1. Introduction

1.1. Soil and Soil Engineering

1.2. Scope of Soil Mechanics

1.3. Origin and formation of soil.

1.1. Soil and Soil Engineering

- The upper layer of the earth is called soil.
- The material which is called soil by the geologist is known as top soil in geotechnical energineering or soil engineering.
- The top soil contains a large quality of organic matter.
- The term 'soil' in soil engineering is defined as an unconsolidated material, composed of solid particles, produced by the disintegration of rocks.
- A natural aggregate of mineral particles bonded by strong and permanent cohesive force is called 'rock'.

Transportation of soil :-

① Water Transported soils :-

- Flowing water is one of the most important agents for transportation of soils.
- ... swift water can carry the particles of large

size such as boulders and gravels.

- All types of soil carried and deposited by water are called Alluvial deposits / soil.

② Wind Transported soil :-

- Soil deposited by wind is called Aeolian deposits / soil.
- The bearing capacity of such soil is very low.

③ Glacier - deposited soils :-

- Deposits directly made by melting of glaciers are called till.

④ Gravity deposited soil :-

- Alluvial soil → such as talus, have been deposited by the gravity.

⑤ Soil transported by combined Action :-

- Sometimes, two or more agents of transportation act jointly and transport the soil.

Scope of Soil Mechanics :-

- The term "Soil Mechanics" was coined by Dr. Karl Terzaghi
- According to Terzaghi "Soil Mechanics is the application of laws of mechanics and hydraulic to engineering problems dealing with sediments and other unconsolidated accumulation of solid particles produced by the mechanical and chemical disintegration.

- Geotechnical Engineering :- It is the branch of civil engg. concerned with the engineering behaviour of earth material like, analysis, design and construction of foundation etc.

1. Foundation design and construction :-

- Foundation is an important element of all civil engineering structures like buildings, bridge, Highway, tunnel, canal or dam etc.

- Therefore, necessary to know the bearing capacity of the soil, the pattern of stress distribution in the soil beneath the loaded area, the probable settlement of the foundation etc.

2. Pavement Design :-

- A Pavement can either be flexible or rigid, and its performance depends upon the sub-soil on which its resist.
- Pavement is a hard crust placed on the soil for the purpose of providing a smooth and strong surface on which vehicles can moves.

3. Design of under-ground structures and earth retaining structures:-

- The design and construction of under-ground and earth retaining structures constitute an important phase of engineering.

- Examples of underground structures are :- Tunnels, Pipe lines, under ground buildings, drainage structures etc.

→ Examples of earth retaining structures are :- Gravity retaining walls, anchored bulk heads and cofferdams.

4. Design of embankments and excavations :-

- When the surface of the soil structure is not horizontal, the components of gravity tends to move the soil downward, and may disturb the stability of the earth-structure.
- Deep excavations require lateral braces and sheet walls to prevent caving in.

5. Design of earth dam :-

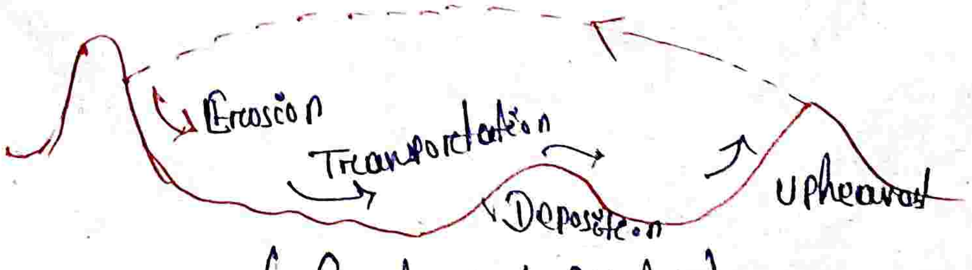
- The construction of an earth dam requires a very thorough knowledge of whole of the soil mechanics.

- Soil is used as the only construction material in an earth dam, which may either be homogeneous or of composite section.

- Physical properties of soil are :- Index properties such as density, plasticity characteristics and specific gravity etc.

1.3 Origin and formation of Soil :-

- Soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition.
- When a rock surface gets exposed to atmosphere for an appreciable time, it disintegrates or decomposes into small particles and thus the soils are formed.
- Soil may be considered as an incidental material obtained from the geologic cycle which goes on continously in nature.
- The geologic cycle consists of erosion, transportation, deposition and upheaval of soil.
- Exposed rocks are eroded and degraded by various physical and chemical process. The products are picked up by various agent and are carried to new locations where they are deposited.
- This shifting of the material disturbs the equilibrium of forces on the earth and causes large scale earth movements and upheavals. This process results in further exposure of rocks, and the geologic cycle gets repeated.
- If the soil stays at the place of its formation just above the parent rock, it is known as residual soil or sedentary soil.



(Geological Cycle)

Formation of Soils :-

- Soils are formed by either
  (A) Physical disintegration
  (B) Chemical decomposition.

(A) Physical disintegration :-

= Physical disintegration or mechanical weathering of rocks occures due to the following physical Process :-

1. Temperature changes.
2. Wedging action of Ice.
3. Spreading of roots of Plants.
4. Abrasion.

(B) Chemical Decomposition :-

The following Chemical Process are take Place :-

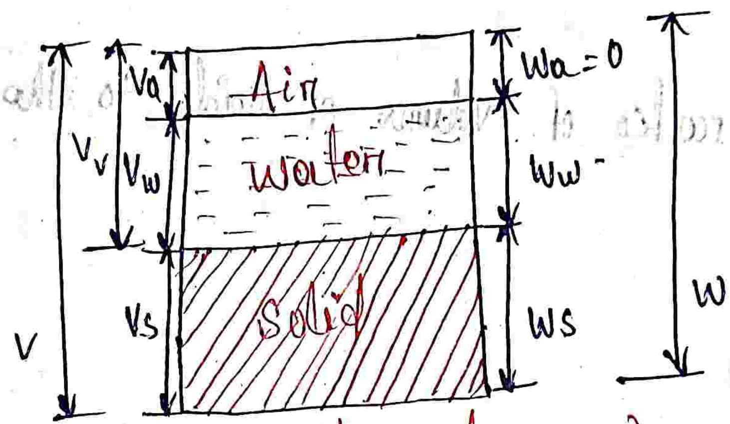
1. Hydration
2. Carbonation
3. Oxidation
4. Solution
5. Hydrolysis.

CH-2. [illegible] & Relationship

2.1 :- Soil as a three phase system.

2.2 :- Water content, Density, Specific gravity, void Ratio, Porosity, Percentages of Air voids, Air content, degree of saturation, density. Index, Bulk/saturated/submerged density, Inter-relationship of various soil parameters.

Soil as a Three Phase diagram :-

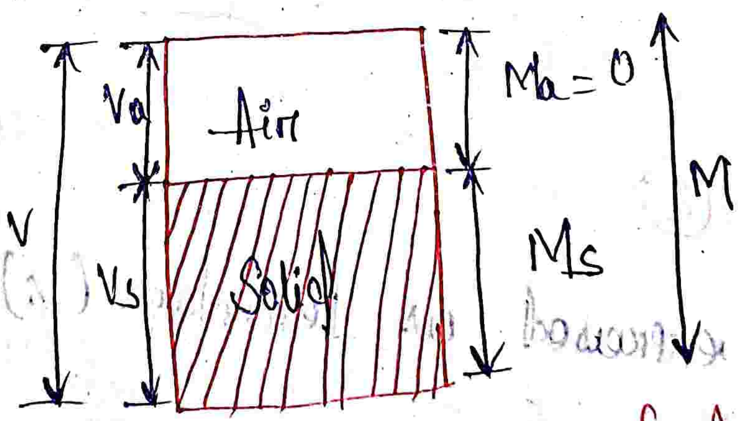


(Three Phase diagram)

V_a = Volume of Air
V_w = Volume of water
V_s = Volume of Solid
V = Total volume.
V_v = Volume of voids
W_a = weight of Air
W_w = weight of water
W_s = weight of Solid
W = Total weight.

Case-1

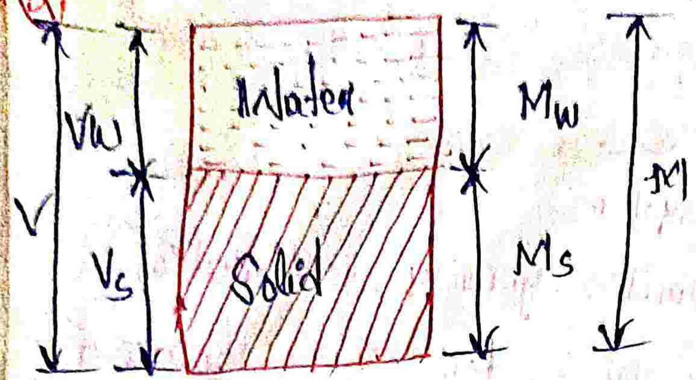
① when the soil is absolutely dry, the water phase disappers :-



V_a = Volume of Air
V_s = Volume of Solid.
M_s = Mass of Solid.
M_a = Mass of Air.
M = Total mass.

Two-Phase diagram of dry Soil.

(2)



Two phase diagram of (Saturated soil)

V_w = volume of water
V_s = Volume of Solid
V = Total volume
M_w = Mass of water
M_s = Mass of Solid
M = Total mass.

Volumetric Relations :-

(1) Void Ratio :- (e)

It is defined as the ratio of volume of voids to the volume of solids.

$$e = \frac{V_v}{V_s} \quad \text{--- (1)}$$

(2) Porosity :- (n)

- It is defined as the ratio of volume of voids to the total volume.

$$n = \frac{V_v}{V} \quad \text{--- (2)}$$

- Porosity is generally expressed as Percentage (%).

$$n = \frac{e}{1+e}, \quad e = \frac{n}{1-n}$$

③ Degree of Saturation :- (S)

- The degree of Saturation is the ratio of the volume of water to the volume of voids.

$$S = \frac{V_w}{V_v} \quad \text{— (3)}$$

- The degree of Saturation is generally expressed as a Percentage.

④ Percentage Air voids (n_a) :-

It is the ratio of the volume of air to the total volume.

$$n_a = \frac{V_a}{V} \quad \text{— (4)}$$

- Expressed as Percentage (%)

⑤ Air content :- (a_c)

- Air Content is defined as the ratio of the volume of air to the volume of voids.

$$a_c = \frac{V_a}{V_v} \quad \text{— (5)}$$

⑥ Water Content :- (w)

- The water content is defined as the ratio of the mass of water to the mass of Solids.

$$w = \frac{M_w}{M_s}$$ — Expressed as %.

Volume - Mass Relations :-

① Bulk - Mass Density (ρ) :-

- The bulk mass density is defined as the total mass per unit total volume.

$$\boxed{\rho = \frac{M}{V}} \quad \text{— ①}$$

- Also known as the wet mass density.
- Expressed in kg/m³, gm/ml or Mg/m³.

② Dry - mass Density - (ρ_d)

- The dry mass density (ρ_d) is defined as the mass of solids per unit total volume.

$$\boxed{\rho_d = \frac{M_s}{V}} \quad \text{— ②}$$

- Also known as dry density.

③ Saturated Mass Density :- (ρ_{sat})

- The saturated mass density is the bulk-mass density of the soil when it is fully saturated.

$$\boxed{\rho_{sat} = \frac{M_{sat}}{V}} \quad \text{— ③}$$

M_{sat} → Saturated.

- When the soil exists below water, it is in submerged condition.
- It is defined as the submerged mass per unit of total volume.

$$\rho' = \frac{M_{sub}}{V} \quad (4)$$

(M_{sub} → Submerged)

⑤ Mass - Density of solids :- (ρ_s)

- The mass density of solid is equals to ~~the~~ the ratio of the mass of solids to the volume of solid.

$$\rho_s = \frac{M_s}{V_s} \quad (5)$$

Volume - Weight Relationship :-

① Bulk - unit weight :- (γ)

- Bulk-unit weight (γ) is defined as the total weight per unit total ~~weight~~ volume

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

- Unit → N/m^3 or KN/m^3.

② Dry - unit weight :- (γ_d)

- It is defined as the weight of solids per unit total volume

$$\gamma_d = \frac{W_s}{V}$$

③ Saturated unit weight :- (γ_{sat})

- The saturated unit weight (γ_{sat}) is the bulk unit weight when the soil is fully saturated.

$$\gamma_{sat} = \frac{W_{sat}}{V} \quad \text{—(3)}$$

④ Sub-merged unit weight :- (γ')

- When the soil exists below water, it is in a submerged condition.
- It is defined as the submerged weight per unit of total volume.

$$\gamma' = \frac{W_{sub}}{V} \quad \text{—(4)}$$

⑤ Unit-weight of soil solids :- (γ_s)

- The unit weight of solids is equal to the ratio of the weight of solid to the volume of solids.

$$\gamma_s = \frac{W_s}{V_s} \quad \text{—(5)}$$

Inter-relation between Mass and unit weight

Specific Gravity :- (G)

- The specific Gravity of Solid Particles is defined as the ratio of the mass of a given volume of solids to the mass of an equal volume of water at 4°c.

$$G = \frac{\rho_s}{\rho_w} \quad \text{--- (1)}$$

- The mass density of water (ρ_w) at 4°c is 1 gm/ml
1000 Kg/m³

Relation Between the void ratio and the water content

- The relation between void ratio and water content :-

$$w = \frac{Se}{G}$$

where w = water content.
S = Degree of Saturation.
e = void ratio
G = Specific Gravity.

1. $S = \frac{V_w}{V_v}$

2. $\gamma = \frac{(G + Se)\,\gamma_w}{1+e}$

3. $\gamma_d = \frac{G\gamma_w}{1+e}$

4. $\gamma_{sat} = \frac{(G+e)\,\gamma_w}{1+e}$

5. $\gamma' = \frac{(G-1)}{1+e}\,\gamma_w$

* For a fully saturated soil,
S = 1.0.

Water contents CH

Index Properties of Soil

3.1 Water content

3.2 Specific Gravity

3.3 – Particle size distribution – Sieve Analysis, wet mechanical analysis, Particle size distribution Curve and its uses

3.4 – Consistency of soils, Atterberg's Limits, Plasticity Index, Consistency Index, Liquid Index.

Particle size distribution :–

1) Engineering Properties :–

The main engineering properties of soils are Permeability, compressibility and shear strength.

Permeability :– The facilities with which water can flow through soils.

Compressibility :–

– Compressibility is related with the deformations produced in soils when they are subjected to compressive loads.

Shear strength :–

– Shear strength of soil is its ability to resist shear stresses.

(2) Index Properties :-

- The Properties of soils which are not of Primary interest to the geotechnical engineering but which are indicative of the engineering properties are known as index Properties.

- Main index Properties of coarsed grained soils are Particle size and the relative density.

- For fine-grained soil, the main index Properties are Atterberg's limits and the consistency.

- Two categories :-
  1. Properties of individual Particles
  2. Properties of the soil mass.

Mechanical Analysis :-

- The mechanical analysis, also known as Particle size analysis, is a method of separation of soil into different fraction based on the particle size.

- It expressed quantitatively the Proportions, by mass of various sizes of Particles Present in a soil.

- The mechanical analysis is done in two stages :-
  1. Sieve Analysis
  2. Sedimentation Analysis / wet Analysis.

- Sieve analysis is meant for coarse (Particle size greater than 75 micron), which can easily pass through a set of sieves.

- The second analysis is used for fine grained soil (size smaller than 75 μ).

- Sedimentation Analysis is also known as wet Analysis.

- Particles size smaller than 0.2 micron cannot be determined by the sedimentation method. These can be determined by an electron micro-scope or by x-ray difraction techniques.

Sieve Analysis :-

- The soil is sieved through a set of sieve.
- Sieves are generally made of spun brass and phosphor bronz sieve cloth.
- Sieves of various sizes ranging from 80 mm to 75 microns are available.
- The diameter of the sieve is generally between 15 to 20 cm.
- The Sieve Analysis is done for Coarse-grained soils.
- The coarse grained soil is further devided into 2 types.
  1. Gravel fraction (size > 4.75 mm)
  2. Sand fraction (75 μ < size < 4.75 mm).

- A set of coarse sieve, consistency of the sieves of size 80mm, 40mm, 20mm, 10mm and 4.75mm is required for a gravel fraction.
- The 2nd set of sieve, consisting of the sieve size of 2mm, 1mm, 600μ, 425μ, 212μ, 150μ and 75μ is used for sieves minus 4.75mm fraction.

(a) Dry-sieve Analysis :-

- The larger the particle size, the greater is the quantity of soil required.
- This soil should be oven dry.
- It should not contains any lump. If necessary it should be pulverized.
- If the soil contain organic matter, it can be taken air-dry instead of oven dry.
- The sample is sieve through a 4.75mm sieve.
- Dry sieve analysis is suitable for cohesionless soil.

b) wet Sieve Analysis :-

- If the soil contains a substantial quantity of fine particles, a wet sieve analysis is required.
- All lumps are broken into individual particles.

- A representive Soil Sample in the required quantity is taken, using a riffler and dried in an oven.
- The dried Sample is taken in a tray and Soaked with water.
- If deflocculation is required, Sodium hexameta-phosphate, at the rate of 2gm. per lit. of water is added.
- The sample is stirred and left for a soaking period of at least 1 hr.
- The slurry is then Sieved through 4.75 mm IS sieve, and washed with a jet of water.
- The material retained on the sieve is the gravel fraction.
- It is dried in an oven, and sieved through set of Coarse Sieves. Coarse Sieves the size of Sieves are 2mm, 1mm,
- In fine sieves the size 600μ, 425μ, 212μ, 150μ, and 75μ.
- The material retained on each sieve is collected and weighted.

Stoke's law:-

- Stoke's law States that the force that retards a sphere moving through a viscous fluid is directly proportional to the velocity of the sphere, the radius of the sphere and the viscosity of the fluid.

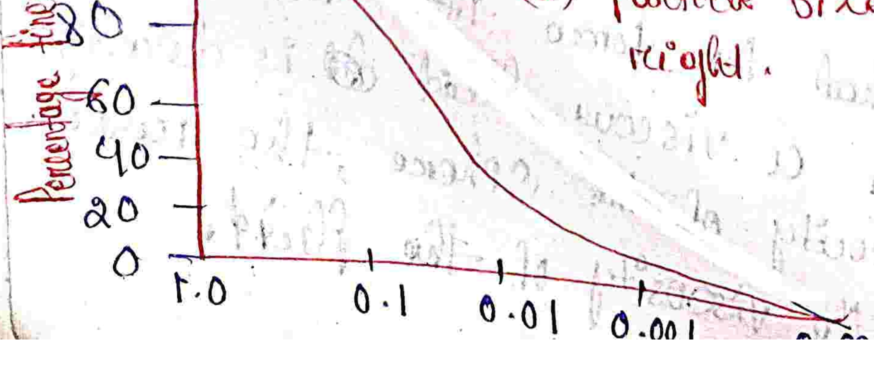
- Soil Particles finer than 75μ sieve cannot be sieved.
- The Particle size distribution of such soils is determined by Sedimentation Analysis.
- When a small sphere settles in a fluid, its velocity first increases under the action of gravity, but the drag force comes into action and retards the velocity.
- The drag force, F_D, experienced by a sphere of radius 'r', when it falls through a fluid of viscosity 'η' is given by

$$F_D = 6\pi\eta r V$$

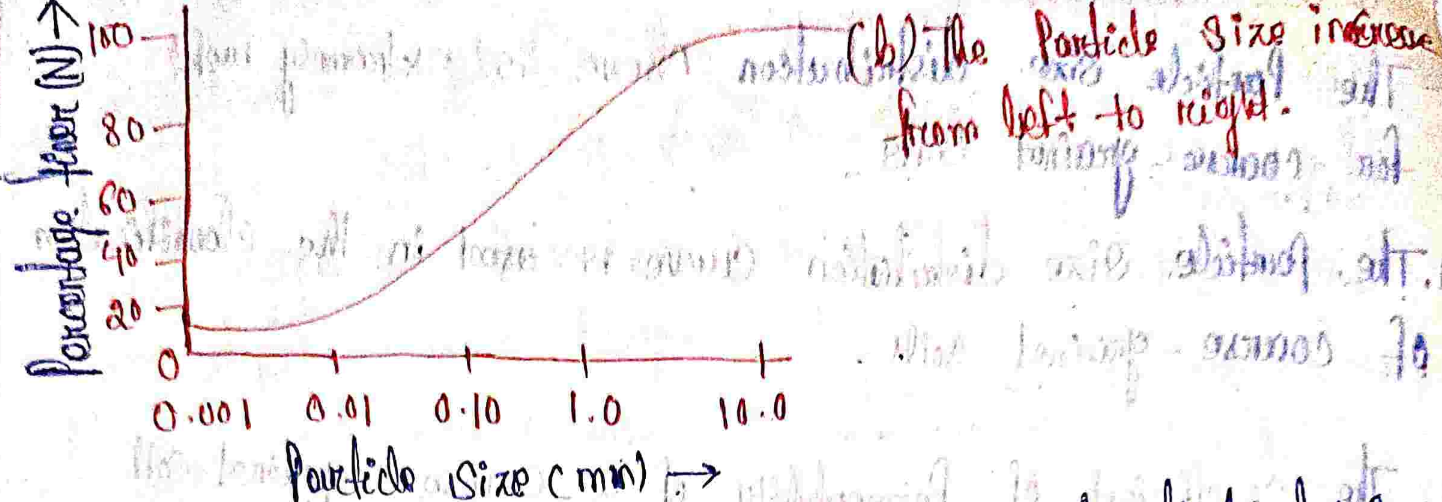
V = velocity.

Particle size distribution curve :-

- The particle size distribution curve, also known as a gradation curve, represents the distribution of particles of different sizes in the soil mass.
- The Percentage finer 'N' than a given size is plotted as ordinate and the particle size.



(a) Particle size decreases from left to right.



- The uniformity of a soil is expressed qualitatively by a term known as uniformity co-efficient "Cu".

$$C_u = \frac{D_{60}}{D_{10}}$$

where D_{60} = Particle size such that 60% of the soil is finer than this size

D_{10} = Particle size such that 10% of the soil is finer than this size.

Co-efficient of Curvature (Cc) :-

- The general shape of the particle size distribution curve is described by another co-efficient known as "Coefficient of Curvature" (Cc) :-

$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$$

where D_{30} is the particle size corresponding to 30% finer.

Use of Particle Size distribution Curve :-

- The Particle Size distribution curve is extremely useful for coarse-grained Soils.

1. The Particle Size distribution curve is used in the classification of coarse-grained soils.

2. The co-efficient of Permeability of a coarse-grained soil depends to a large extent on the Size of the Particle. ~~on discussed~~

3. The Particle Size is used to known the Susceptibility of a soil to frost action.

4. The Particle size distribution curve is required for the design of drainage filters.

5. The Particle Size distribution curve Provides an index to the Shear Strength of the Soil. Generally, a well-graded, compacted Sand has high shear strength.

6. The Particle size distribution curve is useful in soil stabilization and for the design of Pavements.

- The Particle Size distribution curve of a residual soil may indicate the age of the Soil deposit.

Relative Density :- (D_r / I_D)

- The most important index aggregate Property of a cohesionless soil is its relative density.
- The engineering properties of a mass of a cohesionless soil depend to a large extent on its relative density (D_r), also known as density index (I_D).

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100 \quad \text{—— (1)}$$

e_{max} = maximum void ratio of the soil in the loosest condition.

e_{min} = minimum void ratio of the soil in the densest condition.

e = void ratio in the natural state.

$$D_r = \frac{\rho_{max}}{\rho_d} \left(\frac{\rho_d - \rho_{min}}{\rho_{max} - \rho_{min}} \right) \quad \text{—— (2)}$$

Consistency Limits :-

- The Consistency of a fine - grained Soil is the Physic State in which it exists.
- Consistency of a soil indicated by such terms as s firm or hard.

Atterberg's Limit :-

- In 1911, a Swedish agriculture engineer Atterb mentioned that a fine - grained soil can exist in four States, namely liquid, Plastic, Semi- Solid or Solid - state. ~~The water Contents at which the~~
- The water contents at which the Soil changes fro one State to the other are Known as Consiste limits or Atterberg's limits.
- Thus Consistency limits are very important index Properties of fine - grained soils.

Liquid Limit :- (LL) (W_L)

- The water Content at which the Soil changes from the liquid State to the Plastic State is Known as liquid limit (LL)

Plastic Limit :- (PL) (W_P)

- The water Content at which the soil becomes Semi- Solid is known as the Plastic limit (PL)

The numerical difference between the liquid limit and Plastic limit is known as Plasticity index (PI, I_P)

$$PI = LL - PL$$ $$I_P = W_L - W_P$$

Shrinkage limit :- (SL, W_S)

- The water content at which the soil changes from the Semi-Solid state to the solid state is known as the Shrinkage limit. (SL, W_S)
- Below the shrinkage limit, the soil does not remain saturated.

or

- The lowest water content at which the soil is fully saturated.

Test :-

① Liquid Limit Test :-

- At the liquid limit, the clay is Practically like a liquid but possesses a small shearing strength.
- The shearing strength at that stage is the smallest value that can be measured in the laboratory.
- The liquid limit of soil depends upon the clay mineral present.
- The stronger the surface charge and the thinner the particle the greater will be the amount of adsorbed water, therefore the higher will be the liquid limit.

Limitation of Sedimentation Analysis :-

The analysis is based on the :-

- Soil Particles are Spherical, while in actual Practice the soil Particles are not spherical.
- Particles settle independ of others Particles and
- the neighbouring Particles don't have effect on its velocity of Settlement.
- The walls of the jar in which the suspension is kept also donot affect the settlement.

Consistency Index :- I_C

The consistency index or the relative consistency is defined as the ratio of the liquid limit minus the natural water content to the Plasticity index of the soil.

i.e. $$I_C = \frac{W_L - W}{I_P}$$ where (w = Natural water content of soil)

estimated by the following eqn:-

$$W_L = W_n \left(\frac{n}{25}\right)^e$$ n = no. of blows.

where W_n = water content of the soil when the groove closes in n below.

W_L = water content at liquid limit.

e = Index, the value varies from 0.068 - 0.121

- If 'n' is betⁿ 20-30 blows, Index 'c' can be taken as 0.1.
- However this method is used to get a rough value of liquid limit.
- The accepted ranges of 'n' is 15-35 → for soil with $w_L < 50\%$.

- Alternatively for no. of blow betⁿ 15-95, the liquid limit is computed by the formula.

$$w_L = \frac{w_n}{1.3213 - 0.23\log_{10} n}$$

or $w_L = C \cdot w_N$ where C = Correction factor.

Flow Index :-

Flow index is the slope of the flow curve and is given by :-

$$I_f = \frac{w_1 - w_2}{\log_{10} \frac{n_2}{n_1}}$$

- n_2 & n_1 corresponding to the no. of blows over one log-cycle difference.
- When the flow ~~index~~ curve is extended at either end so as to intersect the coordinates corresponding

at 10 & 100 blows gives directly the flow index.

One point Method the liquid limit

- It is determined by taking one reading of water content and its corresponding no. of blows.
- The liquid limit is then estimated from the following ~~equation~~ eqn :-

$$W_L = W_n \left(\frac{n}{25}\right)^e$$

where W_n = water content corresponding to n-number of blows.

W_L = water content at liquid limit.

e = index, the value of which varies from 0.068 to 0.121

Liquid Index :-

- The liquidity index is other-wise known as water plasticity ratio.
- It is expressed in percentage.
- It is defined as the ratio of natural water content of a soil minus its plastic limit to its plasticity index.

$$I_L = \frac{W - W_P}{I_P}$$

where W = Natural water content of the soil.

Toughness Index :- (I_T)

- Toughness Index is defined as the ratio of the plasticity index to the flow index.
- It is denoted by I_T.

i.e. $$I_T = \frac{I_P}{I_f}$$

(ii) Determination of Plastic limit by laboratory method :-

- Plastic limit is the water - content below which the soil stop behaving as a plastic material.
- For determination of plastic limit of a soil, 30gm of soil is taken in an evaporating dish which is air - dried and sieved through a 425 μ is sieve.
- It is then mixed throughly with distilled water till ~~of~~ it becomes plastic & can be easily moulded with fingures.
- About 10 g.m. of the plastic soil now is taken in one - hand and a ball is formed.
- The ball is then rolled with fingures on a glass plate to form a soil thread of uniform diameter.
- ~~Thread~~ The rate of rolling is kept about 80-90 strokes per minute.

Shrinkage Index (I_s)

The shrinkage index is the numerical difference between the liquid limit (w_L) and shrinkage limit (w_s)

$$\therefore I_s = w_L - w_s$$

Shrinkage Ratio:-

The shrinkage ratio (SR) is defined as the ratio of a given volume change expressed as a percentage of dry volume, to the corresponding change in water content.

i.e.

$$SR = \frac{\frac{V_1 - V_2}{V_d}}{w_1 - w_2} \times 100$$

where V_1 = Volume of soil mass at water content w_1

V_2 = Volume of soil mass at water content w_2

V_d = Volume of dry soil mass.

When 'V_2' is at the shrinkage limit:-

$$SR = \frac{\frac{V_1 - V_2}{V_d}}{w_1 - w_s} \times 100.$$

CH-4

Classification of Soil

4.1 → General

4.2 → I.S. Classification, Plasticity Chart.

4.1 → General

- The Purpose of soil classification is to arrange various types of soils into groups according to their engineering or agricultural properties and various others characteristics.

- For soil classification system to be useful for the geotechnical engineers, it should have the following basic requirements.

1) It should have a limited no. of groups.

2) It should be simple and should use the terms which are already understood.

3) It should be based on engineering properties which are most relevant for the purpose for which the classification has been made.

- The classification may be done with the objective of finding the suitability of the soil for construction of dams, highways or foundations.

- Soil may be classified by the following systems:—
  1. Particle size classification.
  2. Textural classification.
  3. High-way Research Board (HRB) classification
  4. United Soil classification and IS classification System.

1. Particle size classification:—

- In this system, soil are arranged according to the grain size.
- Other systems are:—
  (i) U.S. Bureau of Soil and Public Road Administration (PRA) system of United States.
  (ii) International Soil classification, Proposed at the International soil Congress at washington, D.C. in 1927.
  (iii) The M.I.T. classification Proposed by Prof. Gilboy.
  (iv) Indian Standard classification based on the M.I.T System.

(A) U.S. Bureau of Soils and PRA Classification

0.005 mm	0.05	0.10	0.25	0.50	1.0	2.00 mm	
Clay (Size)	Silt (Size)	V.F	Fine	Medium	Coarse	Fine Gravel	Gravel
		Sand					

(B) International Classification :—

	0.0002	0.0006	0.002	0.006	0.02	0.05	0.1	0.2	0.5	1.0	2.0 mm
Ultra clay	F	C	F	C	F	C	F	M	C	VC	Gravel
	Clay		Silt		MO (Majalo)		Sand				

(C) M.I.T Classification :— (Massachusetts Institute of Technology)

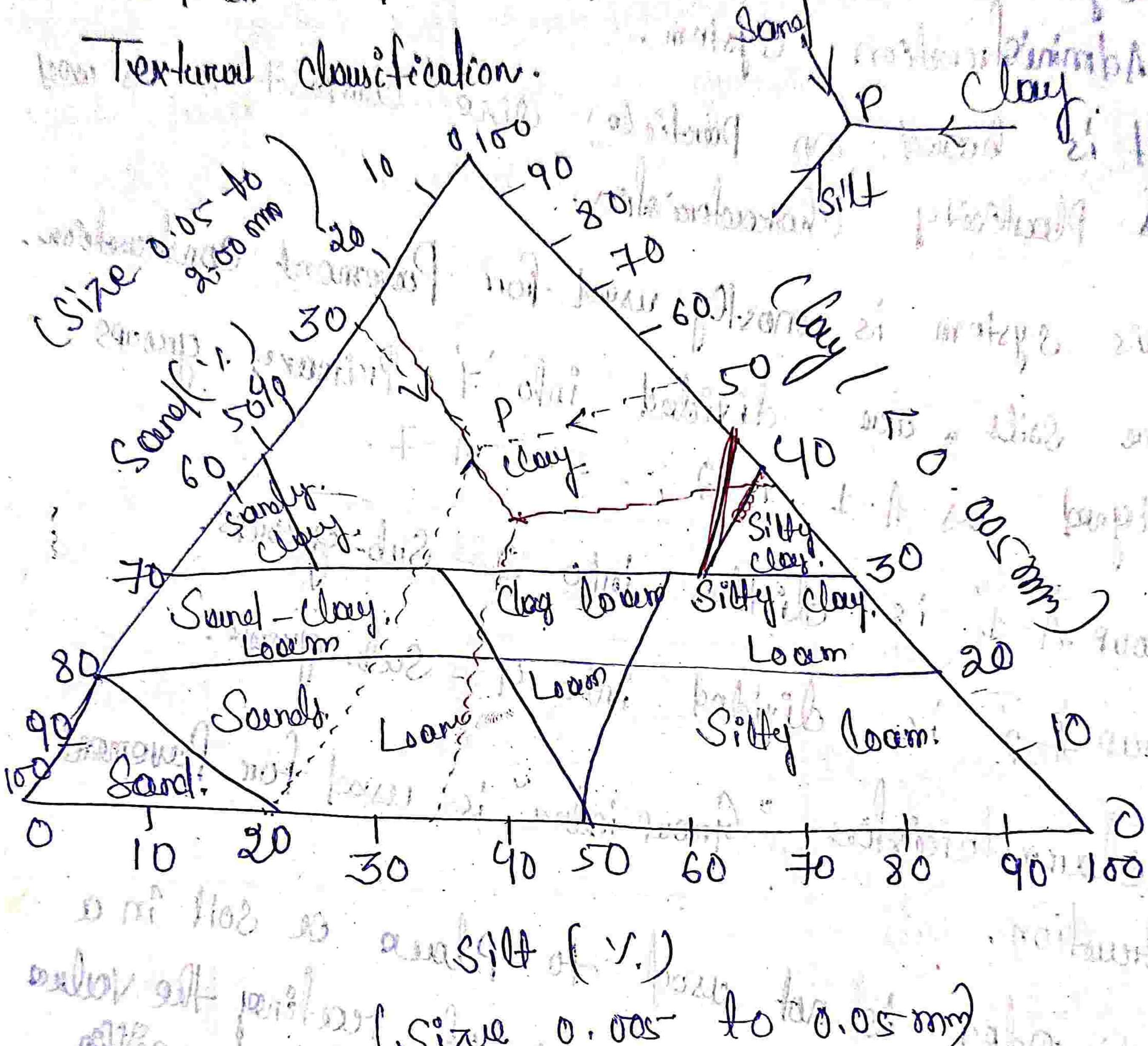
	0.0002	0.006	0.02	0.06	0.02	0.06	2.0 mm
Clay (Size)	Fine	Medium	Coarse	F	M	C	Gravel
	Silt (size)			Sand			

(D) I.S. Classification :—

	0.002 mm	0.075 mm	0.425 mm	2 mm	4.75 mm	20 mm	80 mm	300 mm
Clay	Silt	F	M	C	F	C	Cobble	Boulder
		Sand			Gravel			

② Textural classification

- Soil classification of composite soils exclusively based on the particle size distribution is known as Textural classification.



- Developed by US Public Roads administration.
- This classification is based on the percentage of sand, silt & clay size.
- More suitable for describing coarse grained soil.
- Clay soil properties are less dependent on Particle size distribution.

(8) High-way research Board classification (HRB):-

- The highway Research Board (HRB) classification system, is also known as Public Road Administration system.

- It is based on Particle size composition as well as Plasticity characteristics.

- This system is mostly used for Pavement Construction.

- Here soils, are divided into '7' - Primary groups designed as A-1, A-2, ... A-7.

- Group 'A-1' is divided into 2 - Sub-groups.

  Group 'A-2' is divided into 4 - Sub-groups.

- A characteristics "Group index" is used for Pavement Construction.

  Group index is not used to place a soil in a particular group, it is a means of rating the value of a soil as a sub-grade ~~of the~~ material within its own groups.

- The higher the value of the index, the poorer is the quality of the material.

4. ~~United - Soil classification and ... system~~

Unified Soil classification system

- As per unified soil classification system classification soils are classified into 4 - groups.
  - (i) Coarse grained
  - (ii) Fine grained
  - (iii) Organic soil.
  - (iv) Peat.

	Symbols	Description
Primary	G	Gravel
	Pt	Peat
	S	Sand
	M	Silt (symbol 'M' is obtained from Swedish word ...)
	C	clay.
	O	organic.
Secondary	W	well - graded
	P	Poorly graded
	M	Non - plastic fines
	C	Plastic fines
	L	Low plasticity
	H	High Plasticity.

- In this system, the soils are classified into 15-grou...
- The soils are first classified into two categories -
  1. Coarse - grained soils.
  2. Fine - grained soils.

① Coarse - grained soil :-

- The coarse-grained soils are designated as gravel (G), if 50% or more of coarse fraction is retained on 4.75 mm sieve.

- If the coarse-grained soils contain less than fines and are well-graded (W), they are given the symbol GW and SW, and if poorly graded, symbols GP and SP.

- If the coarse-grained soils contain more than 12% fines, these are designated as GM, GC, SM or SC.

- If the percentage of fines is between 5 to 12% dual symbols such as GW-GM, SP-SM are used.

② Fine - grained soils :-

- Fine - grained soils are further divided into two-types :- ① Soils of low compressibility (L), &

② soil of high compressibility (H).

① Soils of low compressibility (L), if the liquid limit is more than 50%. These are given the symbols ML, CL and OL.

② Soils of High compressibility (H), if the liquid limit is ~~more~~ less than 50%, these are given the symbols MH, CH and OH.

③ **Highly Organic Soils:-**

- Highly organic soils are identified by visual inspection. These soils are termed peat (Pt).

Indian Standard classification system:- (ISCS)

- Indian standard classification (ISC) adopted by Bureau of Indian Standards is in many respects similar to the unified soil classification (USC) sys

- ISC system classifies the soils into 18 groups.
- Soils are divided into three broad divisions.
  - (i) Coarse grain soils, when 50% or more of the total materials by weight is retained on 75 μ IS sieve.
  - (ii) Fine-grained soils, when more than 50% of the total material passes 75 μ IS sieve.
  - (iii) If the soil is highly organic and contains a large percentage of organic matter and particles of decomposed vegetation, it is kept in a separate category marked as peat (Pt).

1. Coarse grained Soils :-

- Coarse-grained soils are sub-divided into gravel and sand.
- The soil is termed gravel (G) when more than 50% of coarse fraction is retained on 4.75 mm IS sieve and termed sand (S) if more than 50% of the coarse fraction is smaller than 4.75 mm IS sieve.

2. Fine-grained Soils :-

- The fine-grained soils are further divided into three sub-divisions, depending upon the value of the liquid limit:

(a) Silts and clays of low compressibility → These soils have a liquid limit less than 35 → Represented by (L)

(b) Silts and clays of medium compressibility → These soils have a liquid limit greater than 35 but less than 50 & represented by (I)

(c) Silts and clays of High compressibility - These soils have a liquid limit greater than 50 and represented by (H)

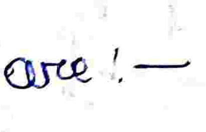
Clay Mineralogy :-

- Clay mineralogy is the Science dealing with the Structure of clay minerals on microscopic, molecular and atomic scale.
- It also includes the study of mineralogical composition and electrical Properties of the clay Particles.
- The study of clay minerals is important for Particles smaller than about 2 micron size.

Soil Structure :-

- Soil Structure is the geometrical arrangement of Soil Particles in a soil mass.
- It is concerned with Shape, Size and Orientation of Particles.
- The following types of soil Structure are :-
  - (i) Single grained Structure
  - (ii) Honey comb Structure
  - (iii) flocculated Structure
  - (iv) Dispersed Structure
  - (v) Coarse grained Skeleton
  - (vi) Cohesive matrix

(i) Single grained Structure :-



- An arrangement to form a Soil mass.
- Coarse - grained Soils having dia > 0.02mm are settled down in water due to the weight of the Soil Particles.
- They may be deposited in a loose state in having

high void Ratio ... void Ratio.

(ii) Honey Comb Structure :-

- An arrangement of Soil Particles having comparatively loose and stable structure resembling a honey comb is known as a honeycomb structure.

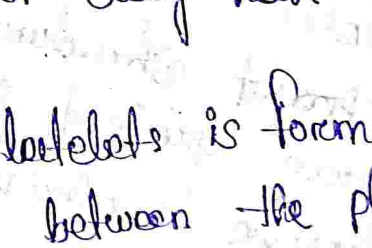
- The soil mass is composed of loosely arranged bundles of particles.
- Such a structure exists in grains of silts or rock flour, having diameter smaller than 0.02 mm and larger than 0.0002 mm.
- The structure is formed has high void ratio & is capable of carrying relatively heavy loads.

(iii) Flocculated Structure :-

- It is an arrangement of "flocs" of soil particles instead of individual soil particles.
- The particles are oriented edge-to-edge or edge-to-face with respect to one another.
- Generally very fine particles of clay have this kind of structure.
- Flocculated structure of clay platelets is formed when there are edge to edge contacts between the platelets.

(iv) Dispersed Structure :-

- An arrangement composed of particles having a face to face or parallel orientation.



Dispersed or oriented structure is formed when the net electrical forces between adjacent soil particles at the time of deposition are repulsion.

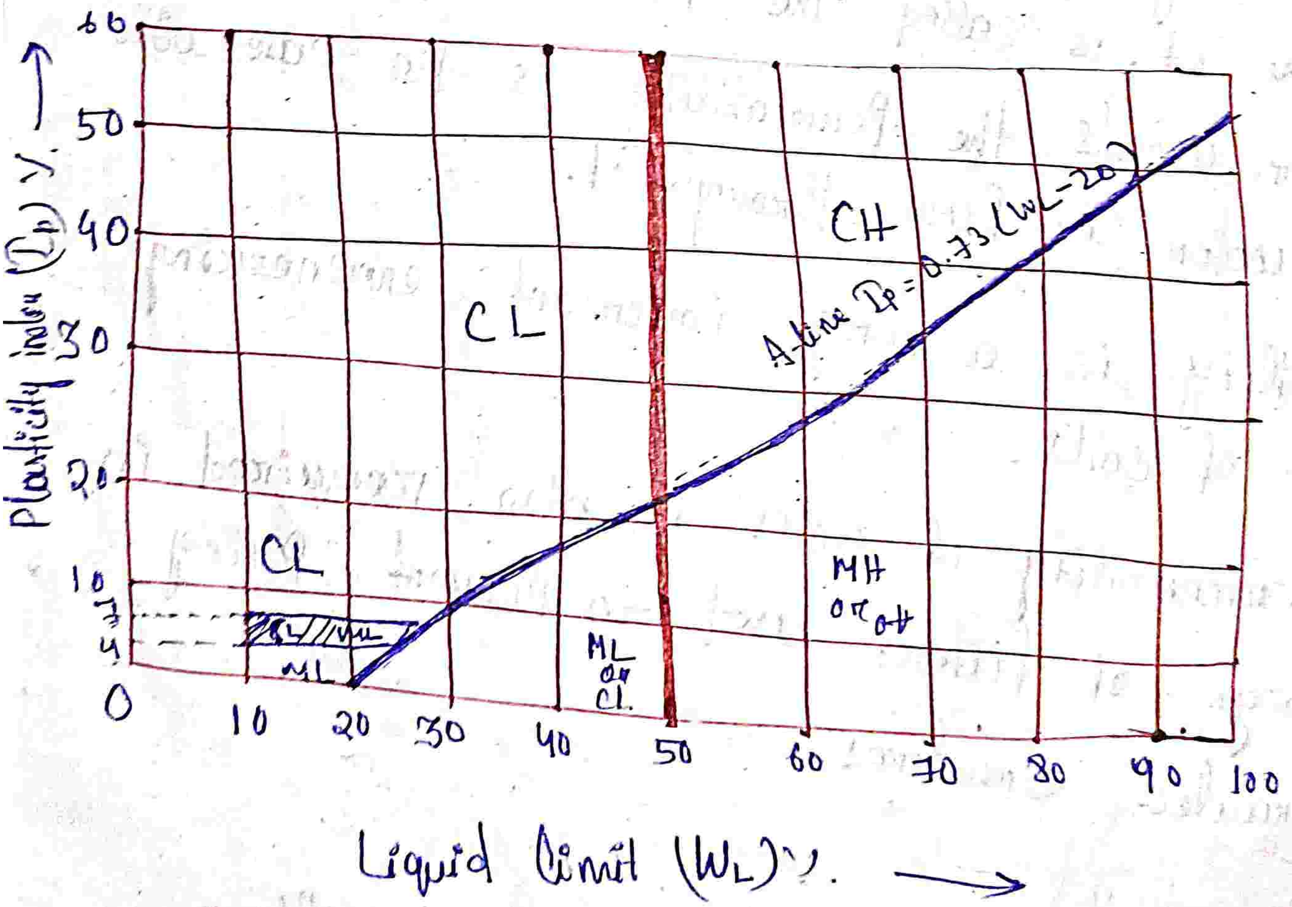
v) Coarse grained Skeleton:-

- An arrangement of coarse grains forming a skeleton with its intersections partly filled by a relatively loose aggregation of finest soil grains.

vi) Cohesive Matrix:-

- In this ~~matrix~~ arrangement, the particle to particle contact of coarse fraction is not possible as the coarse grains remain embedded in a large mass of cohesive fine grains.

Casagrande's Plasticity Chart:-



Ch-5 Permeability & Seepage

5.1 → Concept of Permeability, Darcy's law, Co-effic[ient] of Permeability.

5.2 – Factor affecting Permeability.

5.3 – Constant and falling head Permeability Test.

5.4 – Seepage Pressure, effective stress, Phenomenon of qu[ick] Sand.

Concept of Permeability :–

- The Property of a soil which Permits flow of wa[ter] through it, is called the Permeability.
- In other words, the Permeability is the ease with which water can flow through it.
- Permeability is a very important engineering Property of soils.
- The Permeability of soils is also required in the design of filters used to prevent Piping in hydraulic structures.

Hydraulic Head :–

- The velocity head is equal to $v^2/2g$
- The total head at '1' 'h' and that at point '3' is zero. The head 'h' is known as the hydrau[lic] head.

- It is equal to the difference in the elevations of water levels at the entry and exit points in a soil mass.
- It is equal to the loss of head through the soil.
- The hydraulic head is also known as the effective head.

$$i = h/L$$

where h = hydraulic head.
L = length of the soil specimen.

(ii) Darcy's Law :-

- The flow of free water through soil is governed by Darcy's law.
- In 1856, Darcy demonstrated experimentally that for laminar flow in a homogeneous soil.
- The velocity of flow (v) is given by

$$v = Ki$$

where K = Co-efficient of Permeability.
i = hydraulic Gradient.

- The velocity of flow is also known as the discharge velocity or the superficial velocity.

- The discharge 'q' is obtained by multiplying the velocity of flow (v) by the total cross-sectional area of soil (A) normal to the dirn of flow.

Thus,

$$q = VA = K.i.A.$$

- The Area 'A' includes both the solids and the voids.

Co-efficient of Permeability :— [L/T = LT⁻¹]

- The co-efficient of Permeability can be defined, If the hydraulic gradient is unity, the co-efficient of Permeability is equal to the velocity of flow.

- The co-efficient of Permeability is defined as the velocity of flow which would occur under unit hydraulic Gradient.

- It has the dimensions of velocity [L/T].

- It measured in mm/sec, cm/sec, m/sec, m/day.

- The co-efficient of Permeability depends upon the Particle size.

- According to USBR, the soils having the co-efficient of Permeability greater than 10^{-3} mm/sec.

- The soils with the co-efficient of Permeability between 10^{-5} to 10^{-3} mm/sec are designated as Semi-pervious.

Determination of co-efficient of Permeability:

- The co-efficient of permeability of a soil can be determi[ned] using the following methods:—

(a) Laboratory Methods:—

- The co-efficient of permeability of a soil sample can be determined by the following methods:—
  - (i) Constant-head permeability test.
  - (ii) Variable-head Permeability Test.
- The instruments used are known as Permeameters.

(b) Field method:—

- The co-efficient of permeability of a soil deposit insitu conditions can be determined by the following field methods:—
  - (i) Pumping-out tests.
  - (ii) Pumping-in tests.
- The Pumping-out tests influence a large area around the Pumping well, and give an overall value of the co-efficient of Permeability of the soil deposit.

(c) Indirect Methods :-

- The co-efficient of Permeability of the soil can be determined indirectly from the soil parameters by :-

(i) Computation from the particle size or its specific surface.

(ii) Computation from the consolidation test data.

- The first method is used if the particle size is known.
- The second method is used when the co-efficient of volume change has been determined from the consolidation test on the soil.

(d) Capilarity - Permeability Test :-

- The co-efficient of permeability of an unsaturated soil can be determined by the capillarity - Permeab[illegible] test.

Factor affecting Permeability of Soils

The following factors affect the Permeability of soils.

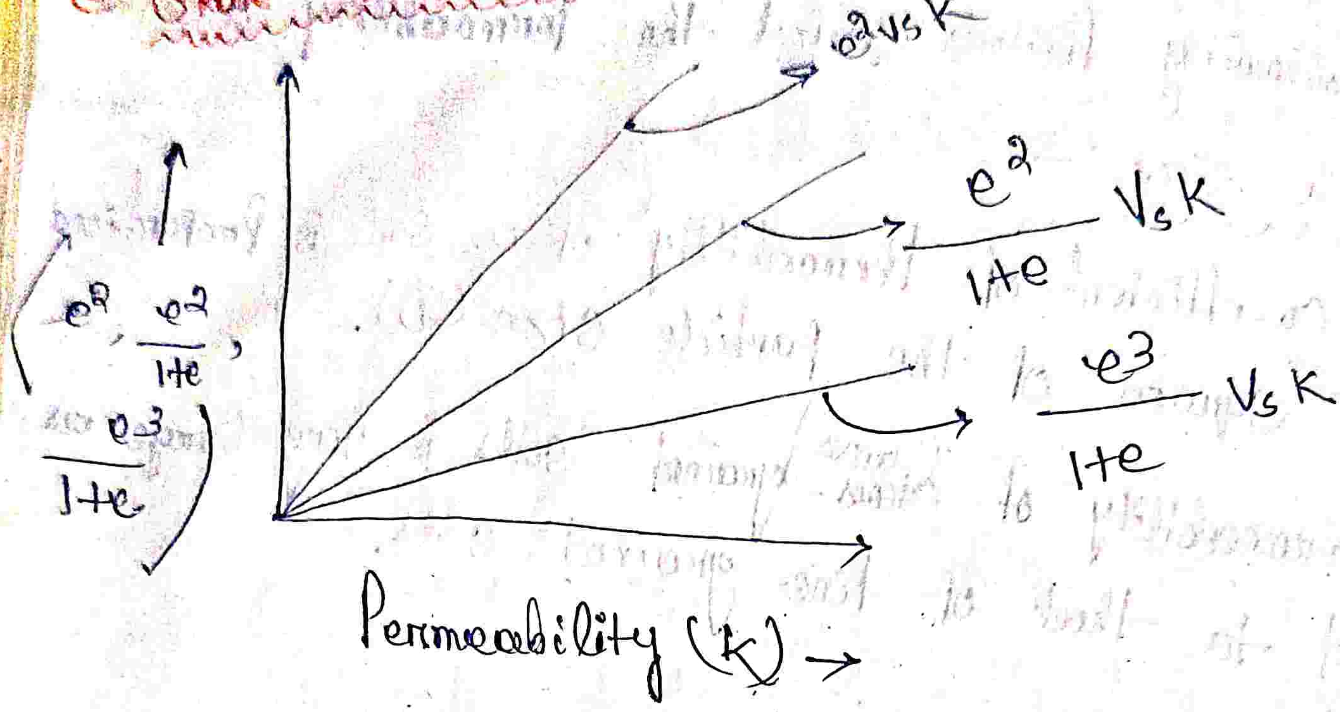
① Particle size :-

- The co-efficient of Permeability of a soil is Proportional to the square of the particle size (D).
- The Permeability of Coarsed-grained soils is very large as compared to that of fine-grained soils.

② Structure of soil mass :-

- The co-efficient 'c' in takes into account the shape of the flow passage.
- The size of the flow passage depends upon the structural arrangement.
- For the same void ratio, the Permeability is more in the case of flo-culated structure as compared to the case of in the dispersed structure.
- Permeability of a soil also depends upon shrinkage - cracks, joints, fissures and shear zones.
- Loess deposits have greater Permeability in the vertical direction than in the horizontal direction.
- The effect of disturbance is more pronounced in the case of fine-grained soils than in the case of Coarse - grained soils.

⑧ Shape of Particles :-



- The Permeability of a soil depends upon the Shape of particles.

- Angular Particles have greater Specific Surface area as compared with the rounded particles.

- For the same void Ratio, the Soils with angular Particles are less Permeable than those with rounded Particles, as the Permeability is inversely Proportional to the Specific Surface.

⑨ Void Ratio :-

- Co-efficient of Permeability varies as $\frac{e^3}{1+e}$

- For a given soil, the greater the void Ratio, the higher is the value of the co-efficient of Permeabili[ty]

- If the Permeability of a soil at a void Ratio of 0.85 Known, it value at another void ratio of 'e' can be determined using the following eqn given by Casagrande.

$$k = 1.4 k_{0.85} e^2$$

where $K_{0.85}$ = Permeability at a void Ratio of 0.85.

k = Permeability at a void ratio of 'e'.

⑤ **Properties of Water :-**

- The co-efficient of Permeability is directly Proportional to the unit weight of water (γ_w) and is inversly Proportional to its viscosity (μ).
- The co-efficient of Permeability increases with an increase in temp. due to reduction in the viscosity.
- For conversion of the Permeability to 27°C.

$$K_{27} = K_t \frac{\mu_t}{\mu_{27}}$$

where K_{27} = Co-efficient of Permeability at 27°C when viscosity is μ_{27}.

K_t = Co-efficient of Permeability of $t°C$ when viscosity is μ_t.

$$K_{27} = C_t K_t$$

C_t = The correction factor, equal to (μ_t / μ_{27}).

(6) Degree of Saturation :-

- If the soil is not fully saturated, it contains air pockets formed due to entrapped air or due to air liberated from percolating water.

- Permeability is reduced due to presence of air which causes blockage of passage.

- The permeability of a partially saturated soil is considerably smaller than that of a fully saturated soil.

- The permeability of a partially saturated soil is measured in the laboratory by the capillarity - permeability test.

(7) Adsorbed water :-

- The fine-grained soil have a layer of adsorbed water

- This adsorbed water layer is not free to move under gravity. It causes an obstruction to flow of water in the pores and hence reduces the permeability of soils.

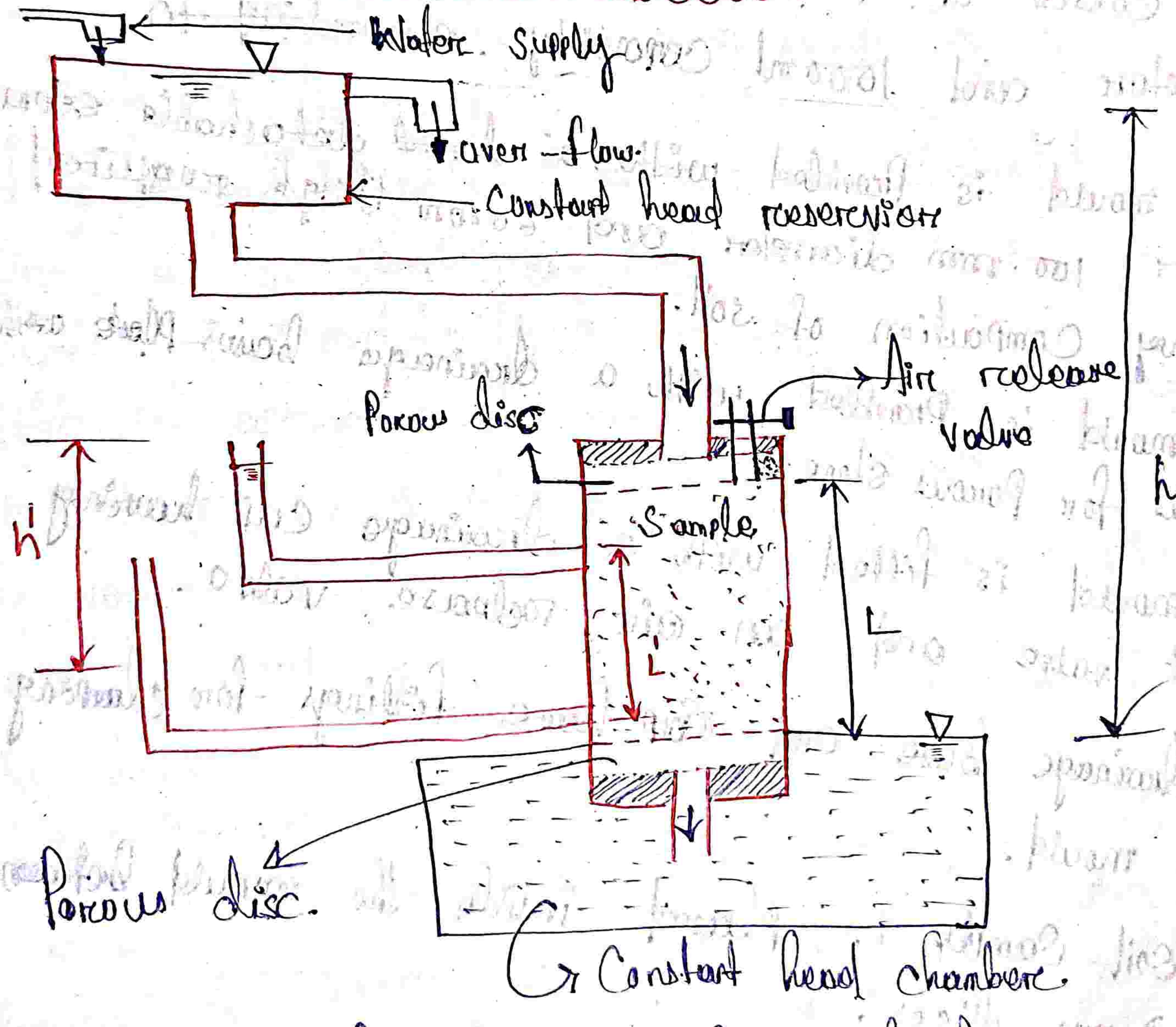
- The void ratio occupied by adsorbed water is about 0.10.

③ Impurities in Water :-

- Any foreign matter in water has a tendency to plug the flow passage and reduce the effective voids and hence the permeability of soils.

Constant & falling Head Permeability Test :-

(i) Constant - Head Permeability Test :-



(Constant Head Permeameter)

Seepage Pressure:-

Co-efficient of Permeability By Indirect Method

(1) Allen Hazen's formula:-

- Allen Hazen conducted a large no. of tests on filter sands of particle size betn 0.1mm and 3.0mm, having co-efficient of uniformity of less than 5, and gave the following relation;

$$k = C D_{10}^2$$

where k = co-efficient of Permeability (cm/sec)

D_{10} = effective size (cm).

C = Constant, with a value between 100 & 150

(2) Kozeny - Carman equation:-

- The co-efficient of the Permeability of a soil can be estimated using the Kozeny - Carman equation.

$$k = \frac{g \rho_w}{(C_s \mu s^2) T^2} \cdot \frac{e^3}{1+e}$$

where k = co-efficient of Permeability (cm/sec)

C_s = Shape factor, which can be taken as 2.5 for granular soils.

μ = Co-efficient of viscosity.

T = tortuosity, with a value of $\sqrt{2}$ for granular soils.

S = Surface area per unit volume of [illegible] (specific surface) (cm^2/cm^3)

ρ_w = mass density of water (gm/ml)

e = void ratio

g = 981 cm/sec²

Loudon's formula

According to Loudon's —

$$\log_{10}(KS^2) = a + bn$$

K = Co-efficient of Permeability (cm/sec).

S = Specific Surface

n = Porosity, expressed as ratio

a = Constant, with an average value of 1.365

at 10°C.

b = Constant, with an average value of 5.15 at 10°C

③ Consolidation Test data :—

The Co-efficient of permeability of fine-grained soils can be determined indirectly from the data obtained from a Consolidation test conducted on the sample.

It is given by

$$K = C_v \rho_w m_v = C_v \rho_w g\, m_v$$

Effective Stress Principle

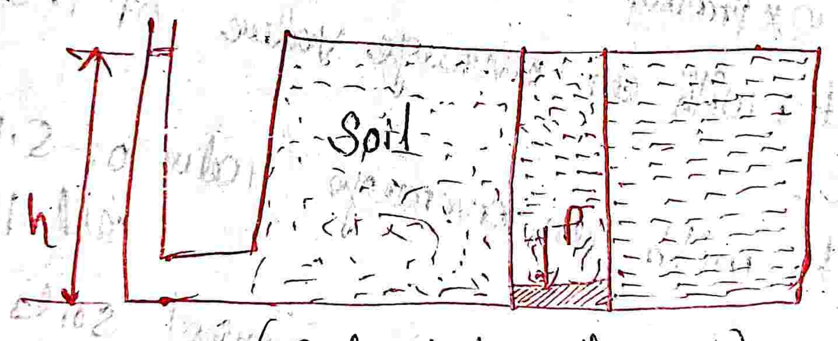
The effective stress Principle coined by Karl Terzaghi in 1936 forms an extremely useful basis of the most important theories in soil Engineering.

The effective stress Principle consist of two Parts:-

– The effective stress Principle

1. Definition of the effective stress.
2. Importance of the effective stress in engineering behaviour of soil.

(1) Definition of the effective stress:-



(Saturated soil mass)

Let us consider a Prism of soil with a cross-sectional area A. The weight 'P' of the soil in the Prism is given by:-

$$P = \gamma_{sat}\, h A \quad (1)$$

where γ_{sat} is the saturated weight of the soil and 'h' is the height of the prism.

- Total stress (σ) on the base of the prism is equal to the force per unit area.

Thus $\sigma = \frac{P}{A} = \gamma_{sat} h$

While dealing with stresses, it is more convenient to work in terms of unit weights rather than density

$\gamma = \rho . g$

where γ is in N/m^3 and ρ is in kg/m^3.

$g = 9.81\ cm/sec^2$

Thus, $\gamma_{sat} = \rho_{sat} \times g = 9.81\ \rho_{sat}$

Generally, the unit weights are expressed in KN/m^3

In that case, $\gamma_{sat} = \frac{\rho_{sat} \times g}{1000} = 9.81 \times 10^{-3} \rho_{sat}$.

(a) Importance of Effective stress :-

- The effective stress controls the engineering properties of soils.
- Compression & shear strength depends upon the effective stress.

Thus :-

Compression $= f(\bar{\sigma})$

Shear strength $= \varphi(\bar{\sigma})$

where f and φ represent some functions.

The hydrodynamic Pressure is due to hydraulic head 'h'.
The seepage force (J) acts on the Soil skeleton due to ~~both~~ flowing water through frictional drag.

$\therefore J = \gamma_w h A$

- The Seepage Pressure (P_s) is the seepage force Per unit Area.

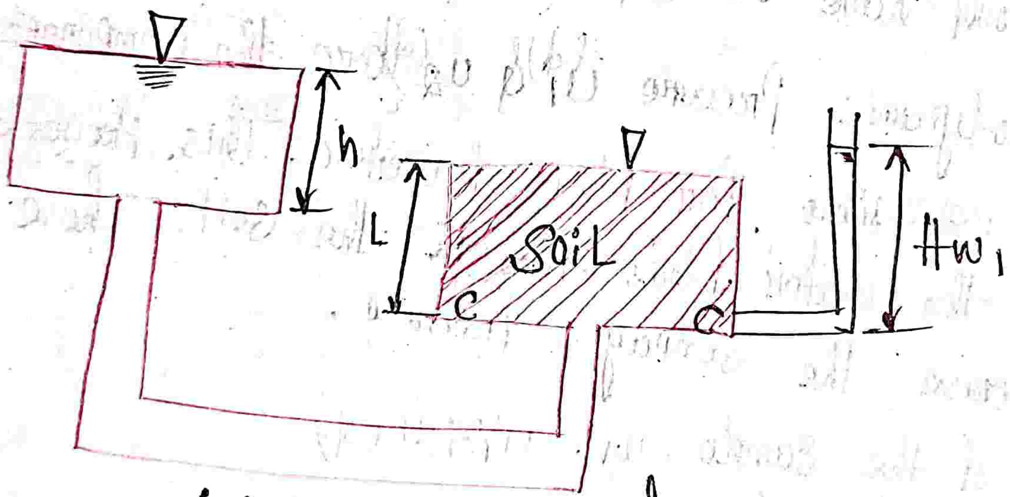
$$P_s = J/A = \gamma_w h$$

The seepage Pressure 'P_s' Can be expressed in terms of the hydraulic gradient.

$$P_s = \gamma_w h = \gamma_w \cdot (h/L) \cdot L$$

$$\boxed{P_s = i \gamma_w L}$$

Phenomenon of Quick Sand Condition :-



(Quick Sand condition)

- The effective stress is reduced due to upward flow of water.
- When the head causing upward flow is increased, a stage is eventually reached when the effective stress is reduced to zero. The condition so developed is known as Quick Sand condition.

- A soil specimen of length 'L' subjected to an upward pressure.

Let us consider the stresses developed at section C-C.

$$\sigma = \gamma_{sat} L = (\gamma' + \gamma_w) L$$

$$u = \gamma_w H_{w1} = \gamma_w (L + h)$$

$$\therefore \bar{\sigma} = (\gamma' + \gamma_w) L - \gamma_w (L + h)$$

$$\boxed{\bar{\sigma} = \gamma' L - \gamma_w h} \quad \text{--- (1)}$$

- The second term can be written in terms of the hydraulic gradient as under.

$$\gamma_w h = \gamma_w \cdot (h/L) \cdot L = \gamma_w \cdot i \cdot L$$

$$\boxed{\therefore \bar{\sigma} = \gamma' L - \gamma_w i L} \quad \text{--- (2)}$$

- The effective stress become zero, if $\gamma' L = \gamma_w i L$

$$\boxed{i = \gamma' / \gamma_w} \quad \text{--- (3)}$$

- The hydraulic gradient at which the effective stress become zero is known as the critical gradient (i_c).

Thus $$\boxed{i_c = \gamma' / \gamma_w} \quad \text{--- (4)}$$

- Substituting the value of the submerged unit weight in terms of void ratio in eqn :—

$$\boxed{i_c = \frac{G - 1}{1 + e}} \quad \text{--- (5)}$$

Compaction and Consolidation

Compaction → Compaction, light and heavy compaction Test. Optimum moisture content of soil, maximum dry density, zero air void line, factors affecting compaction. field compaction methods and their suitability

Consolidation → Consolidation, distinction between Compaction and consolidation. Terzaghi's model analogy of compression.

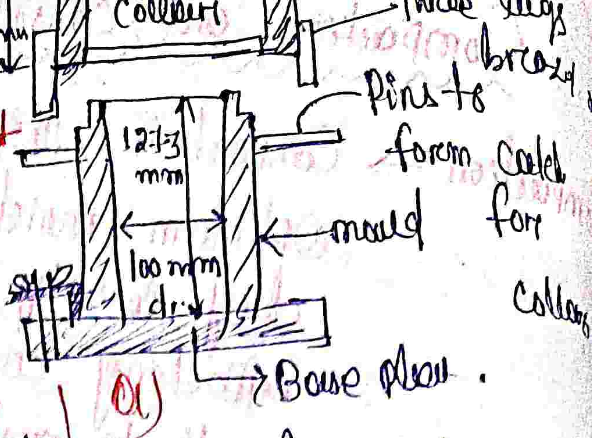
Compaction

- Compaction means Pressing the soil Particles close to each other by mechanical method.
- Compaction of a soil mass is done to improve its engineering Properties.
- Compaction generally increases the shear strength of the soil, and hence the stability and bearing capacity.
- It is also useful in reducing the compressibility and permeability of the soil.

- Compaction of soil is required for the construction of earth dams, canal embankments, highways, runways and in many other engineering applications.

Light and ...

Light Compaction Test:- or Standard Proctor Test

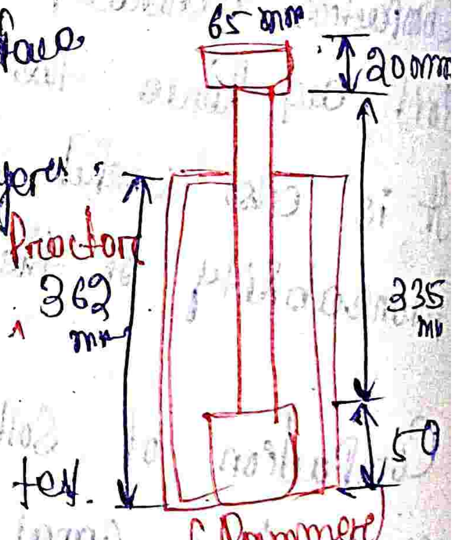


Apparatus:-

- Cylindrical metal mould
- Rammer
- The mould is fitted with detachable base plate and collar.

Procedure:-

- The empty mould is attached to the base plate and weighed.
- The collar is then attached to the mould at the top.
- The wet and matured soil is placed in the mould and compacted by giving 25 blows of rammer uniformly distributed over the surface
- The soil is compacted in 3 layers.



Heavy Compaction Test or modified Compaction Test:-

- Also known as modified compaction test.
- The modified Proctor Test was developed and standardised by AASHO to represent heavier compaction required for heavier transports.
- The calculation of dry density and maximum dry density is similar to that of Standard

- Proctor Test.
- The modified Proctor test was developed to represent heavier Compaction than that in the Standard Proctor Test.
- The test is used to simulate the field conditions where heavy rollers are used.
- This test was standardised by the American Association of State Highway Officials and is, therefore, also known as modified AASHO - Test.
- If the percentage of soil retained on a 4.75 mm sieve is more than 20%, the large mould of 150 mm internal diameter, effective height of 127.3 mm and capacity 2250 ml is used.
- In this case, 56 blows are required for each.
- The rest of the procedure is similar to that in the Standard Proctor Test.

Optimum moisture content of Soil :- (OMC)

- Optimum moisture content of a soil is the moisture content at which maximum dry density is achieved under a specific compaction effort.
  - * 20% for Standard Proctor Test.
  - * 15% for the modified Proctor Test.
- This relationship is typical for most soils where soil's optimum moisture content decreases as the compaction effort is increased.

Maximum Dry density :— (MDD)

— The dry density obtained by the Compaction of soils at its optimum moisture content.

- The maximum dry density and the optimum water content of the untreated Samples with Particles Smaller than 4.75mm were measured with the application of 596 KJ/m^3 energy.

- To get the maximum dry density and optimum moisture content, Standard Proctor's Compaction test was conducted.

Zero air voids line :—

- A line which shows the water content dry density relation for the compacted soil containing a constant percentage air voids is known as an air-voids line.

$$\rho_d = \frac{(1-n_a)\, G\, \rho_w}{1+wG}$$

where n = Per-cent air voids.

ρ_d = dry density corresponding to w

ρ_w = density of water = 1 g/cm^3

Factors affecting Compactions :-

(i) Water Content (ii) Amount of Compaction (iii) Types of Soil.
(iv) Method of Compaction (v) Admixture.

(i) Water Content :-

- At low water content, the soil is stiff and offers more resistance to compaction.
- As the water content is increased, the soil particles get lubricated.
- The dry density of the soil increases with an increase in the water content till the optimum water content is reached.
- At low water content, the forces of attraction in the adsorbed water layer are large, and there is more resistance to movements of the particles.

(ii) Amount of Compaction :-

- At a water content less than the optimum, the effect of increased compaction is more predominant.
- At a water content more than the optimum, the volume of air voids becomes almost constant and the effect of increased compaction is not significant.

iii) Types of Soil :-

- The dry density achieved depends upon the type of soil.
- Coarse-grained soils can be compacted to higher dry density than fine-grained soils.

- A well graded Sand attains a much higher dry density than a poorly graded soil.
- Cohesive soils have high air voids, These soils attain a relatively lower maximum dry density as compared with the cohesionless soils.

(iv) Method of Compaction :-

- The dry density achieved depends not only upon the amount of compactive effort but also on the method of compaction.
- For the same amount of compactive effort, the dry density will depend upon whether the method of compaction utilizes kneading action, dynamic action or static action
- Different methods of compaction give their own compaction curves.

(v) Admixtures :-

- The compaction characteristics of the soil are improved by adding other materials, known as admixtures.
- The most commonly used admixtures are lime, cement and bitumen. as discussed.
- The dry density achieved depends upon the type and amount of admixtures.

Consolidation

- When the soil mass is subjected to a compressive force, like all other materials, its volume decreases. The property of the soil due to which a decrease in volume occurs under compressive forces is known as the compressibility of soil.

- The compression of soils can occur due to one or more of the following causes:–
  (1) Compression of solid particles and water in the voids.
  (2) Compression and expulsion of air in the voids.
  (3) Expulsion of water in the voids.

- Consolidation is a process by which soils decrease its volume.

Initial consolidation

- When a load is applied to a partially saturated soil, a decrease in volume occurs due to expulsion and compression of air in the voids.

- A small decrease in volume of the soil just after the application of the load is known as initial consolidation or initial compression.

- For saturated soils, the initial consolidation is mainly due to compression of solid particles.

Primary Consolidation

- The decrease depends upon the Permeability of the soil and is, therefore, time dependent. This reduction in volume is called Primary Consolidation.

or

- When a load is applied to a Partially Saturated soil a decrease in volume occurs due to expulsion and compression of air in the voids. After initial consolidation, further reduction in volume of soil mass occurs due to expulsion of water from voids. This is known as Primary Consolidation.

Secondary Consolidation :-

- At the end of Primary Consolidation, Some Settlement is observed that is due to the plastic adjustment of soil fabrics. This stage of consolidation is called Secondary consolidation.
- The magnitude of the secondary consolidation can be calculated as :-

$$S_{cs} = \frac{C_a' h}{\log(t_a / t_1)}$$

where $C_a' = \frac{C_a}{1 + e_p}$

e_p = Void Ratio at the end of Primary Consolidation.

Terzaghi's Theory of One-Dimensional Consolidation

In 1923 Terzaghi gave the theory for the determination of the rate of consolidation of a saturated soil mass subjected to a static, steady load.

The theory is based on the following assumptions :—

Assumptions:

(1) The soil is homogeneous and isotropic.

(2) The soil is fully saturated.

(3) Soil particles and water are incompressible.

(4) The deformation of soil is due entirely to change in volume.

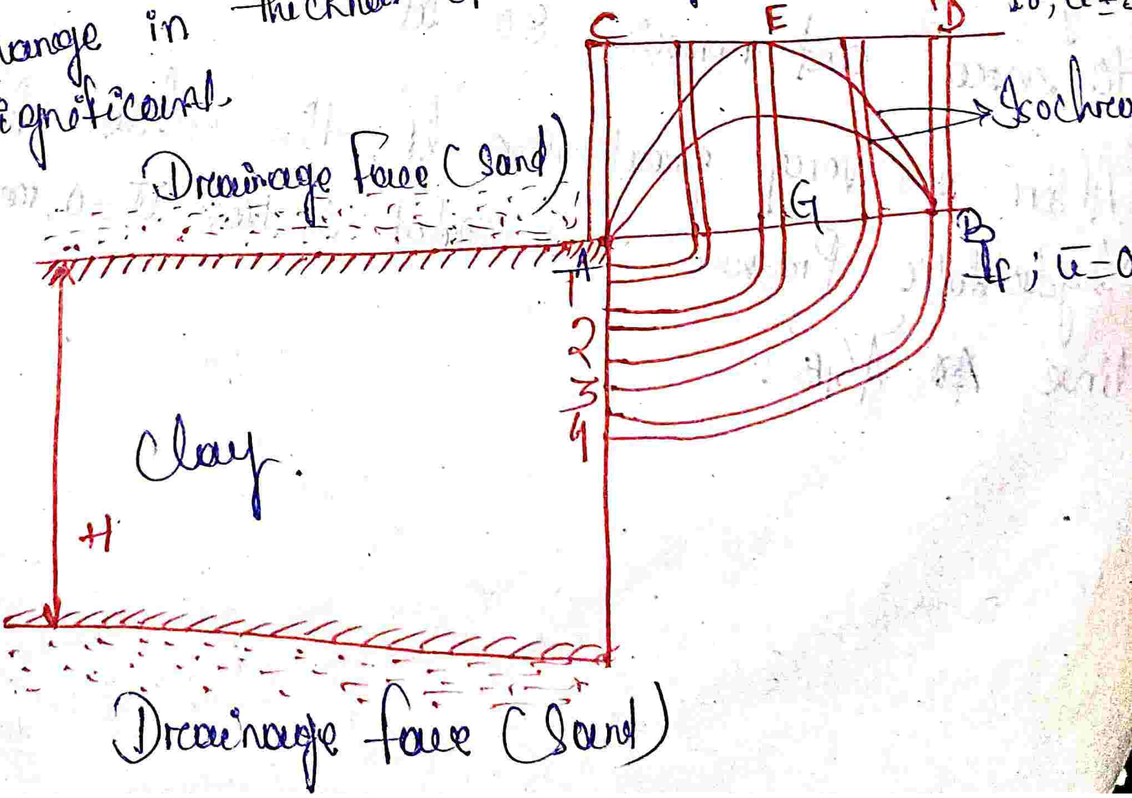
(5) Darcy's Law for the velocity of flow of water through soil is perfectly valid.

(6) Co-efficient of permeability is constant during consolidation.

(7) Load is applied in one direction only and deformation occurs only in the direction of the load application.

(8) The boundary is a free surface offering no resistance to the flow of water from the soil.

(9) The change in thickness of the layer during consolidation is insignificant.



- The above figure shows a clay layer, of thickness H, sandwiched between two layers of sand which serve as drainage faces.

- When the layer is subjected to a pressure increment $\Delta\sigma$, excess hydrostatic pressure is set up in the clay layer.

- At the time t_0, the instant of pressure application, whole of the consolidating pressure $\Delta\sigma$ is carried by the whole pore water so that the initial excess hydrostatic pressure is equals to $\Delta\sigma$, and is represented by a pressure distribution diagram straight line $\bar{u} = \Delta\sigma$ on the pressure distribution diagram.

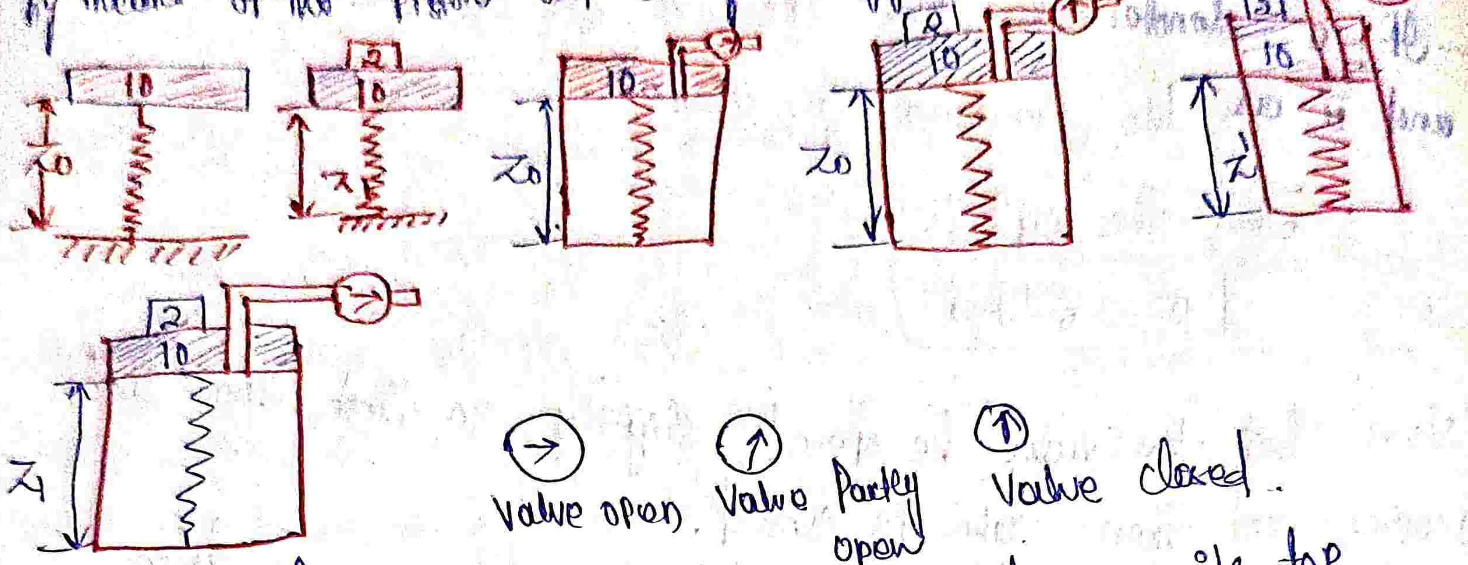
- The straight line CED joining the water levels in the piezometric tubes represent this distribution.

- As water starts escaping into the sand, the excess hydrostatic pressure at the pervious boundaries drops to zero and remains so at all times.

- After a very great time t_f, the whole of the excess hydrostatic pressure is dissipated so that $\bar{u} = 0$, represented by line ~~AB~~ A_1G_1B'.

Spring Analogy :-

- The mechanics of Consolidation was demonstrated by Terzaghi, by means of the Piston and Spring Analogy.



- The above fig. shows a Spring with a Piston on its top.
- Let the length of the Spring be 'z_0' under a Pressure of 10 units.
- If 12 units of Pressure are added to its top, the Spring will be Compressed immediately to a length 'z_1'.
- A Further application of load will result in further decrease in the length of the Spring.
- Within elastic limit, the load deflection curve may be assumed to be straight.
- If this Spring and Piston is Placed in a cylinder Containing water upto the bottom of the piston, and a valve at its bottom, water will be free of stress since the whole load is carried by the Spring alone.
- If the Pressure on the Piston is increased to 12 units, and the valve is closed, the Spring cannot deform since water is incompressible.

- Hence the additional Pressure of 2 units is entirely borne by water.
- If σ denotes the total Pressure, σ' the Pressure in spring and $\bar{u}$ as the Pressure in water

Then the eqⁿ is:-

$$\sigma = \sigma' + \bar{u}$$

- Now, let the valve be opened slightly so that some water escapes and then valve is closed.
- Due to escape of some water, the Piston moves down, the spring is compressed and hence some Pressure, out of Pressure of 2 units entirely borne by water, is now transferred to the spring.
- Thus, at any intermediate stage, the pressure eqⁿ becomes

$$12 = (10 + \Delta\sigma') + (2 - \Delta\sigma')$$

- where $\Delta\sigma'$ is the transfer of Pressure from water to the spring corresponding to a given amount of expulsion of water.
- If the valve is fully opened, sufficient water will escape till the length of spring is reduced to a height of z_1.
- Thus, the whole of 2 units of Pressure is transferred from water to spring, the water becomes free of Pressure and the spring carries

the whole of Pressure.

- The Pressure equation at this stage becomes

$$\sigma = \sigma' + \bar{u}$$

- When there is a Pressure increment, the whole of Pressure is first taken by water.

- As the water escapes out of the system, the load transfer takes place ~~to the~~ from water to the spring till the spring is deformed by the full amount corresponding to the applied stress increment.

Co-efficient of ~~Permeability~~ Consolidation :-

- Co-efficient of consolidation is the rate at which saturated soil undergoes consolidation.

- It can be only measured in laboratory.

- The co-efficient of consolidation C_v can be determined by comparing the characteristics of the theoretical relation between T_v and U.

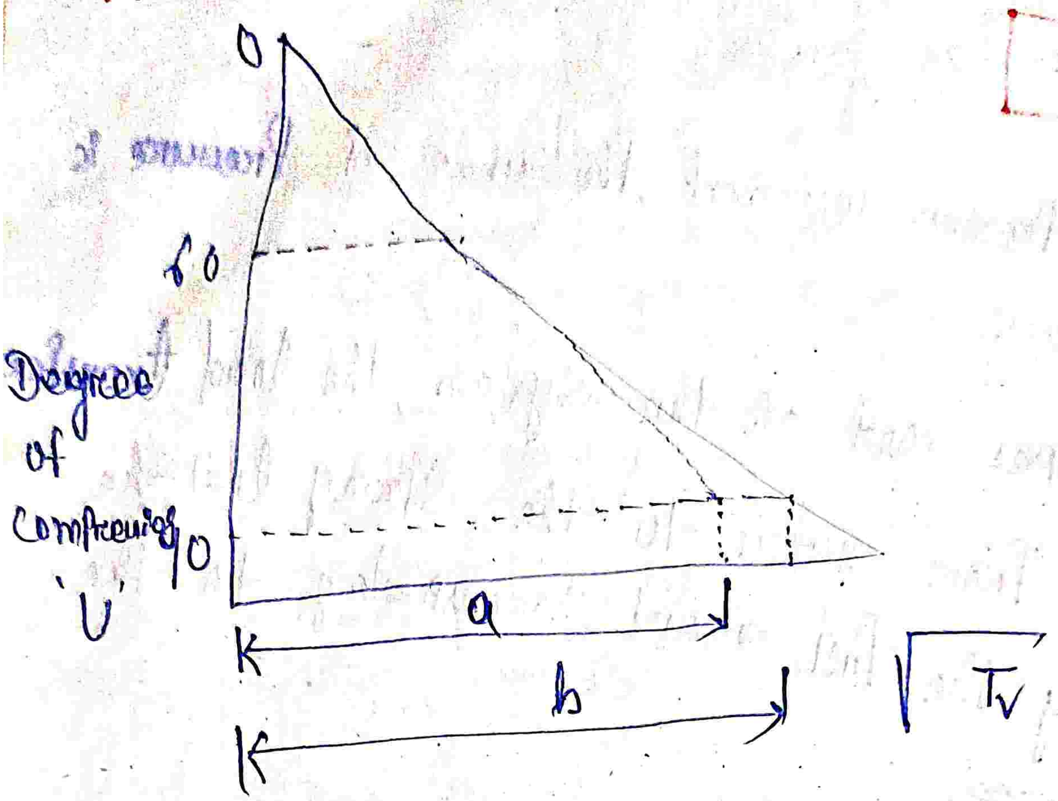
Determination of co-efficient of consolidation :-

There are two method for determination of co-efficient of consolidation ? -

(i) Square root ~~method~~ ~~of~~ of time fitting method.

(ii) Logarithm of time fitting method.

① Square root of time fitting method :-



T_v = Time factor

U = degree of Consolidation

The above fig. shows a theoretical characteristic curve between $\sqrt{T_v}$ and U.

CH-7 Shear Strength

7.1 Concept of Shear Strength, Mohr - Coulomb failure theory, Cohesion, Angle of internal friction, Strength envelope for different types of soil, Measurement of Shear Strength - Direct shear Test, Tri-axial Test, unconfined compression test and vane-shear Test

Concept of Shear Strength

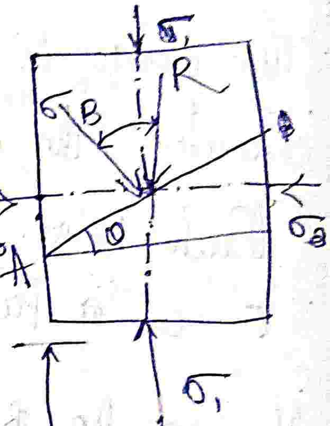
- The shear strength of a soil is its maximum resistance to shear stresses just before the failure.
- Shear strength is the principle engineering property which controls the stability of a soil mass under loads.
- It governs the bearing capacity of soils, the stability of slopes in soils, the earth pressure against retaining structures.
- There are three planes on which the shear stresses are zero. These planes are are known as principal planes.
- The plane with the maximum compressive stress (σ_1) is called the major principal plane, and that with the minimum compressive stress (σ_3) as the minor principal plane.
- The third principal plane is subjected to a stress which has the value intermediate betn σ_1 & σ_3, and is known as the intermediate principal plane.

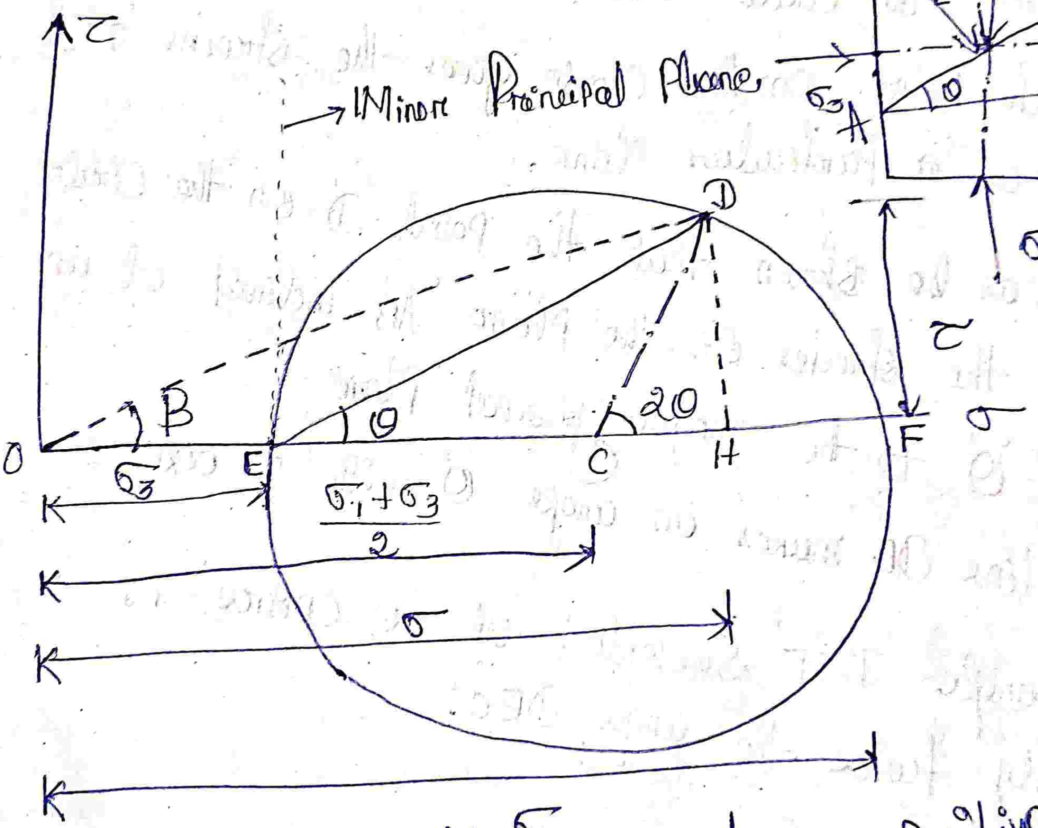
~~Mohr Coulomb failure~~

Mohr's Circle

- Otto Mohr, a German scientist, devised a graphical method for the determination of stresses on a plane inclined to the principal planes. The graphical construction is known as Mohr's circle and is extremely useful.

- In this method, an origin 'O' is selected and the normal stresses are plotted along horizontal axis and the shear stresses on the vertical axis.





- As the compressive stress are taken positive, in the soil engineering, these are plotted towards the right of the origin, i.e. along positive x-axis.

- The shear stress is generally taken as positive if it causes a counterclockwise couple at a point inside the wedge ABC. Thus the shear stress marked on the on the plane 'AB' is positive.

- The positive shear stresses are plotted upward from origin, i.e. along positive y-axis.

- In the above fig., the point 'E' represents the minor principal stress σ_3 and the point 'F', the major principal stress σ_1.

- The point 'C' is the middle point with the normal stress co-ordinate equal to $(\sigma_1 + \sigma_3)/2$.

- The circle is drawn with 'C' as the centre and EF diameter. The circle is known as Mohr's circle.

- Each point on the circle gives the stresses 'σ' & 'τ' on a particular plane.

- It can be shown that the point 'D' on the circle gives the stresses on the plane 'AB' inclined at an angle 'θ' to the major principal plane.

- The line 'DE' makes an angle 'θ' with σ-axis.

- The angle 'DCF' subtended at the centre is obviously twice the angle DEC.

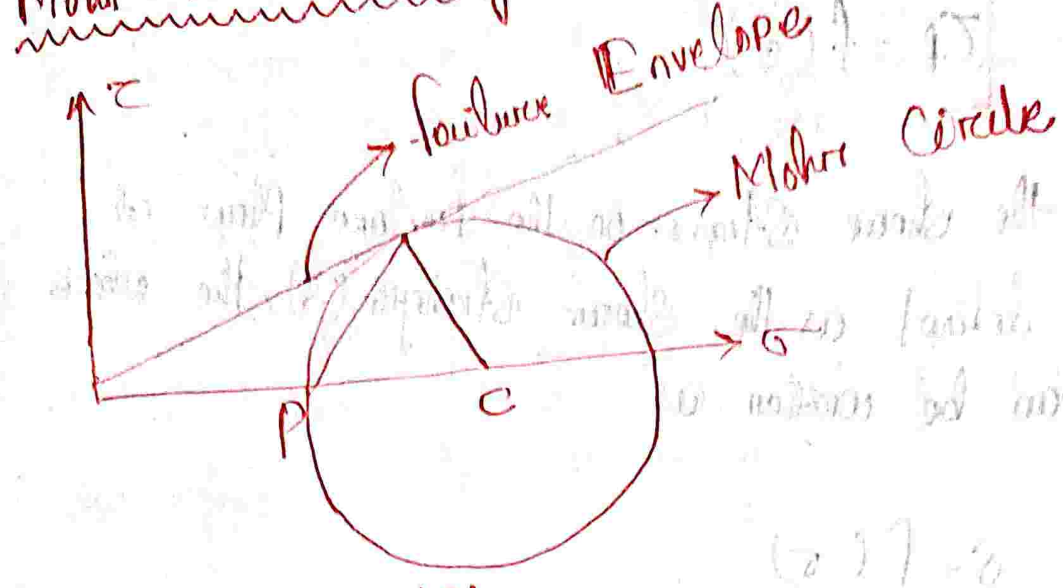
From the fig:-

$$OH = OC + CH$$

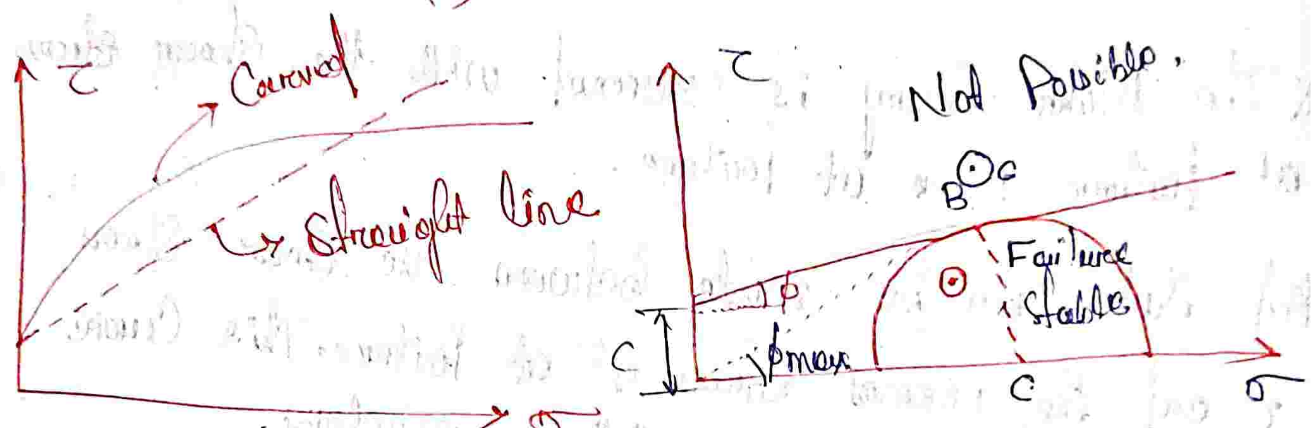
$$\Rightarrow OH = \frac{\sigma_1 + \sigma_3}{2} + \frac{(\sigma_1 - \sigma_3)}{2} \cos 2\theta = \sigma$$

$$\Rightarrow DH = CD \sin 2\theta = \frac{\sigma_1 - \sigma_3}{2} \sin 2\theta = \tau$$

Mohr - Coulomb Theory



(a)



(failure Envelope)

- The soil is a Particulate material.
- The shear failure occurs in soils by slipage of Particles due to shear stresses.
- The failure is essentially by shear, but shear stresses at failure depend upon the normal stresses on the Potential failure plane.

- According to Mohr, the failure is caused by a critical combination of the normal and shear stresses.
- The soil fails when the shear stress ($τ_f$) on the failure plane at failure is a unique function of the

Limitations:

(1) It neglects the effect of the intermediate principal stress (σ_2).

(2) It approximates the curved failure envelope by a straight line, which may not give correct results.

(3) When the Mohr failure envelope is curved, the actual obliquity of the failure plane is slightly smaller than the maximum obliquity. Therefore, the angle of the failure plane, as found, is not correct.

(4) For some clayey soils, there is no fixed relation between the normal and shear stresses on the plane of failure. The theory cannot be used for such soils.

Different Types of Tests and Drainage Conditions

(1) Direct Shear Test.

(2) Triaxial Compression Test.

(3) Unconfined Compression Test

(4) Shear Vane Test.

(1) Unconsolidated - Undrained Condition :-

- In this type of Test, no drainage is Permitted d… the Consolidate in the first Stage. The drainage i… Permitted until the consolidation is Complete.

- ~~In the second stage when the specimen is sh… no drainage is Permitted.~~

- As no time is allowed for consolidation or dissipation of excess Pore-water Pressure, the test can be Conducted quickly in a few minutes. The … is known as unconsolidated - undrained Test or quick Test.

(2) Consolidated - Undrained Condition :-

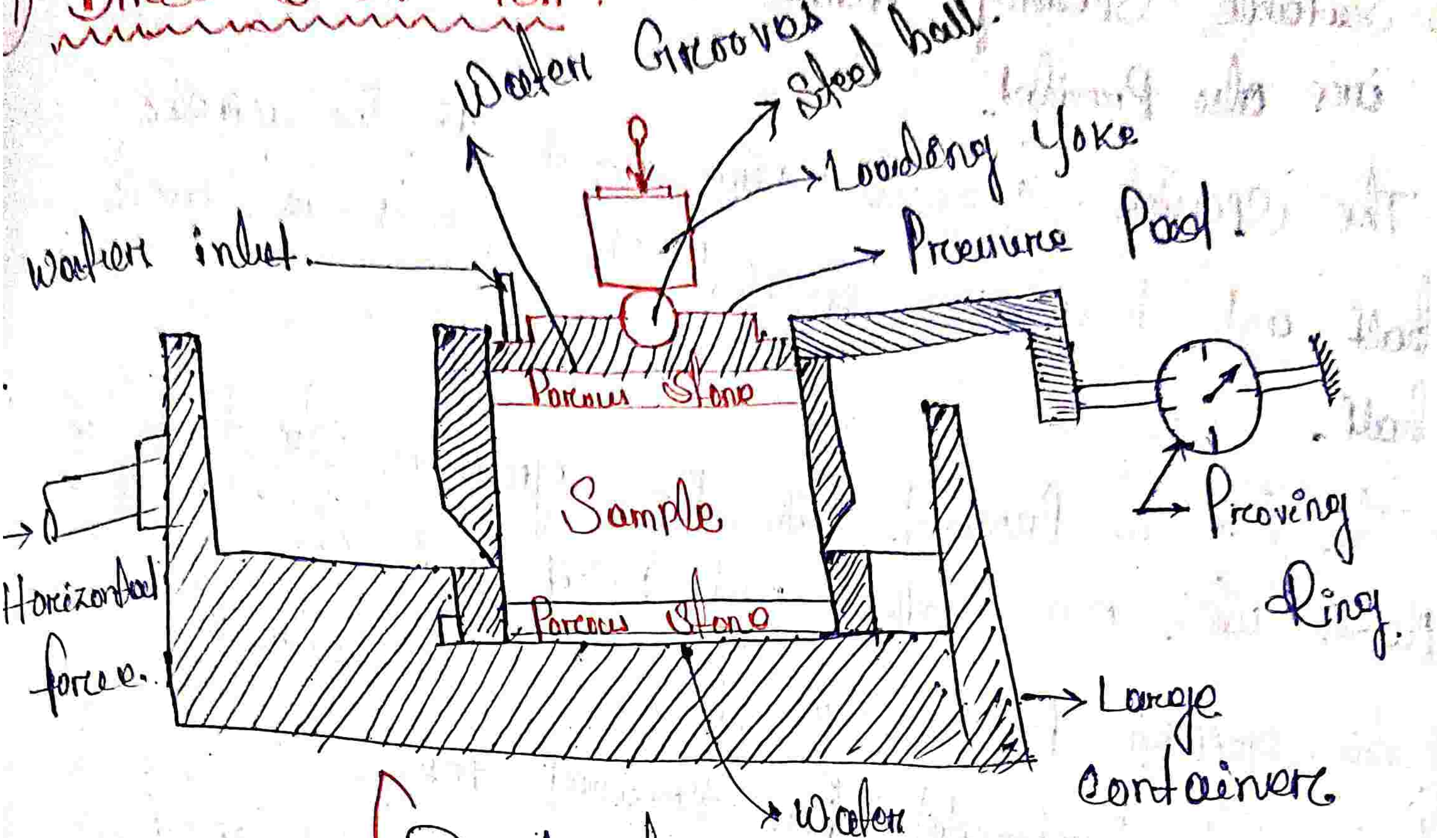
- In a consolidated - undrained test, the Specimen is allowed to Consolidated ~~undrained test~~ in the first Stage. The drainage is Permitted until the Consolidation is complete.

(3) Consolidated - Drained Condition :-

- In a consolidated - drained Test, the drainage of the Specimen is Permitted in both the stage.

- When the consolidation is complete, it is sheared at a very slow rate to ensure that fully ~~saturated~~ drained condition exist and the excess Pore water is zero. The test is …

1) Direct Shear Test :-



(Direct Shear Test)

Apparatus :-

- A direct shear test is conducted on a soil specimen in a shear box which is split into two halves along a horizontal plane at its middle.
- The shear box is made of brass or gun-metal.
- It is either square or circular in plan.
- A square box of size 60x60x50 mm is commonly used.
- The box is divided horizontally such that the dividing plane passes through the centre.
- The two halves of the box are held together by locking pins.

Mohr's Circle:—

- In the direct shear test, the stresses on planes other than horizontal plane are not known & hence it is not known & hence it is not possible to draw Mohr circle, at diff. shear loads.

- In the above figure, point 'B' represents the failure condition for a particular normal stress.

- The Mohr circle at failure is drawn such that it is tangential, to the failure envelope at 'O'.

- The horizontal line BP gives the direction of failure plane, point 'P' is the pole.

- Lines PD & PA gives the directions of the Major & minor principal planes.

Merits & Demerits of Direct Stress:—

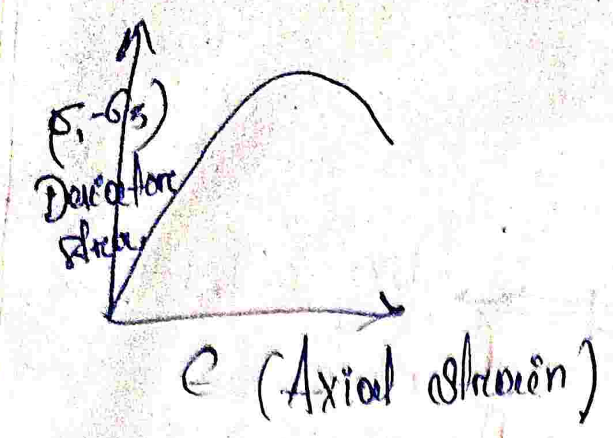
Merits:—

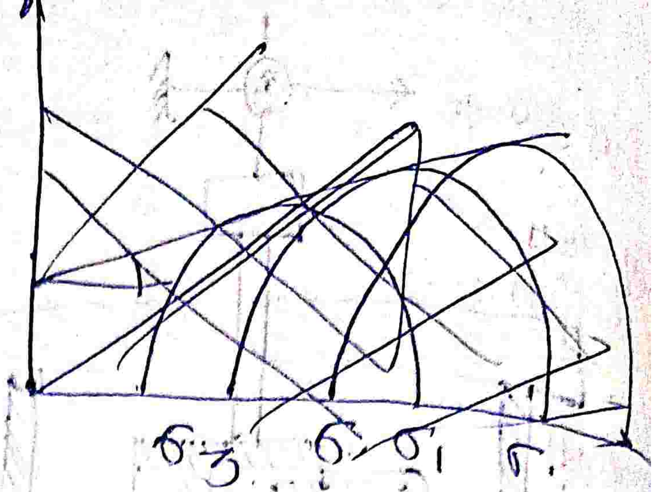
- The sample preparation is easy test is sample & convinient.
- The apparatus is relatively cheap.
- It is ideally suited for conducting drained tests on cohesionless soils.

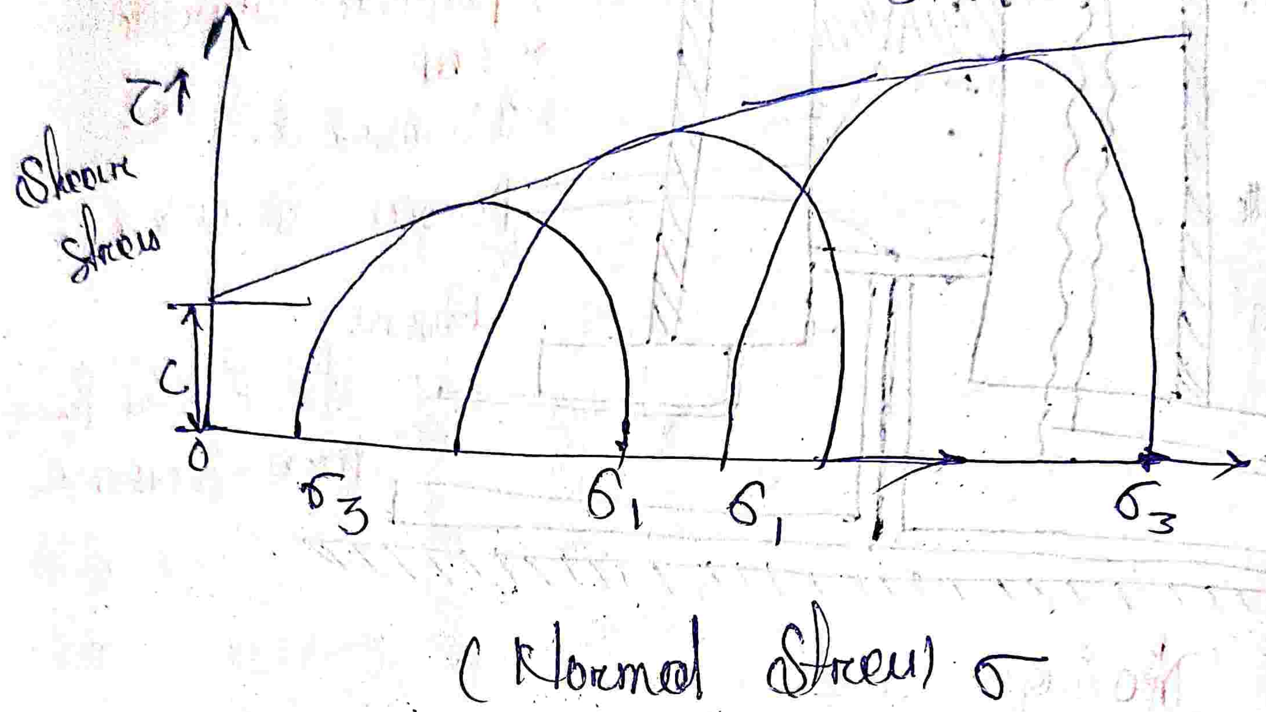
- The measurement of pore water pressure is not possible.
- Control on the drainage condition is very difficult.
- The shear stress distribution is not uniform & there is progressive failure from the edge towards the center.
- The soil fails only on the plane separating two halves of the box & not along the weakest plane.

Triaxial Compression Test :-

- This type of test is very versatile and is being extensively used for research and conventional testing.
- The soil sample can be subjected to a wide ranges and sequence of stresses and the volume & pore water pressure changes can be obtained through out the test.
- The soil sample in the form of a cylinder usually 38 mm diameter & 76 mm length is used for the test.
- It is encased by a thin rubber membrane & placed in a perspex chamber (glass like).







Merites

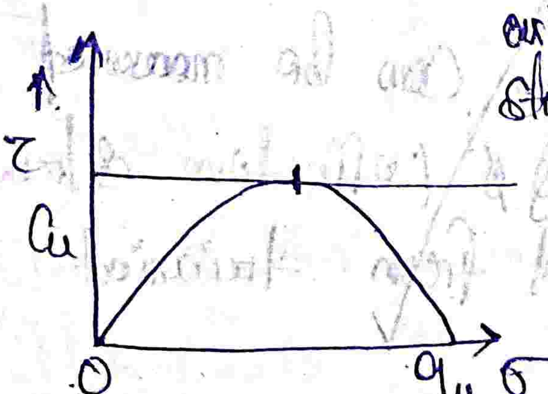
- There is complete control over the drainage condition, tests can be easily conducted for all three types of drainage condition.
- Pore Pressure changes & volumetric changes can be measured directly.
- The stress distribution on the failure plane is uniform.
- The test is suitable to know the state of stress at all intermediate stages.

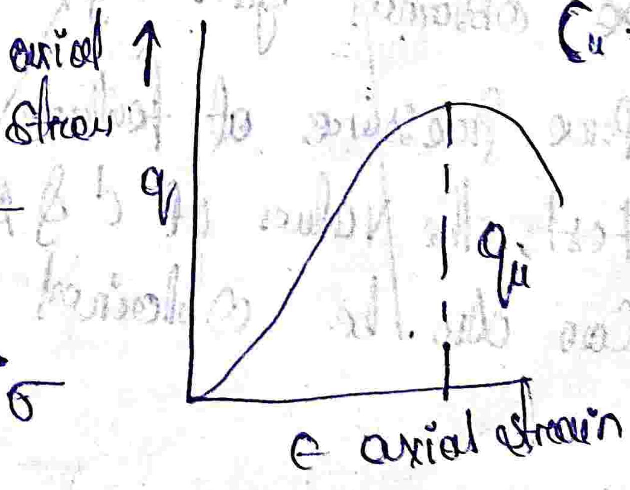
Demerits

- The apparatus is costly & bulky.
- The drained test takes a longer period as compared with that in a direct shear test.
- The consolidation of the specimen in the test is ~~isot~~ isotropic where as in the field the consolidation is anisotropic.

Un-Confined Compression Test :-

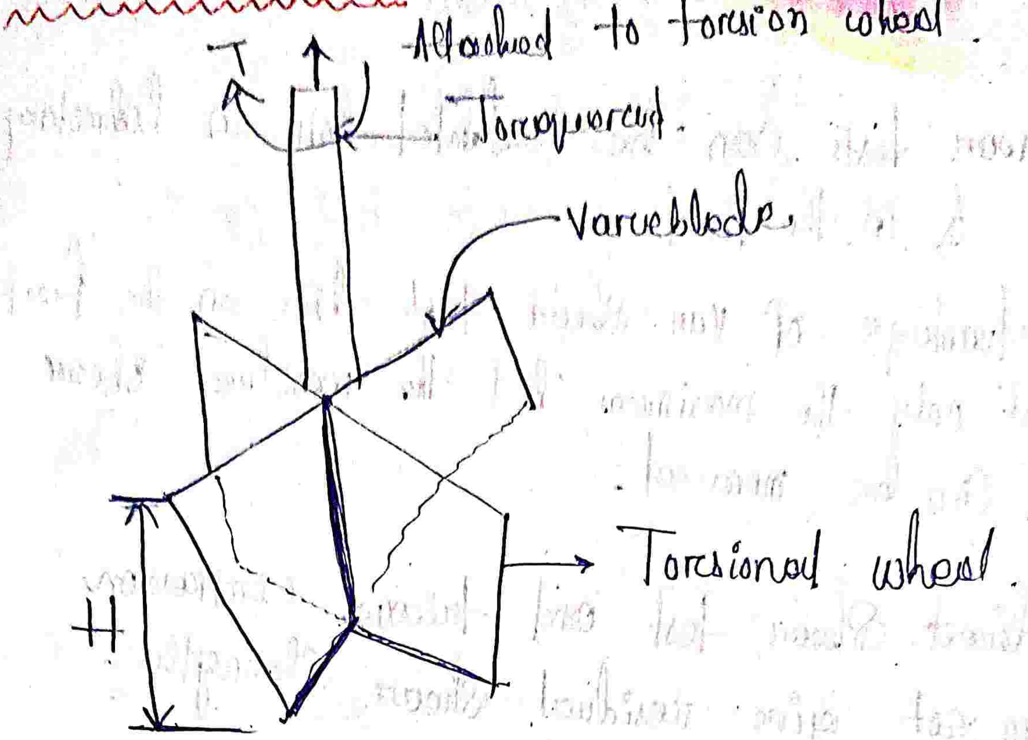
- This is a special type of tri-axial test, but can be easily carried out using simple equipment on cohesive soil. (self supporting soil sample)
- There is no need of lateral pressure ($\sigma_3 = 0$), hence only a vertical force (σ_1) is applied on the sample.
- Hence deviator stress $\sigma_1 - \sigma_3 = \sigma_1 - 0 = \sigma_1$
- This test is carried out quickly & no drainage is permitted. Time of failure is (generally 10 minutes)
- The un-confined compressive strength is recorded as the value of the vertical stress.





C_u = Unconfined Cohesion.

Vane Shear Test :-



- Soil which donot show any friction & are purely cohesive can be tested in pore shear.
- A twisting moment is applied to the soil which generates pure shear stress & the stress at failure can be related to the twisting moment applied.
- In this test, a shear vane which consists of four thin steel plates welded to a steel rod is pushed into the soil.
- The torque is applied to rotate the vane at a uniform speed 6-12° per minute.
- The relation between the torque 'T' & the shear strength is given by :-

$$S = \frac{T}{\pi\left[\frac{(D^2 H)}{2} + \frac{D^3}{6}\right]}$$

9.1 Functions of foundations, Shallow & deep foundation, different types of Shallow and Deep foundations with Sketches. Types of failure (General Shear, Local and Punching Shear)

9.2 Bearing capacity of soil, bearing capacity of soil using Terzaghi's formulae & I.S Code formula for strip, circular & square footings, Effect water table on bearing capacity of soil.

9.3. Plate load test and Standard Penetration test

Foundation Engineering :–

- A Foundation Engg. is defined as that part of the structure, that supports the weights of the structure and transmit the load to underlying soil or rock.

Or

- It is the part of the structure which supports the structure by distributing its load on the soil.

Geotechnical Engg.:–

- Geo-technical Engg. is the branch of civil Engg., concerned with the Engg. behaviour of earth materials like analysis, foundation design and construction of foundation.

— It Provid... undermining or scouring due to burrowing animals and flood water.

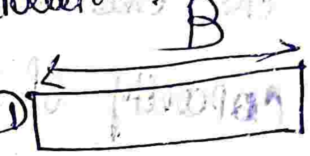
6. Protection Against Soil movements :—

Special foundation measures Prevents or minimizes the distress in the super structure, due to expansion and Contraction of the sub soil b'coz of moisture movement in some Problematic soils.

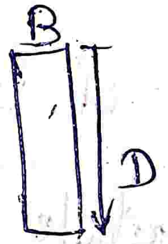
Types of foundation

— There are two types of foundation :—

(i) Shallow foundation



(ii) Deep foundation



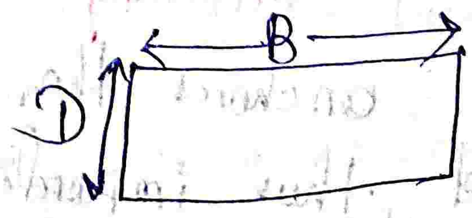
(i) Shallow foundation :—

- Shallow foundation is the types of foundations which ~~trans~~ transmits the loads to the strata at a shallow depth.

or

- In which foundation width is greater than depth, then this is called shallow foundation.

- According to Terzaghi :— $\frac{B}{D} \geq 1$



- According to Skempton :— $\frac{D}{B} \leq 2.5$

(ii) Deep foundation

- A deep foundation transmit the load at considerable depth below the ground surface.
- In which foundation width is smaller than the depth then this is called deep foundation.

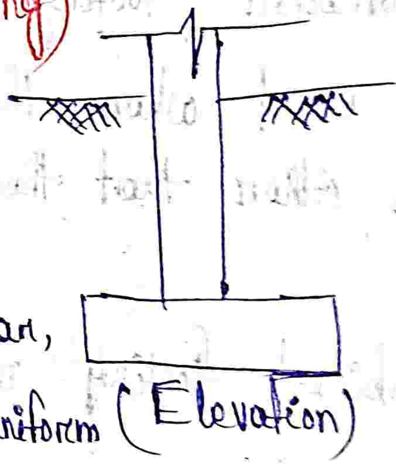
According to Terzaghi → $\frac{D}{B} > 1$

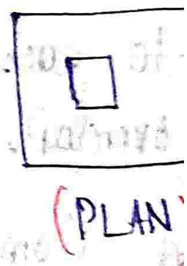
According to Skempton → $\frac{D}{B} > 2.5$

Types of Shallow foundation :-

1. Isolated footing
2. Strip footing
3. Combined footing
4. Raft footing
5. Cantilever footing

1) Isolated footing :- / (Spread footing)

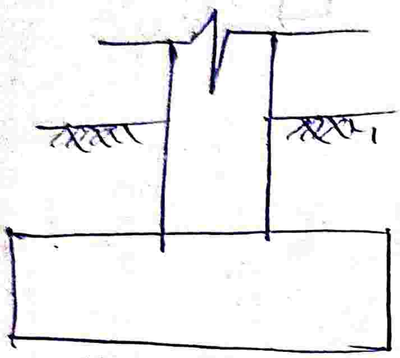


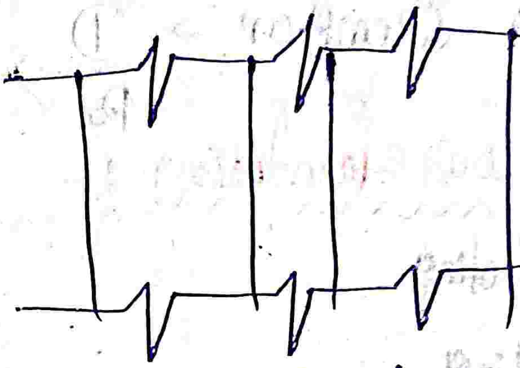


- A isolated footing is provided to support an individual column.
- A Isolated footing is circular, square or rectangular slab of uniform thickness.

② Strip footing :-

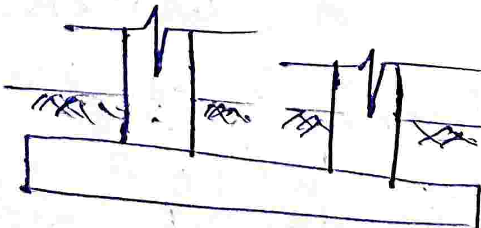
- A strip footing is provided for a load bearing wall.
- A strip footing also provided for a row of columns which are so closely spaced that their spread footing overlap or nearly touch each other.

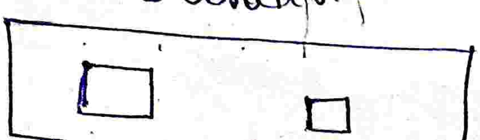

(Elevation)


(Plan)

③ Combined footing :-

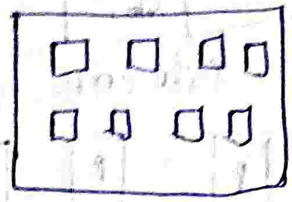
- A combined footing supports two columns.
- It is used when the two columns are so closed to each other that their individual footings would overlap.
- A combined footing may be rectangular or trapezoid in plan.


Elevation.



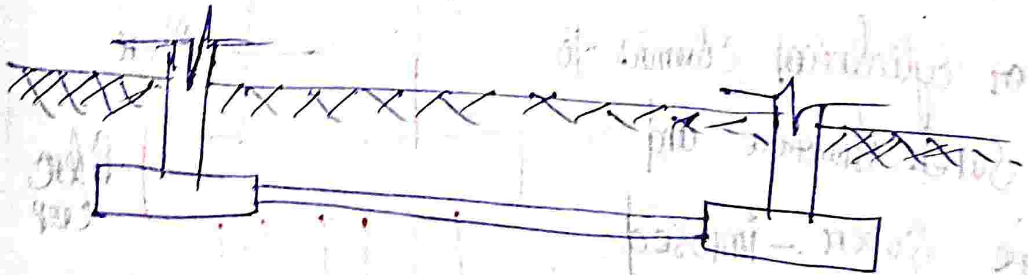
④ Raft footing :-

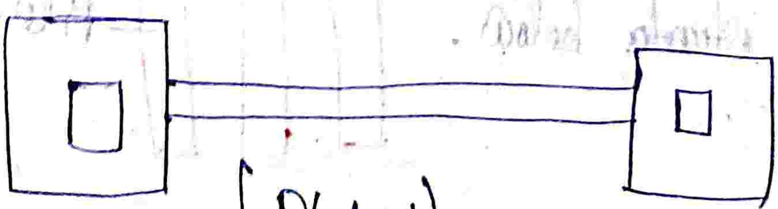
- A raft foundation is a large slab supporting a no. of columns and walls under the entire structure or a large part of the structure.



⑤ Cantilever footing :- (Strap footing)

- A strap footing consists of two isolated footing connected with a structural strap or a lever.
- The strap connects the two ~~thing~~ footings such that they behave as one unit.
- The strap simply acts as a connecting beam and does not take any soil reaction.



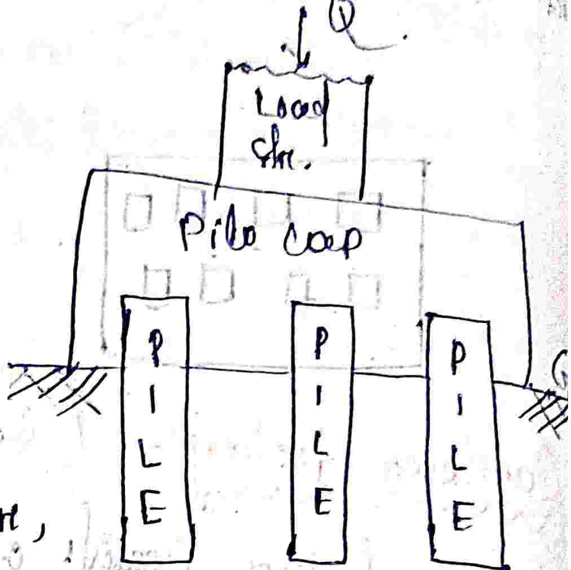


(PLAN)

(I) Deep Foundation

1. Pile foundation.
2. Pier foundation.
3. Well foundation.

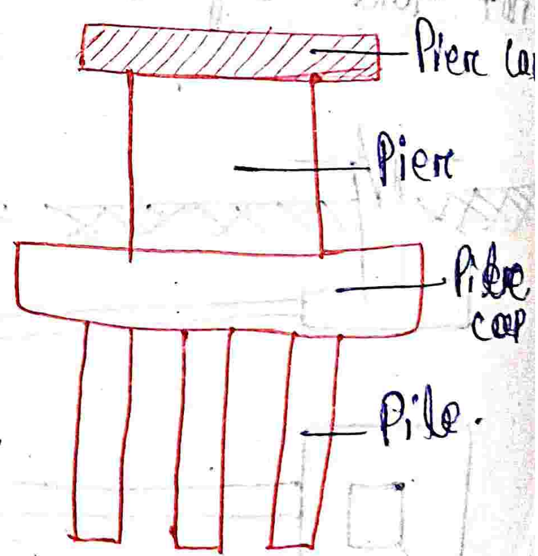
1) Pile foundation :-



- Pile foundations are deep foundations.
- They are formed by long, slender, columnar elements, typically made from steel or reinforced concrete, or sometimes timber.
- A foundation is described as "piled" when its depth is more than three times its breadth.

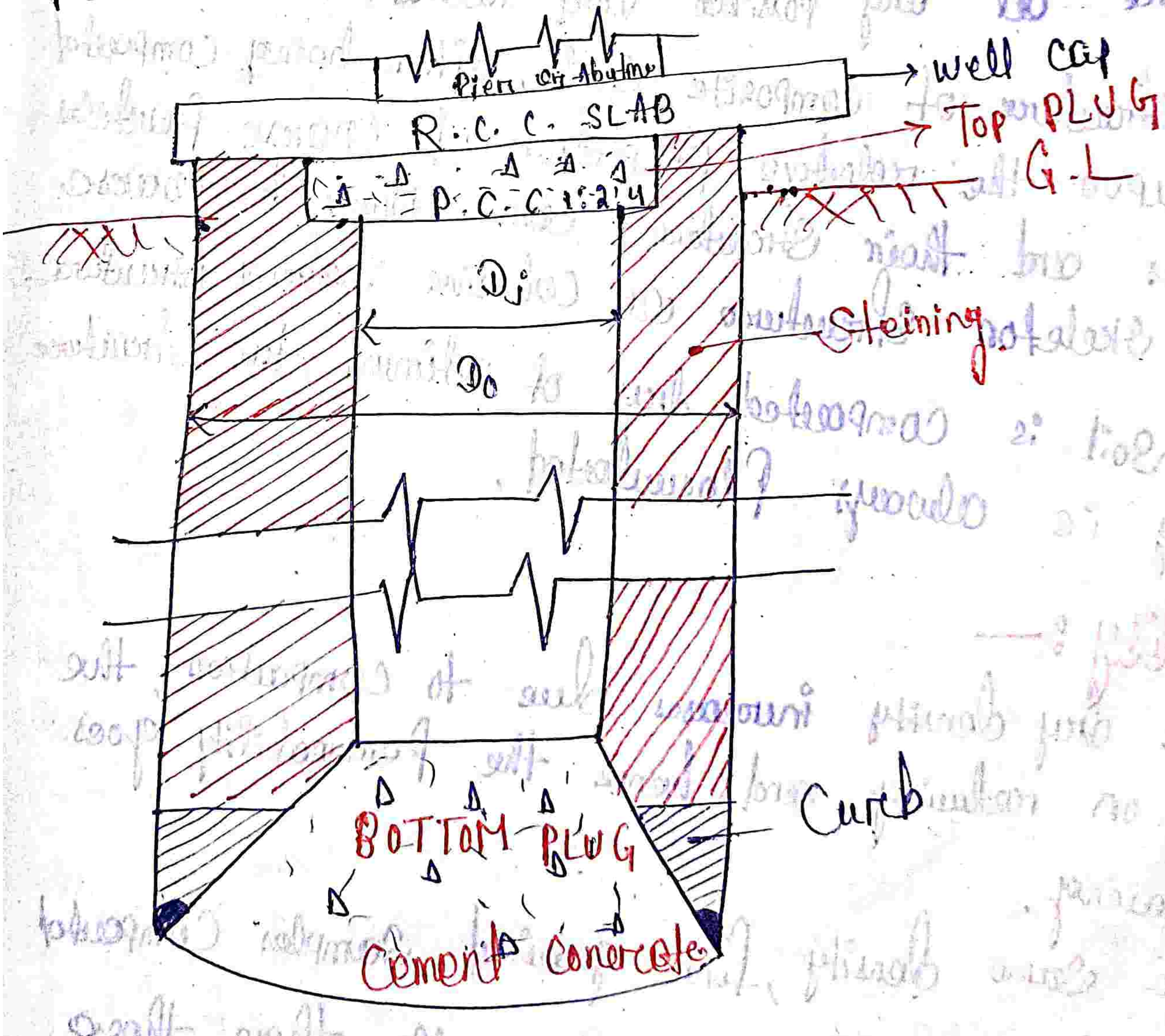
2) Pier foundation :-

- A pier foundation is a collection of large diameter cylindrical columns to support the super-structure and transfer large super-imposed loads to the firm strata below.



3. Well foundation :-

- Well foundation can be constructed on the dry bed or after making a sand island.
- Well foundation is a type of deep foundation which is generally provided below the water level for bridges.
- At location where the depth of water is greater than 5m to 6m. and the velocity of water is high, wells can be fabricated on the river bank and then floated to the final position and grounded.
- Well can be fabricated on the river bank and then floated to the final position and grounded.



Soil Hydraulic

Modes of occurrence of water in soil :-

- Water present in the voids of soil mass is called soil water.
- It can be classified as :-

(a) Broad classification

1. Free water or gravitational water
2. Held water :-
   (i) Structural water
   (ii) adsorbed water
   (iii) Capillary water

(b) Classification on Phenomenological basis :-

(i) Ground water
(ii) Capillary water.
(iii) Adsorbed water
(iv) Infiltered water

(c) Classification on structural aspect :-

(i) Pore water
(ii) Solvate water
(iii) Adsorbed water
(iv) Structural water.

Ground water :—

- It is sub-surface water that fills the voids continuously and is subjected to no forces other than gravity. Hence this water is also known as gravitational water and bore holes.
- Ground water fills up the voids in the soil upto the ground water table and translocates through them.
- Ground water obeys laws of hydraulic and is capable of moving under hydrodynamic forces.

Capillary water :—

- It is that water which is lifted up by surface tension above the free ground water surface. This water is in suspended condition within the interstices and pores of capillary size of the soil.
- The capillary water fills all the pores in the soil, to a certain distance above the water table, this distance is known as zone of capillary saturation.

Adsorbed water :—

Adsorbed water compreses of
 (i) hygroscopic water
 (ii) Film water → iron-containing minerals and excess organic surface matt.

- Hygroscopic water or contact moisture or surface bound moisture or surface bound moisture is that water which the soil particles freely adsorb from atmosphere and is held by by the physical forces of attraction by forces of adhesion.

Infiltrated water:
- It is that portion of surface precipitation which soaks into ground, moving towards through aeration zone.
- It is subjected to capillary forces.

*** Classification based on structural aspects:—**

(i) Free water:—
- From the point of view of inter-particle forces soil water can also be divided into two heads.
(i) The adsorbed water which is attracted by forces within the soil strong enough to influence its behaviour.
(ii) Free water which is essentially free of strong soil attractive force.

(ii) Solvate water:—
- It is that water which forms a hydration shell (Presumably not more than 200 molecules thick) around soil grains.
- It is subjected to polar electrostatic and ionic binding forces.
- It remains mobile under hydrodynamic forces, through its density and viscosity are greater than those of ordinary water.

Stress condition in ...

- At any plane in a soil mass, the total stress or unit pressure σ is the total load per unit area.
- This pressure may be due to:—
  (i) Self-weight of soil (Saturated weight, if the soil is saturated).
  (ii) Over-burden on the soil.
- The total pressure consist of two distinct components.
  (i) Intergranular pressure or effective pressure
  (ii) The neutral pressure or pore pressure

i) Intergranular Pressure or effective Pressure :—

- Effective pressure (σ') is the pressure transmitted from particle through their point of contact through the soil mass above the plane.

This pressure is effective in decreasing the void ratio of the soil mass and in mobilising its shear strength.

ii) Neutral Pressure or Pore Pressure :—

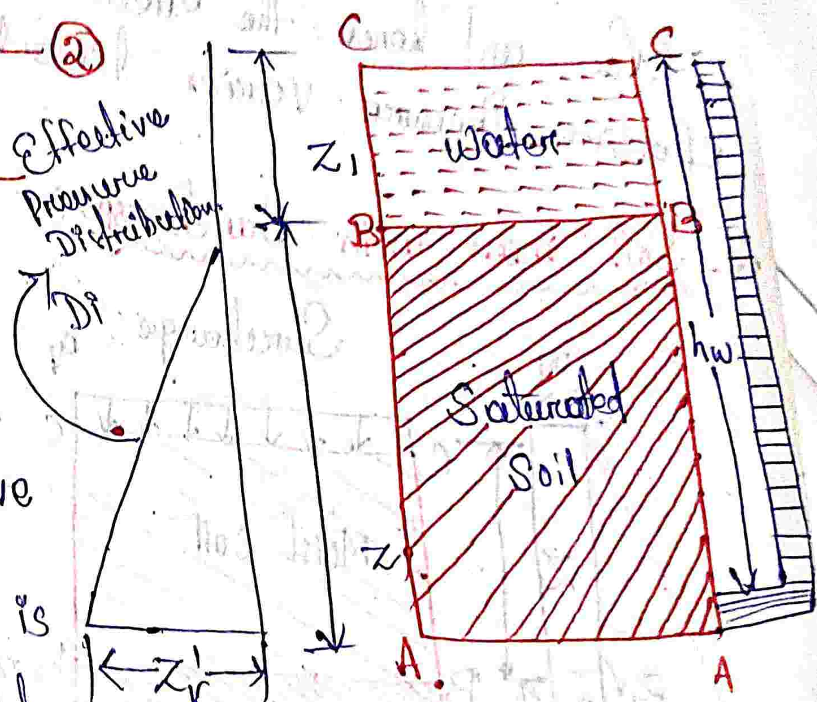
- The neutral pressure or the pore water pressure or pore pressure is the pressure transmitted through the pore fluid.
- This pressure, equal to water load per unit area above the plane, does not have any measurable influence on the voids ratio or any ...

- Therefore, this Pressure is also called neutral Pressure i.e.
- Since the total vertical Pressure at any plane is equal to the sum of the effective pressure and the pore Pressure, we have:—

$$\boxed{\sigma = \sigma' + u} \text{ — (1)}$$

- At any plane, the Pore Pressure is equal to Piezometric head 'h_w' times the unit weight of water;

i.e. $\boxed{u = h_w \gamma_w}$ — (2)



1. Submerged Soil Mass:—

- The above fig. Shows a saturated Soil mass of depth 'z', Submerged under water of height 'z_1' above its top level.
- If a Piezometric tube is inserted at level AA, water will raise in it upto level CC.
- Now, total Pressure at 'AA' is given by:—

$$\boxed{\sigma = z\gamma_{sat} + z_1\gamma_w}$$

Also, Pore Pressure $u = \gamma_w h_w$

$\therefore \sigma' = \sigma - u = z\gamma_{sat} + z_1\gamma_w - h_w\gamma_w$

$= z\gamma_{sat} + z_1\gamma_w - (z+z_1)\gamma_w$

$$\Rightarrow \boxed{\sigma' = z(\gamma_{sat} - \gamma_w) = z\gamma'}$$

4) Partially Saturated Soil :-

- In a Partially saturated Soil, a Part of void space is occupied by air.
- According to Bishop (1959), the effective Stress is

$$\sigma' = \sigma - u_a + \chi (u_a - u_w)$$

where u_a = Pore air Pressure.

u_w = Pore water Pressure.

χ = Factor of unit cross-section area occupied by water = A_w/A

A_w = Area of water.

A = Area of cross-section of soil.

Permeability

- Permeability is defined as the Property of a Porous material which Permits the Passage or Seepage of water through its interconnecting voids.
- Gravels are highly Permeable while stiff clay is the least Permeable.
- Clay may be termed impermeable.
- The flow of water through soils may either be a laminar flow or a turbulent flow.

Laminar Flow:—

- In laminar flow, each fluid particle travels along a definite path which never crosses the path of any other particle.

Turbulent Flow:—

- In turbulent flow, the paths are irregular and twisting, crossing and recrossing at random (Taylor, 1948)

Requirement of Seepage:—

1. Determination of rate of settlement of a saturated compre[ssible] soil layer.

2. Calculation of seepage through the body of earth dam and stability of slopes.

3. Calculation of uplift pressure under hydraulic structures and their safety against piping.

4. Ground water flow towards wells and drainage of soil.

1) Darcy's Law:—

- The law of flow of water through soil was first studied by Darcy in 1856.