3rd Semester, Civil Engineering

GEOTECHNICAL ENGINEERING(TH-4)

UNIT- I: OVERVIEW OF GEOLOGY AND GEOTECHNICAL ENGINEERING

A. 02 MARKS QUESTIONS:

Q1. Define origin of soil?

Ans. Soils are formed by weathering of rocks and minerals at or near the earth's surface by either:

i. Physical disintegration due to the action of natural or mechanical agents,

ii. Chemical decomposition due to the action of chemical agents.

Q2. Illustrate the different methods of soil formation?

Ans. Following are the two methods of soil formation:

1. Physical Disintegration: It is due to :

i. Temperature changes.
ii. Abrasion.
iii. Wedging action of ice
iv. Spreading of roots of plants.

2. Chemical Decomposition: It includes :

i. Hydration.
ii. Carbonation.
iii. Oxidation.
iv. Leaching.
v. Hydrolysis.

Q3. What is muck?

Ans. Fine particles and highly degraded organic debris are combined to form muck. It has a silky consistency and is a deep shade of black.

Q4. **Define Geology and state its branches?**

Ans. Geology : The science that deals with the study of earth as a planet as,
1. It deals with origin, age, interior or structure and history of the earth.

2. It deals with evolution and modification and extinction of various surface features.

3. It deals with material making up the earth.

Branches:

1. Physical geology

2. Geomorphology

3. Mineralogy

4. Petrology

5. Historical geology

6. Structural geology

7. Economic geology

8. Engineering geology

9. Geo informatics.

Q5. Define soil as per IS?

Ans. Soil is the sediments and other unconsolidated accumulations of solid particles produced by the mechanical and chemical disintegration of rocks regardless of whether or not they contain an admixtures of organic constituent.

Q6. Define Rocks?

Ans. Naturally occurring compact, solid and massive material in the earth's crust or on the surface are known as rocks.

Q7. Define classification of rocks?

Ans. The rocks from which stones are derived are broadly classified into three types. They are:

1. Geological classification

2. Structural or Physical classification

3. Chemical classification

Q8. Define Igneous rocks?

Ans. Molten rock materials found below the earth's crust are known as magma. During volcanic eruption, this magma, under very temperature and pressure, and varieties of complex phenomena occurring below earth's crust beyond the comprehension of human being, comes out to the surface. The rocks formed due to cooling and consolidation of molten magma on the surface is known as igneous rock.

Q9. Define plutonic rocks?

Ans. The igneous rocks formed at a greater depth below the surface of earth are called plutonic rocks. These rocks are exposed on the surface due to erosion of overlying secondary rocks. These are coarsely crystallised. Examples of plutonic rocks are granite, syenite, gabbro.

Q10. Define volcanic rocks?

Ans. These are formed due to cooling and solidification of molten magma from numerous volcanic eruptions on the surface of earth. Examples of such rocks are basalt, trap and rheolite.

Q11. Define hypabyassal rocks?

Ans. The rocks formed on account of cooling and solidification of molten magma at a shallower depth of about 2 to 3 km below the surface of earth. They show crystals that are partly coarse and partly fine. Examples of such rocks are aplites, dolerites, etc.

Q12. Define sedimentary rocks?

Ans. The secondary rocks which are formed by chemical or mechanical activities of the weathering agents such as temperature, water, air, ice, etc. on the pre-existing rocks are known as sedimentary rocks.

Q13. Define Metamorphic rocks?

Ans. Igneous rocks and sedimentary rocks undergo structural change under the influence of high temperature, pressure and chemical action and thus the original character of the parent rock are partly or wholly changes. Such process is known as metamorphosis and the rocks so formed are known as metamorphic rocks. Examples: marble, slate, gneiss, etc.

Q14. Define chemical classification of rocks?

Ans. On the basis of dominant chemical composition, three main types of rocks are:

a. Silicious rocks

b. Calcareous rock

c. Argillaceous rocks

Q15. Define structural classification of rocks?

Ans. On the basis of physical characteristics of the rocks, the manner and arrangement of different particles rocks are classified into three categories. They are:

1. Stratified rock
2. Unstratified rock
3. Foliated rock

B. 05 MARKS QUESTIONS:

Q1. Define Sedimentary rocks and its types with examples?
Ans.

i. The secondary rocks which are formed by chemical or mechanical activities of the weathering agents such as temperature, water, air, ice, etc. on the pre-existing rocks are known as sedimentary rocks.
ii. Weathering agents like wind, water, ice, atmospheric gases, etc. cause disintegration of the pre-existing rocks and thus sediments (particles) are formed. These sediments are transported and deposited by the agencies like river, seas, oceans, etc.
iii. The particles so deposited are gradually compressed and compacted under their own weight so as to form massive rocks. Rocks thus formed are known as sedimentary rocks.

iv. The process of formation of sedimentary rocks takes place for millions of years.

v. Sedimentary rocks are also known as secondary rocks as they are formed due to weathering and erosion of primary rocks. These are also called stratified rocks because these rocks are formed in layers. Limestone and sandstone belong to this category of rocks.

vi. Like igneous rocks, sedimentary rocks are formed in different ways. On the basis of the formation, sedimentary rocks are divided into three different categories.

   a. Clastic rocks
   b. Chemically formed sedimentary rocks
   c. Organically formed sedimentary rocks

a. Clastic rocks: The sedimentary rocks formed by deposition and consolidation of disintegrated sediments and fragments from previously formed rocks. These are formed in river basins, lake basins and sea basins. These types of stones are most widespread. They include sandstones, shales, breccias and conglomerates. Sandstones are very suitable as building stones.

b. Chemically formed sedimentary rocks: Many sedimentary rocks are precipitated from river, lake and especially from sea water by evaporation. Some of the components of the previous rocks are taken in solution during the process of weathering and erosion. The waters may get saturated with these compounds with passage of time and precipitate them. The huge accumulation of these precipitates evaporates ultimately may form rock deposits of considerable importance. Limestones, gypsum, anahydrite and rock salts are few examples of chemically formed sedimentary rocks. These are not used as building stone.

c. Organically formed sedimentary rocks: A great variety of life exists in the water bodies such as seas and oceans. Many sea animals have their hard parts made of bones which are a mixture of calcium and magnesium carbonates. After the death of these marine animals, the dead parts accumulate on the sea beds. Gradually huge thickness of such deposits gets formed and compacted and consolidated with passage of time. These are the organically formed sedimentary rocks. Limestone is an example of this rock.

Q2. Explain geological classification of rocks and its types?

Ans. The classification of rock based on the mode of formation or the process of formation is known as geological classification. According to this classification rocks/ stones are are of three types.

1. Igneous rocks
2. Sedimentary rocks
3. Metamorphic rocks

1. Igneous rocks:

Molten rock materials found below the earth's crust are known as magma. During volcanic eruption, this magma, under very temperature and pressure, and varieties of complex phenomena occurring below earth's crust beyond the comprehension of human being, comes out to the surface. The rocks formed due to cooling and consolidation of molten magma on the surface is known as igneous rock. Not all the magma during a volcanic eruption comes out to the surface of earth. Depending on the depth of the solidification of molten magma, igneous rocks are divided into three types.

a. Plutonic rocks

b. Volcanic rocks

c. Hypabyssal rocks

2. Sedimentary rocks :

The secondary rocks which are formed by chemical or mechanical activities of the weathering agents such as temperature, water, air, ice, etc. on the pre-existing rocks are known as sedimentary rocks. Weathering agents like wind, water, ice, atmospheric gases, etc. cause disintegration of the pre-existing rocks and thus sediments (particles) are formed. These sediments are transported and deposited by the agencies like river, seas, oceans, etc. The particles so deposited are gradually compressed and compacted under their own weight so as to form massive rocks. Rocks thus formed are known as sedimentary rocks. The process of formation of sedimentary rocks takes place for millions of years. Sedimentary rocks are also known as secondary rocks as they are formed due to weathering and erosion of primary rocks. These are also called stratified rocks because these rocks are formed in layers. Limestone and sandstone belong to this category of rocks.

3. Metamorphic rocks:

Igneous rocks and sedimentary rocks undergo structural change under the influence of high temperature, pressure and chemical action and thus the original character of the parent rock are partly or wholly changes. Such process is known as metamorphosis and the rocks so formed are known as metamorphic rocks. Examples: marble, slate, gneiss, etc. Marble is formed from limestone ($CaCO_3$) by gradual heating over a very large period of time.

Q3. Explain chemical classification of rocks and its types?

Ans. On the basis of dominant chemical composition, three main types of rocks are:

a. Silicious rocks

b. Calcareous rock

c. Argillaceous rocks

a. Silicious rocks:

Silica is the predominant constituent of this rock and is more than 50% of the bulk composition of the rock. Some sedimentary and metamorphic rocks are entirely made of silica. These rocks are very strong and hence may be treated as good building stones. Examples of these rocks are granite, sandstone, gneiss.

b. Calcareous rocks:

In these rocks carbonate is the dominant chemical component. These rocks generally belong to sedimentary and metamorphic rocks. Limestone, dolomite and marbles are entirely carbonate rocks and are very good building stones.

c. Argillaceous rocks:

In these rocks clay (hydrous alumina silicate of K, Na, Ca and Mg) is the dominant component. These are mostly sedimentary and metamorphic rocks. These are very soft and hence not recommended as building stones. Examples of these rocks are slates and schists.

4. Explain structural classification of rocks and its types?

Ans . On the basis of physical characteristics of the rocks, the manner and arrangement of different particles rocks are classified into three categories. They are:

1. Stratified

2. Unstratified

3. Foliated

1. Unstratified Rocks:

These rocks occur in huge masses without showing any layered structure in them. Igneous rocks and many metamorphic rocks are unstratified in nature. Some of the sedimentary rocks may be of unstratified in nature.

2. Stratified Rocks:

These rocks occur in distinct layers of same or different colour and composition. Most of the sedimentary rocks are stratified rocks. The different layers are called beds and separated by planes, called bedding planes. These bedding planes are the planes of weakness and thus play an important role in deciding the structural behaviour of the rocks as building material.

3. Foliated rocks:

Some rocks have in them profuse development of well defined bands of different composition. Such rocks are known as foliated rocks. Examples of such rocks are schists and gneiss. Sometimes such layers are induced under pressure. These are not very good building stones.

Q5. **Explain the importance of geology in civil Engineering Construction?**

Ans. Importance of geology in civil engineering construction:

1. Geology is essential to know the nature if substrata and hence helpful to decide the depth of foundation for important structures.
2. Geology is also required to know the properties of rock beneath the earth surface which becomes beneficial to design earthquake resistance structures.
3. It is important to find the most suitable site for dams, bridges etc
4. Geology plays vital role in groundwater survey and related recharging process.
5. It is significant in tunnel excavation projects as it provides information of rock strata and its engineering properties.
6. It is also important to excavate raw materials for stone crushing plant to manufacture aggregates.

C. 10 MARKS QUESTIONS:

Q1. Explain field applications of geotechnical engineering and State two civil engineering situations where knowledge of geotechnical engineering is used?

Ans.

Field applications of Geotechnical Engineering:

1. **Design of foundation for various civil structures:**

As foundation resting on soil carries load of any particular structure, geotechnical engineering is applicable to design such stable foundations for various loads.

2. **Design of pavement for various types of roads:**

Layers of pavement made up of sand, gravel is laid on sub grade soil can be designed in terms of thickness, load carrying capacity using geotechnical engineering.

3. Design of earth retaining structures:

Geotechnical engineering is also applicable to design and construct earth retaining structures
like retaining wall and sheet pile useful for hill roads, landslides.

4. Design of water retaining structures:

Geotechnical is very much applicable for easy and safe design and execution and maintenance
of earthen dam, weir, barrage etc.

5. Design of underground structures:

Underground pipelines i.e. water supply and sewage lines require geotechnical engineers for
effective work. It is also significant in safe excavation of proposed alignment.

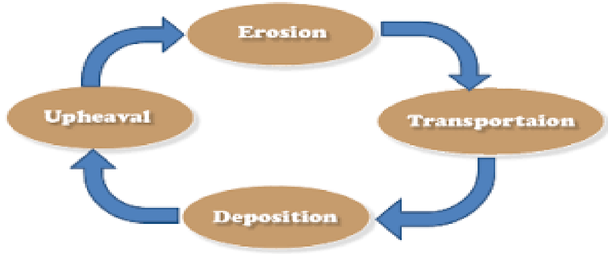
Civil engineering situations where knowledge of Geo-Technical Engineering (GTE) is used:

1. Geo-Technical Engineering knowledge is required to find most suitable site for proposed construction work.
2. GTE knowledge is also useful to find the suitability of available soil for planned construction activity.
3. GTE knowledge is useful to design and construction of foundation for various structures like building by knowing bearing capacity, shear strength of soil.
4. It is also helpful for design and construction of pavement for various roads by knowing properties sub grade soil, pavement layers like compaction, bulk and dry density etc.
5. GTE concepts are essential to design and construction of earth retaining structures i.e. retaining wall, sheet pile by studying earth pressure theory.
6. GTE theories are beneficial in design and construction of water retaining structures i.e. dam, weir etc. by determining permeability, shear strength etc.
7. GTE test procedures are necessary in design and construction of abutments of bridge by testing shears strength, earth pressure etc.
8. It plays vital role in design construction of underground structures i.e. pipeline, tunnels etc. by knowing soil erosion, slope stability.

Q2. State formation and classification of soil?

Ans. Soil formation :

Soil formation is essentially with weathering process of rock. Soil formation mainly takes place due to mechanical disintegration or chemical decomposition of rocks whenever rock get exposed to atmosphere, It is acted by various weathering agencies and it get disintegrated or decomposed into small particles & then it is converted into soil.



Classification of Soil :

Soils as they are found in different regions can be classified into two broad categories:

(1)Residual soils

(2) Transported soils

(1) Residual Soils:

i. Residual soils are found at the same location where they have been formed. Generally, the depth of residual soils varies from 5 to 20 m.
ii. Chemical weathering rate is greater in warm, humid regions than in cold, dry regions causing a faster breakdown of rocks. Accumulation of residual soils takes place as the rate of rock decomposition exceeds the rate of erosion or transportation of the weathered material. In humid regions, the presence of surface vegetation reduces the possibility of soil transportation.
iii. As leaching action due to percolating surface water decreases with depth, there is a corresponding decrease in the degree of chemical weathering from the ground surface downwards. This results in a gradual reduction of residual soil formation with depth, until unaltered rock is found. Residual soils comprise of a wide range of particle sizes, shapes and composition.

(2) Transported Soils:

Weathered rock materials can be moved from their original site to new locations by one or more of the transportation agencies to form transported soils. Transported soils are classified based on the mode of transportation and the final deposition environment.

(a) Soils that are carried and deposited by rivers are called alluvial deposits.

(b) Soils that are deposited by flowing water or surface runoff while entering a lake are called lacustrine deposits. Alternate layers are formed in different seasons depending on flow rate.

(c) If the deposits are made by rivers in sea water, they are called marine deposits. Marine deposits contain both particulate material brought from the shore as well as organic remnants of marine life forms.

(d) Melting of a glacier causes the deposition of all the materials scoured by it leading to formation of glacial deposits.

(e) Soil particles carried by wind and subsequently deposited are known as aeolian deposits.

UNIT II : PHYSICAL AND INDEX PROPERTIES OF SOIL

A. 02 MARKS QUESTIONS:

Q1. Define the term consistency.

Ans. Consistency is a phrase that is used to qualitatively characterise the degree of hardness of a soil using terms like soft, medium, firm, stiff, or hard. It shows how easily a soil can deform in relation to other soils.

Q2. Define bulk unit weight. Write the relation between bulk unit weight and dry unit weight.

Ans. Bulk Unit Weight: It is defined as the total weight per unit total volume. Thus,

$$\gamma = \frac{W}{V}$$

It is expressed as N/m^3 or kN/m^3.

Relation : Dry unit weight, $\gamma_d = \frac{\gamma}{1+w}$

where, γ = Bulk unit weight.

w = Water content.

Q3. Define Consistency limits.

Ans. Consistency Limits (Atterberg Limits): Atterberg limits are also referred to as the liquid limit, plastic limit, and shrinkage limit. The water content at which a change in soil behaviour occurs from a liquid to a plastic state, a plastic state to a semisolid state, and a semisolid state to a solid state is known as the liquid limit, plastic limit and shrinkage limit respectively.

Q4. **What is liquid limit ?**

Ans. Liquid Limit (w_L): It is the soil's water content, which may be determined using any defined process, at which the soil is essentially in a liquid state yet has negligible barrier to flow.

Q5. Define plastic and shrinkage limit?

Ans. i. Plastic Limit: It is described as the amount of water at which a soil would just start to disintegrate if rolled into a thread about 3 mm in diameter.

ii. Shrinkage Limit: The maximum water content at which a reduction in moisture content does not result in a reduction in the volume of the soil mass is known as this water content. With full saturation of the soil mass, it is also the lowest value of water content.

Q6. **Define index properties of soil?**

Ans. Index Properties of Soil: The procedure used to categorize a soil is known as a classification test. The numerical outcomes of such tests are referred to as the soil's index properties. These are divided into two following categories :

- 1. Soil grain properties.
- 2. Soil aggregate properties.

Q7. What is relative density or density index ?

Ans. A cohesionless soil's relative density (I_D) is calculated as the difference between the void ratios in the loosest and densest states divided by the difference between the void ratios in the soil's natural state.

$$D_r \text{ or } I_D = \frac{e_{max} - e_{nat}}{e_{max} - e_{min}} \times 100\ \%$$

Q8. Write down the expressions for coefficient of uniformity and coefficient of curvature.

Ans.

i. Coefficient of uniformity, $C_u = \dfrac{D_{60}}{D_{10}}$

ii. Coefficient of curvature, $C_c = \dfrac{D_{30}^2}{D_{60} \times D_{10}}$

Q9. **Define flow index.**

Ans. The ordinate of the water content on the natural scale against the number of blows on the log scale yields the flow index, which is the slope of the flow curve. It is given by,

$$I_F = \frac{w_1 - w_2}{\log_{10} N_2 / N_1}$$

where, w_1 = Water content corresponding to number of blows N_1

w_2 = Water content corresponding to number of blows N_2.

Q10. Define the toughness index ?

Ans. Toughness index is defined as the ratio of plasticity index to flow index.

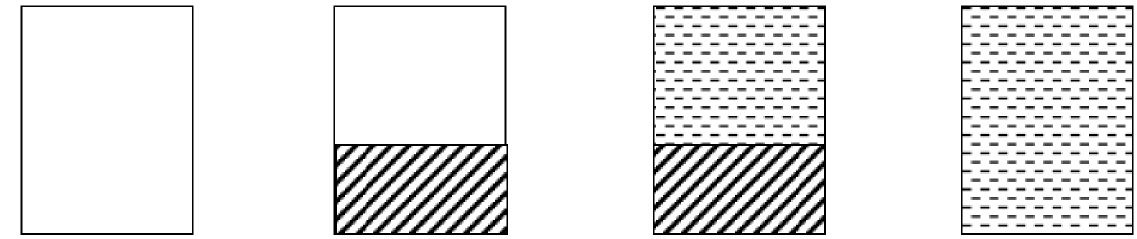
$$I_T = \frac{I_P}{I_F}$$

B. 05 MARKS QUESTIONS

Q1. Give step-by-step procedure to determine specific gravity of soil by pycnometer in laboratory?

Ans.

1. The mass M1 of the clean, dry bottle is found.
2. Suitable quantity of oven-dried soil sample, cooled in a desiccator is put in the bottle and the mass M2 of the bottle with soil is found.
3. Distilled water is then added to the soil inside bottle until the bottle is full, care being taken to see that entrapped air is fully expelled. (either by applying vacuum or by gentle heating and shaking or stirring) The mass M3 of the bottle with soil and water is found.
4. The bottle is then emptied of its contents, cleaned and filled with distilled water only. The outer surface of the bottle is wiped dry and the mass M4 of the bottle with water is found.



The specific gravity of soil solids is computed as;

$$G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

Q2. The plastic limit and liquid limit of soil are 30% and 42% respectively. The percentage volume change from liquid limit to dry state is 35%ofdry volume. Similarly,thepercentage volume change fromplastic limit to dry state is 22% of the dry volume. Determine the shrinkage ratio?

Ans. Given data: Plastic limit (w_p)=30%

Liquid limit (w_l)=42%

$V_l - V_d = 0.35V_d$

$V_p - V_d = 0.22V_d$

Therefore, $V_l = 1.35V_d$

$V_p = 1.22V_d$

$SR = [(V_1 - V_2)/V_d]/(w_1 - w_2) \times 100$

$= [(V_l - V_p)/V_d]/(w_l - w_p) \times 100$

$= [(1.35V_d - 1.22V_d)/V_d]/(42 - 30)$

$SR = (0.13/12) \times 100 = 1.083 \approx 1.1$

Q3. A given cohesionless soil has emax= 0.85 and emin.= 0.50. In the field, the

soil is compacted to a mass density of 1800 kg/m3 at a water content of 8%. Take the mass density of water as 1000 kg/m3 and Gs as 2.7;determine the relative density (in %) of the soil.

Ans. Given, soil with the field properties

Bulk density (ρ) = 1800 kg/m^3

Water content, w=8%=0.08

So, dry density (ρ_d)=ρ/(1+w)

=1800/(1+0.08)

=1666.67 kg/m^3

So, void ratio 'e' at the field condition can be determined by relation

$\rho_d = G\rho_w/(1+e)$

$\Rightarrow e=\{G\rho_w/(\rho_d)\}-1$

$=\{(2.7\times1000)/(1666.67)\}-1$

e=0.62

So $e_{max}=0.85$, $e_{min}=0.50$

Relative density $I_d=\{(e_{max}-e)/(e_{max}-e_{min})\}\times100$

$=\{(0.85-0.62)/(0.85-0.50)\}\times100$

I_d=65.71%

Q4. Explain soil as three phase system with labelled sketch?

Ans. Soil as three phase system:

1. As natural soil contains solid soil particles and water and air present in its voids such complex nature of soil sample is difficult to analyze its physical properties Hence it is simplified and presented in its equivalent 3 phase diagram as shown in figure below.

2. Depending upon three phase diagram of soil its is classified in three categories-

a. Dry soil

b. Partially saturated soil

c. Fully saturated soil.

3. However if we take a dry soil mass, the voids are filled with air only. In case of perfectly saturated soil the voids are filled completely with water. In case of partially saturated soil, both air and water are present in the voids.

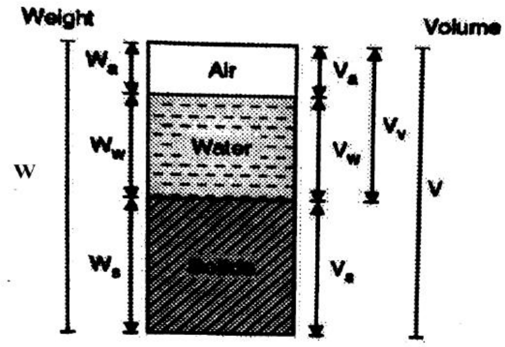


Figure.: Three Phase System of Soil

Q5. What is the dry unit weight of clay soil when the void ratio of sample thereof is 0.50, the degree of saturation is 70% and specific gravity of soil grains is 2.7? Take the value of γ_w to be 9.81 kN/m^3.

Ans: Given data:

e=0.5, S=0.7, G=2.7

We know, Bulk unit weight (γ_b) = $(G+Se)\gamma_w/(1+e)$

$=[(2.7+0.7\times0.5)\times9.81]/(1+0.5)$kN/m^3

=19.947kN/m^3

We know, Se = wG

Water content (w)=Se/G

w=0.7×0.5/2.7=0.1296=12.96%

Dry density $\gamma_d=\gamma_b/(1+w)$

=19.947/(1+ 0.1296)

=17.658kN/m^3.

C. 1O MARKS QUESTIONS

Q1. The total unit weight of the glacial outwash soil is 16 kN/m^3.The specific gravity of soil particles of the soil is 2.67. The water content of the soil is 17%. Calculate

(a) **Dry unit weight**
(b) **Porosity**
(c) **Void ratio**
(d) **Degree of saturation**

(e) **Saturated unit weight**

(f) **Submerged unit weight**

Ans:

Total unit weight (γ) = 16 kN/m^3

Specific gravity G = 2.67

Water content w =17%

(a) Dry unit weight $\gamma_d = \gamma/(1+w)$
= 16/ (1+0.17)
= 13.675 kN/m^3

(b) Void ratio (e) = $(G\gamma_w/\gamma_d) - 1$
= (2.67×9.81/13.675) –1
= 0.9153=0.91

(c) Porosity (n)=e/(1+e)
= 0.9153/ (1+ 0.9153)
= 47.79%

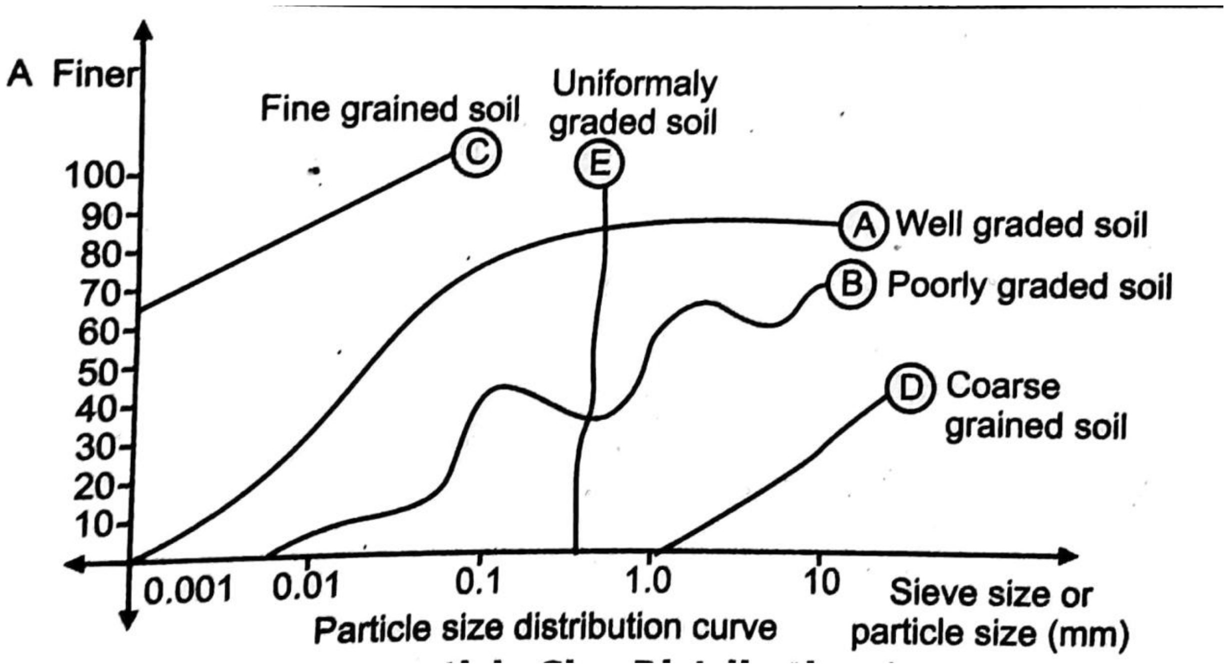
(d) Degree of saturation (S)= wG/e
= 0.17×2.67/.9153
= 49.59%

(e) Saturated unit weight $\gamma_{sat} = (G+e)\ \gamma_w/(1+e)$
= (2.67+0.91)9.81/ (1+0.91)
= 18.38 kN/m^3

(f) Submerged unit weight $\gamma_{sub} = (G-1)\ \gamma_w/(1+e)$
= (2.67-1)9.81/ (1+0.91)
= 8.58 kN/m^3

Q2. Draw particle size distribution curve. Explain mechanical sieve analysis for grading of soil with sketch?

Ans.



Mechanical sieve analysis: The process of analyzing the particle size present in soil by using mechanical means is known as mechanical sieve analysis. By performing mechanical sieve analysis, a particle size distribution curve is plotted for grading of soil.

Procedure:

i) Initially keep the given soil sample in rapid moisture meter for 2-3 hours to get oven dried soil. Break the visible lumps present in soil using fingers with light pressure.

ii) Arrange the set of I.S. sieves in descending order i.e. coarser sieve at top and finer sieve at bottom. The IS sieve set must include sieves of size 4.75mm, 2.36mm, 1.18mm, 600mic., 300 mic, 150 mic, 75 and pan.

iii) Take the soil sample about 500-1000gm and put it on topmost sieve. Keep lid and pan at top and bottom respectively.

iv) Now, shake this assembly of sieve on mechanical sieve shaker for 10-15 minutes, so that soil sample will be sieved completely.

Sieve size	Weight Retained	Percentage Weight Retained	Cumulative percentage weight retained	Percentage Finer

v) Take the weight of soil mass retained on each sieve separately in grams.

vi) Calculate % finer for each sieve using following tabular format.

UNIT-III PERMEABILITY AND SEEPAGE

A. 2 Marks Questions

1. **Define permeability.**

Ans. Permeability is the property of a soil that allows water to flow through its interconnected voids. It governs the rate at which water can pass through the soil under a hydraulic gradient

2. **What is Darcy's law of permeability?**

Ans. Darcy's law states that the discharge through a porous medium is directly proportional to the hydraulic gradient and the cross-sectional area of flow, under laminar flow conditions

$$Q = k \times i \times A$$

Where Q = Discharge (m^3/s), k = Coefficient of permeability (m/s), i = Hydraulic gradient (h/L), A = Cross-sectional area of soil (m^2).

3. **Differentiate between coefficient of permeability and hydraulic conductivity.**

Ans. • Coefficient of permeability (k) considers only the soil's properties.
• Hydraulic conductivity (K) considers both soil and fluid properties, including viscosity and density.

4. **Write two limitations of Darcy's law.**

Ans. 1. It is valid only for laminar flow conditions.
2. It cannot be applied to coarse gravels or fractured rocks where turbulent flow occurs.

5. **What do you mean by phreatic line?**

Ans. The phreatic line is the boundary within an earthen dam that separates the saturated zone from the unsaturated zone, where pore water pressure equals atmospheric pressure.

6. **Define effective stress in soil.**

Ans. Effective stress (σ′) is the portion of total stress that is transmitted through the soil skeleton and controls soil strength.
$\sigma' = \sigma - u$, where σ = total stress, u = pore water pressure.

7. **What is quicksand condition?**

Ans. It is a condition when upward seepage pressure equals the submerged weight of soil, causing the effective stress to become zero and the soil to behave like a liquid.

8. **State two applications of flow net.**

Ans. 1. Estimation of seepage quantity through earth dams or foundations.
2. Determination of uplift pressure and seepage force distribution.

9. **What is seepage pressure?**

Ans. Seepage pressure is the pressure exerted by water as it flows through soil pores due to a hydraulic gradient. It acts in the direction of flow and influences soil stability.

10. State the assumptions made in Darcy's law.

Ans. 1. Flow is laminar and steady.
2. Soil is homogeneous and isotropic.
3. The flow path is continuous and fully saturated.
4. Hydraulic gradient is constant across the sample.

B. 5 Marks Questions

1. **Explain the factors affecting permeability of soil in detail.**

Ans. Permeability (k) is the property of soil that allows water to flow through its pores. The rate of flow depends on several physical and environmental factors related to soil structure and the properties of the fluid.

Factors Affecting Permeability of Soil:

1. Grain Size- Larger grain size → higher permeability.

Coarse-grained soils (sand, gravel) have larger interconnected voids, allowing water to pass easily. Fine-grained soils (silt, clay) have small pores, causing slow seepage.

2. Properties of the Fluid- Viscosity and density of water affect permeability. Higher viscosity (e.g., at low temperature) reduces permeability. Warmer water (lower viscosity) increases permeability.

3. Void Ratio (Porosity)

Higher void ratio (e) → more space for water flow → higher permeability

4. Degree of Saturation- Fully saturated soils have continuous water-filled pores, allowing maximum flow.

Partially saturated soils have air pockets blocking the flow paths, thus reducing permeability.

5. Soil Structure and Fabric- Arrangement of particles influences the continuity of flow channels. Flocculated clay structure has higher permeability than a dispersed one because of larger pore channels.

Stratified soils (layered deposits) show anisotropic permeability — higher along the bedding plane than across it.

6. Impurities and Adsorbed Layers- Presence of colloids, organic matter, or dissolved salts can clog pores and reduce permeability.

Adsorbed water on clay surfaces creates a thin film that resists flow.

7. Compaction- Increasing compaction reduces void ratio and compresses the soil structure, decreasing permeability.

Used effectively in embankments and cores of earthen dams to control seepage.

8. Entrapped Air- Air bubbles in pores interrupt water continuity and reduce effective flow area, lowering permeability.

9. Stress and Overburden Pressure- High confining stress compresses soil and decreases void ratio, hence reducing permeability — particularly important in fine-grained soils.

10. Temperature- With rise in temperature, viscosity of water decreases and permeability increases.

For water, approximately increases by 2–3% per °C rise in temperature.

2. **Differentiate between constant head and falling head tests, and state where each is applicable.**

Ans. Difference Between Constant Head and Falling Head Permeability Tests

Feature	Constant Head Test	Falling Head Test
Principle	Water flows through the soil sample under a	Water flows through the soil sample under a

	constant hydraulic head.	variable (falling) head that decreases with time.
Type of Flow	Steady-state flow.	Unsteady or transient flow.
Suitable Soil Type	Coarse-grained soils such as sand and gravel (high permeability).	Fine-grained soils such as silts and clays (low permeability).
Head Measurement	Head difference across the sample remains constant and is measured directly.	Head difference decreases with time and is recorded at known intervals.
Duration of Test	Short — steady flow achieved quickly.	Long — slow flow due to low permeability.
Apparatus Used	Constant head permeameter.	Falling head permeameter.
Equation Used	$k = QL / (Aht)$	$k = (aL / At) \ln(h_1 / h_2)$
Accuracy	Less accurate for low-permeability soils.	More accurate for low-permeability soils.
Nature of Soil Sample	Usually disturbed or remoulded coarse soil.	Usually undisturbed fine-grained soil.

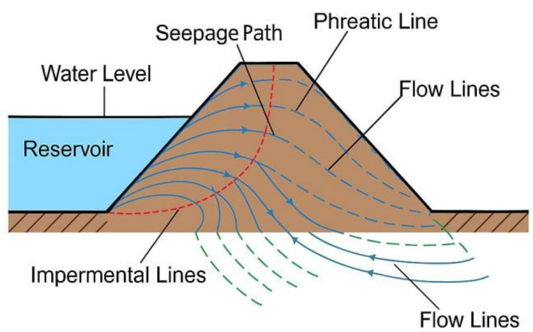
Applications

• Constant Head Test: Used for sands and gravels, such as in the design of filters, drainage layers, and aquifer materials.

• Falling Head Test: Used for silts and clays, where permeability is very low, such as in core materials of earthen dams or impervious liners.

3. Explain the concept of seepage through earthen dams with a neat sketch.

Ans. When water is stored on the upstream side of an earthen dam, it percolates through the dam body and foundation due to the difference in water level between the upstream and downstream sides. This movement of water through the pores of soil is called seepage. The flow of seepage takes place along curved paths within the dam and its foundation — known as flow lines. The space between two consecutive flow lines is called an equipotential drop, and the combination of flow lines and equipotential lines forms a flow net.



Seepage through Earthen Dam

Flow Characteristics:

1. Upstream face: The seepage starts from the reservoir water surface.

2. Downstream face: The flow emerges as a seepage face or through a toe drain/filter.

3. Phreatic line (seepage line): The topmost flow line that separates saturated and unsaturated zones within the dam body. Above it, the soil is unsaturated; below it, fully saturated. Pressure along the phreatic line is atmospheric.

Purpose of Seepage Analysis:

• To determine the quantity of seepage discharge through the dam and foundation.

• To estimate seepage pressure and exit gradient affecting dam stability.

• To design filters, drains, and cutoffs to safely control seepage and prevent piping or failure.

Control Measures:

• Use of impervious cores (clay core).

• Rock toe filters and drainage blankets on the downstream side.

• Cutoff walls or grouting below the dam foundation.

• Proper filter design to prevent migration of fine particles.

4. Write short notes on: (a) Seepage velocity (b) Seepage pressure.

Ans. (a) Seepage Velocity: Seepage velocity (v_s) is the actual velocity with which water flows through the interconnected void spaces of a soil mass.

Expression: $v_s = v / n$

where v = discharge velocity or Darcy velocity

n = porosity of soil

Since water can only move through the voids and not the entire cross-sectional area, the actual velocity through the pores (seepage velocity) is greater than the apparent velocity (Darcy's velocity).

Units: m/s (same as Darcy's velocity).

It gives a realistic estimate of groundwater movement and is important in contaminant transport, groundwater flow, and drainage design.

(b) Seepage Pressure

Definition: Seepage pressure is the pressure exerted by water as it seeps through soil pores due to the hydraulic gradient.

Expression: $p_s = h \times \gamma_w$

where:

h = head loss due to seepage

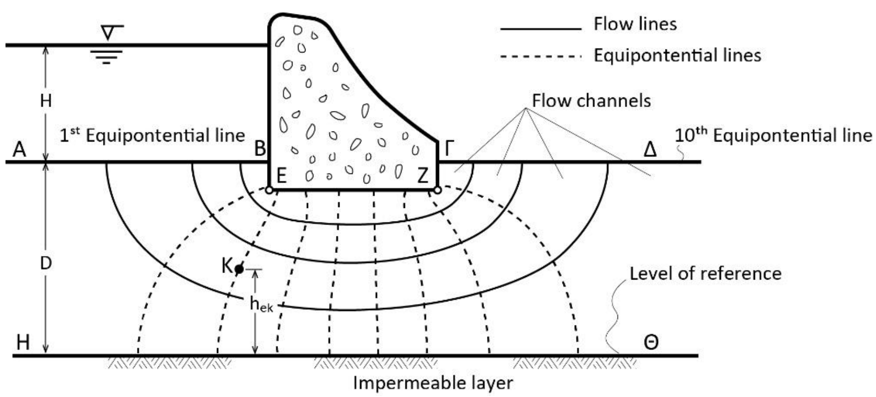
γw = unit weight of water

Seepage pressure acts in the direction of flow and tends to lift the soil particles, reducing the effective stress. When upward seepage pressure equals the submerged weight of soil, it leads to boiling or piping failure.

It affects the stability of hydraulic structures such as dams, weirs, and sheet piles by influencing the effective stress and potential for soil erosion.

5. What is a flow net? Explain its properties and uses.

A flow net is a graphical representation combining flow lines and equipotential lines to study seepage in soils.



Properties:
1. Flow lines and equipotential lines intersect at right angles.
2. Each flow channel has approximately equal discharge.
3. Head loss between successive equipotential lines is constant.

Uses:
- Determining seepage discharge.
- Locating phreatic line and uplift pressure.
- Analyzing stability against piping.

C. 10 Marks Questions

1. **Explain in detail the determination of coefficient of permeability by both constant head and falling head tests with neat sketches, equations, and assumptions.**

Ans. The coefficient of permeability (k) indicates the ability of soil to transmit water. It is determined experimentally using two types of tests depending on soil type.

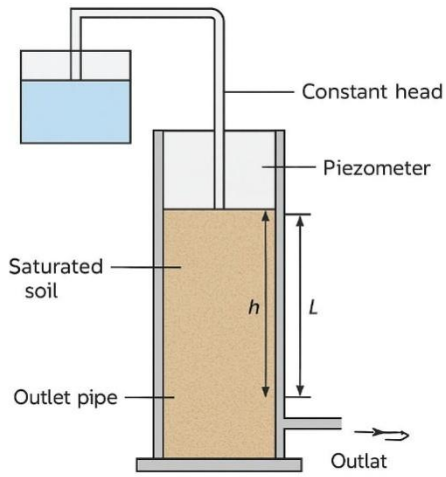
A. Constant Head Test (for coarse soils):

Apparatus: Permeametermould, constant-head tank, outlet valves, measuring jar, stopwatch.

Procedure:

1. Preparation of Sample:Place the saturated soil specimen in the permeameter.Connect the specimen between two porous plates to ensure uniform distribution of water.Apply filter papers at both ends to prevent soil loss.Measure and record the length (L) and cross-sectional area (A) of the specimen.
2. Establish Constant Head:Connect the inlet to a constant head tank to maintain a steady head difference between the inlet and outlet.Ensure the outlet is free for water to discharge without backpressure.
3. Allow Steady Flow:Allow water to flow until a steady state is reached (discharge remains constant).Collect the outflowing water in a measuring jar for a known time.
4. Measurement:Measure the quantity of water (Q) collected in time .Measure the head difference (h) between inlet and outlet piezometers.
5. Repeat Readings:Repeat the test for at least three different head values and note the corresponding discharges to ensure consistency.
6. Computation: Using Darcy's law:

$$K = (Q \times L) / (A \times h \times t)$$



Assumptions:

- Flow is laminar and steady.
- Soil is homogeneous and fully saturated.
- Head loss is proportional to sample length.

B. Falling Head Test (for fine soils):

Apparatus: Standpipe of area a connected to soil sample of area A and length L.

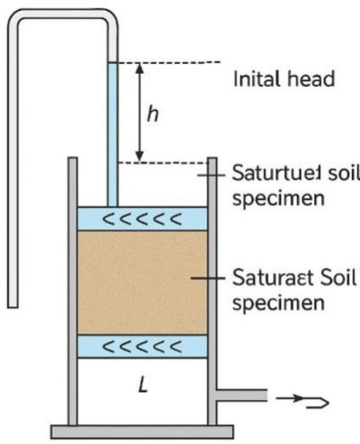
Procedure:

1. Preparation of Sample:The soil specimen (length , cross-sectional area) is saturated and placed between porous stones in the permeameter.The specimen is connected to a standpipe filled with water.
2. Initial Head Measurement:Fill the standpipe with water to an initial head above the outlet level.
3. Flow Initiation:Open the bottom outlet to allow water to flow through the sample.The head in the standpipe gradually falls as water percolates through the soil.

4. Observation:Record the time (t) taken for the head to fall from to. The water levels are measured using a graduated scale attached to the standpipe.
5. Computation:From Darcy's law:
6. Repeat:Perform two or more trials for accuracy and average the results.

Formula:

$$K = (a \times L / A \times t) \times \ln(h_1 / h_2)$$



Falling Head Permeability Test

Assumptions:

1. Soil is homogeneous, saturated, and isotropic.
2. Flow is laminar and follows Darcy's law.
3. Head loss corresponds to the measured fall in the standpipe.

Typical Values:

Coarse sand: $10^{-3} – 10^{-4}$ m/s | Fine sand: $10^{-5} – 10^{-6}$ m/s | Clay: $10^{-8} – 10^{-9}$ m/s.

2. **Discuss in detail the concept of seepage through earthen structures. Explain phreatic line, flow lines, equipotential lines, and the use of flow net in analyzing seepage.**

Ans. When water is stored on one side of an earthen structure such as a dam, embankment, or levee, part of it seeps through the body and foundation of the structure due to the difference in hydraulic head between the upstream and downstream sides. This movement of water through the soil voids is called seepage, and it plays a critical role in the stability and safety of earthen structures.

1. Concept of Seepage

Seepage occurs because of a hydraulic gradient created between the water levels on both sides of the structure. The water flows through the interconnected pores of the soil, following curved flow paths known as flow lines. The direction and quantity of seepage depend on the hydraulic head difference, permeability of soil, and geometry of the structure. Uncontrolled seepage can cause piping, internal erosion, slope instability, or uplift pressure under the foundation.

2. Important Terms in Seepage Analysis

(a) Phreatic Line (Seepage Line):

The phreatic line represents the upper surface of the saturated zone within an earthen dam. It separates the saturated zone below from the unsaturated zone above, and the water pressure along this line is atmospheric. For homogeneous dams, the phreatic line approximately follows a parabolic shape and can be determined using flow nets or Casagrande's method.

(b) Flow Lines:

Flow lines represent the paths followed by water particles as they move through the soil. They are always tangential to the direction of flow and originate at the upstream face and terminate at the downstream toe or drainage filter.

© Equipotential Lines:

Equipotential lines are lines connecting points of equal total head. They are always perpendicular to flow lines. The total head decreases uniformly between successive equipotential lines, and the potential drop between any two lines is constant.

(d) Flow Net:

A flow net is a graphical representation combining flow lines and equipotential lines to visualize seepage through soils. It forms a network of curvilinear squares that helps determine the quantity of seepage and seepage pressure distribution.

Characteristics of Flow Net:

1. Flow lines and equipotential lines intersect at right angles.

2. The figure formed between adjacent lines is approximately a square.

3. The number of equipotential drops (Nd) and flow channels (Nf) can be used to compute seepage discharge.

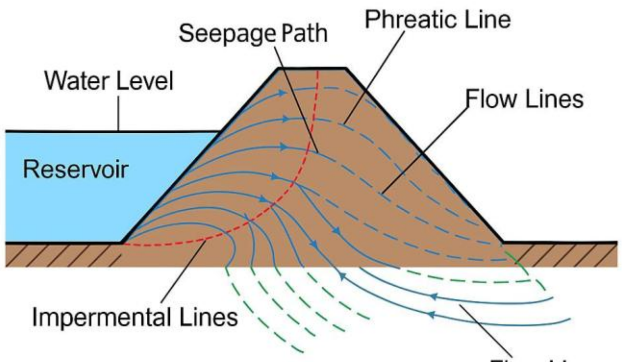
The seepage discharge through the dam is given by:

$Q = k \times h \times (N_f / N_d)$

Where k = coefficient of permeability, h = total head, Nf = number of flow channels, Nd = number of equipotential drops.

2. Uses of Flow Net

- To determine the quantity of seepage through the dam or foundation.
- To compute seepage pressure and exit gradient.
- To locate the phreatic line accurately.
- To check the risk of piping and uplift pressure.
- To design suitable filters, drains, and cutoffs in earthen structures.



Seepage through Earthen Dam

UNIT-IV: COMPACTION, CONSOLIDATION, AND STABILIZATION OF SOIL

Section A (2 Marks Questions)

1. Define compaction of soil.

Ans. Compaction is the process of densifying soil by reducing air voids through mechanical means such as rolling, tamping, or vibration, without changing the water content significantly.

The main objectives are to increase the soil's shear strength, reduce compressibility and permeability, and improve its load-bearing capacity for construction.

2. What is the difference between compaction and consolidation?

Ans. Compaction: Reduction in volume due to expulsion of air, rapid and mechanical.
Consolidation: Reduction in volume due to expulsion of water from saturated soil, slow and time-dependent.

3. State the purpose of Proctor test.

Ans. The Proctor test determines the relationship between the moisture content and dry density of soil to find the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).

4. What is Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)?

Ans. OMC is the water content at which the soil attains maximum dry density under a given compactive effort.

MDD is the highest dry unit weight of soil obtained at the optimum moisture content for a particular compactive effort.

5. What is the significance of Zero Air Voids (ZAV) line?

Ans. The ZAV line represents the theoretical maximum dry density achievable when all air voids are removed (degree of saturation = 100%). It serves as a reference on compaction curves.

6. Name any two field methods of compaction.

Ans. 1. Rolling using smooth or sheepsfoot rollers.
2. Ramming or tamping using hand or mechanical compactors.

7. What is the principle of the Standard Proctor test and modified proctor test?

Ans. Soil compaction increases with water content up to a certain limit (OMC) because water acts as a lubricant between particles, improving packing efficiency.

The Modified Proctor test applies higher compactive energy to simulate heavy construction loads (like highways and airfields), resulting in higher MDD and lower OMC.

8. State any two field implications of consolidation.

Ans. 1. Settlement of building foundations over clayey soils.
2. Slope instability or differential settlement of embankments.

9. What is soil stabilization?

Ans. Soil stabilization is the process of improving soil properties like strength, durability, and bearing capacity by mixing suitable stabilizing materials (e.g., lime, cement, bitumen).

To make weak soils suitable for construction, increase load-carrying capacity, reduce permeability, and prevent swelling or shrinkage.

10. Mention any two methods of soil stabilization.

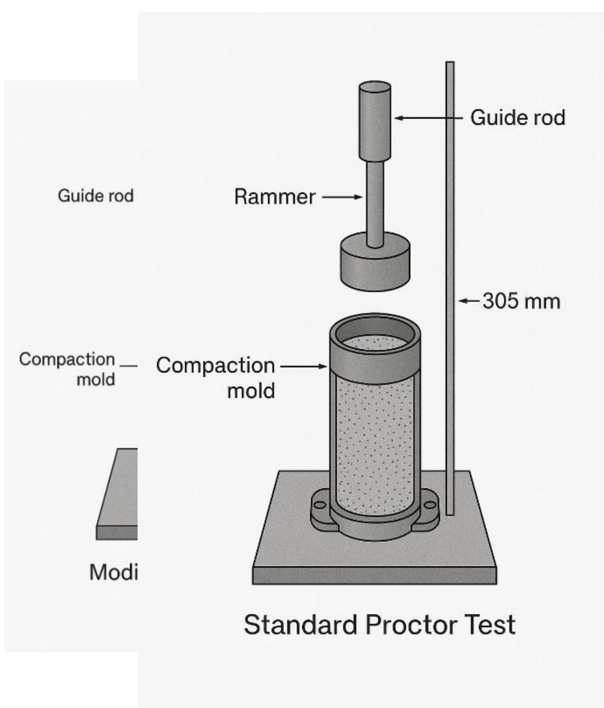
Ans. 1. Mechanical stabilization (blending of soils).
2. Chemical stabilization using lime, cement, or bitumen.

Section B (5 Marks Questions)

1. Explain the Standard Proctor test with neat sketch and procedure.

Ans. Objective: To determine Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for a given soil.

Apparatus: Proctor mould (1000 cm^3), rammer (2.6 kg, drop 305 mm), balance, oven, moisture tins.



Standard Proctor Test

Procedure:
1. Air-dry and sieve soil through 4.75 mm sieve.
2. Add water in increments and compact in 3 layers, each with 25 blows.
3. Determine wet mass and moisture content for each trial.
4. Compute dry density using $\gamma_d = \gamma / (1 + w)$.
5. Plot γ_d vs w to get the compaction curve; the peak gives MDD and corresponding w gives OMC.

2. Explain the Modified Proctor test and its significance.

Ans. The Modified Proctor test follows the same principle as the Standard Proctor test but with higher compactive effort.

Changes:
- Rammer weight = 4.9 kg
- Drop = 457 mm
- Layers = 5 (each with 25 blows)

Compactive energy is about 4.5 times greater than the Standard Proctor test.

Result: Produces higher MDD and lower OMC. Used for highway and runway.

Significance: Ensures soil compaction under heavy loads as per IS 2720 (Part 8).

3. Describe the factors affecting compaction of soil.

Ans. Factors Affecting Compaction of Soil

a. Water Content- Water acts as a lubricant between soil particles.At low water content, soil is stiff, and compaction is difficult because of friction between particles.As water content increases, lubrication improves, allowing particles to pack more closely, and dry density increases.Beyond the Optimum Moisture Content (OMC), excessive water occupies voids and reduces dry density.Hence, the relation between dry density and moisture content gives a parabolic curve with a peak at OMC.

b. Type of Soil,Grain size, shape, and gradation have a strong influence:Coarse-grained soils (sands, gravels) can be compacted to high densities because of less surface area and drainage ease.Fine-grained soils (silts, clays) develop capillary tension and require higher energy for compaction.Well-graded soils compact better than uniformly graded soils because smaller particles fill the voids between larger ones.

c. Compactive Effort- The energy applied per unit volume of soil affects its density.Greater compactive effort → higher dry density and lower OMC.Example: The Modified Proctor Test uses 4.5 times the energy of the Standard Proctor Test, resulting in higher maximum dry density.

d. Method of Compaction- The type of equipment and the manner in which compaction is applied influences the result:

   Static rollers – best for cohesive soils.

   Vibratory rollers – best for granular soils.

   Kneading or tamping rollers – suitable for plastic clays.

   Impact compaction – used in laboratory tests and small-scale field works.

e. Layer Thickness- Soil is compacted in layers; thicker layers reduce the effectiveness of compaction because energy does not reach deeper portions.Optimum layer thickness depends on soil type and equipment; generally 150–200 mm for field work.

f. Number of Passes- The number of roller passes affects the degree of compaction.Initially, density increases rapidly, then becomes nearly constant after reaching a limiting value.Additional passes beyond that do not significantly improve compaction.

g. Environmental Conditions- Temperature and weather affect compaction, especially in fine-grained soils.Higher temperature reduces water viscosity, improving lubrication.In cold or dry climates, moisture loss makes compaction difficult.

h. Type of Additives- Addition of lime, cement, or bitumen can alter soil structure and reduce plasticity, improving compaction properties.

4. Explain field methods of compaction and their suitability for different soils.

Ans. Compaction in the field is carried out using various mechanical equipment to achieve the desired soil density. The choice of compaction method depends on the type of soil, required degree of compaction, and site conditions.

1. Rolling

Rolling is one of the most common field methods for compacting large areas such as embankments, subgrades, and roads.

Type of Roller	Description	Suitable Soil Type
Smooth Wheel Roller	Consists of 2–3 smooth steel drums, provides static pressure (8–12 tonnes).	Granular soils like sand and gravel.

Sheepsfoot Roller	Steel drum with projecting feet producing kneading action.	Clayey and silty soils.
Pneumatic Tyred Roller	Rubber tyres provide static and kneading action (200–700 kN/m²).	Cohesive and well-graded soils.
Vibratory Roller	Applies vibration using an eccentric mass, reduces voids effectively.	Granular soils such as sand and gravel.

2. Ramming (Tamping)

Compact soil by impact blows using hand tampers or mechanical rammers. Used in confined areas like trenches and foundations. Suitable for cohesive soils like clay and silty clay.

3. Vibrating Plate Compactors

Flat plate vibrates rapidly, transmitting vibrations to soil. Used in pavements and granular backfills. Suitable for cohesionless soils like sand, gravel, and crushed stone.

4. Tamping Roller (Grid Roller)

Heavy steel drum with grid or tamping feet, combining static and kneading action. Used for well-graded coarse soils in embankments or subgrades.

5. Earth Rammers (Power Rammers)

Diesel or electric rammers applying repeated impact energy. Used around abutments, retaining walls, and foundations for cohesive soils.

6. Vibratory Compaction

Applies mechanical vibration to rearrange soil particles densely. Best for sands and gravels in foundations and dams.

7. Dynamic Compaction

Heavy weights (10–40 tonnes) dropped from heights (10–30 m) to compact ground. Used for improving loose granular fills or reclamation sites.

8. Kneading Compaction

Applies shearing and pressing action through pneumatic or sheepsfoot rollers. Suitable for cohesive soils like clays and silts.

5. **Differentiate between compaction and consolidation in terms of process and result?**

Ans. Compaction and consolidation are both processes that lead to the reduction of soil volume and increase in its density. However, they differ fundamentally in mechanism, time required, and the type of soils affected.

S.No.	Compaction	Consolidation

1	Compaction is the process of reducing the air voids in soil by applying mechanical energy.	Consolidation is the process of expelling water from the voids of a saturated soil due to long-term static loading.
2	It is an instantaneous process achieved by mechanical means such as rolling, tamping, or vibration.	It is a slow process that occurs gradually with time under sustained loading.
3	Occurs mostly in partially saturated or dry soils.	Occurs only in fully saturated cohesive soils.
4	Caused by external mechanical energy.	Caused by dissipation of pore water pressure under static load.
5	Results in immediate increase in dry density and shear strength.	Results in gradual settlement and decrease in void ratio over time.
6	Generally performed in the field during construction.	Occurs naturally in the ground or under structures like embankments or foundations.
7	No change in water content (mostly air is expelled).	Decrease in water content as water is squeezed out of voids.
8	Studied using Standard or Modified Proctor Test.	Studied using Oedometer (Consolidation) Test.

6.Describe the CBR test procedure and its importance in pavement design.

Ans. The California Bearing Ratio (CBR) test is a penetration test developed by the California Division of Highways. It is used to evaluate the strength of subgrade soil, sub-base, and base courses of pavements. The CBR value obtained from this test is used in the design of flexible pavements to determine the thickness of different layers.

To determine the load-bearing capacity of soil for use in the design of road and airfield pavements.

Apparatus Required

- CBR mould (150 mm diameter, 175 mm height) with base plate and collar
- Loading machine (capacity 50 kN) with a penetration rate of 1.25 mm/min
- Metal rammer (2.6 kg or 4.9 kg) for compaction
- Dial gauges for measuring penetration and load
- Surcharge weights
- Soaking tank for submerging specimens
- Balance, straight edge, and water measuring jar

Preparation of Sample

1. Take soil passing through 20 mm IS sieve.
2. Mix it with water at the optimum moisture content (OMC) determined from the Proctor test.
3. Compact the soil in a CBR mould in 3 or 5 layers using the standard or modified Proctor compaction effort.

4. Level the top surface and place surcharge weights equivalent to pavement weight.
5. The specimen may be tested either immediately (unsoaked condition) or after 4 days of soaking (soaked condition) to simulate worst field conditions.

Test Procedure

1. Place the mould with the compacted soil under the penetration piston in the loading frame.
2. Apply a seating load of 4 kg to ensure contact between the piston and soil surface.
3. Apply load at a uniform penetration rate of 1.25 mm/min.
4. Record the load corresponding to each penetration up to 12.5 mm using the proving ring or load cell.
5. Plot the load vs. penetration curve and obtain the corrected load values for 2.5 mm and 5 mm penetration.
6. Calculate the CBR value using the formula:

CBR (%) = (Test Load / Standard Load) × 100

Standard Loads: 1370 kg at 2.5 mm and 2055 kg at 5 mm penetration.

Calculation and Result

Usually, the higher value of CBR at 2.5 mm and 5 mm penetration is taken as the CBR of the soil. However, if the 5 mm value is greater, the test is repeated for confirmation.

Importance in Pavement Design

• The CBR value is a crucial parameter in flexible pavement design as per Indian Roads Congress (IRC:37-2018).
• It indicates the strength of subgrade soil and determines the thickness of pavement layers.
• Soils with higher CBR values require thinner pavements, while weaker soils (low CBR) need thicker pavements.
• The CBR test establishes an empirical relationship between soil strength and pavement performance, making it widely used in road design.

Typical CBR Value Range

Type of Soil	Typical CBR Value (%)
Clayey soil (poor subgrade)	2 – 5
Silty or sandy clay	5 – 10
Well-graded sand or gravel	10 – 20
WMM / Granular sub-base	20 – 50
Crushed stone or base course	50 – 100

9. Conclusion

The CBR test is simple, economical, and reliable for assessing the strength of subgrade soils. It provides essential input data for pavement design and ensures the construction of safe and cost-effective roads by evaluating soil performance under loading conditions.

C. 10 Marks Questions

1. Discuss the concept of compaction in soils. Explain the compaction curve, Zero Air Voids line, and the factors affecting compaction in detail.

Ans. Compaction is the process of increasing the dry density of soil by reducing air voids through mechanical means such as rolling, tamping, or vibration. It rearranges soil particles into a denser configuration without removing water, thereby improving the engineering behavior of the soil.

Objectives of compaction include:

• Increasing bearing capacity
• Reducing settlement
• Minimizing permeability
• Enhancing slope stability and durability

Compaction differs from consolidation: compaction is a short-term mechanical process that removes air from voids, while consolidation is a long-term process involving expulsion of water under sustained load.

Compaction Curve

When a soil is compacted at different moisture contents using the same energy, its dry density varies. If dry density is plotted against water content, a parabolic curve known as the Compaction Curve is obtained.

Key features of the compaction curve:

1. At low water content, soil is dry and stiff; compaction is difficult, resulting in low dry density.
2. As water content increases, lubrication improves and particles pack closer, increasing dry density.
3. At high water content, excess water occupies voids and pushes soil grains apart, reducing dry density.
4. The maximum point on the curve represents the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

• Optimum Moisture Content (OMC): The water content at which soil attains maximum dry density for a given compactive effort.
• Maximum Dry Density (MDD): The highest dry density obtained from the compaction test corresponding to the OMC.

Zero Air Voids (ZAV) Line

The Zero Air Voids line represents the theoretical maximum dry density of the soil when all air is expelled (100% saturation). In practice, complete saturation cannot be achieved during compaction, so the compaction curve always lies below the ZAV line.

Equation for ZAV line:

$\rho_d = (G \times \gamma_w) / (1 + w \times G)$

where:
ρ_d = dry density
G = specific gravity of soil solids
γ_w = unit weight of water
w = water content

Significance: The ZAV line acts as a reference line for checking test accuracy. No compaction curve should cross it.

Factors Affecting Compaction

Factor	Description
Water Content	Acts as a lubricant between soil particles; dry density increases with moisture up to OMC, then decreases beyond it.
Soil Type	Coarse-grained soils compact easily; fine-grained soils need higher moisture and energy for effective compaction.
Compactive Effort	Higher energy (e.g., Modified Proctor Test) yields higher MDD and lower OMC.
Method of Compaction	Different equipment affects results; vibration suits sand, kneading suits clay.
Layer Thickness	Thinner layers ensure uniform compaction; typical field thickness is 150–200 mm.
Number of Passes	More roller passes increase dry density until a maximum is reached.
Environmental Conditions	Temperature and evaporation affect moisture content and compaction efficiency.
Type of Additives	Lime, cement, or bitumen improve soil structure and compaction characteristics.

Typical Compaction Curve

A typical compaction curve shows dry density versus water content. The curve rises with increasing water content, peaks at the MDD corresponding to OMC, and then falls. A Zero Air Voids line is drawn above the curve as a theoretical limit.

2. **Describe the necessity and various methods of soil stabilization. Explain the role and utilization of the CBR test in pavement construction.**

Ans. Soil stabilization is the process of improving the engineering properties of soil—such as strength, stability, and durability—by mechanical or chemical means. It is used to make weak soils suitable for construction purposes like roads, foundations, embankments, and airfields.

Necessity of Soil Stabilization

Soil stabilization is necessary when the natural soil does not have adequate strength or stability. The main reasons include:

• Low bearing capacity – increases load-carrying ability of soil.

• Excessive settlement – reduces uneven settlement under load.

• Volume change due to moisture – controls swelling and shrinkage in expansive soils.

• Improvement of subgrade for pavements – provides a stable base for highways and airfields.

• Prevention of erosion – enhances durability against wind and water erosion.

• Economic construction – allows use of locally available soils instead of costly borrow materials.

Methods of Soil Stabilization

Soil stabilization techniques are broadly classified into mechanical, chemical, and additive-based methods.

A. Mechanical Stabilization

Achieved by changing the gradation or compacting the soil effectively. It involves mixing two or more types of soils to improve gradation and interlocking. Compaction increases density and strength by reducing air voids.
Suitable for: granular soils and subgrade improvement.

B. Cement Stabilization

Involves mixing soil with Portland cement (3–10%) and water, followed by compaction and curing. Cement reacts chemically with soil minerals to form a hard, durable mass.
Advantages: High strength and water resistance.
Suitable for sandy and silty soils; used for base or sub-base layers of pavements.

C. Lime Stabilization

Used mainly for clayey soils. Lime reacts with clay minerals, reducing plasticity and swelling, and forms cementitious compounds.
Advantages: Reduces plasticity, increases strength and workability.
Applications: Subgrade stabilization in highways.

D. Bituminous Stabilization

Mixing soil with bitumen or asphalt binds and waterproofs the particles. Effective for coarse-grained soils and road bases.
Advantages: Reduces water infiltration, increases resistance to weathering and erosion.

E. Chemical Stabilization

Uses chemicals such as calcium chloride, sodium silicate, or polymers to modify soil properties and reduce moisture movement.
Applications: Desert roads, dust control, and airfields.

F. Electrical Stabilization (Electro-osmosis)

Used for fine-grained soils, particularly clays. A DC electric current is passed through soil using electrodes, driving water toward the cathode and increasing strength.
Advantages: Effective in reducing pore water and improving slope stability.

G. Thermal Stabilization

Soil is heated or frozen to alter its structure and improve strength. Heating removes moisture and increases dry strength, while freezing provides temporary stability and impermeability.

H. Use of Geosynthetics

Geotextiles, geogrids, and geomembranes are used to reinforce soil, improve drainage, and enhance load-bearing capacity.
Applications: Embankments, retaining walls, and road pavements.

UNIT-V SHEAR STRENGTH OF SOIL

A. 2 MARKS QUESTIONS

Q1. Define shear strength of soil?

Ans. Shear strength of soil is the maximum resistance offered by the soil against shearing stresses before failure occurs. It depends on cohesion and internal friction between soil particles.

Q2. What are the components of shear strength of soil?

Ans. The two main components of shear strength are:

(i) Cohesion (c) — the bonding force between particles.

(ii) Angle of internal friction (ϕ) — resistance due to interlocking and friction between particles.

Q3. What is angle of internal friction?

Ans. Angle of internal friction (ϕ) is the angle made by the failure envelope with normal stress axis and represents the shear resistance due to friction between soil particles.

Q4. What is punching shear failure?

Ans. Punching shear failure occurs when a highly loaded area, such as under a footing, penetrates or punches into the soil without general shear failure of the surrounding area.

Q5. Write the strength equation for purely cohesive soil?

Ans. For purely cohesive soil (ϕ = 0):

$$\tau = c$$

Where τ = shear strength and c = cohesion.

Q6. Write the strength equation for cohesionless soil?

Ans. For cohesionless soil (c = 0):

$$\tau = \sigma \tan \phi$$

where σ = normal stress and ϕ = angle of internal friction.

Q7. State any two laboratory methods to determine shear strength?

a. Direct shear test
b. Triaxial compression test

(Other examples: Unconfined compression test, Vane shear test)

Q8. What are the advantages of triaxial test over direct shear test?

a) Drainage conditions can be controlled.
b) Uniform stress distribution on the failure plane.
c) Pore pressure can be measured accurately.

Q9. State any two factors affecting shear strength of soil?

Ans.

a) Type and gradation of soil.
b) Moisture content and degree of saturation.

(Also affected by density, confining pressure, and strain rate.)

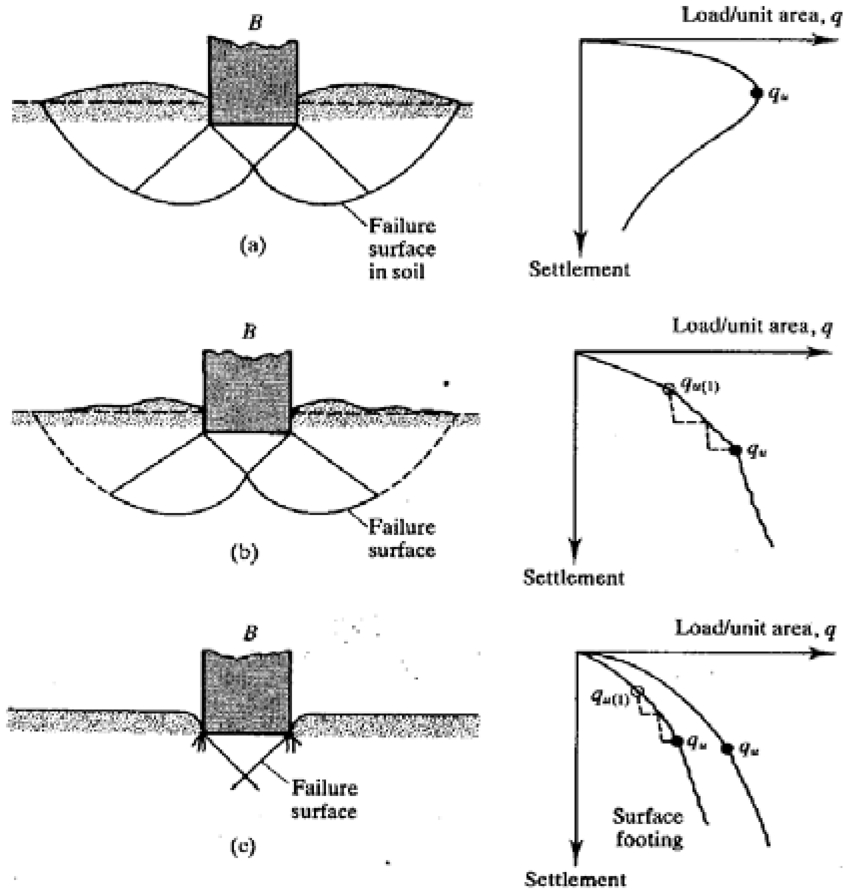
Q10. Define shear failure plane?

Ans. Shear failure plane is the surface or plane along which the soil mass experiences maximum shear stress and failure occurs due to sliding of one part over another.

B.5 Marks Question

Q1. Describe general shear failures in foundation?

Ans. Shear Failures in Soils are categorized into three primary classes: general shear failure, local shear failure, and punching shear failure.



1. **General Shear Failure:** This is the most frequent type of shear failure. It occurs when the soil beneath a footing cannot support the load placed on it. The failure surface is well-defined and extends from the edge of the footing to the ground surface. Characterized by sudden collapse, tilting of the footing, and bulging of the soil surface. It's common in dense and stiff soils that undergo low compressibility.
   - i) Upon the increase in stress, settlement of soil will not take place,stresses in the soil near footing will keep on increasing with increasing the load.
   - ii) Gradually, zones of failures will develop completely.
   - iii) Soil will change its state from elastic to plastic state.
   - iv) In plastic state, volumetric strain will be high, hence volume increase will cause bulging,
   - v) Significant amount of bulging/ heaving at G.L will take place.
   - vi) When max. c and ϕ are mobilised then, soil will fail in shear causing slipping of footing and will cause overturning of footing.
   - vii) Failure will be because of overturning and not because of settlement.

Q2. Discuss the factors affecting shear strength of soil with examples?

Ans. The **shear strength of soil** is affected by several factors that influence how soil particles resist sliding over each other. The main factors are:

1. **Moisture Content (Water Content):**
    - Water reduces effective stress by increasing pore water pressure, which decreases shear strength.
    - *Example:* Clay becomes weak and soft when wet.
2. **Density (Degree of Compaction):**
    - Densely packed soils have higher interparticle friction, giving greater shear strength.
    - *Example:* Compacted sand is stronger than loose sand.
3. **Normal Stress:**
    - Higher normal stress increases frictional resistance, thus improving shear strength.
    - *Example:* Deep soil layers have more strength due to high overburden pressure.
4. **Type of Soil and Particle Size:**
    - Coarse-grained soils (like sand and gravel) have high frictional resistance, while fine-grained soils (like clay) have lower friction but higher cohesion.
    - *Example:* Sandy soil shows high shear strength compared to silt.
5. **Cohesion:**
    - The attraction between soil particles gives cohesive strength, especially in clays.
    - *Example:* Clay lumps hold together due to cohesion even without compaction.
6. **Drainage Conditions:**
    - In undrained conditions, pore water pressure increases, reducing effective stress and shear strength.
    - *Example:* During heavy rain, slope failure occurs due to poor drainage.
7. **Structure of Soil (Fabric):**
    - The arrangement of soil particles affects strength. Well-graded, interlocked particles give higher strength.
    - *Example:* Flocculated clay structure is stronger than dispersed structure.

Q3. Explain Mohr-Coulombs failure theory?

Ans. The following are essential points of Mohr's strength theory

According to **Mohr–Coulomb's theory**, a soil fails when the **shear stress (τ)** on a plane reaches a value that is **equal to the shear strength (τf)** of the soil, given by:

$$\tau\_f = c + \sigma \tan\ \phi$$

Where **τf** = Shear strength of soil

c = Cohesion of soil
σ = Normal stress on the failure plane
ϕ (phi) = Angle of internal friction

1. Theoretical basis:

- a graphical representation of the state of combined normal and shear stresses at a point in a material.

- The Mohr–Coulomb failure envelope: a straight-line tangent to Mohr's circles for increasing normal stresses.

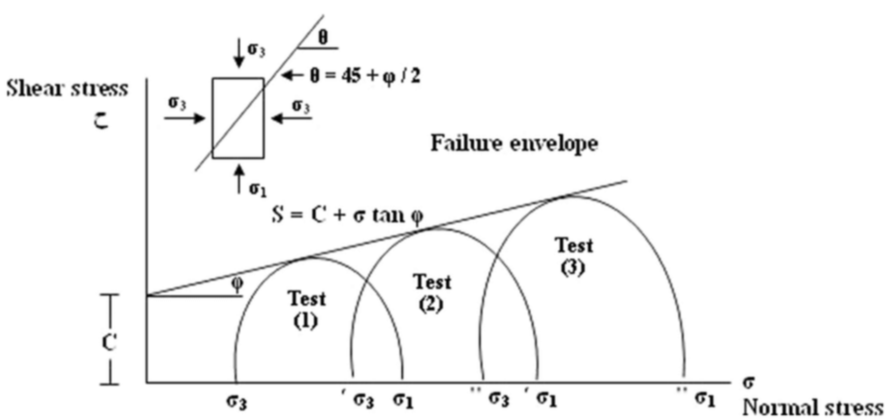
- failure occurs when the shear stress on some plane reaches a limiting value given by

$$\tau\_f = c + \sigma \tan\ \phi$$

- This can also be expressed in terms of major & minor principal stresses:

$$\sigma_1 = \sigma_3 \tan 2\left(45^{\blacksquare} + \frac{\varphi}{2}\right) + 2c \tan \quad \left(45^{\blacksquare} + \frac{\varphi}{2}\right)$$

2. Graphical representation



- Material fails essentially by shear. The critical shear stress causing failure depends upon the properties of the material as well as on normal stress on the failure plane.

- The ultimate strength of the material is determined by the stresses on the potential failure plane or plane of shear.

- When the material is subjected to three dimensional principal stress (i.e. $\sigma 1, \sigma 2, \sigma 3)$ the intermediate principal stress does not have any influence on the strength of material. In other words, the failure criterion is independent of the intermediate principal stress.

- The plot has shear stress (τ) on the vertical axis and normal stress (σ) on the horizontal axis.
- Each Mohr circle represents the stress state on different potential planes.
- The straight line (failure envelope) drawn tangent to these circles marks the limit of shear strength; when a circle touches the line, failure is assumed to occur on the corresponding plane.
- The intercept of the line on the τ-axis is c.
- The slope gives $\tan\phi$.
- The envelope thus summarizes the combination of normal and shear stresses that will cause failure.

Q4. Explain direct shear test of soil?

- The direct shear test is a laboratory method to determine the shear strength of soil by applying a normal load to a soil sample in a split shear box and then pulling the two halves of the box in opposite directions until failure occurs.
- Readings from a proving ring (for shear force) and dial gauges (for horizontal and vertical displacement) are recorded as the test progresses. The results are used to calculate the cohesion and angle of shearing resistance, which are critical for designing geotechnical structures like foundations and retaining walls.

- At first soil is placed in the shear box, either undisturbed or remoulded.A normal load is applied vertically to simulate overburden pressure.
- The lower half of the box is fixed.
- The upper half is moved horizontally at a constant rate.
- Shear force and displacement are recorded until failure occurs.
- After that the maximum shear force at failure is noted.
- Multiple tests are conducted at different normal stresses.

Shear strength parameters (cohesion $c$and angle of internal friction ϕ) are determined using the **Mohr-Coulomb failure criterion**:

$$\tau = c + \sigma \cdot \tan(\phi)$$

where $\tau$is shear strength and $\sigma$is normal stress.

- Advantages of this test is-
  Simple and quick
  Cost-effective
  Useful for preliminary assessments
- In this test the two or three nos of limitation are also included i.efailure plane is predetermined (not natural),
- not suitable for saturated clays or soils with complex behaviour
- Less accurate than triaxial tests for critical projects

Q5. Write the test procedure of Triaxial test?

Sample Preparation

1. Obtain an **undisturbed** or **remoulded** cylindrical soil sample (usually 38 mm diameter × 76 mm height).
2. Trim the specimen carefully to the required dimensions.
3. Place **porous stones** at the top and bottom of the specimen with **filter papers** if required.
4. Encase the specimen in a **rubber membrane** using a membrane stretcher to prevent direct contact with the cell fluid.
5. Mount the sample on the **base pedestal** inside the triaxial cell.

Test Procedure

(a) Mounting and Cell Assembly

1. Assemble the triaxial cell and fill it with de-aired water.
2. Apply a **cell pressure (σ_3)** to simulate confining stress.
3. Allow drainage (if consolidation is required) until volume change ceases.

(b) Application of Deviator Stress

1. Apply **axial load** on the specimen through the loading frame at a constant strain rate (usually 0.5–2% per minute).
2. Record:
   - Axial deformation (from the dial gauge),
   - Proving ring or load cell readings,
   - Pore water pressure (for CU and CD tests).
3. Continue loading until the specimen fails (identified by peak load or 20% axial strain).

(c) Repeat for Different Confining Pressures

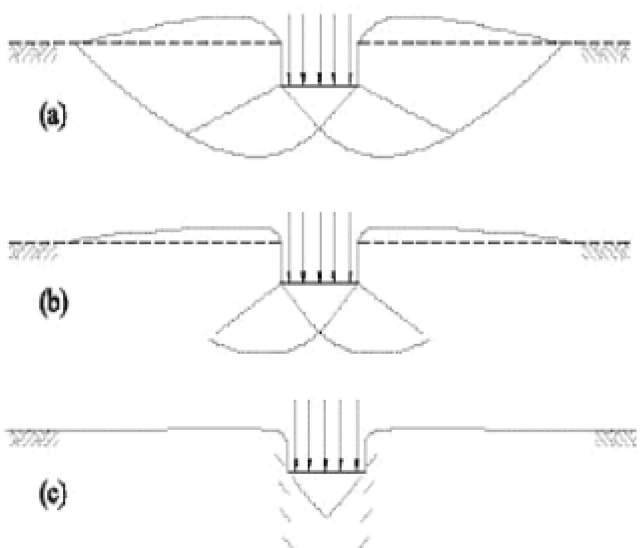
- Conduct at least **three tests** on identical specimens under different confining pressures (σ_3).
- Plot **Mohr's circles** for each test and determine the **failure envelope**.

C. 10 Marks Question

Q1. What are the types of shear failures? Describe with neat sketch.

Depending on the stiffness of foundation soil and depth of foundation, the following are the modes of shear failure experienced by the foundation soil.

1. General shear failure (Fig.1(a))
2. Local shear failure (Fig.1(b))
3. Punching shear failure (Fig.1(c))



General Shear Failure

This type of failure is seen in dense and stiff soil. The following are some characteristics of general shear failure.

1. Continuous, well defined and distinct failure surface develops between the edge of footing and ground surface.
2. Dense or stiff soil that undergoes low compressibility experiences this failure.
3. Continuous bulging of shear mass adjacent to footing is visible.
4. Failure is accompanied by tilting of footing.
5. Failure is sudden and catastrophic with pronounced peak in $p-\Delta$ curve.
6. The length of disturbance beyond the edge of footing is large.
7. State of plastic equilibrium is reached initially at the footing edge and spreads gradually downwards and outwards.
8. General shear failure is accompanied by low strain (<5%) in a soil with considerable ϕ (ϕ >36°) and large N (N > 30) having high relative density (I_D> 70%).

2.Local Shear Failure

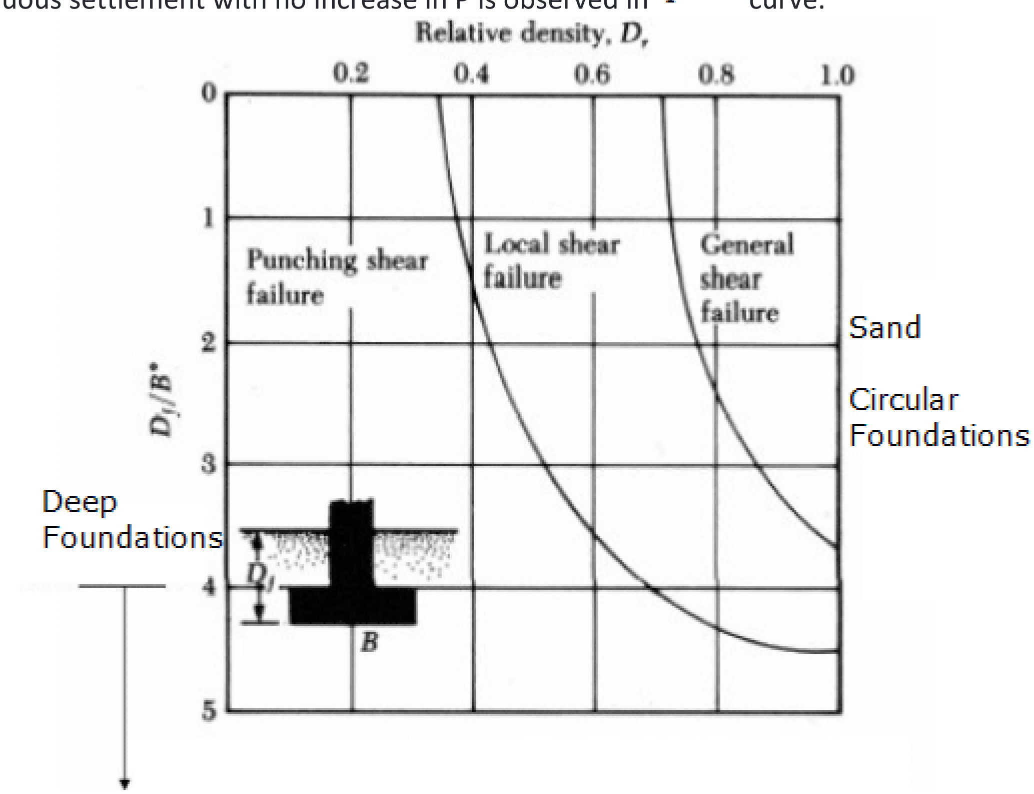
This type of failure is seen in relatively loose and soft soil. The following are some characteristics of general shear failure.

1. A significant compression of soil below the footing and partial development of plastic equilibrium is observed.
2. Failure is not sudden and there is no tilting of footing.
3. Failure surface does not reach the ground surface and slight bulging of soil around the footing is observed.
4. Failure surface is not well defined.
5. Failure is characterized by considerable settlement.\
6. Well defined peak is absent in $p-\Delta$ curve.
7. Local shear failure is accompanied by large strain (> 10 to 20%) in a soil with considerably low ϕ (ϕ<28o) and low N (N < 5) having low relative density (I_D> 20%).

3.Punching Shear Failure of foundation soils

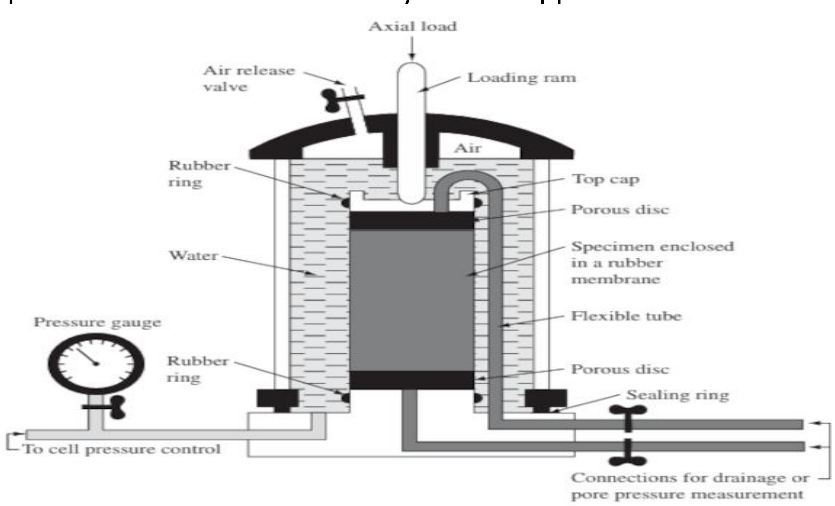
This type of failure is seen in loose and soft soil and at deeper elevations. The following are some characteristics of general shear failure.

4. This type of failure occurs in a soil of very high compressibility.
5. Failure pattern is not observed.
6. Bulging of soil around the footing is absent.
7. Failure is characterized by very large settlement.
8. Continuous settlement with no increase in P is observed in $p-\Delta$ curve.



Q2. Explain in details triaxial shear test of soil with neat sketch?

- The triaxial shear test is one of the most reliable and widely used laboratory tests to determine the shear strength parameters of soil — namely cohesion (c) and angle of internal friction (ϕ).
- It is more versatile and accurate than the direct shear test.
- The test equipment specially consists of a high pressure 'cylindrical cell, made of Perspex or other transparent material, fitted between the base and the top cap. Three outlet connections are generally provided through the base cell fluid inlet, pore water out let from the bottom of the specimen and the drainageoutlet from the top of the specimen.
- A separate compressor is used to apply fluid pressure in the cell. Pore pressure developed in the specimen during the test can be measured with the help of a separate pore pressure measuring equipment. The cylindrical specimen is enclosed in a rubber membrane. A stainless-steel piston running through the centre of the top cap applies the vertical compressive load (called the deviator stress) on the specimen under test.
- The load is applied through a proving ring. with the help of a mechanically operated load frame. Depending upon the drainage conditions of the test, solid nonporous discs or end caps, or porous discs are placed on be top and bottom of the specimen and the rubber membrane is sealed on to these end caps by rubber rings.
- The length of the specimen is kept about 2 to 2.5 times its diameter. The cell pressure σ_3 (=σ_2) acts all-round the specimen; it acts also on the top of the specimen as well as the vertical piston meant for applying the deviator stress.
- The vertical stress applied by the loading frame, through the proving ring is equal to ($\sigma_1 - \sigma_3$), so that the total stress on the top of the specimen = $(\sigma_1 - \sigma_3) + \sigma_3 = \sigma_1$ = major principal stress. This principal stress difference (σι – σ3) is called the deviator stress recorded on the proving ring dial. Another dial measures the vertical deformation of the sample during testing. It is desirable to maintain the cell pressure reservoir and mercury control apparatus.



- A particular confining pressure $\boldsymbol{\sigma}_3$ is applied during one observationgiving the value of the other stress $\boldsymbol{\sigma}_1$ at failure.
- A Mohr circle corresponding to this set of ($\sigma_{1,3}$) thus be plotted. Various sets of observations are taken for different confining pressure$\boldsymbol{\sigma}_3$ and the corresponding values of σ_1 are obtained.
- Thus, a number of Mohr circles. corresponding to failure conditions, are obtained. A curve, tangential to these strsss circles. gives the failure envelope for the soil under the given drainage conditions of the test.
- Shear tests can be performed in the triaxial apparatus under all the three drainage conditions. For undrained test, solid (nonporous) end caps are placed on the top and bottom of the specimen. In the consolidated-undrained test, porous discs are used. The specimen is allowed to consolidate under the desired confining pressure by keeping the pore water oultet open. When the consolidation is complete, the pore water outlet is closed, and the specimen is sheared under undrained conditions. The pore water pressure can be measured during the undrained part of the test. In the drained test, porous discs are used, and the pore water outlet is kept open throughout the test. The compression test is carried out sufficiently slowly to allow for the full drainage during the test.

Measurement of pore pressure during the test:

- It mainly consists of
    1) the null indicator,
    2) the control cylinder,
    3) pressure gauge,
    4) mercury manometer, and
    5) burette.
- The null indicator consisting of a single straight section of glass capillary tube dipping into an enclosed trough of mercury, connected to the trixial cell through valve a by a copper tube, and to the control cylinder etc. through valve k.
- An increase in pore pressure in the sample during the test will tend to depress the mercury in the limb of the null indicator.
- This can be immediately balanced by adjusting the piston in the control cylinder to increase the pressure in the limb by an equal amount which is registered in the pressure gauge. Valves m, f and j ire kept closed during the pore pressure measurements.
- In addition to the pressure gauge, mercury manometer is also provided. This is used (i) for negative pore pressure, (ii) for accurate measurement of low positive pore pressure, and (iii) for checking the zero error of the pressure gauge.
- When this manometer is connected through valves k and m, valves! and n are kept closed. The graduated tube or burette connected to the valve f is used for determining the gauge and manometer readings corresponding to zero pore pressure. In the case of fully saturated samples, this graduated tube can also be used to measure volume change during the consolidation stage of test in which drainage is permitted through the base of specimen.

UNIT VI: BEARING CAPACITY OF SOIL AND FOUNDATION

A. 02 MARKS QUESTIONS

Q1. **Define bearing capacity of soil?**

Answer: The load carrying capacity of foundation soil or rock which enables it to bear and transmit loads from a structure. It is usually expressed as:

qu=Ultimate bearing capacity

$q_{safe} = q_u / FOS$

where FOS= Factor Of safety

Q2. What are the types of bearing capacity?

Answer:

1. **Ultimate bearing capacity (q_e):** Maximum load intensity causing failure.

2. **Net ultimate bearing capacity (q_{nu}):** $q_{nu}=q_u-q$ (where *q* = overburden pressure at foundation base).
3. **Net safe bearing capacity (q_{ns}):** $q_{ns}= q_{nu}$ / F.O.S
4. **Gross safe bearing capacity (q_s):** $q_s = q_{ns} + q$

Q3. State Terzaghi's bearing capacity equation for a strip footing?

Answer:

For a **strip footing** (width B, depth D_f) on c–ϕ soil:

$$qu=cNc+qNq+0.5\gamma BN\gamma$$

where:

$q=\gamma D_f$ and Nc,Nq,Nγ are **bearing capacity factors** depending on ϕ.

Q4. What are the values of bearing capacity factors for ϕ = 0° (pure clay)?

Answer:

For ϕ=0°:

- Nc=5.7
- Nq=1.0
- Nγ=0

Hence,

$$qu=5.7c+\gamma D_f$$

Q5. **Define the term earth pressure?**

Ans. The soil that is kept in place at a slope that is steeper than it can support due to its shearing strength pulls on the retaining wall. The term "earth pressure" refers to this lateral force exerted by soil on a retaining structure is known as earth pressure.

Q6. **Classify the lateral earth pressure?**

Ans. The three categories of lateral earth pressure are:

i. At rest earth pressure. ii. Active earth pressure. iii. Passive earth pressure.

Q7. **What are the limitations of Rankine theory?**

Ans. Following are the limitations in Rankine theory:

i. The retained soil might not always be free of cohesiveness.

ii. The back of the wall isn't usually vertical.

iii. Because the wall's back is never smooth, friction forms.

Q8. **Give the factors affecting of coefficient of earth pressure?**

Ans. Coefficient of earth pressure depends upon:

i. The angle of back of soil,

ii. The soil wall friction value,

iii. The angle of backfill.

Q9. Define safe bearing capacity?

Ans. Ultimate bearing capacity divided by the factor of safety. The factor of safety in foundation may range from 2 to 5, depending upon the importance of the structure, and the soil profile at the site.

It is defined as the maximum intensity of loading which can be transmitted to the soil without the risk of shear failure, irrespective of the settlement that may occur.

Q10. Define allowable bearing pressure?

Ans. The maximum allowable net loading intensity on the soil at which the soil neither fails in shear nor undergoes excessive or intolerable settlement, detrimental to the structure.

B. <u>05 MARKS QUESTIONS</u>

Q1. Write down the assumptions made in theory of Terzaghi's analysis of bearing capacity?

Ans.

Assumptions of Terzaghi's bearing capacity theory:

1. Soil behaves like ideally plastic material.
2. Soil is homogeneous , isotropic and its shear strength is represented by Coloumb's equation.
3. The total load on footing is vertical and uniformly distributed.
4. The footing is long enough with $L/B = \infty$.
5. The shear strength above base of footing is neglected and taken as uniform surcharge γD_f.
6. The elastic zones developed has straight boundaries inclined at $\psi = \phi$.

Q2. Write down the factors affecting bearing capacity?

Ans.

The following are the factors which affect bearing capacity,

(i)Nature of soil and its physical and engineering properties;
(ii)Nature of the foundation and other details such as the size, shape , depth below the ground surface and rigidity of the structure
(iii)Total and differential settlements that the structure can withstand without functional failure
(iv)Location of the ground water table relative to the level of the foundation and
(v)Initial stresses, if any.

Q3. **Differentiate between active and passive earth pressure?**

Ans.

<table>
<tr><th colspan="2">Active Earth Pressure</th><th colspan="2">Passive Earth Pressure</th></tr>
<tr><td>1</td><td>The pressure exerted by backfill soil on retaining wall, is called as active earth pressure.</td><td>1</td><td>The pressure exerted by retaining wall on soil is known as passive earth pressure.</td></tr>
<tr><td>2</td><td>It is developed due to movement of wall away from backfill</td><td>2</td><td>It is developed due to movement of wall towards backfill.</td></tr>
<tr><td>3</td><td>Active earth pressure should be less for stability of retaining structures.</td><td>3</td><td>Passive earth pressure should be more to ensure stability of retaining structures.</td></tr>
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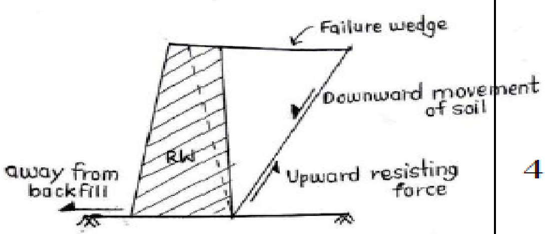


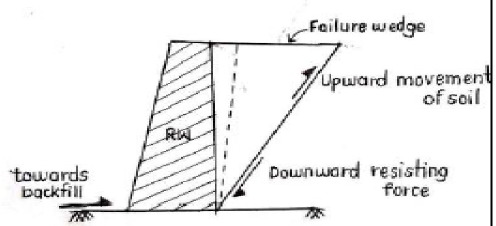
Fig : Active Earth Pressure</td><td>4</td><td>


Fig. : Passive Earth Pressure</td></tr>
</table>

Q4. **A continuous footing of width 2.5m rests 1.5m below the ground surface in clay. The unconfined compressive strength of the clay is 150kN/m^2. Calculate the ultimate bearing capacity of the footing. Assume unit weight of soil is 16kN/m^3.**

Ans.

Continuous footing $b = 2.5$ m $D_f = 1.5$ m

Pure clay.

$\phi = 0°$ $\quad q_u = 150$ kN/m^2 $\quad \gamma = 16$ kN/m^3

$$c = \frac{q_u}{2} = 75 \text{ kN/m}^2$$

For $\phi = 0°$, Terzaghi's factors are: $N_\gamma = 0$, $N_q = 1$, and $N_c = 5.7$.

$$q_{ult} = cN_c + \frac{1}{2}\gamma b N_\gamma + \gamma D_f N_q = cN_c + \gamma D_f N_q, \text{ in this case.}$$

$$\therefore \quad q_{ult} = 5.7 \times 75 + 16 + 1.5 \times 1 = 451.5 \text{ kN/m}^2 \approx \mathbf{450 \text{ kN/m}^2}.$$

Q5. What is the ultimate bearing capacity of a square footing resting on the surface of a saturated clay of unconfined compressive strength of 100kN/m^2?

Ans. For Square footing on Saturated clay, ϕ=0° & D_f=0.

Terzaghi's factors for $\phi = 0°$ are : $N_c = 5.7$, $N_q = 1$, and $N_\gamma = 0$.

$$q_u = 100 \text{ kN/m}^2$$

$$\therefore \quad c = \frac{1}{2} q_u = 50 \text{ kN/m}^2$$

$$q_{\text{ult}} = 1.3\, cN_c = 1.3 \times 50 \times 5.7 = 370 \text{ kN/m}^2$$

$$\therefore \quad q_{\text{ult}} = \mathbf{370 \text{ kN/m}^2}.$$

C. 10 MARKS QUESTIONS

Q1. A steam turbine with base 6m × 3.6m weighs 10,000kN. It is to be placed on a clay soil with C=135kN/m2. Find the size of the foundation required if the factor of safety is to be 3. The foundation is to be 60cm below ground surface?

Skempton's equation:

$$q_{\text{net ult}} = 5c\left(1 + 0.2\frac{b}{L}\right)\left(1 + 0.2\frac{D_f}{b}\right) \text{ for } D_f/b \le 2.5.$$

$$D_f = 0.6 \text{ m}$$

For $\phi = 0°$, $N_\gamma = 0$ and $N_q = 1$ Assume $\gamma = 18$ kN/m^3.

Adopt $b/L = 0.6$, same as that for the turbine base.

$$D_f/b = 0.6/b$$

Area,
$$A = bL = \frac{b^2}{0.6} = \left(\frac{5b^2}{3}\right) \text{ m}^2$$

$$\therefore \quad q_{\text{net ult}} = 5 \times 135\,(1 + 0.2 \times 0.6)\left(1 + \frac{0.2 \times 0.6}{b}\right) = 756\left(1 + \frac{0.12}{b}\right) \text{ kN/m}^2$$

$$q_{\text{safe}} = \frac{q_{\text{net ult}}}{\eta} + \gamma D_f = \left[\frac{756\left(1 + \frac{0.12}{b}\right)}{3} + 18 \times 0.6\right] \text{ kN/m}^2$$

$$Q_{\text{safe}} = q_{\text{safe}} \times A = \frac{5b^2}{3}\left[756\,\frac{\left(1 + \frac{0.12}{b}\right)}{3} + 10.8\right] \text{ kN}$$

Equating Q_{safe} to 10,000, we have

$$420\, b^2\left(1 + \frac{0.12}{b}\right) + 18\, b^2 = 10{,}000$$

Solving for b,

$b = 4.72$ m, say 4.80 m. ($D_f/b < 2.5$ is satisfied)

$L = 4.8/0.6 = 8.0$ m

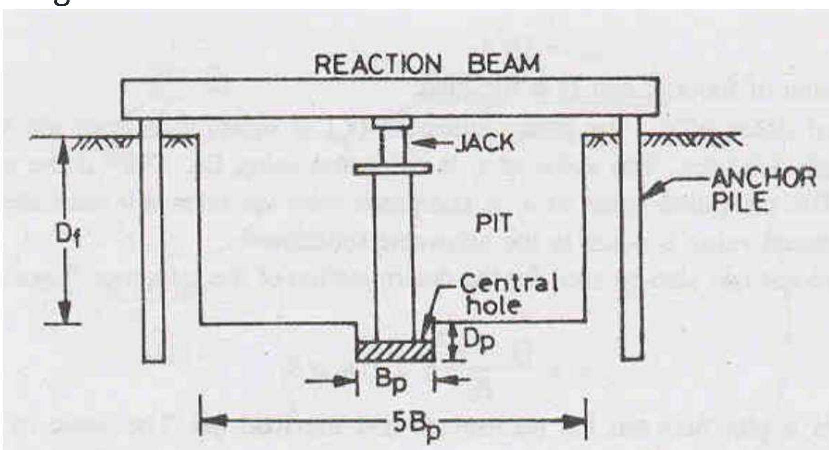
Hence, the size of the foundation required is **4.8 m × 8.0 m.**

Q2. Explain the procedure for determining the bearing capacity by conducting plate load test?

Ans.

Plate load test is done at site to determine the ultimate bearing capacity of soil and settlement of foundation under the loads for clayey and sandy soils. So, plate load test is helpful for the selection and design the foundation. To calculate safe bearing capacity suitable factor of safety is applied.

A pit is excavated in the ground at which foundation is to be laid. The size of pit is generally 5 times the size of the plate. The depth excavated should be equal to proposed foundation depth. The plate used is made of mild steel. It may be square (0.3m x 0.3m) or circular (0.3m diameter) with 25mm thickness. After excavation of pit, at center of excavated pit steel plate sized hole is excavated and the plate is arranged in it.



After arranging the plate in central hole hydraulic jack is arranged on top of plate to apply load. Reaction beam or reaction trusses is provided for the hydraulic jack to take up the reaction. Otherwise, a loaded platform is created (using sand bags etc.) on the top of hydraulic jack and provided the reaction. After that seating load is applied to set the plate and released after some time. Now load is applied with an increment of 20% of safe load. Dial gauges are arranged at bottom to record the settlement values.

At 1min, 5min, 10min, 20min, 40min, and 60min and after that for every one hour interval the settlement is observed and noted. The observations are made until the total
settlement of 25mm has occurred.

The load- settlement curve is plotted and from that bearing capacity is calculated.

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