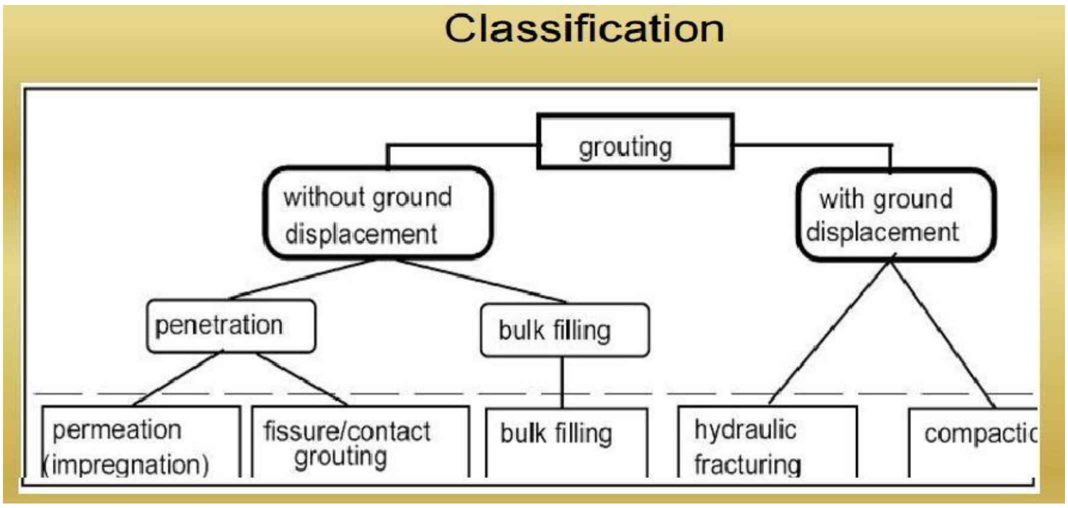
Example: bitumen and water. Foams created by emulsifying a gas into the grout material, which could be cement or an organic chemical. Foaming agents increase surface tension; assist in forming bubbles by agitation.

3. **Solutions:** Liquid homogeneous molecular mixtures of two or more substances. Example: sodium silicate, organic resins, and a wide variety of other so called chemical grouts.

Principal type of Grout:

	State								
	Suspensions				Liquids				
	Unstable			Stable	Chemical products		Aerated emulsions		
Grout type	Cement	Bentonite + cement		Deflucculate bentonite	Sodium silicate hard gels	Sodium silicate diluted gels	Organic resins	cement foams	Organic foams
Range of uses	Fissures	Sand and Gravels k m/s					Cavities	High water flows	
		$>5\times10^{-4}$	$>10^{-4}$	$>10^{-5}$	$>10^{-5}$	$>10^{-6}$			
Grouting control	Refusal pressure	Limited Quantities					Filling		
Relative cost for the products to fill 1 m^3 voids	4.2 (deposite) with Y_d = 1.2	1 (cement 200kg, betonite 30kg)	0.8 -1	6	2.4	10-500	1.2	10	

Classification Of Grouting



Different Types Of Grouting

Types of Grouting

- Penetration grouting or Permeation grouting
- Displacement grouting
- Compaction grouting
- Grouting of Voids
- Jet grouting
- Electro grouting

Penetration grouting or Permeation grouting

This method describes the process of filling joints or fractures in rock or pore spaces in soil with a grout without disturbing the formation

Displacement grouting

It is the injection of grout into a formation in such a manner as to move into the formation, it may be controlled, as in compaction grouting or uncontrolled. As in high pressure soil or rock grouting which leads to splitting of the ground, also called hydro fracture.

Compaction grouting

Grout mix is specifically designed so as not to permeate the soil voids or mix with the soil. Instead, it displaces the soil into which it is injected.

Jet grouting

The high-pressure water or grout is used to physically disrupt the ground, in the process modifying it and thereby improving it

Grouting of Voids

Using this process, grout is pumped under pressure into a void beneath a structure. The cavity might have been caused by a water supply or drainage line break where the soils have been washed away. It is ideal for situations during new construction or machine placement where a void cannot be easily filled without extensive rip out. To account for proper travel and strength qualities, the grout mix is custom-designed for each application.

Electro grouting

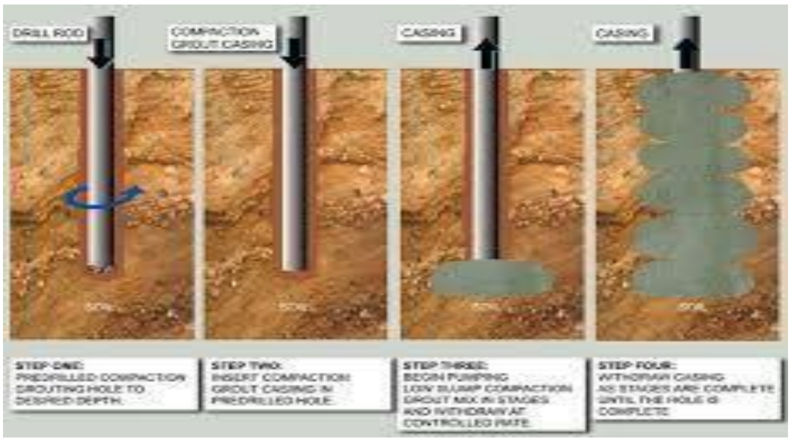
Electro grouting is a term used for promoting electrochemical hardening during electro osmosis by adding chemicals, such as sodium silicate or calcium chloride, at the anode. Under the influence of the electric field, these chemicals permeate the ground, flowing in the direction of the cathode, while the anode becomes a grout injection pipe.

Compaction Grouting

- Compaction grouting is a ground treatment technique that involves injection of a thick-consistency soil-cement grout under pressure into the soil mass, consolidating, and thereby densifying surrounding soils in place.

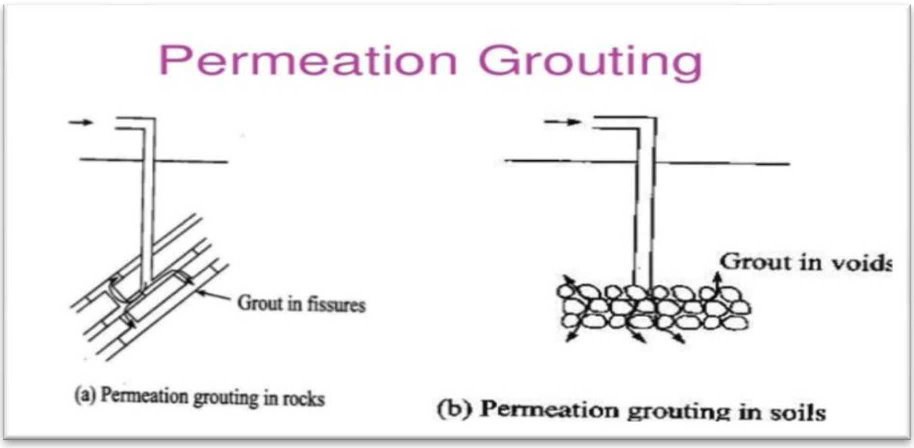
The injected grout mass occupies void space created by pressure-densification. Pump pressure, as transmitted through low-mobility grout, produces compaction by displacing soil at depth until resisted by the weight of overlying soils.

- When injected into very dense soils or bedrock, compaction grout remains somewhat confined, since the surrounding material is quite dense.
- However, when injected into under-consolidated or poorly compacted soils, grout is able to "push" these materials aside.
- When grouting treatment is applied on a grid pattern, the result is improved compaction of displaced soils and greater uniformity of the treated soil mass.
- As a secondary benefit, the resulting grout columns add strength in the vertical axis, as typical grout compressive strengths exceed those of the surrounding soils.
- Compaction grouting applications include densification of foundation soils, raising and relieving of structures and foundation elements, mitigation of liquefaction potential, augmentation of pile capacity and pile repair, and densification of utility trench backfill soils.



Permeation Grouting

- Permeation grouting is a term used to describe a ground treatment method in which grout is injected into a porous medium without disturbing its original structure.
- In geotechnical engineering, this usually refers to the process of filling the pores and joints in a soil and/or rock deposit to change its geotechnical properties.
- Almost any grout material may use for permeation grouting, but there are distinct limits on the grout mix used for specific types of soil or rock.
- Applications are for enhanced foundation bearing value, improvement of excavation character in sands and reduction of liquefaction potential.



- The image shows a sample of permeation grouted sand from a project that required steep-walled footing excavations in running sands.
- The proposed excavation area was permeation grouted with a micro fine cement slurry prior to cutting footing trenches, resulting in a significant reduction in project cost. Unconfined compressive strength tests performed

confirmed the improvement

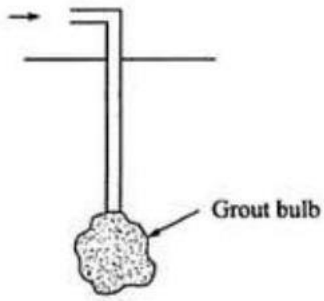
Particulate grouts are typically water-based slurries of cement, fly ash, lime or other finely ground solids that undergo a hardening process with time.

- These materials may be used to fill pores and joints in soil and rock, provided the grout particles are small enough to be carried through the pore or joint openings.
- A good rule of thumb is that the effective particle diameter in the grout suspension should be less than the dimension of the pore or joint aperture divided by 5.
- Slurry grout mixes used for permeation grouting are designed primarily to promote passage of the grout particles into the porous medium. The grain size of the slurry is matched to the pore aperture and steps are taken to assure the grout particles are properly dispersed in the grout.
- To eliminate the effect of bleed on Portland cement grout, additives are used to hold the cement grains in suspension at water to cement ratios that would otherwise be quite unstable. The most common additive is a water suspension of bentonite. Even small amounts of bentonite increase the inter particle forces dramatically and hold the cement particles in suspension.
- **Permeation grouting** is also known as Penetration grouting.

Displacement Grouting:

Displacement grouting is the injection of grout into a formation in such a manner as to move the formation, it may be controlled, as in compaction grouting or uncontrolled, as in high-pressure soil or rock grouting which leads to splitting of the ground, also called hydro fracture.

- Displacement grouting involves the use of grout to displace soil
- Such displacement can fill voids, cap sinkholes, deal with poor soils and leave grout mass in place.
- Displacement grouting constitutes a method of introducing support elements into a soil which cannot otherwise be modified readily.
- Such grouting takes on a number of names such as pressure grouting, cement grouting, slurry grouting, all of which are designations of both grouting and grout.
- The grouts involved in Displacement grouting range from compaction grout, through low mobility non-cohesive grout, to thinner and less viscous materials.
- Many are cement based because of low cost although ground rubber, walnut shells, oyster shells, and many other available things have been used in grout, depending on the problem.

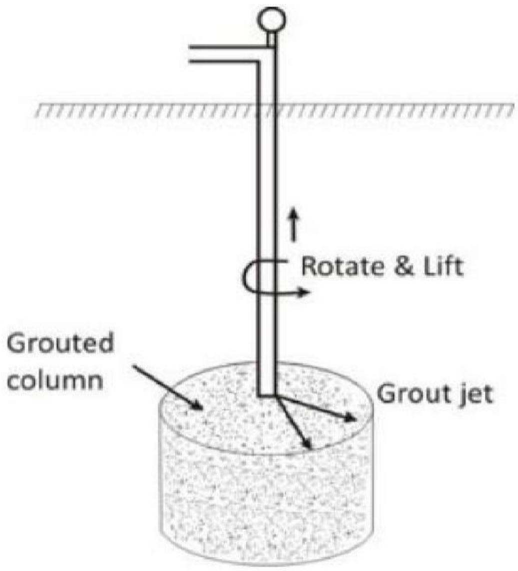


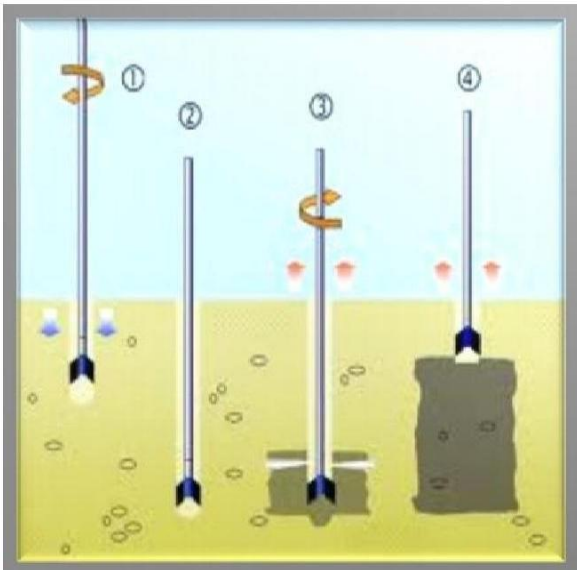
(c) Displacement (compaction) grouting

Jet Grouting

Jet grouting is a technique where high-speed water jets emanating from a drill bit cut into alluvial soils; as the drill bit is withdrawn, grout is pumped through horizontal nozzles and mixes with or displaces the soil. The original foundation material is thus replaced with a stronger and/or more impermeable grout-soil mixture. Jet grouting may be used to form cut-off walls, do underpinning, or form deep foundations similar to grouted auger piles.

- The high-pressure water or grout is used to physically disrupt the ground, in the process modifying it and there by improving it.
- Jet grouting blasts extremely high pressure fluids into the ground at ultra-high velocities. The soil is broken up and mixed with the fluids to become one mass which then hardens.
- Depending on the application and soils to be treated, one of three variations is used: the single fluid system (slurry grout jet), the double fluid system (slurry grout jet surrounded by an air jet) and the triple fluid system (water jet surrounded by an air jet, with a lower grout jet).
- The jet grouting process constructs soil create panels, full columns or anything in between (partial columns) with designed strength and permeability.
- Jet grouting has been used to underpin existing foundations, construct excavation support walls, and construct slabs to seal the bottom of planned excavations.
- Jet grouting is effective across the widest range of soil types of any grouting system, including silts and most clays. Because it is an erosion-based system, soil erodibility plays a major role in predicting geometry, quality and production.
- Cohesion less soils are typically more erodible by jet grouting than cohesive soils. Since the geometry and physical properties of the soil create are engineered, the properties of the soil create are readily and accurately predictable.
- Jet grouting's ability to construct soil create in confined spaces and around subsurface obstructions such as utilities, provides a unique degree of design Flexibility.
- Indeed, in any situation requiring control of groundwater or excavation of unstable soil (water-bearing or otherwise) jet grouting should be considered.





Stages in grouting flow

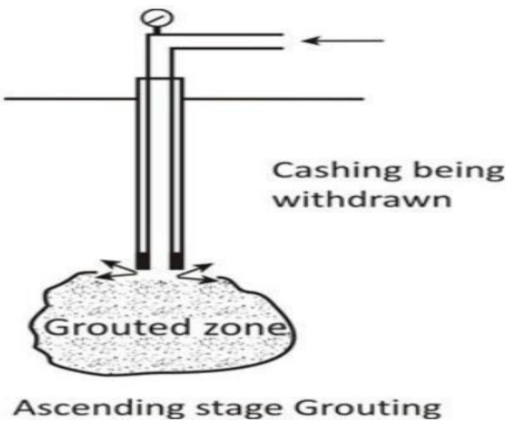
Grouting in stage may be in a descending or ascending direction.

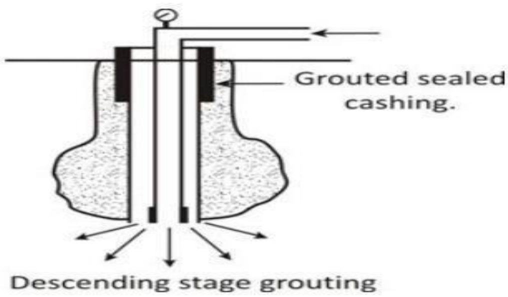
In **descending method**, impregnation of the ground occurs in advance of the borehole, which is advantageous in loose soil or rock.

In **ascending technique**, grouting follows drilling as a separate phase
Water pressure testing is possible immediately prior to grouting, allowing for a choice of the most suitable grout type, pressure and quantity of grout for that particular stratum.

Following points to be taken care of:

- Minimum wastage of grout.
- Least damage to the ground.
- Maximum gain in strength or reduction in seepage.

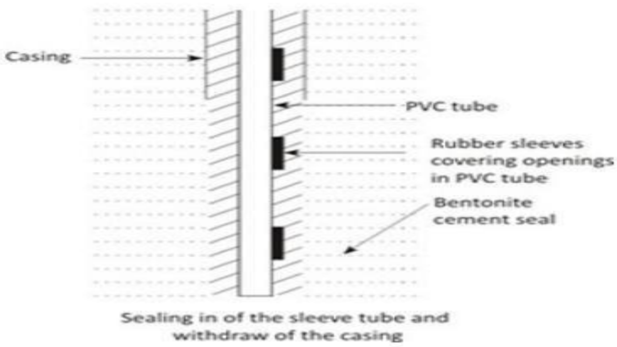


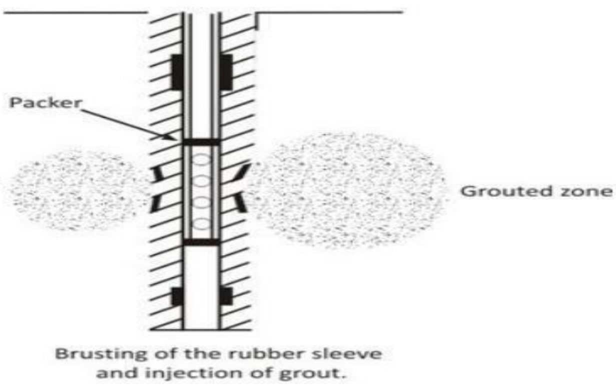


Grouting Techniques and controls

- The hole is drilled and cased
- A steel or plastic tube, slotted at regular intervals is inserted. The vertical slots are covered with a rubber sleeve.
- As the casing is withdrawn, the space between the sleeve tube and the borehole wall is sealed with a cement-bentonite grout.
- After the seal has set, the grouting tube is inserted grout exist between two packers allowing injection through selected slots with increasing pressure, the rubber sleeve bursts and grout flows into the soil.

With the sleeve tube technique, grouting can be repeated in the same hole using different viscosity grout or different chemicals in a planned sequence.



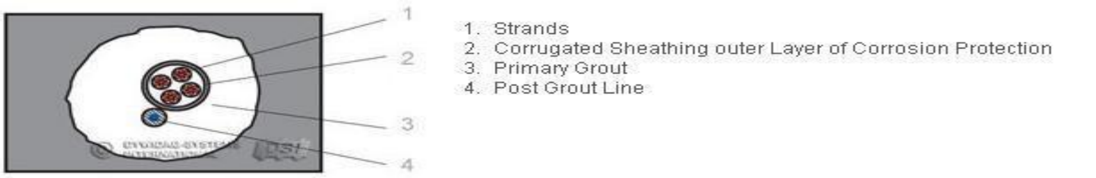


Post Grout Test

Post Grouting of anchors can significantly improve the load carrying capacity of anchors in cohesive soils by increasing the skin friction of the anchor grout body with the soil.

Post-grouting process is performed by the following stages:

- Constructing bored pile with the nowadays commonly used technology is grout spouting technology attached to the steel cage at least 2 bottom sealed steel pipe D90, symmetry through the center, along the length of the pile, 10-20cm distance from the bottom of pile
- The bottom of the pile spouting grout structure; after installing steel cages conducting concrete bored piles
- Drilling the bottom hole of two D90 steel pipes to soil under the pile tip
- Pumping high pressure water with 80-200 bar to wash bottom of the pile until the ejected water is as fresh as pumped water



Drill Hole Section prior to Post Grouting

Drill Hole Section after Post Grouting

IMPORTANT QUESTIONS

1. What is dewatering? Explain its importance in civil engineering works.
2. List various well point dewatering systems and explain their suitability for different soils.
3. What are the objectives of dewatering? What are the types of foundation drains?
4. Explain the electro osmosis method to control ground water in low permeable soil?
5. What is grouting? Explain in detail various field of applications of grouting.
6. Explain compaction grouting, penetration grouting and fracture grouting with neat sketches.
7. What are the properties of the grout mixes: (i) Solutions such as water glass (silicate). (ii) Emulsions such as chemical grout.
8. Explain the following grouting methods: (i) Compaction. (ii) Jet grouting.
9. Discuss briefly the important points to be considered in design of dewatering system.
10. Discuss in detail with suitable examples the field conditions which necessitate dewatering in soil.
11. What do you understand about soil stabilization by grouting? Explain in detail various fields of applications of grouting.
    (b) Describe the equipment used in the grouting technique
12. Discuss in details various well point techniques for dewatering soils.
    Explain the criteria for the selection of a particular fill material around the drains.
13. Explain briefly various methods of grouting.

UNIT-2

DENSIFICATION METHODS IN GRANULAR SOIL

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

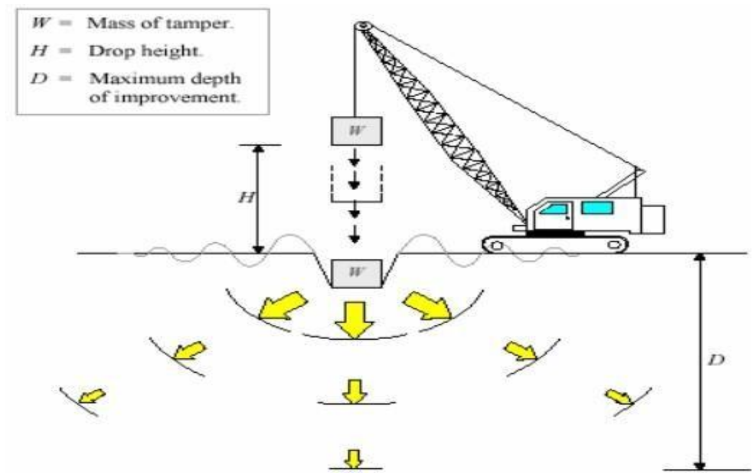
Need for densification of granular soils

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

Dynamic compaction

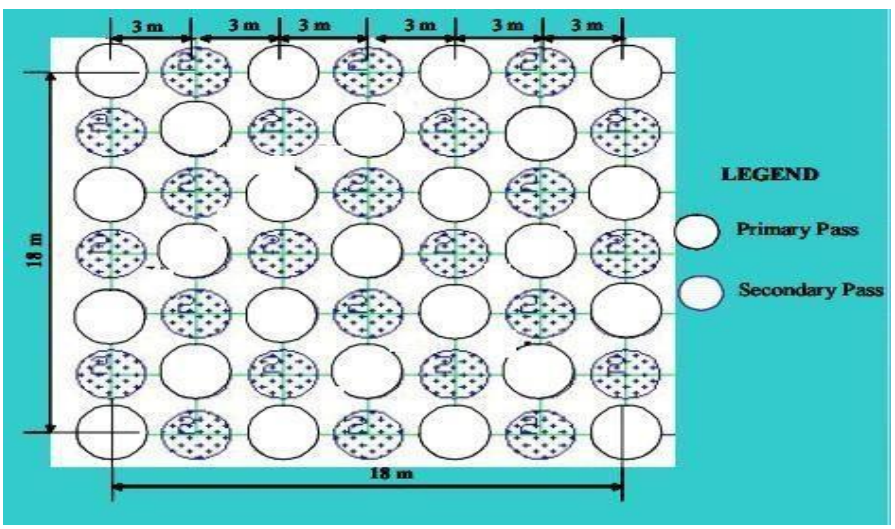
- Technique involves repeatedly dropping a large weight from a crane
- Weight may range from 6 to 172 tons

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



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

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



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

- Heave around craters is generally small

Types Of Dynamic Compaction

Dynamic Compaction:

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

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

Dynamic consolidation

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

Dynamic replacement

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

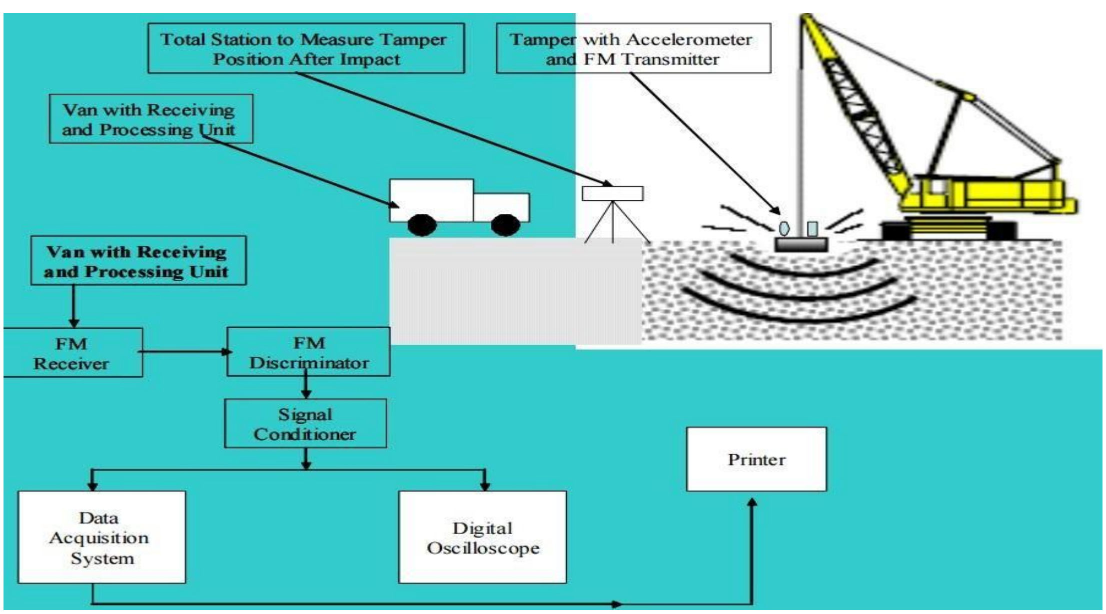
Rotational dynamic compaction

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

Rapid impact dynamic compaction

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

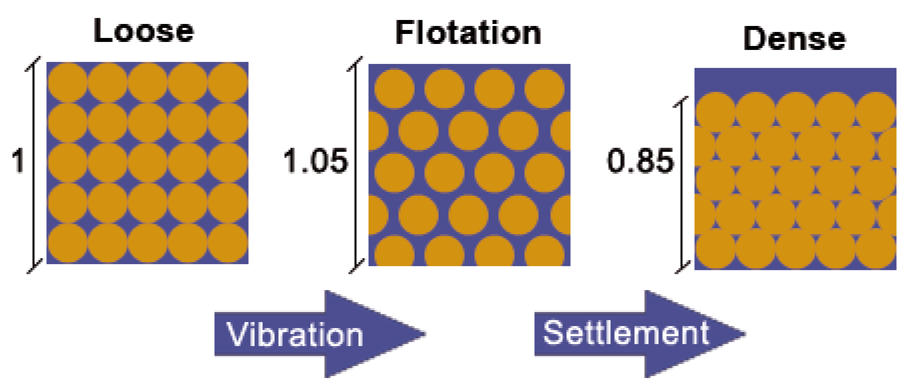
The Step Wise Layout Of Monitoring And Control In Dynamic Compaction Test



vibro compaction method of densification

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

The following diagrams illustrate the compaction process:



The principle of sand compaction (Vibroflotation):

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

Effects of Compaction

The sand and gravel particles rearrange into a denser state.

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

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

The friction angle typically increases by up to 8 degrees.
Enforced settlements of the compacted soil mass are in the range of 2 % to 15 %, typically 5 %
The stiffness modulus can be increased 2 to 4 fold.

Test Pattern

On large projects the optimal compaction grid spacing has to be determined by test grids.
The compaction effect in the test grids should be as close as possible to the treatment in the later production areas.
In order to achieve this it is advisable to arrange the test grids close to each other.

Advantages

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

Applications

The most common applications are as follows :

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

Densification By Compaction Piles

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

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

DENSIFICATION METHODS IN COHESSIVE SOILS

In-Situ Densification Methods in Cohesive Soils

The conditions improved when unsuitable soils are encountered

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

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

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

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

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

Classification Of Ground Improvement Techniques

Mechanical Modification:

Soil density is increased by the application of mechanical force, including compaction of surface layers by static vibratory such as compact roller and plate vibrators.

Hydraulic Modification:

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

Physical and chemical modification:

- Stabilization by physical mixing adhesives with surface layers or columns of soil.
- Adhesive includes natural soils industrial byproducts or waste. Materials or cementations or other chemicals which react with each other and/or the ground.
- When adhesives are injected via boreholes under pressure into voids within the ground or between it and a structure the process is called grouting.
- Soil stabilization by heating and by freezing the ground is considered thermal methods of modifications.

Modification by inclusions and confinement:

- Reinforcement by fibers, strips bars meshes and fabrics imparts tensile strength to a constructed soil mass.
- In-situ reinforcement is achieved by nails and anchors. Stable earth retaining structure can also be formed by confining soil with concrete, Steel, or fabric elements

Various Methods Of Ground Improvement Suitable For Cohesion Less Soils

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

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

Vibratory surface and Deep Vibro-compaction

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

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

Preloading

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

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

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

Methods of preloading

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

Applications of preloading in civil works

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

Advantages of preloading

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

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

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

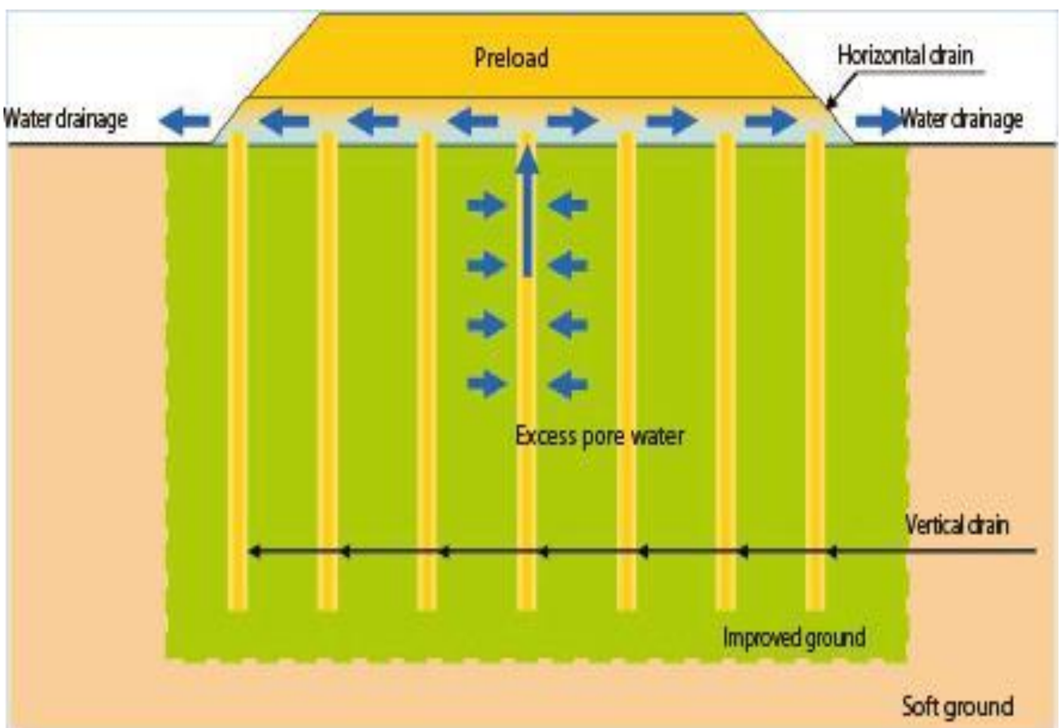
Preloading With Vertical Drains For A Building Site

Vertical Drains

- This method is suitable for deep deposit of soft clay. The natural moisture content in this stratum can be brought down substantially by installing vertical drains with a preloading.
- The presence of vertical drains reduces the drainage path of water in the pores of soil and thereby reduces the time required for consolidation.
- The spacing of drains depends on the speed at which required improvement is to be achieved. In earlier days, such vertical drains were installed by driving a close ended steel pipe of 100-200 mm diameter up to the full thickness of such soft clay deposit.
- The pipe is then filled with sand and withdrawn in stages to form a vertical sand drain. The pipe is generally refused for installing other drains.
- In the recent past, there has been number of different materials developed to replace the sand drains. These are basically flexible plastic sections having thickness varying from 5 to 10 mm and width from 100 to150 mm.
- The section has channels to permit flow of water. The perimeter of the section is covered with a layer of geo-textile to prevent the entry of soil particles into the channel.
- The advantage of such drain is that it results in minimum remoulding of surrounding soil during installation. The process of installation is also very fast.
- The machine is mounted on a crane and typical drain up to 10 m depth can be installed in a period varying from 1-2 minutes including the time for shifting the machine to the new location.
- The percentage consolidation which can be achieved by such vertical drains can be theoretically predicted from the design charts developed based on theory of three

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

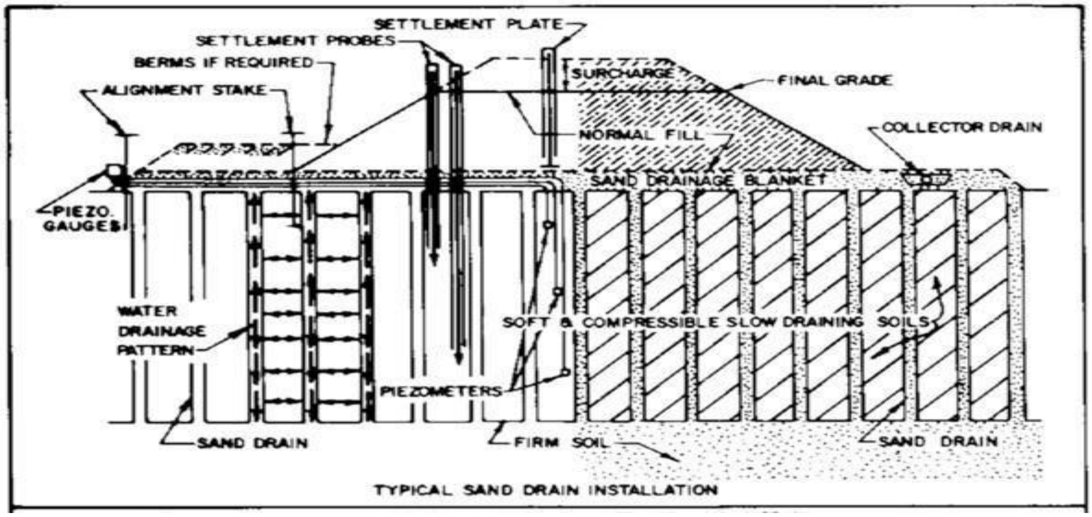
- Depending on the time available for improvement, the degree of consolidation is worked out and the effective over burden pressure (*p*) is computed. From plasticity index of the soil, the ratio Su / p is determined. This ratio normally remains constant and therefore with increase in value of p is determined.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



increases.

Sand Drains

The theory and method of sand drains is shown below.



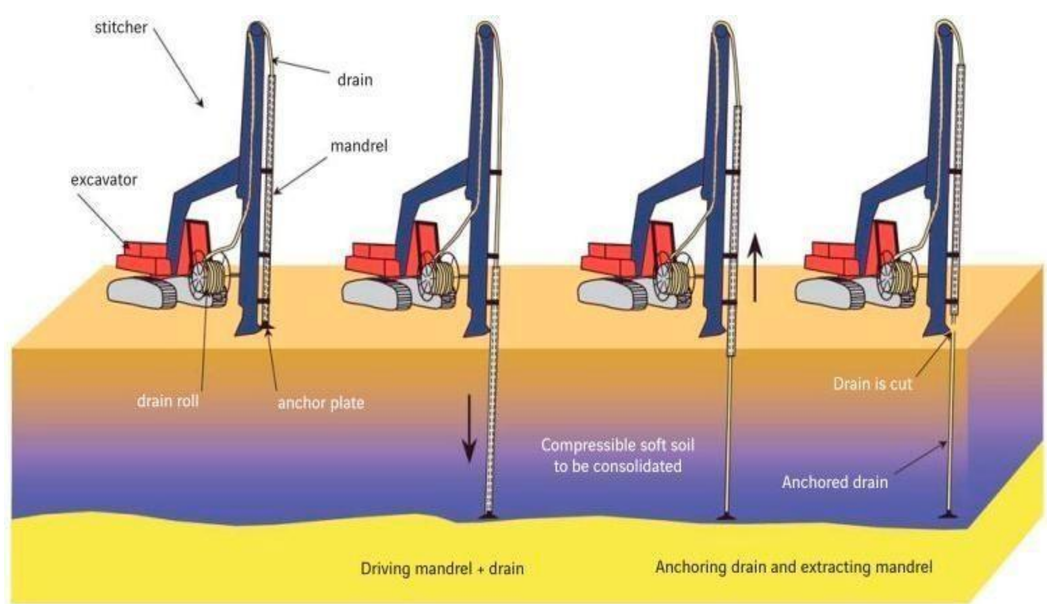
- A sand drain is basically a hole drilled in a cohesive soil and filled with sand.
- Since the sand has larger particle size, its permeability is much higher, thus water will flow through it much more easily.
- As shown above, an array (it's actually a two-dimensional array) of sand drains is installed,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

Sand Wicks

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

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

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



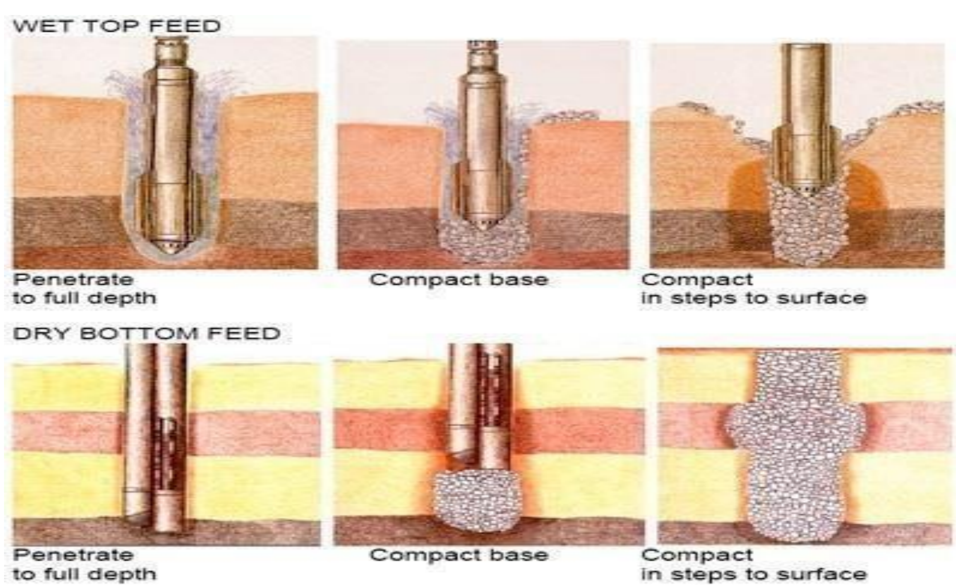
Mechanism of stabilization using Stone Columns

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

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

Installation Procedure of Stone Columns

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



Installation Procedure of Stone Columns

Advantages:

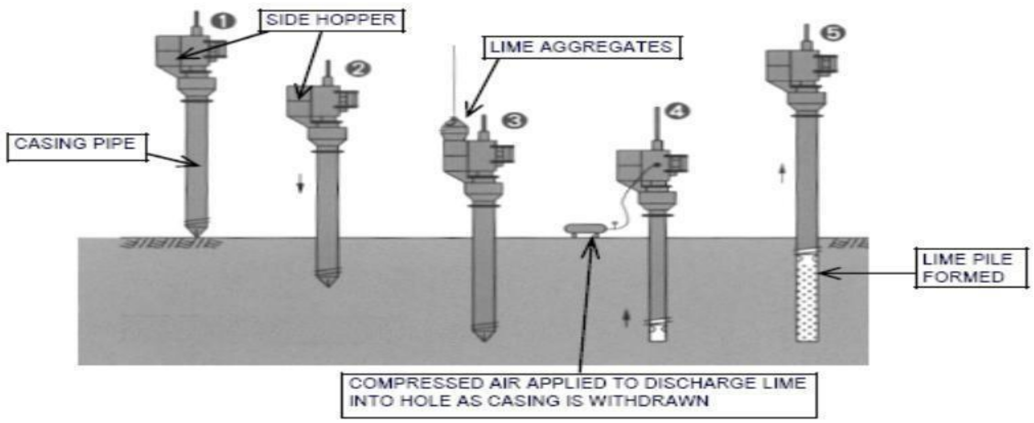
- Stone Columns are designed to reduce settlements of compressible soil layers in order to be able to build most structures with shallow footings and slab-on-grades on very soft soil;
- When applicable, their draining characteristics result in an increase in the time rate of consolidation settlement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

Mechanism of stabilization using Lime Columns

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

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

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



Effect of lime columns on the adjacent soil

a) Consolidation / dewatering effect

Quick lime, CaO, absorbs water from the surrounding ground, causing the lime to swell and forms slaked lime ($Ca(OH)_2$) as per the following chemical reaction $CaO + H_2O \rightarrow Ca(OH)_2 +$ 15.6 Kcal/mol

b) Ion exchange effect

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

c) Pozzolanic effect

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

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

Mechanism of stabilization using Thermal methods

Methods based on temperature control are classified as:

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

Temperature control method (Heat treatment) depend on

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

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

Ground freezing method

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

IMPORTANT QUESTIONS

1. Discuss the principles of ground improvement in cohesion less soils.
2. Discuss the effectiveness of both vibro flotation and compaction piles for compacting the granular soils.
3. (a) With neat sketches explain in-situ densification methods in cohesive soils.

   (b) Discuss how the stress history of a soil deposit affects its suitability for preloading with vertical drains.
4. (a) Compare vibratory probe compaction and dynamic compaction.

   (b) Explain the vibrocompaction method for cohesionless soils.
5. (a) Explain with a neat sketch sand drain to accelerate the drainage of impervious soils.

   (b) What are the advantages of using wick geo drains?
6. Discuss the need of ground improvement and write the principles of ground improvement in cohesionless soils.

   (b) Briefly explain about methods of impact at ground surface and at depth used in densification of granular soil deposits
7. (a) Write short notes on densification of cohesive soils by Lime columns.

   (b) Discuss the important formulae used in the improvement of soft clay deposits using stone columns.
8. (a) Explain briefly with a neat sketch the vibro compaction method of densifying deep granular deposits.

   (b) Explain the impact at ground surface method to densify granular soils.
9. (a) Explain in detail the in-situ densification of cohesive soils by using pre-loading with vertical drains.

   (b) What is a sand drain? How is it constructed and is useful in densifying cohesive soil deposits?
10. Explain various insitu densification methods for cohesive soils.

UNIT-4

REINFORCED EARTH

- The concept of combining two materials of different strengths characteristics to form a composite material of greater strength is quite familiar in civil engineering practices and is in use for ages.
- The reinforced concrete constructions are examples for such composite materials.
- It combines the high tensile strength of steel with the high compressive, but relatively low tensile strength of concrete.
- Likewise, soils which have little if any tensile strength can also be strengthened by the inclusion of materials with high tensile strength.
- This mobilization of tensile strength is obtained by surface interaction between the soil and the reinforcement through friction and adhesion.
- The reinforced soil is obtained by placing extensible or inextensible materials such as metallic strips or polymeric reinforcement within the soil to obtain the requisite properties.
- Soil reinforcement through metallic strips, grids or meshes and polymeric strips sheets is now a well-developed and widely accepted technique of earth improvement.
- Anchoring and soil nailing is also adopted to improve the soil properties. The use of reinforced earth technique is primarily due to its versatility, cost effectiveness and ease of construction.
- The reinforced earth technique is particularly useful in urban locations where availability of land is minimum and construction is required to take place with minimum disturbance traffic.

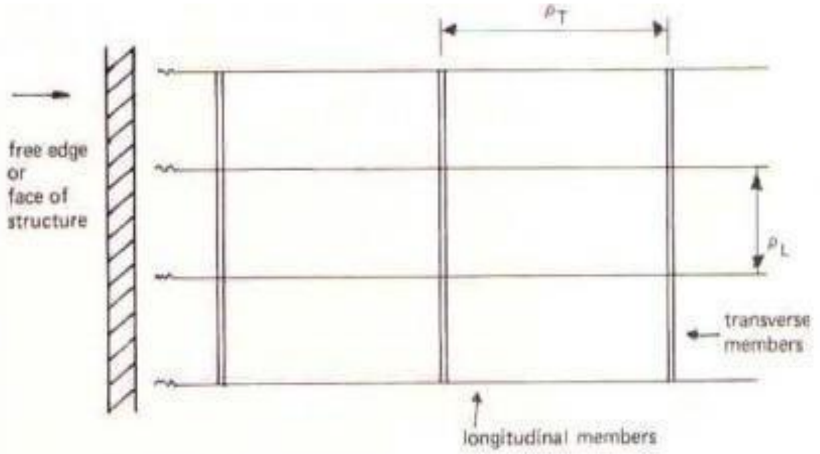
Types of reinforcing materials:

i) Strips: These are flexible linear element normally having their breadth, „ b‟ greater than their thickness, „t‟. Dimensions vary with application and structure, but are usually within the range t = 3-5 mm, b = 5-100 mm. The most common strips are metals. The form of stainless, galvanized or coated steel strips being either plain or having several protrusions such as ribs or gloves to increase the friction between the reinforcement and the fill. Strips can also be formed from aluminum, copper, polymers and glass fibre reinforced plastic (GRP). Reed and bamboo reinforcements are normally categorized as strips, as are chains.

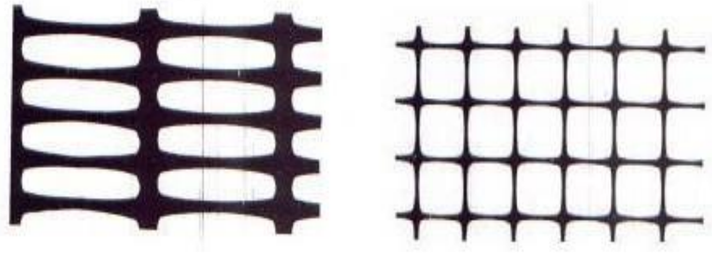
ii) Planks: Similar to strips except that their form of construction makes them stiff. Planks can be formed from timber, reinforced concrete or pre-stressed concrete. The dimensions of concrete planks vary; however, reinforcements with a thickness, „t‟ =

100 mm and breadth, b= 200–300 mm have been used. They have to be handled with care as they can be susceptible to cracking.

iii) Grids and Geogrids: Reinforcing elements formed from transverse and longitudinal members, in which the transverse members run parallel to the face or free edge of the structure and behave as abutments or anchors as shown



The main purpose is to retain the transverse members in position. Since the transverse members act as an abutment or anchor they need to be stiff relative to their length. The longitudinal members may be flexible having a high modulus of elasticity not susceptible to creep. The pitch of the longitudinal members, pL is determined by their load carrying capacity and the stiffness of the transverse element. A surplus of longitudinal and transverse elements is of no consequence provided the soil or fill can interlock with the grid. Mono and Bi Oriented grid as shown



(a) Mono Oriented geogrid (b) Bi- Oriented geogrid

Grids can be formed from steel in the form of plain or galvanized weld mesh, or from expanded metal. Grids formed from polymers are known as “Geogrids” and are normally in the form of an expanded proprietary plastic product.

iv) Sheet reinforcement: May be formed from metal such as galvanized steel sheet, fabric (textile) or expanded metal not meeting the criteria for a grid.

v) Nailing: Earth may be protected by geo-synthetics with earth nailing.

vi) Anchors: Flexible linear elements having one or more pronounced protrusions or distortions which act as abutments or anchors in the fill or soil. They may be formed from steel, rope, plastic (textile) or combinations of materials such as webbing and tyres, steel and tyres, or steel and concrete

vii) Composite reinforcement: Reinforcement can be in the form of combinations of materials and material forms such as sheets and strips, grid and strips and anchors, depending on the requirements.

The Components Of Reinforced Earth

SOIL

- It should be granular, cohesion less material, not too much silt or clay having particle size not more than 125 mm.
- Not more than 10 percent of the particles shall pass 75 micron sieve & the earth reinforcement coefficient of friction to be either higher than or equal to 0.4 & Plasticity Index < 6.
- The soil must have moisture content suitable for compaction.
- The materials shall be substantially free of shale or other soft, poor durability particles.

SKIN

- Skin is the facing element of the reinforced soil wall.
- These elements keep the reinforcement at a desired elevation in the reinforced soil wall and also protect the granular at the edge falling off.
- Made of either metal units or precast concrete panels.

REINFORCING MATERIAL

A variety of materials can be used as reinforcing materials

- Steel
- Concrete
- Glass fibre
- Wood
- Rubber
- Aluminum
- Reinforcement may take the form of strips, grids, anchors & sheet material, chains, planks, rope, vegetation and combinations of these or other material forms.

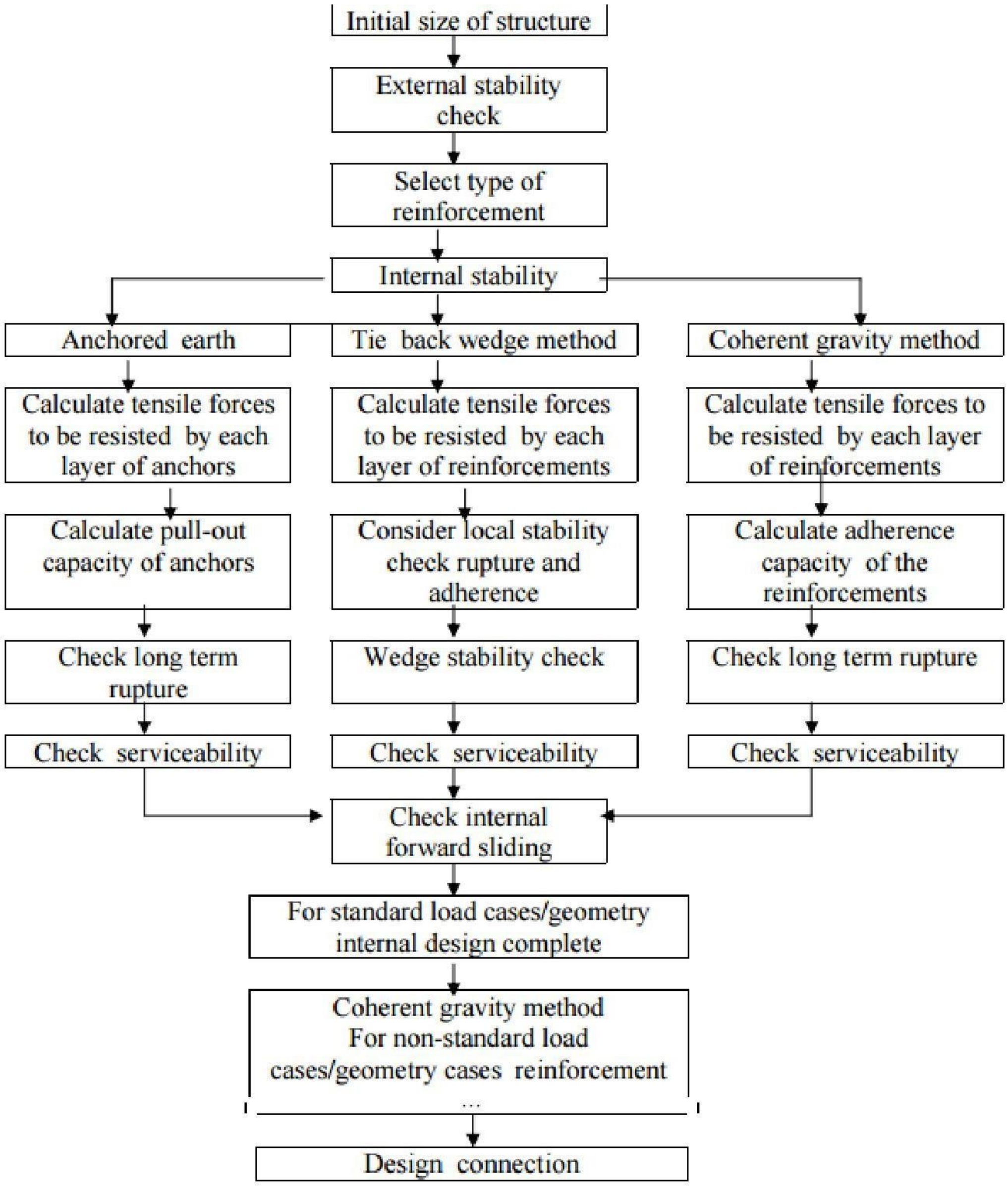
THE DESIGN PRINCIPLES OF REINFORCED EARTH WALL

- Rankine or Columb earth pressure theory should be used
- Active earth pressure or passive earth pressure or at rest earth pressure are adopted.
- The various forces acting horizontal, vertical and shear stress should be distributed on reinforced earth.
- Suitable geometry surface failure is assumed on reinforced earth Reinforcing strip length can resist the failure occurred by the slippage.
- Safety factors are required and calculated from Rankine, Active earth pressure theory.
- The earth pressures on a reinforced earth walls can be calculated by both horizontal and vertical earth pressures

Factors affecting the behavior and Performance of Reinforced Soil

REINFORCEMENT	**REINFORMENT DISTRIBUTION**	**SOIL**	**SOIL STATE**	**CONSTRUCTIO N**
Forms(fibers,grid,anchor, bar,strip)	Location	Particle size	Density	Geometry of structure
Surface properties				compaction
Dimensions	Orientation	Grading	Over burden	Construction system
Strength		Mineral Content	States of stress	Aesthetics
Stiffness	Spacing	Index properties	Degree of Saturation	Durability

The Design Procedure For Reinforced Earth Wall In Form Of A Flowchart



Stability Checks:

External Stability (as for any earth-retaining structure)

The external stability of a reinforced soil wall is easily investigated since it behaves essentially as a rigid body and conforms to the simple laws of statics external stability assessment should consider the effects of dead loads, other loads (live load, dynamic load etc.) and forces acting on the structure. The failure for sliding, overturning, tilting/bearing and slip should be checked by external stability

- Sliding
- Overturning
- Bearing Capacity

Short and long term stability of soil needs to be considered to allow for the construction and in-service condition as well as in changes in pore water pressure. Passive earth pressure acting on the foot of the wall/structure below ground level may be ignored while considering various forces for stabilization.

Internal Stability (MSE retaining structures)

Stability within a reinforced structure is achieved by the reinforcing elements carrying tensile forces and then transferring to the soil by friction, friction and adhesion, or friction and bearing. In addition forces can be transferred the soil through fill trapped by the elements of the grid. The fill is than able to support the associated shear and compressive forces. In the case of anchored earth such as soil nailing, stability within a structure is achieved by the anchor elements carrying tensile forces and transferring these by friction along the anchor shaft or anchor loop and bearing of the anchor to the surrounding fill.

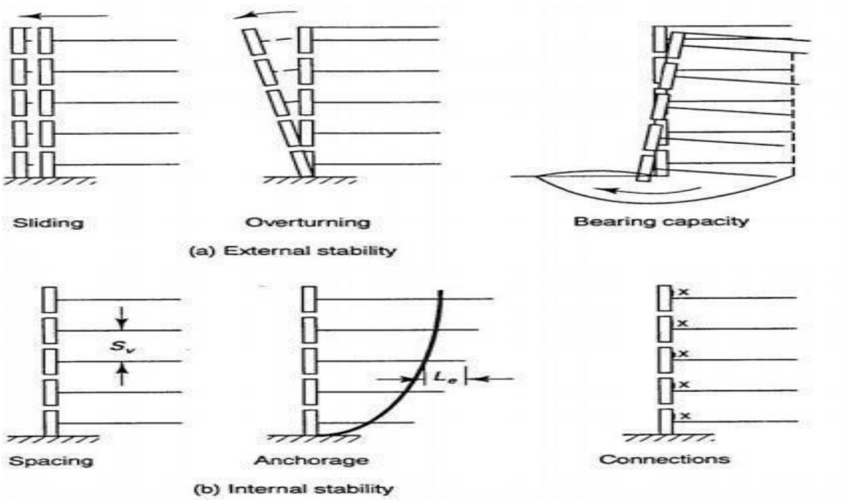
- Reinforcement Failure
- Pullout
- Failure of Reinforcement/Facing Connection

Local stability check

The resistance of the reinforcing element should be checked against rupture and adherence failure whilst carrying the factored loads.

Wedge stability

The reinforcement structure will assume to fail internally in the form of wedge. It is not known at which level the wedge is originated. Therefore the wedge originate from different level to be checked. Checked for stability considering all the forces acting on it. Wedges are assumed to behave as rigid bodies and may be any size and shape. Stability of any wedge is maintained when friction forces acting on the potential failure plane in connection with the tensile resistance/ bond of the group of reinforcing elements or embedded in the fill beyond the plane are able to resist the applied loads tending to cause movement,



Geosynthetics

- Geo-synthetics are synthetic products used to stabilize terrain.
- These are human-made materials made from various types of polymers used to enhance, augment and make possible cost effective environmental, transportation and geotechnical engineering construction projects.
- They are used to provide one or more of the following functions; separation, reinforcement, filtration, drainage or liquid barrier.
- They are generally polymeric products used to solve civil engineering problems.
- These include eight main categories geotextiles, geogrids, geonets, geomembranes, geosynthetic clay liners,geofoam, geocells and geocomposites.
- The polymeric nature of the products makes them suitable for use in the ground where high levels of durability are required.
- They can also be used in exposed applications.
- Geo-synthetics are available in a wide range of forms and materials.

These products have a wide range of applications and are currently used in many civil, geotechnical, transportation, hydraulic and private development applications including roads, airfields, railroads, embankments, retaining structures, reservoirs, canals, dams, landfill liners, land fill covers structures.

The Important Properties Of Geo-Synthetics Required For Reinforcement Function

Basic Physical Properties

a. Constituent material and method of manufacture b.

Mass per unit area

c. Thickness

d. Roll width, roll length

- Mechanicalproperties

a. Tensile strength

b. Tensile modulus

c. Seam strength

d. Interface friction

e. Fatigue resistance

f. Creep resistance

Hydraulic Properties

a. Compressibility

b. Opening size

c. Permittivity

d. Transmissivity

Constructability/survivability Properties

a. Strength and stiffness

b. Tear resistance

c. Puncture resistance

d. Penetration resistance

e. Burst resistance

f. Cutting resistance

g. Inflammability

h. Absorption

Durability (Longevity)

a. Abrasion resistance

b. Ultra-violet stability

c. Temperature stability

d. Chemical stability

e. Biological stability

f. Wetting & drying stability

The Functions Of Geo-Synthetics

- Reinforcement
- Filtration
- Separation
- Drainage
- Erosion Control
- Barrier/Protection

Reinforcement:

Reduction of Stress Intensity (Concentration) through Wider Distribution The stresses over the subgrade are higher in unreinforced flexible pavements than in geo-synthetic-reinforced pavement due to stress distribution factor

Reinforcement Mechanisms Induced by Geo-synthetics:

(a) Lateral Restraint

(b) Increased Bearing Capacity; and

(c) Membrane Tension Support

Filtration

Retaining soil particles subjected to hydraulic forces which allow the passage of liquids/gases. This function is often partnered with separation.

Separation

a. Preventing intermixing of soil types or soil/aggregate to maintain the integrity of each material yet still allow the free passage of liquids/gases. Commonly used in between sub-base/subgrade and around drainage materials.

b. Contamination of the base course layers leads to a reduction of strength, stiffness and drainage characteristics, promoting distress and early failure of roadway.

Drainage

Allowing fluids and gases to flow both through the plan of the material. Commonly used as components in geo-composites used for surface water runoff or for gas collection under membranes.

Separation and Drainage Functions

a. Piping Resistance: Apparent Opening Size - AOS (as related to soil retention),

b. Permeability: Flow capacity, and clogging potential.

c. Strength and Durability: Grab, Puncture strengths

Erosion Control

Protecting and reinforcing slopes and drainage channels from erosive agents whilst allowing the establishment of vegetation cover.

Barrier/Protection

Preventing or limiting localized damage to an adjacent material, usually a geomembrane used to line a lagoon or a landfill. Thick geotextiles prevent puncture or excessive strain in the membrane.

Geo synthetics classified

Geo synthetics are classified as follows

- Geotextiles
- Geogrids
- Geonets
- Geo-membranes
- Geo-synthetic clay liners
- Geocells/geo web members
- Geofoam
- Geo-composites

Geotextiles are defined as "any permeable textile used with foundation soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system".

Geogrids

They have open grid like configuration i.e. they have large aperture between individual ribs.They have Low strain and stretch about 2% under load.

Strength is more that other common geotextiles. Function: Used exclusively for reinforcement

Geonets are open grid-like materials formed by two sets of course, parallel, extruded polymeric strands intersecting at a constant acute angle. The network forms a sheet with in-plane porosity that is used to carry relatively large fluid or gas flows.

Geomembranes are continuous flexible sheets manufactured from one or more synthetic materials. They are relatively impermeable and are used as liners for fluid or gas containment and as vapour barriers.

Geosynthetic clay liners (GCLs) are geocomposites that are prefabricated with a bentonite clay layer typically incorporated between a top and bottom geotextile layer or geotextile bentonite bonded to a geomembrane or single layer of geotextile. Geotextile-encased GCLs are often stitched or needle punched through the bentonite core to increase internal shear resistance. When hydrated they are effective as a barrier for liquid or gas and are commonly used in landfill liner applications often in conjunction with a geomembrane.

Geocells are relatively thick, three-dimensional networks constructed from strips of polymeric sheet. The strips are joined together to form interconnected cells that are infilled with soil and sometimes concrete. In some cases 0.5 m to 1 m wide strips of polyolefin geogrids have been linked together with vertical polymeric rods used to form deep geocell layers called geomattresses. soil confinement

Geofoam blocks or slabs are created by expansion of polystyrene foam to form a low-density network of closed, gas-filled cells. Geofoam is used for thermal insulation, as a lightweight fill or as a compressible vertical layer to reduce earth pressures against rigid walls.

Geocomposites are geosynthetics made from a combination of two or more geosynthetic types. Examples include: geotextile-geonet; geotextile-geogrid; geonet geomembrane; or a geosynthetic clay liner (GCL). Prefabricated geocomposite drains or prefabricated vertical drains (PVDs) are formed by a plastic drainage core surrounded by a geotextile filter.

The Properties Of Geotextiles

- Physical properties
  Mechanical properties
  Hydraulic properties
  Endurance properties
  Degradation properties

Physical properties of Geotextiles

a. Specific gravity
b. Mass per unit area
c. Thickness
d. Stiffness

Mechanical properties of Geotextiles

a. Compressibility

b. Tensile strength
c. Seam strength
d. Fatigue strength
e. Burst strength
f. Tear strength
g. Impact strength
h. Puncture strength
i. Friction strength
j. Pull out strength

THE CLASSIFICATION OF GEO TEXTILES

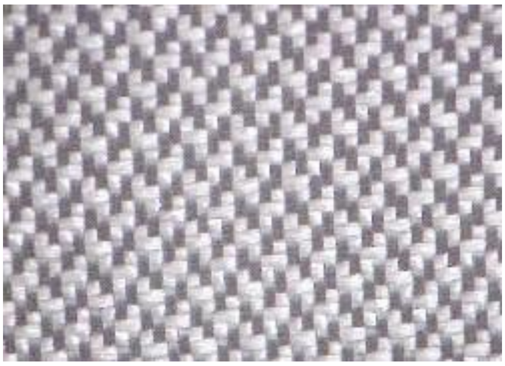
Geotextile:

Geotextiles are polymer fabrics used in the construction of roads, drains, harbour works, and breakwaters,and for land reclamation and many other **civil engineering purposes**. Geotextiles, a newly emerging field in the civil engineering and other fields, offer great potential in varied areas of applications globally.

Types of geotextiles:

Geotextiles are a permeable synthetic material made of textile materials. They are usually made from polymers such as polyester or polypropylene. The **geotextiles** are further prepared in three different categories – woven fabrics, non-woven fabrics and knitted fabrics.

Woven Fabrics: Large numbers of geosynthetics are of woven type, which can be sub-divided into several categories based upon their method of manufacture. These were the first to be developed from the synthetic fibers. As their name implies, they are manufactured by adopting techniques which are similar to weaving usual clothing textiles. This type has the characteristic appearance of two sets of parallel threads or yarns .the yarn running along the length is called warp and the one perpendicular is called weft.



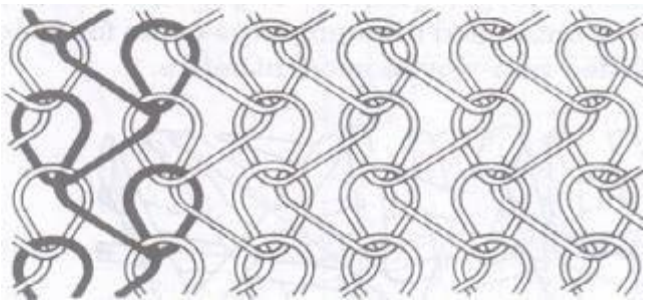
Woven fabric

The majority of low to medium strength woven geosynthetics are manufactured from polypropylene which can be in the form of extruded tape, silt film, monofilament or multifilament. Often a combination of yarn types is used in the warp and weft directions to optimize the performance/cost. Higher permeability is obtained with monofilament and multifilament than with flat construction only.

Non-woven: Non-woven geo-synthetics can be manufactured from either short staple fibre or continuous filament yarn. The fibers can be bonded together by adopting thermal, chemical or mechanical techniques or a combination of techniques. The type of fibre (staple or continuous) used has very little effect on the properties of the non – woven geo synthetics. Non-woven geotextiles are manufactured through a process of mechanical interlocking or chemical or thermal bonding of fibres/filaments. Thermally bonded non-wovens contain wide range of opening sizes and a typical thickness of about 0.5-1 mm while chemically bonded non-wovens are comparatively thick usually in the order of 3 mm. On the other hand mechanically bonded non-wovens have a typical thickness in the range of 2-5 mm and also tend to be comparatively heavy because a large quantity of polymer filament is required to provide sufficient number of entangled filament cross wires for adequate bonding.

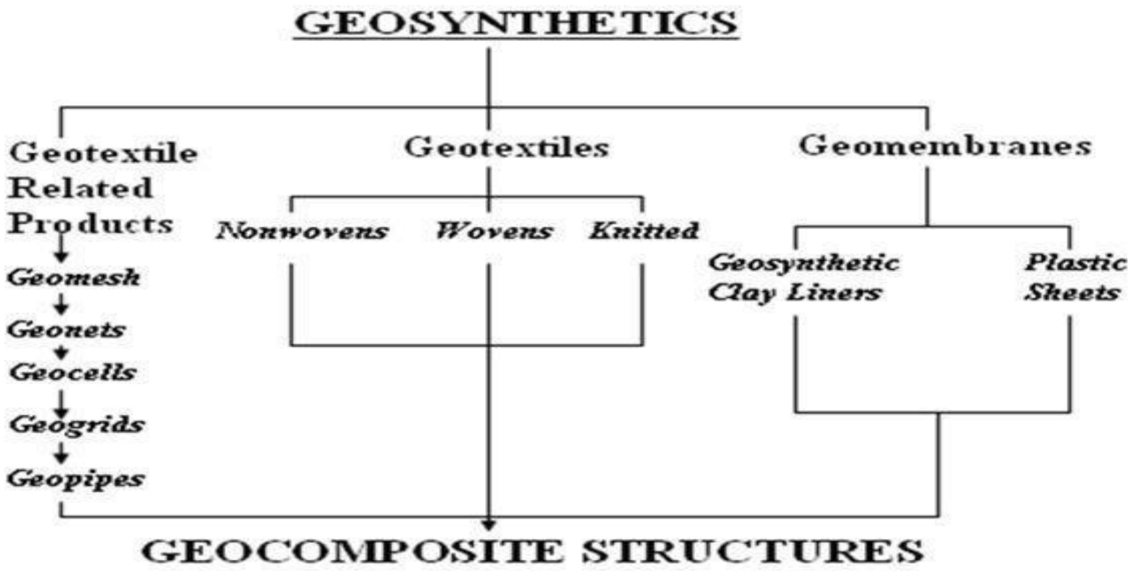
Nonwoven

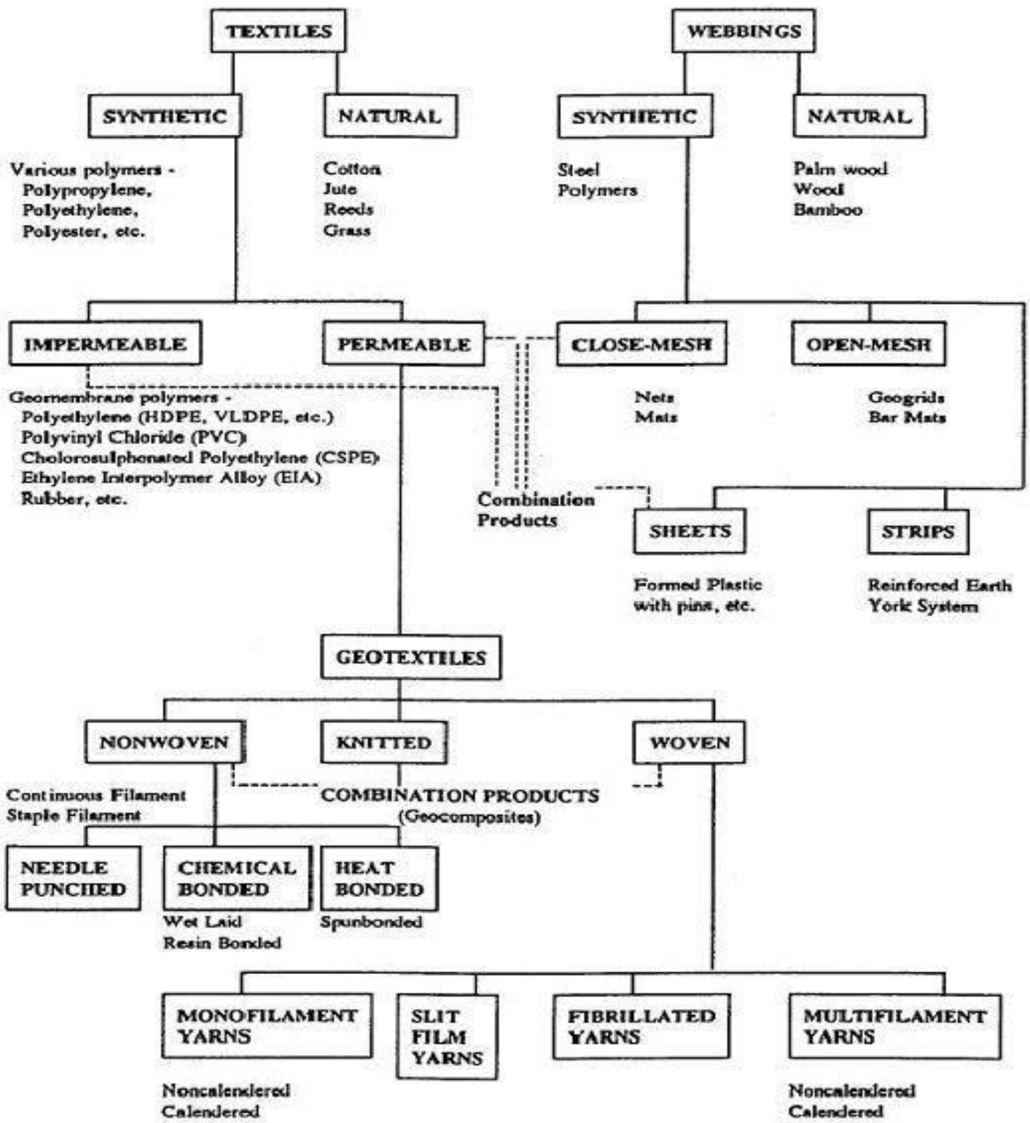
Knitted Fabrics: Knitted geosynthetics are manufactured using another process which is adopted from the clothing textiles industry, namely that of knitting. In this process interlocking a series of loops of yarn together is made. An example of a knitted fabric is illustrated in figure. Only a very few knitted types are produced. All of the knitted geosynthetics are formed by using the knitting technique in conjunction with some other method of geosynthetics manufacture, such as weaving.



Knitted fabric

Apart from these three main types of geotextiles, other geosynthetics used are geonets, geogrids, geo-cells, geo membranes, geo composites, etc. each having its own distinct features and used for special applications.


GEOSYNTHETICS
Geotextile Related Products
Geomesh
Geonets
Geocells
Geogrids
Geopipes
Geotextiles
Nonwovens
Wovens
Knitted
Geomembranes
Geosynthetic Clay Liners
Plastic Sheets
GEOCOMPOSITE STRUCTURES


TEXTILES
SYNTHETIC
Various polymers - Polypropylene, Polyethylene, Polyester, etc.
NATURAL
Cotton
Jute
Reeds
Grass
WEBBINGS
SYNTHETIC
Steel
Polymers
NATURAL
Palm wood
Wood
Bamboo
IMPERMEABLE
Geomembrane polymers - Polyethylene (HDPE, VLDPE, etc.) Polyvinyl Chloride (PVC) Cholorosulphonated Polyethylene (CSPE) Ethylene Interpolymer Alloy (EIA) Rubber, etc.
PERMEABLE
CLOSE-MESH
Nets
Mats
OPEN-MESH
Geogrids
Bar Mats
Combination Products
SHEETS
Formed Plastic with pins, etc.
STRIPS
Reinforced Earth
York System
GEOTEXTILES
NONWOVEN
Continuous Filament
Staple Filament
KNITTED
WOVEN
COMBINATION PRODUCTS (Geocomposites)
NEEDLE PUNCHED
CHEMICAL BONDED
Wet Laid
Resin Bonded
HEAT BONDED
Spunbonded
MONOFILAMENT YARNS
Noncalendered
Calendered
SLIT FILM YARNS
FIBRILLATED YARNS
MULTIFILAMENT YARNS
Noncalendered
Calendered

Applications And The Purpose Of Geotextiles And Geomembranes

- **Pavements on soil soil** Increase in bearing capacity
- **Pavement overlays Inhibit** crack propagation.
- Rail roads

Prevent ballast contamination, distribute load on subgrade.
Embankments
Improve stability, provide drainage.

Retaining structures Reinforce and protect backfill

Natural slopes

Protect slope against erosion, reinforce soil, and provide drainage.
Rivers, canals and reservoirs
Replace or improve traditional filter layers, erosion control.

- Water pollution control

Extract and collect granular pollutants, reinforce and protect geomembranes, relieve pore water or gas pressure below membranes.

- Shore protection

Prevent erosion and sand migration, act as filter and drainage layer
Building elements
Form soil- cement filled bags and tubes to create columns

IMPORTANT QUESTIONS

1. (a) Write the advantages and applications of reinforced earth structures with neat sketches.
   (b) Discuss the external stability aspects in the design of reinforced earth wall.
2. (a) What is the main difference between geo-grid and geo-textile? Explain the field applications of geo-grid and geo-textiles.
   (b) Explain separation and filtration functions of geo-textile. Mention applications based on these functions.
3. (a) What is the objective of soil reinforcement?
   (b) What are the factors governing the design of reinforced earth walls?
4. (a) What are geomembranes? How geomembranes differ from geo textiles?
   (b) What are the applications of geotexitiles?
5. Explain the basic mechanism of reinforced earth. Discuss the various design formulae in reinforced earth wall.
6. (a) What are geotextiles? Write a note on common nomenclature of geosynthetics.
   (b) Explain with suitable examples the principles involved in geo-textile material as reinforcement for improving the bearing capacity of soil.
7. (a) Explain any four engineering applications of reinforced earth with sketches.
   (b) Describe the procedure of designing a reinforced earth wall.
8. (a) Distinguish between geo textiles and geo grids.

(b) Explain the applications of geo-textiles based on their separation and drainage functions.

9. Explain the design principle of reinforced earth wall.
10. Explain clearly the functions of Geotextiles.
11. (a) What is reinforced earth? How does it differ from reinforced cement concrete and mechanically stabilized soil?

    (b) Distinguish between “frictional fill” and “cohesive frictional fill” used in reinforced earth constructions.
12. (a) Distinguish between woven and non woven geotextiles. How they are manufacture and what functions they can perform?

    (b) What is a geo-grid? Explain different types of geo grids. How do they differ from geotextiles functionally?
13. (a) What are the factors governing design of reinforced wall?

    (b) With a neat sketch explain the various components of reinforced earth structure.
14. (a) What polymers are used as geosynthetics? What are their properties?

    (b) Compare geotextiles and geomembrane.

UNIT 3 P. Swapna (1) 3 Sets

Stabilisation: methods of stabilization - Mechanical - Cement - lime - Bituminous - chemical stabilization with calcium chloride, sodium silicate & Gypsum

Soil stabilization is referred to as a procedure in with a special soil proportioned / added / or removed or a cementing material or other chemical material is added to a natural soil material to improve one or more of its properties. The stabilizing materials include cement, lime, bitumen / asphalts, polymers & other chemicals.

Requirements;

It depends upon the character of the soil & its deficiencies. In case of a cohesionless soils the strength could be improved by providing confinement or by adding cohesion with a cementing or binding agent. In case of cohesive soil, the strength could be increased by drying, making the soil moisture - resistant adding the clay electrolyte concentration increasing cohesion with a cementing agent & adding frictional properties

Every stabilization process will be satisfy following things

(i) Be compatible with the soil material
(ii) Be permanent
(iii) Be easily handled & processed
(iv) Cheap & safe

P. K. Jhansi.

Types of stabilization process:-

(i) Mechanical stabilization
(ii) Cement "
(iii) chemical "
(iv) Thermal "
(v) Electrotreatment
(vi) Biotechnical stabilization etc.

Chemical additives:-

* cementing agent (primary additive is chemical)
* lime
* calcium & sodium chloride
* Lignin
* [illegible]

* Natural & synthetic polymers
* Aggregalis & dispersants
* other Chemical stabilizers
  - → Tung oil
  - → linseed oil
  - → cotton seed oil
  - → castor oil
  - → Rubber latex
  - → plasticized sulpher
  - → Molasses
  - → Mineral oil
  - → sodium carbonate
  - → parabbin

① Lime stabilization :-

It is done by adding lime to a soil (clayey soils). After the reaction b/w Lime & soil. The soil decreases its plasticity property & resulting material is more friable than the original clay & Therefore the soil is more suitable as a subgrade material in pavement construction.

$$\text{lime stone} \xrightarrow[\text{in Kiln}]{\text{Burning}} \text{lime}$$

Property of lime depends upon its parental stone Types of lime

a) High calcium, quick lime (CaO)
b) Hydrated, high calcium lime ($Ca(OH)_2$ · Slaked lime)
c) Dolomite lime ($CaO + MgO$)

* Quick lime is more Effective stabiliser than hydrated lime but hydrated lime is generally used as it is more safe & Convenient to handle.
* Magnesium content ↑ in lime ⟶ (↓) affinity of H_2O & heat generate during mixing
* Amount of lime required for soil stabilisation is 2 to 10%.
  a) 2 to 5% for clay gravel material (<50% silt - clay)
  b) 5 to 10% for soil (>50% , silt - clay)
  c) 3 to 7% if the particle size is b/w a & b.
  d) above 10% for heavy clays
* lime stabilization is not effective for sandy soils. so Such soil can be stabilised with the Combination of clay, fly ash & other pozzolonic materials

Calcium chlorides: ($CaCl_2$)

* when calcium chloride is added to soil, it causes colloidal reaction & alters the characteristics of soil water. As $CaCl_2$ is deliquescent & hygroscopic, it reduces the loss of moisture from the soil.
* $CaCl_2$ is very effective as dust palliative, so this method is effective for silty & clayey soils which lose strength with an increase in water content.
* The amount of chemical required is about 1/2 % of the weight of the soil.

Sodium Silicate:

* The chemical is used as solution in water, known as water glass; The chemical is injected into the soil.
* sodium silicate gives strength to soil when it reacts with it. It also makes the soil impervious. The maximum dry density of the soil increases
* The amount of chemical required is 0.1 to 0.2 % of the wt. of soil. The method of stabilization is inexpensive.

Portland Cement Stabilization:

→ portland cement & bitumen addition cause stabilization of soil by cementing

→ In a soil-~~co~~ cement more of coarse grained particles are cemented & the proportion of fine grained cementation is small.

1) Nature of soil:

→ All inorganic soils which can be pulverised is stabilised using cement

→ presence of clay in soil causes problems in pulverization, mixing & compacting the mixture

→ Calcium is the most desirable ion for ease of cement stabilization.

→ The best results are obtained for well-graded soils having less than 50% of its particles finer than 0.074 mm (4)

(ii) Amount of cement:

Cement content varying from 5 to 20% for satisfactory stabilization.

	Cement (%)
for gravel	5 to 10%
" Sand	7 to 12%
" silt	12 to 15%
" clay	12 to 20%

→ The cement content is determined by measuring the compressive strength of specimen with different proportions of cement.

(iii) Mixing:-

→ Increase in continued mixing causes a decrease in the degree of mixing & may lead to segregation of components

→ mixing made in laboratory have high strength & greater durability.

Moisture content:

· It plays 2 important role

i) it influences the compaction characteristics

ii) It furnishes water for cement hydration

→ The best moisture content for compaction is governed by the soil type & method of compaction

Compaction condition:

→ It is observed that at optimum moisture content the compaction results is better.

Age & Curing:

→ The compressive strength of soil-cement increases with the age.

→ Soil-cement cures rapidly with increase in temperature although it will harden all temperatures.

~~Adv~~ → stabilization of some soil are not responsive to cement.

Advantages: Advantages

i) reducing the additive quantity needed to perform
ii) reducing the total stabilizer cost.

BITUMINOUS STABILIZATION:-

→ Bitumens are non-aqueous system of hydrocarbon in which the primary components are natural or refined petroleum bitumens
→ It stabilizes the soil either by binding the particles together or protecting the soil from the ~~dte~~ deterious effect of water.
→ Asphalt are produced by 3 processes
i) vacuum distillation producing straight run asphalt
ii) High temperature pyrolysis of refinery heavies
iii) High temperature air blowing straight run asphalt.

Nature of soil:
→ All inorganic soils can be stabilized by asphalt.
→ Asphalt stabilization can not be Effective in fine grained soils with high pH & dissolved salts.

Amount of Asphalt:
→ In fine grained soils addition of asphalt does not increase the strength but improves the water-proofing property

Mixing:
A thorough incorporation of the additive with the soil yeilds a better stabilized soil.

Compaction condition:
→ The density of a mixture of soil & asphalt is governed by the volatiles content & amount & type of compaction.
→ In plastic soils the volatiles content which gives the maximum cured strength & that which gives optimum density be quite different.

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UNIT 4

REINFORCE EARTH AND GEOSYNTHETICS

SIA GROUP

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. What are the principle requirements of reinforced earth?

Answer :

Model Paper-I, Q1(g)

The principle requirements for the reinforcement of different soil materials are,

1. It should have high strength.

   Example weak soil should be reinforced to have high strength,
2. Cost of handling
3. Stability
4. Durability
5. High coefficient of friction
6. Adherence with soil
7. Soil should be mixed together with low cost and
8. It should be readily available.

Q2. What is the objective of soil reinforcement?

Answer :

April-15, Set-1, Q6(a)

Objective of Soil Reinforcement

Soil offers good resistance to compression but is weak against tensile and shear loads (or forces). Soils can withstand on their own only upto their respective angles of repose. Therefore, to hold soil at steeper slopes, lateral supports are required.

The main objective of the soil reinforcement are mentioned as follows,

(a) To increase tensile and shear strength of the soil.

(b) To restrain its displacements.

(c) To provide lateral support in order to hold it at steep angles.

(d) To reduce distortion under stress i.e., to increase elastic modulus.

The most significant objective of soil reinforcement is that they can undergo differential settlements without any significant loss of strength or without any failure. While, in the case of conventional supporting systems (retaining walls), they do not offer flexibility and sometimes may fail due to settlements.

Q3. Define and explain reinforced earth technique.

Answer :

Reinforced Earth Technique

Reinforced earth comprises of a compacted soil mass having reinforced elements or members. In this friction gets developed between the layers of compacted soil and reinforcing elements. The soil transfers the forces to the reinforced results tension in the reinforcement members. Tension is due to the shear stresses developed in it which prevents the lateral deformation of soil. The main application of reinforced earth is reinforced earth walls.

Q4. What are reinforced earth retailing walls ?

Answer :

Reinforced earth retaining walls are the structures which are used for supporting the soil mass laterally so that soil can be retained at different levels on both sides.

Shear force and bending moment of the structures can be determined in the design of reinforced earth walls. The retaining wall prevents the retained earth to exert a lateral earth pressure on the wall.

Q5. In reinforced earth wall, the fill soil is generally selected as cohesionless soil. Why?

Answer : Model Paper-II, Q1(g)

In reinforced earth wall, cohesionless soil is generally preferred because it improves the existing marginal fill as well as it develops friction between the soil and the reinforcement. These soil are, compacted to gain a volumetric expansion of soil, which are best suited for reinforcing structures.

Cohesionless soil is suitable for the reinforced earth structures because of the following.

- These are well drained soils and is stable.
- Transfers the stress between the reinforcement and the fill.
- It increase shear strength.
- It behaves as elastic material.
- These are Non-Corrosive in nature.
- No frost action is observed.

Q6. What are the various modes of failure of a reinforced earth wall ?

Answer :

Failure Modes

The factors responsible for the design of reinforced earth are of two types. They are,

1. External failure mode
2. Internal failure mode.

1. External Failure Mode

External failure can occurs on the outside plane of reinforced earth mass. These external failure is analysed based on the conventional engineering soil which is used in practice.

The various external modes of failure are,

(i) Deep seated failure

(ii) Bearing failure

(iii) Sliding

(iv) Overturning.

2. Internal Failure Mode

Internal failure modes occur by,

(i) Rupture of reinforcement

(ii) Slippage of reinforcement and

(iii) Excessive/Deformation of buckling face elements.

Q7. What is Geosynthethic?

Answer :

Geosynthetic

Geosynthetic is defined as the branch of science that is used in geotechnical engineering for defining/describing the permeable fabrics. It was came into picture in the late 1970s. These geosynthetic are the artificial fabrics used in addition with rock or soil.

Geosynthetic can be divided into two groups,

1. Geotextile and
2. Geomembrane.

In these geotextile is a permeable fabric and geomembrance is an impermeable fabric.

Q8. What are the different types geosynthetics?

Answer :

Types of Geosynthetic

Geosynthetic can have a variety of different types based on the purpose they are used,

1. Wovens
2. Non-wovens
3. Knitted
4. Nets and grids
5. Biodegradable
6. Three dimensional mats
7. Membranes and
8. Composites.

Q9. List out the different field applications of geosynthetic.

Answer :

The following are the different field applications of geosynthetics,

1. Geospacers
2. Geoproducts
3. Geosynthetic
4. Geofabric
5. Geocomposites
6. Geogrids
7. Geowebs.

Q10. What are the properties of geosynthetics?

Answer : Model Paper-I, Q1(l)

Properties of Geosynthetics

The properties of geosynthetics depends on the function it has to fulfill. The various functions of geosynthetics are,

(i) Reinforcement
(ii) Filter
(iii) Drainage.
(iv) Separation layer etc.

In mechanical properties, reinforcement purpose is emphasized to modulus of elasticity and strength.

In hydraulic properties filters are emphasized to hydraulic conductivity taking in account all the aspects the properties of geosynthetics can be divided into five types. They are,

1. Fibre and material properties
2. Geometrical aspects
3. Mechanical properties
4. Hydraulic properties and
5. Durability or chemical properties.

Q11. Define geo-textile. What are the functions of geo-textile ?

Answer :

Geo-textile

Geo textiles is defined as the branch of science used for defining the permeable fabrics.

Functions of Geotextile

The basic functions where geotextile are used is as follows,

1. Drainage
2. Filtration
3. Seperation
4. Reinforcement
5. Formwork
6. Tensioned membrane
7. Cushioning
8. Erosion and dispersion control
9. Screening or fencing.

Q12. What is the function of geo-textile when used as separator?

Answer :

Function of Geotextile When Used as Seperator

When geotextile is introduced in the soil, it prevents inter-mixing of soil particles with different properties. These are commonly applicable for unpaved roads, paved roads, railways and protection of geomembranes.

The functions of geotextile in unpaved and paved roads are,

1. It separates the granular sub-base and sub-grade of the soil.
2. It restricts the propagation of reflection cracks.
3. It Improves tensile strength and longer fatigue life.
4. It also acts as a filter within the track bed.
5. These are used for protecting the geomembranes from hazards

Q13. What are the properties of geo-textile?

Answer :

Properties of Geotextile

The properties of geotextile involves the following,

1. It increases the bearing capacity of the soil and decreases degree of rutting.
2. It improves stability and provides drainage facility.
3. It prevents soil erosion sand migration and protects the slope.
4. It protects the back-fill and reinforces the retaining structure.

Q14. Explain how geotextiles are used in slope stabilization and in embankment construction in soft soils.

Answer :

Geo-textiles in Slope Stabilisation

Geo-textiles improves the foictional properties of soil. The rotational stability analysis a considers that ultimate tensile strength resists the active moment. The most critical failure surfaces is determined by circular are method which adds strength to the geotixtile layers and resists the rotational sliding.

The main function of geo-textile in slope stability is to protect the materials from stresses and strains. It also contross the erosion of materials.

Geo-textiles in Embankment stabilisation

The primary function of geotextile in embankment stabilisation is to reduce the vertical and horizontal deformations. The presence of geo-textiles increases the overall modulus of elasticity of reinforced embankment. The main advantage of geo-textile is, it reduces the lateral movement and the loads which are applied to the soft foundation materials are similar to the loads applied in laboratory consolidation test.

Q15. List out the applications of geo-textile based on the reinforcement functions.

Answer :

The following are the applications of geotextiles on the basis of reinforcement functions:

(a) Foundations

(b) Slopes and Embankments

(c) Retaining walls

(a) **Foundations**

(i) The bearing capacity of weak soil increases.

(ii) The stability of footing increases progressively.

(b) **Slopes & Embankments**

(i) Internal stability and foundation stability can be achieved.

(ii) Bearing capacity of subsoil increases.

(iii) Tensile strength gets increased.

(c) **Retaining Walls**

(i) It controls the water leakage problems.

(ii) The bending moment decreases.

Q16. What are the advantages and disadvantages of woven and non-woven text-tiles ?

Answer :

Woven Geotextiles

Advantages

(a) It strengthens and supports the aggregates.

(b) It increases the effective strength of structure.

(c) It is chemically inert in nature.

Disadvantages

(i) It reduces the performance of filter media.

Non-woven Geotextiles

Advantages

(a) It provides excellent rate of filtration.

(b) It enhances the good performance in separating the layer.

(c) It is effective towards erosion control.

Disadvantages

(i) The tensile strength is limited

(ii) It does not work as a load resistant.

Q17. Write the difference between geotextiles and geomembranes.

Answer :

Model Paper-II, Q1(h)

Differences between Geo Textiles and Geo Membranes

	Geo Textiles		Geo Membranes
1.	These are porus fabric materials	1.	These are thin materials
2.	These are manufactured from synthetic materials which are basically petroleum products.	2.	These are manufactured from synthetic or bituminous products.
3.	The permeability is high in geo textiles	3.	The permeability is very low in geomembranes.
4.	Geo textiles are used in a variety of civil engineering works.	4.	Geomembranes are used in the construction of waterproof or gasproof barriers.
5.	Geotextiles can be applied for bank and bed protection, embankments vertical and horizontal drainage and in road and railway construction.	5.	Geomembranes can be applied for sealing against fluid percolation (On sea coast, river banks, etc.) and buffers against pollutants.

PART-B

ESSAY QUESTIONS WITH SOLUTIONS

4.1 REINFORCED EARTH : PRINCIPLES-COMPONENTS OF REINFORCED EARTH-FACTORS GOVERNING DESIGN OF REINFORCED EARTH WALLS – DESIGN PRINCIPLES OF REINFORCED EARTH WALLS

Q18. Explain the different reinforced earth materials that are used in construction of any reinforced soil structure.

Answer :

Materials

The different reinforced earth materials that are used in construction of any reinforced earth structure are mainly depends on three materials. They are,

1. Fill/Soil matrix
2. Anchor (or) Reinforcement system
3. Facing.

The materials that are used in construction of different elements such as foundation, drainage that connects the elements, barrier and fencing elements different other materials are used for construction.

1. Fill/Soil Matrix

In this soil/fill type, generally shear properties of soil are improved and used for reinforcing earth structures. For conventional structures soil used should be well graded cohesionless soil. The advantage of cohesionless soil/fill are,

(i) Stable
(ii) Free from drainage and
(iii) Not susceptible to frost action.

Disadvantage is based on the relative cost.

2. Reinforcement

Different reinforcement materials used as reinforcing are,

(i) Steel
(ii) Concrete
(iii) Wood
(iv) Fibre
(v) Glass
(vi) Rubber
(vii) Aluminium and
(viii) Thermoplasts materials.

These reinforcing materials are in the form of strips, anchors, grids, rope, sheet materials, planks, chain, vegetation and combination of different material forms.

Q19. Explain the different applications of soil reinforcement for ground improvement.

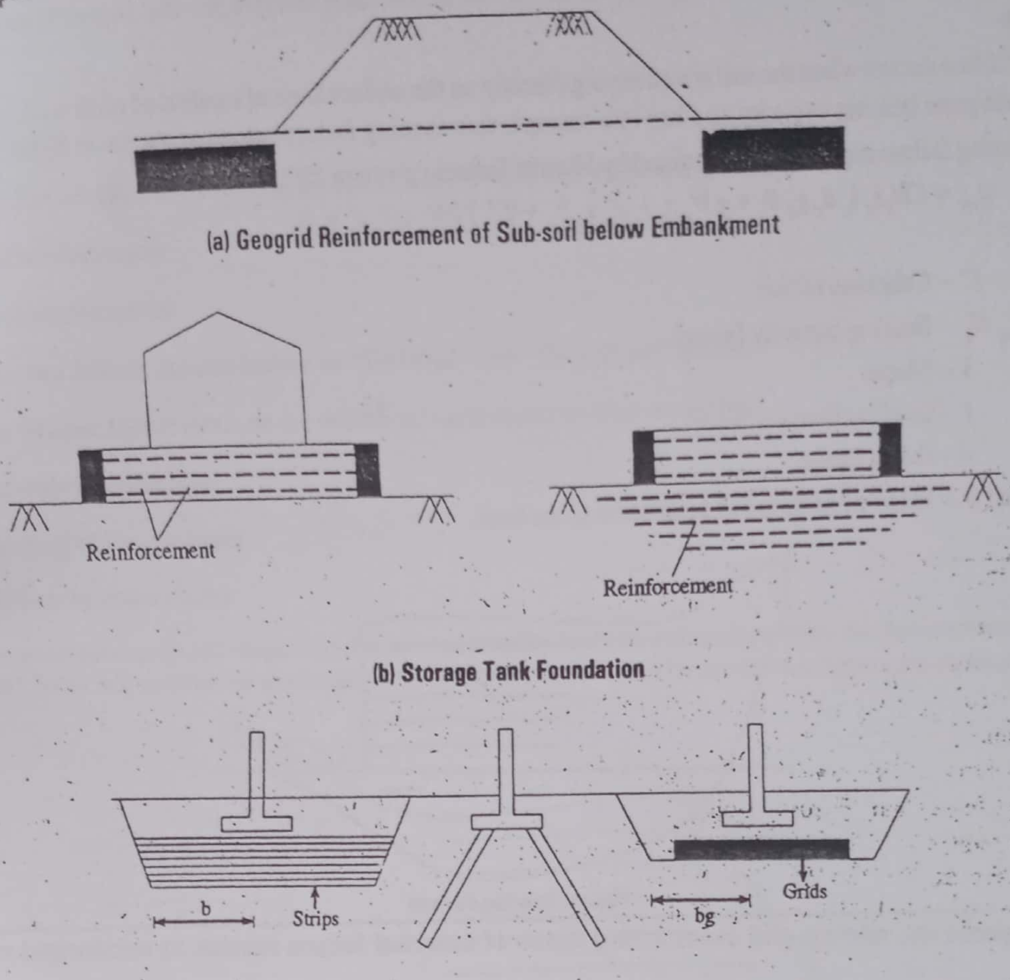
Answer : Model Paper-II, Q8

Applications

The different application areas used in earth reinforcement are as follows and various field applications identified by the Jones in 1985 are,

1. Bridge works
2. Dams
3. Embankments
4. Foundations
5. Highways
6. Housing
7. Industry
8. Military
9. Railway
10. Pipe works
11. Root pile systems
12. Water way structures and
13. Underground structures.

Ground improvement applications related to soil are as shown in figure.



(a) Geogrid Reinforcement of Sub-soil below Embankment

(b) Storage Tank Foundation

(c) Reinforcement Foundation

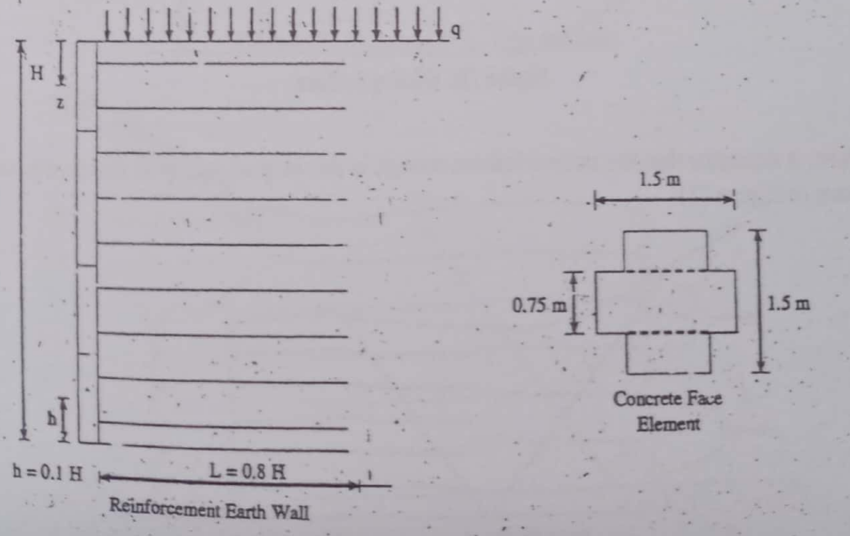
Figure: Application to Reinforced Earth for Ground Improvement

Q20. Draw a neat sketch showing the components of reinforcing earth strips and face panels and write down their advantages.

Answer :

Reinforcing Strips and Face Panels

The reinforced earth retaining structures consists of different horizontal layers made up of soil and galvanized steel strips that should be attached to concrete face panels as shown in figure.



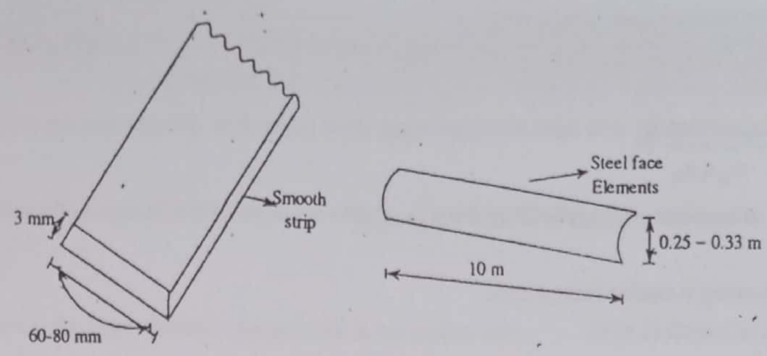


Figure: Typical Reinforced Earth Details

Advantages

1. These elements can deform easily.
2. Adjust settlement in backfill.
3. Surface area is reduced when subjected to corrosion.

Q21. Explain the design principles of reinforced earth wall.

Answer :

Design Principles of Reinforced Earth Wall

- Rankine (or) Coulomb earth pressure theory should be used.
- Active earth pressure (or) Passive earth pressure (or) At-rest earth pressure magnitude are adopted.
- The various forces acting horizontal, vertical and shear stress should be distributed on reinforced earth.
- Suitable geometry surface failure is assumed on reinforced earth.
- Reinforcing strip length can resist the failure occurred by the slippage.
- Safety factors are required and calculated from Rankine, Active Earth Pressure theory.
- The earth pressures on a reinforced earth walls can be calculated by both horizontal and vertical earth pressures.
- Their magnitudes can be derived based on the assumptions adopted by different theories.

Q22. How can the horizontal spacing of reinforcing strips are derived for material in a retaining wall.

Answer :

Let 'S_H' and 'S_V' be the horizontal and vertical spacing of strips or ties placed at centre to centre.

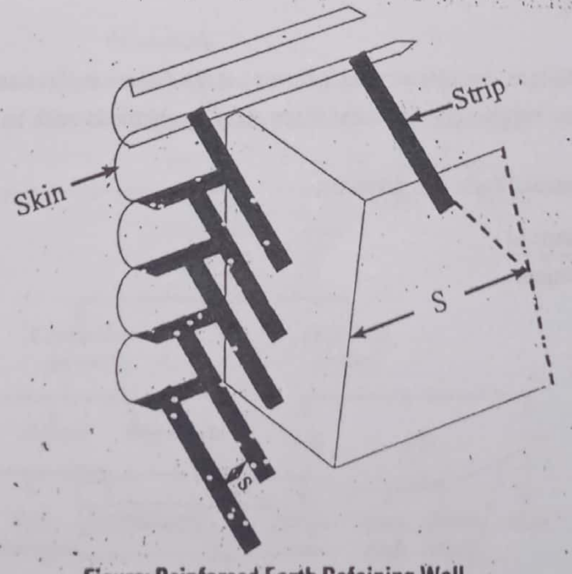


Figure: Reinforced Earth Retaining Wall

Maximum frictional force 'F_R' for a strip at a given depth 'Z' is given by,

$$F_R = 2\, x_e\, y \sigma_v \tan \phi_u$$

Where,

x_e – Effective length of strip

σ_v – Effective vertical pressure at a depth 'Z'

ϕ_u – Frictional angle between soil – strip.

Factor of safety against strip pullout at any depth 'Z'

$$(Fs)_p = \frac{\text{Maximum frictional force}}{\text{Strip force per unit length of the wall}}$$

$$(Fs)_p = \frac{2x_e \gamma \sigma_v \tan\phi_u}{\sigma_a s_v s_H} \quad \text{...(1)}$$

The total length of strips at any depth 'Z' is, $x = x_r + x_e$.

Where,

x_r – Length along Rankine failure zone

x_e – Effective length of strip.

From equation (1),

$$x_e = \frac{(F_s)_p \sigma_a s_v s_H}{2_y \sigma_v \tan\phi_u} \quad \text{...(2)}$$

At, any depth 'Z',

$$x_r = \frac{(H-Z)}{\tan\left(45+\frac{\phi^1}{2}\right)} \quad \text{...(3)}$$

From equations (1), (2), (3) we get,

$$x = \frac{(H-Z)}{\tan\left(45+\frac{\phi^1}{2}\right)} + \frac{(F_s)_p \sigma_a s_v s_H}{2_y \sigma_v \tan\phi_u}.$$

Q23. Explain about the deep seated external failure mode that occurs on a reinforced earth.

Answer :

Deep Seated Failure

This type of failure is generally adopted in the case of,

(i) Poor back fill material and

(ii) Soft foundation strata

- In this deep seated failure, circular surface is formed at the failure surface as shown in figure.
- It can be analysed by various conventional slope stability methods such as method of slices, simplified slip circle method etc.

Factor of safety for deep seated failure is given by,

$$F_s = \frac{\text{Resisting moment}}{\text{Driving moment}}$$

$$\boxed{\therefore F_s = \frac{F_R}{F_d}}$$

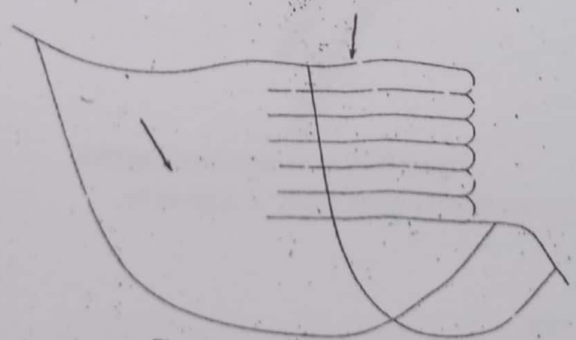


Figure: Deep Seated Failure

Q24. Explain about the bearing failure that occurs on a reinforced earth.

Answer :

Bearing Failure

Bearing failure occurs when the soil is underlying directly on the surface/base of reinforced earth wall and reinforced earth wall has the inadequate bearing capacity and has less strength then bearing failure occurs as shown in figure.

- Bearing failure capacity is determined by Hansen formula given in 1970 is as follows.

$$q_{wt} = CN_c s_c i_c d_c g_c b_c + q N_q s_q i_q d_q g_q b_q + 0.5\, YBN_y s_y i_y d_y g_y b_y$$

Where,

C – Cohesion of soil

N_c, N_q, N_y – Bearing capacity factors

s – Shape

i – Load inclination factor

d – Depth factor

g and b = Slope of surface and inclination of the base.

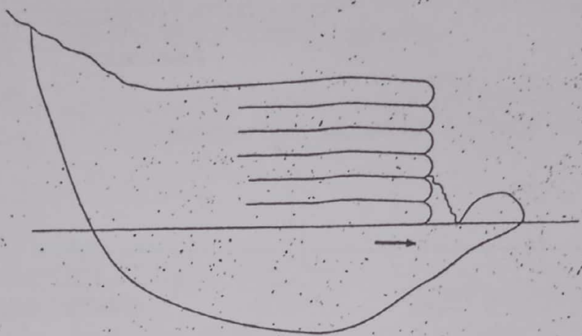


Figure: Bearing Failure

Q25. Explain about the sliding and overturning types of external failure modes in reinforced earth.

Answer : Model Paper-I, Q8

Sliding

In this type of failure, the reinforced earth base is normally kept at a suitable depth below the ground surface to prevent the surface as shown in figure (1).

- In this, at ground surface, some passive resistance is developed at the toe that should be relied.
- The failure due to sliding can be analysed by the conventional methods.

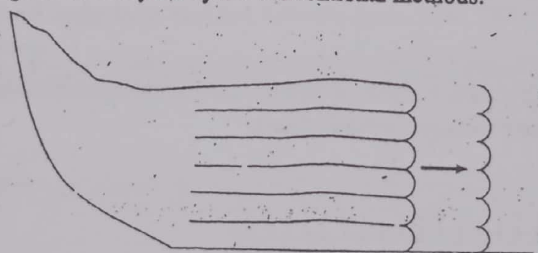


Figure (1): Sliding Failure

Overturning

In this type of failure, it assumes that the active failure wedge is developed and wall friction is developed at the back face of reinforced earth as shown in figure (2).

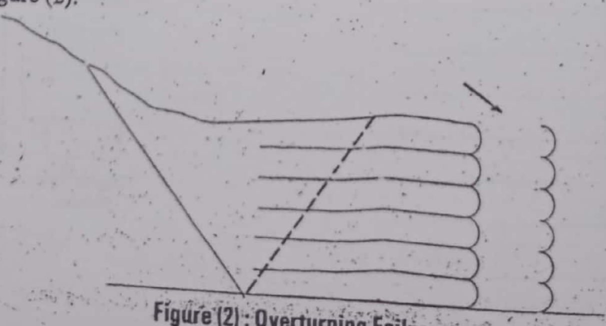


Figure (2) : Overturning Failure

Q26. Explain the internal failure modes that occur in reinforced earth.

Answer :

Internal Failure Modes

Internal failure modes that developed on the reinforced earth soil mass are given by,

1. Rupture of reinforcement
2. Slippage of reinforcement.

The above two failures are also known as "Tie break" and "Tie pull out" failure.

The internal failure mode on the reinforced earth mass can also occurs by,

(i) Excessive deformation
(ii) Backing of face elements
(iii) Failure by connections.

In these reinforced earth soil mass, once the internal stability analysis and earth pressure are known, then structural design elements of wall faces will not face an special problem on the structure. The different failure figures are as shown in figure.

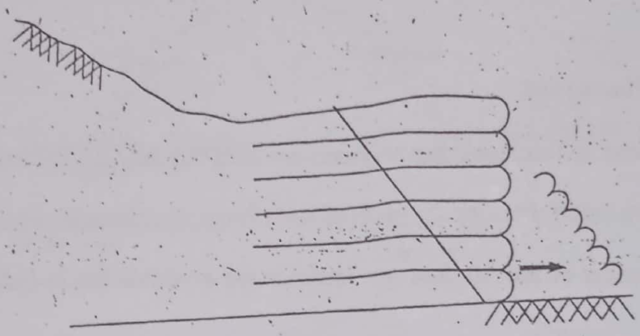


Figure (1): Rupture of Reinforcement

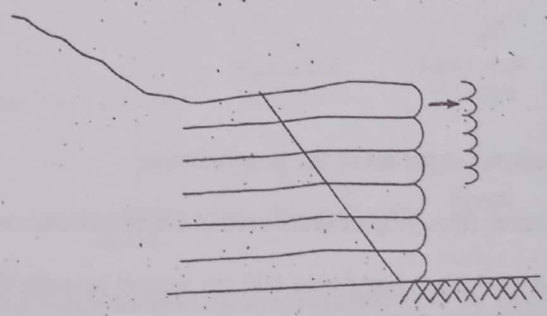


Figure (2): Slippage of Reinforcement

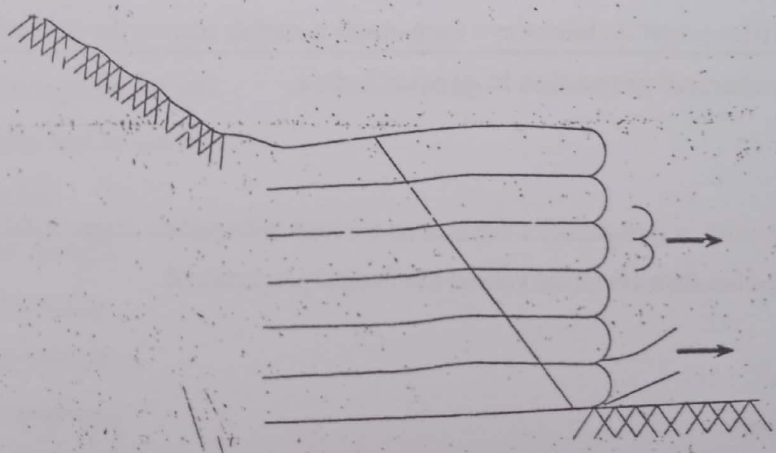


Figure (3): Excessive Deformation (or) Buckling of Face Elements

4.2 GEOSYNTHETICS : GEOTEXTILES-TYPES-FUNCTIONS AND APPLICATIONS-GEOGRIDS AND GEOMEMBRANES-FUNCTIONS AND APPLICATIONS

Q27. Explain about the geosynthetic different field applications that are identified.

Answer :

The different field applications of geosynthetic as observed and identified by John in the year 1987 and gave the different terms as follows,

1. **Geospacers**

   These geospacers are the impermeable spaces used in tin drains only.

2. **Geoproducts**

   These products are obtained from natural fibres, geospacers and metallic soil reinforcements.

3. **Geosynthetic**

   It generally consists of geotextile and geomembrane. Mostly geotextile products are used those should be man-made fibres.

4. **Geofabric**

   These are geotextile products such as planar flat sheet geotextile and in these geotextile mats are not used.

5. **Geocomposites**

   It generally consists of more than one geoproducts.

6. **Geogrids**

   Geogrids also consists of geotextile products. If the geotextile products are made up of large rectangular apertures then they are commonly known as geotextile grids and non-rectangular apertures, then they are commonly known as geotextile nets.

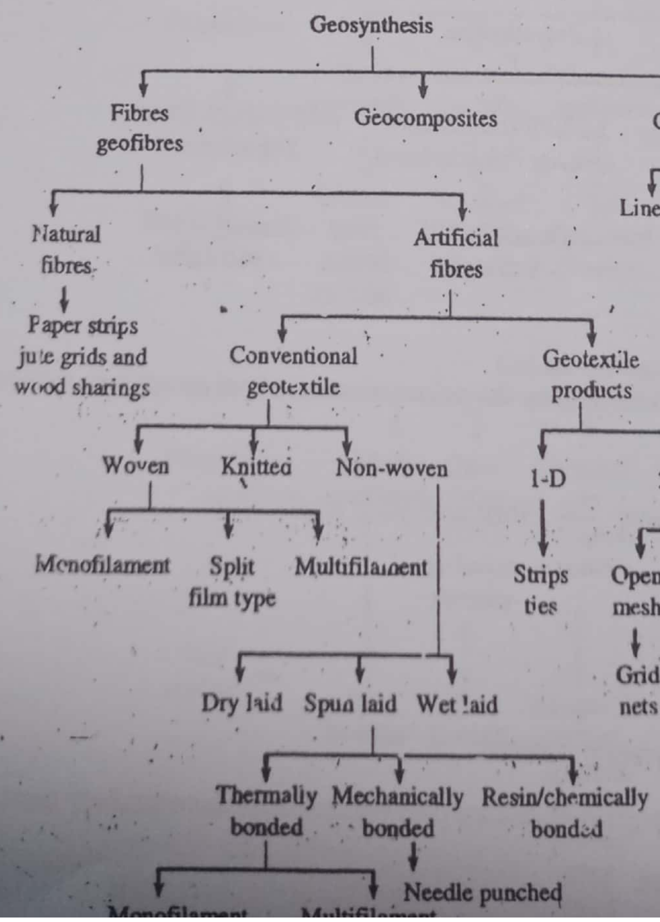
7. **Geowebs**

   These geowebs is generally an American term. These geowebs are used in cellulose geotextile.

Q28. Explain the classification of geosynthetic.

Answer :

The classification of geosynthetic groups can be mainly based on fabrics, membranes and composites. Its sub-groups are as follows (given by John in 1987).



Q29. Explain the different raw materials used in geosynthetic.

Answer :

Raw Materials

The different raw materials that are used in the manufacture of geosynthetics are thermoplastics. Geosynthetic can be either natural biodegradable fibres or artificial fibres. The biodegradable materials are jute, paper strips and wood shaving. The various raw materials are as follows,

1. Polyamide

Polyamide (PA)

Aliphatic polyamide → Polymerisation of petroleum derivative e-caprolatam → Chains (not has ring shaped structures) are formed

Aliphatic polyamide → Polymerisation of salt of adipic acid and hexamethylene diamine (petroleum products) → Thread or tape that are cut into granules are formed in the manufacturing process

2. Polyester

These are also made by the petroleum products. The polyester is formed by the polymerisation of ethylene glycol with dimethyl/terephthalate or terephthalic acid.

If more reactors are used in series, then it produce continuous process.

3. Polyethylene (PE)

Polyethylene is of crystalline form and has characteristics of fibre forming polymer.

Polyethylene

LDPE (Low Density Polyethylene) → Density = 920 – 930 kg/m³

LLDPE (Linear Low Density Polyethylene) → Density = 925 – 945 kg/m³

HDPE (High Density Polyethylene) → Density = 940 – 960 kg/m³

4. Polypropylene

It is also a crystalline thermoplast which is formed by the polymerisation of polypropylene manomer and catalyst stereo-specific is used.

Polypropylene → Homo polymers → Fibre and yarn application

Polypropylene → Copolymers

5. Polyvinylchloride

Polyvinylchloride (PVC) can be a rigid polymeric material.

- ❖ As a thermoplastic coatings material and in geomembranes polyvinylchloride is commonly used.
- ❖ The PVC can be available in powdered form.

Different raw materials are exists with different forms and used for different purposes.

Q30. Explain about fibre and material properties in geosynthetics.

Answer :

Fibre and Material Properties

The fibre and material properties of a geosynthetic manufacture involve various raw materials such as,

(i) Polyamide

(ii) Polyester

(iii) Polyethylene

→ LDPE

→ LLDPE

→ HDPE

→ LDPE

(iv) Polypropylene

(v) Polyvinylchloride

(vi) Ethylene copolymer bitumen and

(vii) Chlorinated polyethylene and various other polymers are used but their market value is relatively less.

❖ Various standard methods are used for testing the material and fibre properties and considering geosynthetics as a whole.

❖ In some countries, large number of standardised test methods are available but in India complete standardization test method is not available.

❖ The two aspects considered in these geosynthetic properties (i.e., material and fibre properties) are,

1. Temperature and

2. Water content.

❖ These two aspects effect the various properties of the geosynthetics.

❖ For building linear macro molecules, fibre properties are used in the manufacture of geosynthetics.

❖ These fibre properties are based on the bonding forces that are present between the atoms.

❖ Fibre properties further depends on the structure that the macro molecules are to be arranged.

❖ These materials and fibre properties behave as a visco-elastic materials because the materials used in these are polymers.

Q31. Explain about mechanical properties in geosynthetics.

Answer :

Mechanical Properties

The mechanical properties in geosynthetics depends on the load-deformation characteristics.

❖ The mechanical properties depends on the various mechanical properties of,

(i) Fibre material

(ii) Fibre structure

(iii) Yarn structure and

(iv) Structure of geosynthetics.

❖ The various mechanical properties considered are,

(i) Creep resistance

(ii) Fatigue resistance

(iii) Friction interface

(iv) Tear strength

(v) Abrasion resistance and

(vi) Seam strength.

❖ Burst and puncture strength are relevant properties in mechanical properties.

❖ Function of geosynthetics is based on the role of properties and characteristics applied in geosynthetics mechanical properties are as shown in below figure,

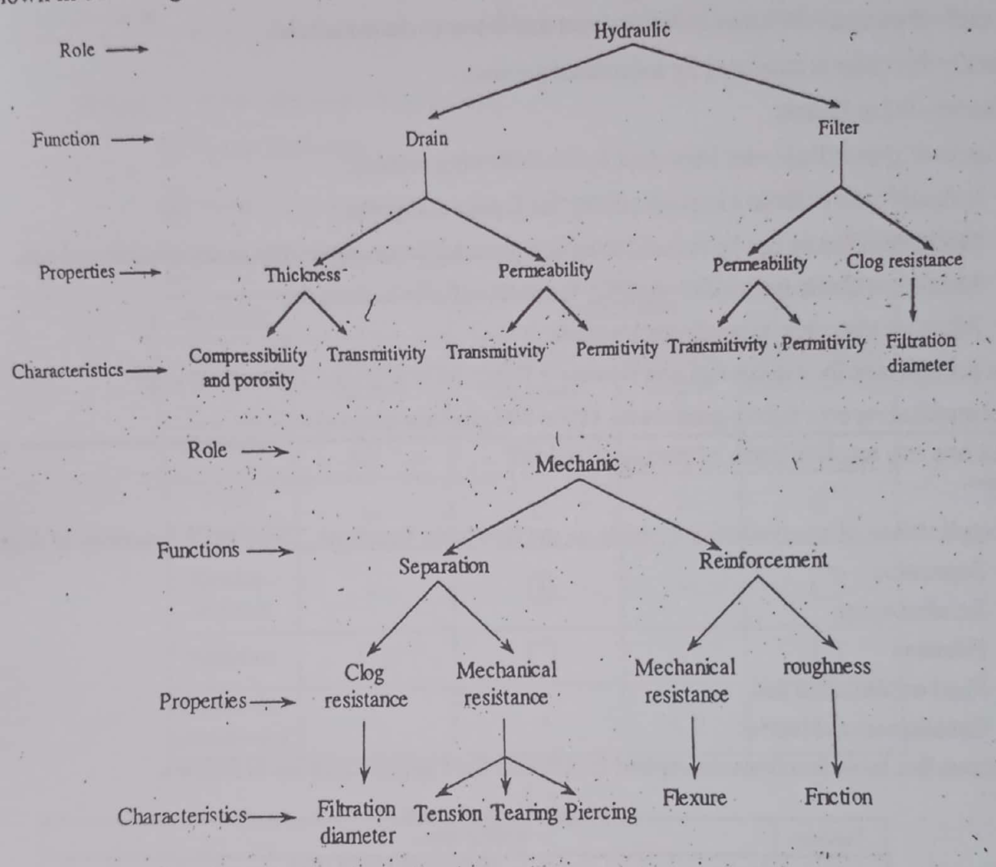


Figure: Role of Properties and Characteristics Related to the Type of Functions

Q32. Explain different geosynthetic properties and their testing methods.

Answer :

The various geosynthetic properties are,

1. General properties used for manufacture

2. Index properties for

   (i) Mechanical strength

   (a) Uniaxial loading

   (b) Rupture resistance.

   (ii) Endurance properties

   (iii) Hydraulic.

3. Soil geotextile system performance properties.

The various testing methods for the geosynthetic properties are as follows,

I → Geosynthetic General Properties for Manufacture

Property	Testing method
Type and construction	N/A
Polymer	N/A
Weight	ASTM is proposed
Thickness	ASTM is proposed
Roll length	Measured
Roll width	Measured
Roll weight	Measured
Roll diameter	Measured
Specific Gravity and density	FHWA manual
Absorption	FHWA manual
Surface characteristics	N/A
Geotextile isotropy	N/A

II → Index Properties

Mechanical Strength – Uniaxial Loading

Property		Test method
Tensile strength	Grab strength	ASTM D-4632
	Strip tensile strength	ASTM D-1682
	Wide width strength	ASTM D-4595
Poissons ratio		No test
Stress strain characteristics		ASTM D-4595
Dynamic loading		No standard test method
Creep resistance		FHWA manual
Friction/ adhesion		Modified corps of engineers EM-1110 -2-1906
Seam strength		ASTM D-4632 D-1682 D-4595 depends on requirement
Tear strength		ASTM D-4533

Mechanical strength – Rupture resistance

Property	Test method
Burst strength	Mullen burst ASTM D-3786
Puncture resistance	Modified ASTM 0-4833
Penetration resistance	No standard method
Fabric cutting resistance	No standard method
Flexibility (Stiffness)	Modified ASTM D-1388

Endurance Properties

Property	Test method
Abrasion resistance	ASTM D-4886
Ultra Voilet (UV) radiation stability	ASTM D-4355
Chemical and biological resistance	No specific method, methods such as D-5760 5762 2015 2016 2053
Wet and dry stability	No standard method
Temperature stability	No standard method

Hydraulic

Property → / Test method →

- Opening characteristics
  - AOS → ASTM D-475
  - Porimetry → Used AOS for O_{95}, O_{85}, O_{50}, O_{15}, O_5
  - POA → FHWA manual
  - η → No standard method
- Permeability (k) And permitivity → ASTM 0-4491
- Soil retention ability → Emperical relations
- Clogging resistance → No standard method
- In-plane flow capacity transmissivity → ASTM D-4716

AOS → Apparent Opening Size
POA → Percent Open Area
η → Porosity

III – Performance Properties for Soil Geotextile System

Property → / Test method →

- Stress strain characteristics →
  - (i) Tension test
  - (ii) Triaxial
  - (iii) California bearing ratio
- Creep tests → Shear box Test FHWA Manuai
  - → Tension test
  - → Triaxial test
  - → Extension test
- Friction/ adhesion → Direct shear method → Corps of engineers procedure
- Dynamic and cyclic loading resistance → No standard method
- Filtration and soil retention properties →
  - (i) Slurry method
  - (i) FHWA manual

Q33. Explain about the geometrical aspects in geosynthetics.

Answer :

Geometrical Aspects

The geometric aspects can depends on the different types of geosynthetics.

- Geometrical aspects depend on the,
  - (i) Particular type of geosynthetics adopted
  - (ii) Construction techniques and various properties suitable for construction are required.

- Various aspects that are considered for selection of geometrical aspects are,
  - (i) Field boundary
  - (ii) Execution methods.
- In a definite choice of geosynthetics used for construction it depends on,
  - (i) Width and length
  - (ii) Thickness
  - (iii) Mass per unit area and
  - (iv) Available prefabricated technique.
- Length of geosynthetics is unlimited.

  Limited for transport facility system involved for ease of execution and handling on site.
- Mass per unit area length varies from 50 to 200 m.
- Width – 5 to 5.5 for wovens and non wovens.
- Geotextile thickness – Distance between upper and lower surface material.

  Generally thickness is measured by a specified pressure.
- Thickness – 0.2 to 10 mm.
- Thickness of geotextile is very important for the following reasons,
  - (i) It should have sufficient impermeability for liquids and gases.
  - (ii) Mechanical forces can be resisted to ensure geomembrane, especially in construction phase.
  - (iii) Membrane sheets are welded together to ensure reliable technique.
  - (iv) Allowance for embossing the geomembrane.

  Mass per unit area for wovens and non wovens = 100 to 1000 g/m^2 and 100 to 2000 g/m^2
- In geometrical aspects, lighter grades with 100 to 200 g/m^2 are adopted.

Q34. What are the applications of geosynthetics?

Answer :

The applications of geosynthetics depends on the five basic functions. These basic functions of a geosynthetics are,

(i) Separation

(ii) Reinforcement

(iii) Filtration

(iv) Fluid transmission and

(v) Containment and barrier.

- The above five basic functions are applied in different field applications are as follows,

Function	Applications					
	Containments	Coastal and river protection	Unpaved roads.	Areas of granular fill	Retaining wall drains	Below geomembranes
Separation	•	□	□	□	○	•
Fluid transmission	•	○	○	○	□	□
Reinforcement	•	⊙	⊙	⊙	•	⊙
Filtration	•	□	⊙	•	○	•
Barried containment	□	•	•	•	•	•

Where, • ⟶ Not important function

○ ⟶ Important

⊙ ⟶ Very important

□ ⟶ Dominant function

Function	Applications					
	Nearly horizontal drains	Embankment reinforcement	Reinforced soil walls	Embankment piles	Rock fall nets	Erosion control
Separation	○	⊙	•	⊙	•	⊙
Fluid transmission	□	○	•	•	○	○
Reinforcement	⊙	□	□	□	□	□
Filtration	•	•	•	•	•	□
Barrier and containments	•	•	•	•	•	•

Where, • ⟶ Not important function

○ ⟶ Important

⊙ ⟶ Very important

□ ⟶ Dominant function

Function	Applications			
	Trench drains	Flexible formwork	Pollutant buffers	Encapsulated Hydraulic fill
Separation	⊙	○	•	⊙
Fluid transmission	○	○	•	○
Reinforcement	•	⊙	•	□
Filtration	□	□	•	□
Barrier and containment	•	•	□	•

Where, • ⟶ Not important function

○ ⟶ Important

⊙ ⟶ Very important

□ ⟶ Dominant function

Q35. Distinguish between drainage and filtration function of geotextiles. Mention the applications based on each function.

Answer :

Functions of Geo-textiles Based on Drainage

(i) It attains a relatively higher water-carrying capacity.

(ii) The direction of the drain is perpendicular to the plane of the sheet.

(iii) Stability of structure can be improved.

(iv) The method of accessing the system is simple and quick.

Function of Geo-textiles Based on Filtration

(i) It controls the movement of soil particles due to seepage forces.

(ii) The entry of silt particles is prevented in core and shell structures.

(iii) It eliminates the filter sand with dual media back-fill.

Applications of Geo-textiles

(a) **Based on Drainage**

(i) Highways

(ii) Canal lining

(iii) Land fills.

(iv) Trench drains

(b) **Based on Filtration**

(i) Rail roads

(ii) Embankments

(iii) Pavement overlays

(iv) Retaining wall drains

(v) Unpaved roads

(vi) Coastal and river protection.

Q36. Explain about the applications of geotextile.

Answer :

The geotextile applications are used everywhere and combined, adopted to different circumstances.

- Geotextile, based on versatile is used they are combined with many traditional and new building materials.
- The various application areas of geotextile used is,

(i) **Rail Roads**

The purpose of geotextile is to distribute the load on subgrade and prevents from ballast contamination.

(ii) **Share Protection**

Protects from sand migration and from erosion.

(iii) **Embankments**

It generally improves stability.

(iv) **Natural Slopes**

These slopes protect from the erosion and soil reinforcement.

(v) Pavement overlays.

(vi) Pavements on soft clays.

(vii) Rivers, canals and reservoirs to control erosion.

(viii) Water pollution control.

(ix) Building elements.

Q37. Explain about geosynthetic grids and nets.

Answer :

Grids and Nets

Geosynthesis grids consists of geotextile products. The geonets generally consist of two sets of polymeric strands at a constant angle. If the geotextile products are made up of large rectangular apertures then they are commonly known as geosynthesis grids or geogrids.

- Geosynthesis nets can be made up of strands and aperture size 2 to 7 mm respectively.
- The strands should be partially melted and rolled to produce thermal bonds.
- Generally strength varies from 2 to 10 kN/m for geonets.
- For low strength soil reinforcement, these geonets are used.
- Grids are made up of extended sheets from the polymeric lattices.
- The various rawmaterials used in geogrids are polypropylene or high density polyethylene.
- The extruded sheets are perforated initially, then they are formed, sized and distribution of holes is determined by the end product.
- When the sheets are heated gently, the sheets are stretched in one direction. In stretching direction it forms a long polymeric chain molecules that are aligned to it stretching.
- Uniaxial and biaxial grids developed by the John in 1987 are as shown in figure.

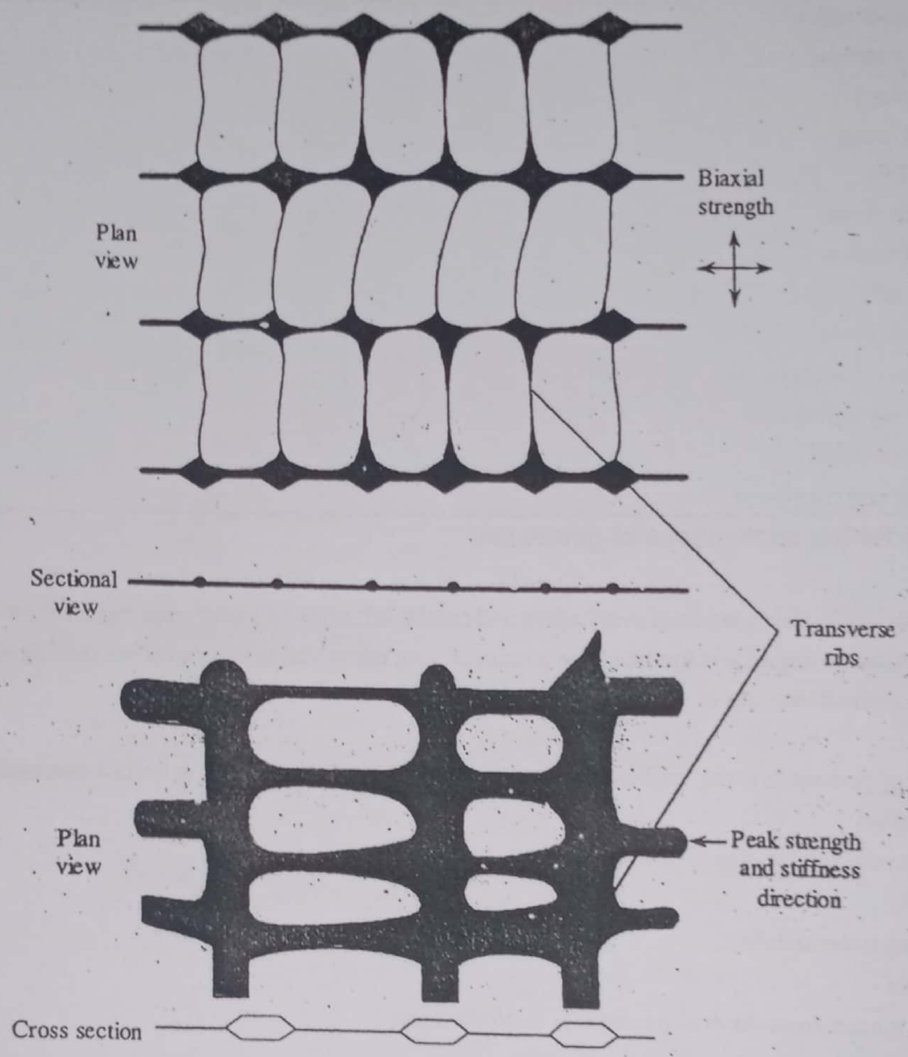


Figure: Geosynthectic Grid Nets

Q38. Explain the functions, properties and applications of geogrids.

Answer :

Model Paper-I, Q9

Functions of Geo-Grids

- Geo-grids gives the stress-strain characteristics of a high-density polyethylene grid, which is pulled in the direction of ribs.
- In general, it points out the design and construction of geosynthetics.
- The durability of geo-grids gives a long-term performance.

Properties of Geo-grids

The properties of geo-grids are as follows,

- These are relatively flexible.
- It improves the strength of the cohesive soil.
- It also improves the stiffness and bearing capacity of soil under static loading.
- It interacts with soil through fiction , adhesion and as well as the passive resistance.

Application of Geo-Grids

Carious applications of geo-grids are as follows:

- It is used in the construction of embarkments and retaining walls.
- It is used in slope stabilization.
- It is also used in unpaved roads and foundation practices.
- Sometimes, these are also used in aircraft landing mats.

Q39. Explain about the geomembranes.

Answer:

Geomembranes

Geosynthetic membranes are also known as geomembranes.

- The geomembr anes are 2-D thin sheets having low permeability.
- The geomembranes are of flexible materials.
- For the formation of gasproof barrier or water proof barrier, geomembranes are used.
- The various raw materials used in the manufacture of geomembrane are HDPE, LDPE, PVC etc and also bitumen produ are also used in the manufacturing of geomembranes.
- The geomembranes are manufactured in factory or fabricated on the site.
- The three steps used in the manufacturing of factory thermoplast geomembranes are,
  1. Non-reinforced geomembrane
  2. Reinforced geomembrane and
  3. Reinforced laminated geomembrane.
- Thickness can vary upto 15 mm for viscous manufacturing technique. In these,

  Width + 2 m, thickness $\rightarrow$ 0.5 – 2.5 mm.
- In on site fabrication of thermoplast membrane, the surface of the membrane is sealed with warm or cold viscous materi applied on it.
- The length = 4 – 5 m and thickness = 1.5 – 6 mm for the geomembranes reinforced with bitumen material.

Q40. Describe the different forms of geomembranes and state their functions in the stabilization of soils.

Answer:

Model Paper-II, (

The various forms of geo-membranes are

(i) High density poly ethylene (HDPE)

(ii) Low density poly ethylene (LDPE)

(iii) Polyvinyl chloride (PVC)

(iv) Ethylene copolymer bitumen (ECB)

(v) Chlorinated Poly ethylene (CPE)

The various functions of geomembrans in stabilization of soils are:

(i) High Density Poly Ethylene

It is mainly used for the production of polyethylene filaments and tapes which is used for geo-textiles. It is highly rigid and resistant to chemical reaction.

(ii) Low Density Poly Ethylenc

It is mainly used for the production of various thin films. This process is carried out in a very low pressure.

(iii) Polyvinyl Chloride

It is used as a coating material and mainly used in geomembranes.

(iv) Ethylene Copolymer Bitumen

It is mainly used for sealing materials and is chemically resistant against the acid attacks.

(v) Chlorinated Poly Ethylene

The main function of chlorinated polyethylene is its performance which mainly depends on the quality of polyethylene and the degree of chiorination.

4. Explain the functions, properties and applications of geomembranes.

er:

ns

is used to control frost-susceptible soils.

is used to conduct water flow into specified paths.

Used as cutoffs for seepage control.

For spillways, these are used as linings.

Used as waterproof materials for tunnels and pipe lines.

ties

The main physical properties of geomembranes are,

Thickness

Density

Melt flow index

Weight

Vapour transmission.

The mechanical properties of geomembrances are,

Tensile strength

Elongation

Tear and impact resistance

Shear strength

Anchor strength

Stress cracking

Puncture resistance.

ications

The main applications of geomembranes are,

Canal lining

Landfills

Tunnel lining

Water proofing.

UNIT 5

EXPANSIVE SOILS

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. What are expansive soils?

Answer :

Expansive Soils

The soils which have tendency to increase in volume by adding water and decrease in volume by removal of water are known as expansive soils. The change in volume in swelling soils creates many problems in the structures that come in their contact or away for them.

Q2. Write a short notes on:

(a) Swelling Pressure

(b) Swelling Potential

Model Paper-I, Q1(i)

Answer :

(a) Swelling Pressure

The pressure required to prevent the expansion of volume in soil in contact with water is known as swelling pressure P_s. The measurement of swelling pressure in a laboratory Oedometer differs from that in the field. The swelling pressure measured in the laboratory is always more than the actual field swelling pressure.

(b) Swelling Potential

The swell percentage of laterally confined sample in an oedometer test soaked under 7 kPa surcharge load after the compaction to maximum dry density.

Q3. Write a short notes on Free swell.

Answer :

Free Swell

Free swell can be defined as,

$$S_f = \frac{V_f - V_i}{V_i} \times 100$$

Where; V_i = Initial dry volume of poured soil

V_f = Final volume of poured soil.

As per the concept of Holtz and Gibbs, 10 cm^3 of dry soil passing through sieve number 40 is poured into graduated cylinder of 100 cm^3 having water. The value of V_f comes by measuring the volume of settled soil after 24 hours. The free swell value of bentonite-clay is supposed to be in the range of 1200-2000 percent. The increase in free swell is related to plasticity index.

Q4. Write short notes on the field conditions that favour swelling.

Model Paper-II, Q1(i)

Answer :

A high swelling potential may be present in a soil but the soil may or may not swell. This is based on many factors such as field moisture content and the equilibrium moisture content. If the equilibrium moisture content is more than the field moisture content, then the soil will swell appreciably. Whereas, if the equilibrium moisture content is less than the field moisture content, the soil will shrink.

There is more swell in an area where the fill has high degree of compaction. If more load is placed on the swelling soil, then the swelling of soil is inhibited. The swelling is more pronounced when light loads are imposed.

Q5. State the various foundation pratices that are employed for expansive soil.

Answer :

Following are the various types of foundations employed for expansive soil.

(i) The isolated structures being kept from the swelling effects of the soil

(ii) The foundations designed will not get damaged inspite of swelling

(iii) Swelling potential of soil is eliminated.

Q6. Explain in brief about the CNS technique of foundation on expansive soil.

Model Paper-I, Q1(j)

Answer :

The technique of cohesive non-swelling soil depends of the concept of providing same environment existing in saturated expansive soil at no volume change by placing a soil system which does not have clay mineral of expanding type but has cohesion. It is recommended that, settlement aspects and bearing capacity of CNS must be considered and upto sufficient extent, the CNS should be provided.

In this method, it is required to conduct large scale tests and controlled compaction in layers is needed due to which this method is not competitive on economy considerations.

Q7. Write a note on granular pil foundation.

Model Paper-II, Q1(j)

Answer :

Granular Pile Foundation

By using effective stress analysis, assume $C' = 0$ for a granular soil. The equation $Q_u = q_{pu} A_b + F_s A_s$ is used to obtain the ultimate load capacity of a single pile, driven into a granular soil.

In the granular soil, $q_{pu} = \bar{\sigma} N_q$

For driven piles in sand, take the value of $\phi = \dfrac{\phi + 40°}{2}$ where Q_1 is the value of insitu of shearing resistance angle. Therefore, Q_{pu} can be determined by the equation $Q_{pu} = q_{qu} A_b$ with known pile dimensions and soil properties.

The equation $q_{pu} = \bar{\sigma} N_q$ appears to suggest that there is increase in unit point resistance in direct proportion to the embedded length of the pile. Many observations of the field show that these values increase only upto the limited depth, after which it remains constant. This depth is known as 'critical depth of the pile'. The critical depth is based on width of the pile and angle of shearing resistance ϕ. The concept of critical depth cannot be applied to the piles embedded in clay strata. The maximum value of unit point resistance should be limited to 5000 kN/m^2 for calcareous sand and 11000 kN/m^2 for normal silica sand. Its values differ from 15 diameter in loose to medium sands to 20 diameter in dense sands.

Q8. What are the catalyst and accelerators of better use of ground improvement techniques?

Answer :

April-15, Set-1, Q8(b)

Catalyst and Accelerators of Ground Improvement Techniques

1. For a given specific type of soil and site conditions, guidelines for finding the suitability of effective ground improvement techniques should be adopted.

2. Encourage the use of new techniques and construction materials such as geo foams, geo composite, etc.
3. The availability of such construction materials can accelerate the better use of ground improvement techniques.
4. Developing new advanced machinery for various ground improvement operations, especially for deep compaction can prove to be a catalyst in ground improvement processes.
5. The available analysis methods and computer modelling techniques should refined for better use.
6. Working with the construction sequence should be encouraged and its significance should be emphasized.
7. Better understanding of geo technical processes would prove helpful in adopting efficient techniques for ground improvement.

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PART-B

ESSAY QUESTIONS WITH SOLUTIONS

5.1 PROBLEMS OF EXPANSIVE SOILS-TESTS FOR IDENTIFICATION METHODS OF DETERMINATION OF SWELL PRESSURE

Q9. Enumerate and explain the various technical methods of identifying expansive soils.

Model Paper-II, Q11

Answer :

Following are the various technical methods of identifying expansive soils,

(i) Differential thermal analysis

(ii) X-ray diffraction method

(iii) Electron microscopy.

(i) Differential Thermal Analysis

This method depends on particular characteristic reactions occurring at specific temperatures for various minerals when the heating of these minerals is carried out at high temperatures, which results in loss or gain of heat. The continuous heating of a soil specimen with the unknown mineral is carried out with an inert substance in an electric oven. Then the change in temperature of mineral plotted against the temperature of oven is obtained. By comparing this by various clay mineral records, the type of minerals present in given soils are identified and the presence of each mineral is known approximately.

(ii) X-ray Diffraction Method

Different minerals with various crystalline structure patterns which diffract X-rays to produce different diffraction patterns of X-ray. It is possible to tell the presence and proportion of minerals by knowing the X-ray diffraction patterns of common clay minerals.

(iii) Electron Microscopy

In this method, the observation of soil is carried out under polarised light in an electron microscope. This method is normally used to supplement other test data and it requires skill and experience.

Q10. What are the laboratory tests used to identify expansive soils? Write about swell pressure test.

Model Paper-I, Q10

OR

Discuss the laboratory based tests for identifying expansive soils.

Answer :

The laboratory based tests to identify expansive soils are,

(i) Free-swell test

(ii) Differential free-swell test.

(i) Free-swell Test

In this test, 10 CC of dry soil is poured through 425 micron sieve into a graduated cylinder of 100 CC filled with water. After 24 hours, the swelled soil volume is read from the graduations of the cylinder. The determination of free swell value in percent is carried out by,

$$\text{Free swell (\%)} = \frac{\text{Final volume} - \text{Initial volume}}{\text{Initial volume}} \times 100$$

Bentonite soil containing montmorillonite is a high swelling soil and may have a free-swell value differing from 1200-2000 percent. Whereas kaolinite differs about 80 percent and illite from 30 to 80 percent. The soils having free swell values as low as 100 percent may show change in volume considerably under light loads.

The free swell values of soils having below 50 percent will not have any problems even under light surcharges. The free-swell test by itself may not be adequate to forecast the swelling potential and must be boosted by other tests.

(ii) Differential Free Swell Test

Two soil samples are taken, each weighing 10 g and passing through 425 micron sieve. One sample of soil is allowed into the 50 CC graduated glass cylinder having kerosene oil and the other soil sample is allowed into the cylinder having distilled water. These two samples must not be disturbed for 24 hours and note their volumes. The differential free swell is expressed as,

$$\text{DFS}\ \% = \frac{\text{Soil volume in water} - \text{Soil volume in kerosene}}{\text{Soil volume in kerosene}} \times 100$$

Q11. Explain briefly the problems associated with expansive soils.

Nov./Dec.-12(R09), Q7(b)

OR

Discuss the various problems related to expansive soils.

Answer :

During dry seasons, the amount of natural water is zero and the soil volume reaches the shrinkage limit. The amount of water increases with depth and reaches a value w_n at D_{us} depth. In wet season, the amount of water increases and reaches maximum at the surface. The amount of water decreases with depth from w_n maximum at nearly same depth D_{us}. This shows that the water intake into the lattice structure of expansive soil is nil at depth D_{us} and high at the surface. The considerable movements in the soil occur due to the drying and wetting of the soil lying within the depth D_{us}. During wet season, due to th lateral movements, the cracks get closed which were developed during dry season.

The zone which lies below the depth D_{us} is known as stable zone and the zone which lies within the depth D_{us} is known as unstable zone. In unstable zone, the structures get damaged due to the considerable differential movements. In dry season, if the structure is built with its foundation lying within the unstable zone, the swelling pressure is developed in the base of the foundation. In wet season, if the structure is built, then the settlement develops during dry season. Therefore, it is better to construct the structure during dry season.

Q12. Explain clay mineralogy and mechanism of swelling.

Answer :

Generally, clays are divided into three groups such as kaolinite, montmorillonite and illite group.

The most stable minerals are the kaolinite group of minerals. The formation of kaolinite mineral is carried out by stacking of crystalline layers of about 7Å thick. These layers are placed one above the other with the silica sheet base bonding to gibbsite sheet hydroxyles by hydrogen bonds. The hydrogen bonds are strong so, many sheet stackings are present in the kaolinite crystals that cannot be dislodged easily. Therefore, the mineral is stable and water cannot enter between the sheets to expand unit cells.

The montmorillonite mineral has the structural arrangement composed of units made of two silica tetrahedral sheets with a central alumina-octahedral sheet. The combination of silica and gibbsite sheets are carried out in such a way that one of the hydroxyl layers of the octahedral sheet and the tips of the tetrahedrons of each silica sheet form a common layer. Oxygen atoms are common to both silica and gibbsite layers. The silica-gibbsite-silica has the thickness of about 10Å. During the stacking of the combined units one above the other, each unit having oxygen layers are adjacent to neighbouring oxygen units with an effect that there is an excellent cleavage and a weak bond between them. In between the sheets, the water can enter and expand them. Thus, there may be a breakage in the structure to a 10Å thick structural unit. If considerable amount of montmorillonite minerals are present in the soil, then it exhibits high swelling and shrinkage characteristics. The structural arrangement of illite group of minerals and montmorillonite group is same. The swelling of illite minerals is less, if potassium is present as a bonding material between units.

Q13. Explain the methods of measuring swelling pressure of soils in laboratory.

Answer :

The swelling pressure of soils is measured by two common methods in the laboratory. In the first method, the undisturbed soils swelling pressure is measured for the condition of 'no volume change'. The continuous pressure adjustment is needed by this method on the soil specimen taken in a consolidation cell so that the soil volume is equal to its initial volume at any time. Remoulded specimens are taken at the amount of moisture and density of the field soil. For example, in the earth embankment where the compacted density required and the amount of moisture of compaction are known. The swelling behaviour of the undisturbed specimen from the field soil is estimated.

In the second method, three or more initially identical soil specimens are taken in consolidation cells of fixed ring type exposing them to various magnitudes of pressures and allowing the soil saturation. Under various load intensities, the compression and swelling of soil specimens are carried out after saturation. This type of differential behaviour is produced by properly selecting the load intensities.

Q14. Write a short notes on:

(a) Expansion Index (EI)

(b) Swell Index (SI).

Answer :

(a) Expansion Index (EI)

The swelling soils characteristics are measured by using expansion index method. Expansion index is a basic index property of soil such as the plastic limit, the liquid limit and the plasticity index of the soil.

The sample is sieved by a number 4 sieve. The degree of saturation is made between 49 and 51 percent by adding water. The compaction of soil is carried out in a mould of 4 inch diameter in two layer to give a total compacted depth of 2 inches approximately. 15 blows of 5.5 lb hammer is dropped to compact each layer. The prepared specimen is made to consolidate under 1 lb/in^2 pressure for 10 minutes then inundated with water.

The expansion index is expressed as,

$$EI = \frac{\Delta h}{h_i} \times 1000$$

Where,

Δh = Change in thickness of sample

h_i = Initial thickness of sample.

(b) Swell Index (SI)

This is a simple method to identify the swell potential of clays. The swell index is defined as,

$$I_s = \frac{w_n}{w_l}$$

Where,

w_n = Natural moisture content in percent

w_l = Liquid limit in percent.

5.2 IMPROVEMENT OF EXPANSIVE SOILD-FOUNDATION TECHNIQUES IN EXPANSIVE SOILS-UNDER REAMED PILES

Q15. Explain sand cushion technique in detail.

Answer :

Sand Cushion Technique

In this method, the total expansive clay stratum depth whether if is deep or thin, is removed and replaced by sand cushion and its compaction is done to the desired thickness and density.

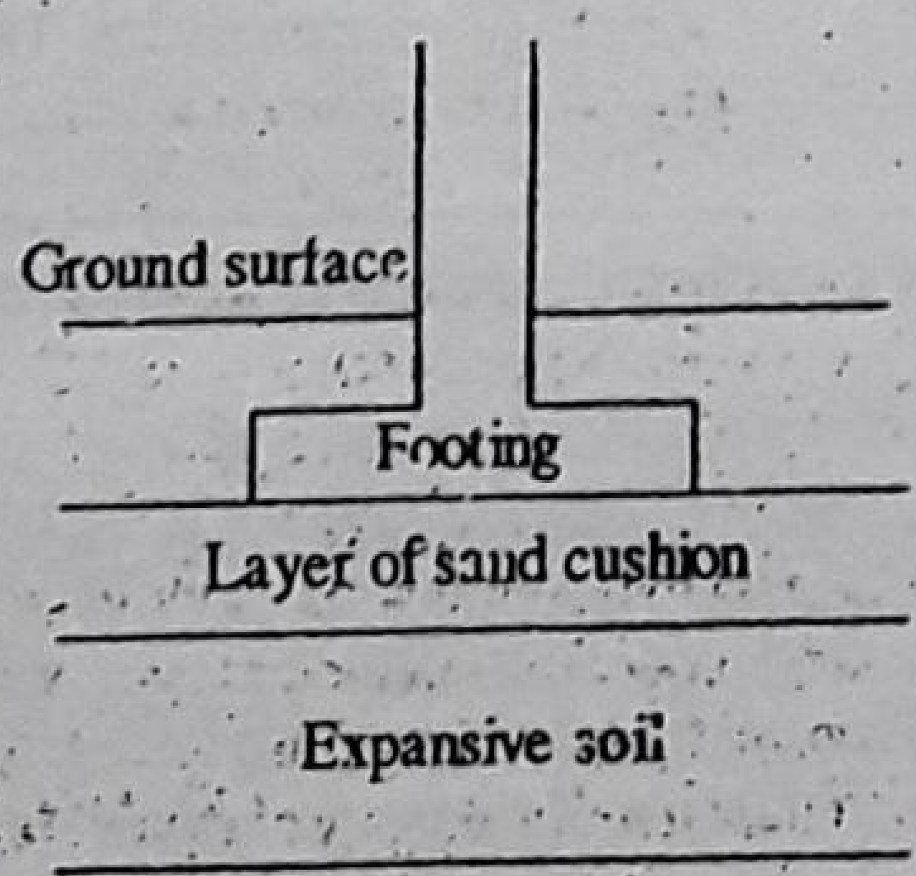


Figure: Sand Cushion Layer

It was explained that swelling pressure differs inversely as sand layer thickness and directly as its density. Therefore, the formation of sand cushions is in their loosest state to prevent the occurrence of highly increasing the swelling pressure. In this method, the basic concept is that the saturated sand in rainy season occupies less volume, considerating heave of unlying expansive soil. Whereas in summer season, the space left by soil shrinkage is occupied by the unsaturated sand bulks.

Q16. What are drilled pier foundations? Explain the procedure for straight-shaft piers in expansive soils.

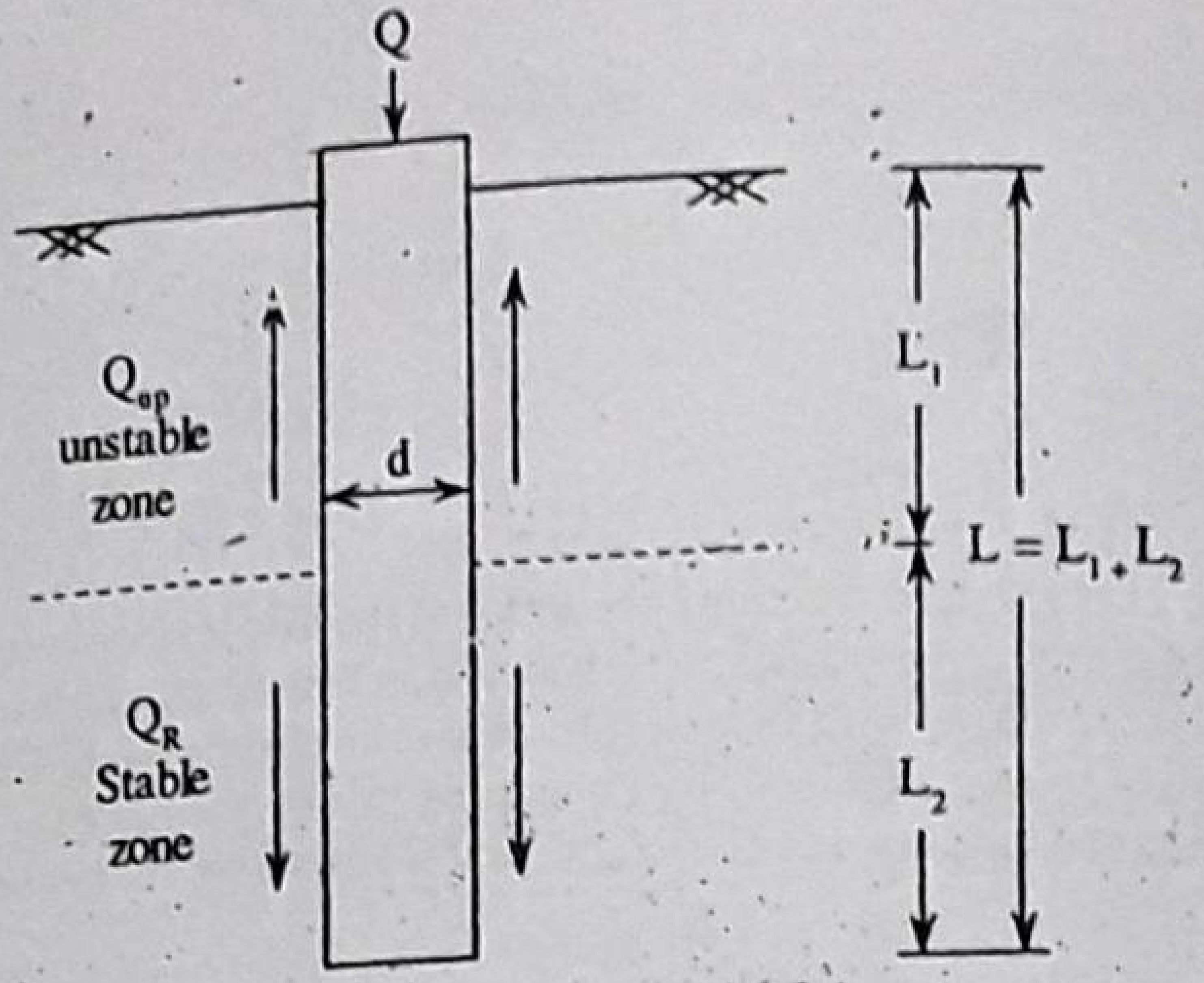
Model Paper-II, Q10

Answer :

Drilled Pier Foundations

Drilled piers are the piers used to control the uplift forces caused by the swelling of soils. When drilled piers are made with an enlarged base, then it is known as belled piers and when enlarged base is not used then it is known as straight-shaft piers.

Straight-shaft Piers in Expansive Soils



Figure

The figure shows the straight shaft drilled pier embedded in expansive soil. The notations used are as follows:

Q = Structural dead load

q = Unit dead load pressure

L_1 = Length of shaft in unstable zone

L_2 = Length of shaft in stable zone

A_b = Base area of pier

d = Diameter of shaft.

During rainy season, when the water is absorbed by the soil in unstable zone, the soil tries to expand but it is prevented by pile shafts rough surface of length L_1. Then, there is development of upward force on the shaft surface which tries to pull the pile. The upward force can be resisted by the downward dead load Q acting on the top of pier and by resisting the force provided by shaft length L_2.

Q17. A drilled pier was constructed in expansive soil. The water table was not encountered. The details of the pier and soil are,

L = 20 ft, d = 12 inch, L_1 = 5 ft, L_2 = 15 ft, Ps = 10,000 lb/ft^2, Cu= 2089 lb/ft^2, SPT (N)= 25 blows per foot

Required:

(a) Total uplift capacity Q_{up}

(b) Total resisting force due to surface friction

(c) Factor of safety without taking into account the dead load Q acting on the top of the pier.

(d) Factor of safety with the dead load acting on the top of the pier.

Assume Q = 10 kips. Calculate Q_{up} by Chen's method.

Answer :

Given that,

Length of pier, $L = 20$ ft

Base dimension, $d = 12$ inch $= 1$ ft

In stable zone, length of pier, $L_1 = 5$ ft

Unstable zone, length of pier, $L_2 = 15$ ft

Swelling pressure, $P_s = 10{,}000$ lb/ft^2

Unit cohesion under undrained

Condition, $Cu = 2089$ lb/ft^2

$= 100$ kN/m^2

Number of blows of SPT $(N) = 25$ blows

(a) **Calculate Uplift Capacity $Q_{up} = ?$**

$$Q_{up} = \pi d\, \alpha_u\, Ps\, L_1$$

$$= \frac{3.14 \times 1 \times 0.15 \times 10{,}000 \times 5}{1000}$$

$$= 23.55 \text{ kips}$$

[$\because$ $\alpha_u = 0.15$ for coefficient of uplift between soil and concrete]

(b) **Resisting Force (Q_R)**

$$Q_R = \pi d\,(L - L_1)\,\alpha\, Cu$$

Hence for resisting force 'α' can be calculated based on correlation between 'α' and Cu/Pa graph in cohesive soils.

$$\therefore \frac{Cu}{Pa} = \frac{100}{101} = 1.0$$

From standard graph, $\frac{Cu}{Pa} = 1$ corresponding

$\alpha = 0.55$

$$\therefore \quad Q_R = 3.14 \times 1\text{ft} \times (20 - 5)\text{ ft} \times 0.55 \times 2089$$

$$= 25.905 \text{ ft}^2 \times 2089 \text{ lb/ft}^2$$

$$= 54115.545 \text{ lb}$$

$$= 54 \text{ kips}$$

(c) **Factor of Safety with $Q = 0$**

From equation, we know that,

$$Q_{up} = \frac{Q_R}{1.2}$$

$$F_s = \frac{54}{23.5}$$

$$= 2.29 > 1.2 \text{ required}$$

$\therefore$ Hence safe

(d) **Factor of Safety with $Q = 10$ kips**

From equation $(Q_{up} - Q) = \dfrac{Q_R}{2.0}$

$$F_s = \frac{Q_R}{(Q_{up} - Q)}$$

$$= \frac{54}{(23.5-10)}$$

$$= \frac{54}{13.5}$$

$$= 4 > 2$$

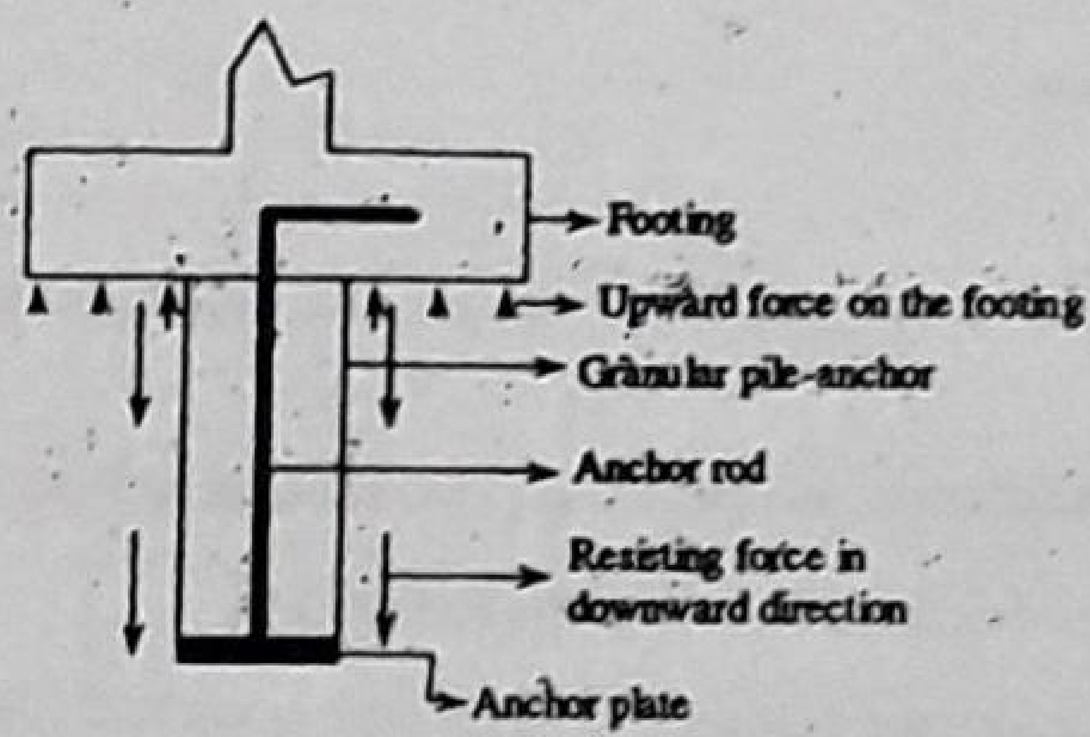
Hence safe.

Q18. Explain in detail about the granular pile anchor technique.

Answer :

The use of granular piles were uptil now confined to non-swelling soils only. But now the effectiveness of granular anchor-pile technique has been examined in lowering the leave content and boosting behaviour of expansive clay beds.

A mere granular pile may not resist the uplift force exerted on the foundation by the swelling soil and if the anchoring of the foundation is done at the bottom of the granular pile to a mild steel plate through a mild steel rod. Now by the effect of anchor, the granular pile becomes tension-resistant and can counteract the uplift force exerted on the foundations. The development of resistance to uplift in a granular pile-anchor is due to the granular pile weight acting in downward direction.



Figure

The figure explains the granular pile-anchor concept showing the different forces acting on it. The upward force which is acting on the foundation tends to lift it up because of expansive soil swelling on water imbition. The resisting force which is acting in the downward direction and preventing the uplift force is because of friction generated along the pile-soil interface.

Q19. What are under-reamed piles? When are they used?

Answer :

Model Paper-I, Q11

Under-reamed Piles

Under-reamed piles are a special type of bored piles,

- Bored piles are those piles which are constructed by drilling/making a hole in the ground and filling it with concrete.
- The piles may be provided with a bell (or pedestal or bulb) at its base (end).
- Then the pile with a bell or bulb or pedestal is called an under-reamed pile.
- If the pile is having only one bulb/bell/pedestal at its base, then it is known as single under-reamed pile.
- If the pile is having more than one bell/bulb/pedestal at its base (end), then the pile is known as multi-under reamed pile.
- In under-reamed piles,
  - Size should be 150 to 200 mm shaft diameter
  - Length should be 3 to 4 m long
  - Bulb diameter of under-reamed piles should be 2.5 times the shaft diameter
  - Generally 2 to 3 times shaft diameter is maintained for under-reamed bulb diameter.

Uses

- Under-reamed piles are mainly used in expansive soils, where shallow foundation is not applicable.
- Under-reamed piles are used to obtain ultimate load carrying capacity for vertical and lateral loads.
- Under-reamed piles are used to obtain the foundations which are below the scour level.
- These are able to reach to the firm strata of the soil.
- Under-reamed piles avoid the undesirable effect of seasonal moisture changes, shrinkage, swelling of such soils i.e, as in expansive soils.

Q20. Explain the various stages in the construction of under-reamed piles with neat sketches.

Answer :

Construction of Under-reamed Piles

The construction of under-reamed piles mainly depends on four stages. They are,

1. Making hole (boring by augers)
2. Forming bulb (under reaming by under-rea er)
3. Concreting reinforcement in position
4. Completed pile.

- In the initial stage, the under-reamed pile is constructed by making a hole on the ground with the help of hand operation equipment "auger".
- After the formation of hole, the bulb/bell/pedestal is inserted into the cleaned hole at the base.
- After the bulb (i.e, under-reamed) is lowered, it is pressed down and rotated.
- Due to rotatory action, the blades open under the pressure, then the soil is cut and filled in the bucket.
- After the bucket is filled, it is pulled out and cleaned and the same process is repeated and lowered again.
- The sketches show a clear identification understanding of the under-reamed pile construction for a single bulb as shown in figure,

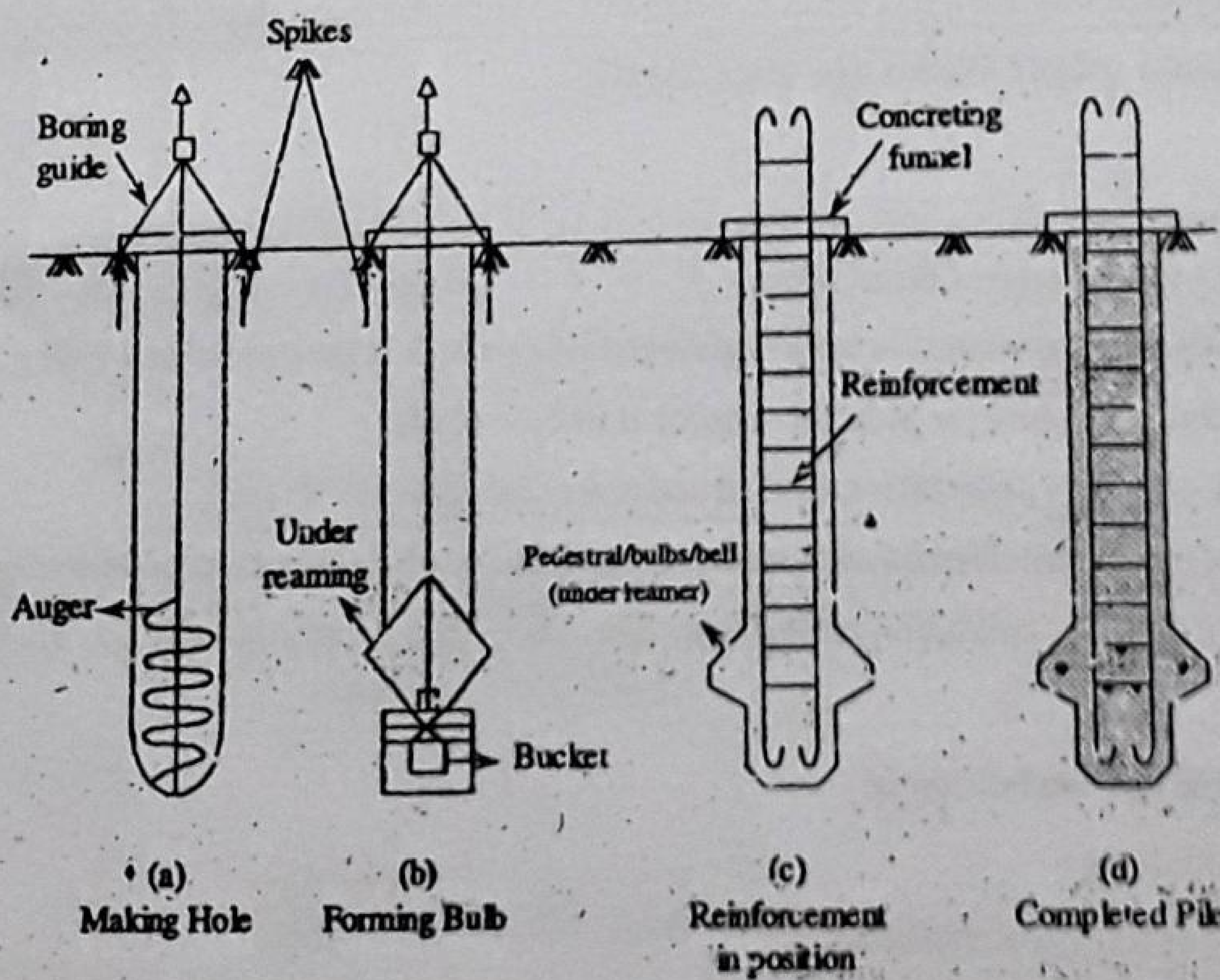


Figure: Stages in Construction of a Single Under-reamed Pile

- The ultimate load carrying capacity of the pile increases by 50% if the bulbs/bells/pedestal is increased from one bulb to two bulbs (under reamed).

Q21. How will you calculate the ultimate load capacity of under-reamed piles for various types of soils?

Answer :

The ultimate load capacity of under-reamed piles can be evaluated based on the soil properties such as unit weight, cohesion and angle of internal friction.

Various types of soils on which the ultimate load capacity of under-reamed piles can be calculated upon,

1. Clayey soils
2. Sandy soils
3. Cohesive-frictional soils.

1. Clayey Soils

The ultimate load carrying capacity (Q_u) for clayey soils is given by,

$$Q_u = A_P N_C C_P + A_a N_C C_a + C_a A'_S + \alpha C_a A_S$$

Where,

Q_u = Ultimate bearing capacity of the pile

A_P = Cross-sectional area of the pile stem at toe

N_C = Bearing capacity factor (usually taken as 9)

C_P = Cohesion of the soil around the toe.

$$A_a = \frac{\pi}{4}(D_u^2 - D^2).$$

Where, D_u and D are the diameters of the under-reamed bulb and stem diameter respectively.

C_a = Average cohesion of soil around the under-reamed bulb

A'_S = Surface area of the cylinder circumscribing the under-reamed bulb

α = Reduction factor (generally 0.5 for clays)

C_a = Average cohesion of the soil around the pile stem and

A_S = Surface area of the stem.

The above expression holds for the usual vertical spacing between the under-reamed bulbs which are not greater than 1.5 times the diameter of under-reamed bulb.

2. Sandy Soils

The ultimate load carrying capacity of an under-reamed pile for sandy soil is given by the following expression as,

$$Q_u = A_P\left[\frac{1}{2}DyN_y + yD_f N_q\right] + A_a\left[\frac{1}{2}D_u nyN_y + yN_q \sum_{r=1}^{r=n} d_r\right] + \frac{1}{2}\pi DyK \tan\delta a d_1^2 + d_f^2 - d_n^2)$$

$$Q_u = \frac{\pi}{4}D^2\left(\frac{1}{2}DyN_y + yD_f N_q\right) + \frac{\pi}{4}(D_u^2 - D^2)\left[\frac{1}{2}D_u nyN_y + yN_q \sum_{r=1}^{r=n} d_r\right] + \frac{1}{2}\pi DyK \tan\delta a d_1^2 + d_f^2 - d_n^2)$$

Where,

D_u = Diameter of under-ream buib

D = Diameter of stem

n = Number of under-reamed bulbs

y = Average field density of soil

N_y and N_q = Bearing capacity factors, depending on the angle of internal friction

d_r = Depth of centre of different under-ream bulbs

d_f = Depth of pile (total depth of pile)

K = Earth pressure constant (usually 1.75 taken for sandy soils)

δ = Angle of wall friction

d_1 = Depth of centre of first under-ream bulb

d_n = Depth of the centre of last under-ream bulb.

Cohesive-frictional Soils

In stratified soils or cohesive frictional soils, the ultimate load bearing capacity can be calculated by using both the formulae (i.e, sandy soils and clayey soils).

Factor of safety is taken as 2.5 in compression and 3 in uplift are recommended to obtain the safe load.

The safe loads for vertical bored cast-in-situ under-reamed piles as in sandy and clayey soils both under compression and uplift as under lateral thrust is given by,

Table 26.3 (IS: 2911, Part-III-1973).