GEOTECHNICAL ENGINEERING

3RD SEMESTER CIVIL ENGINEERING

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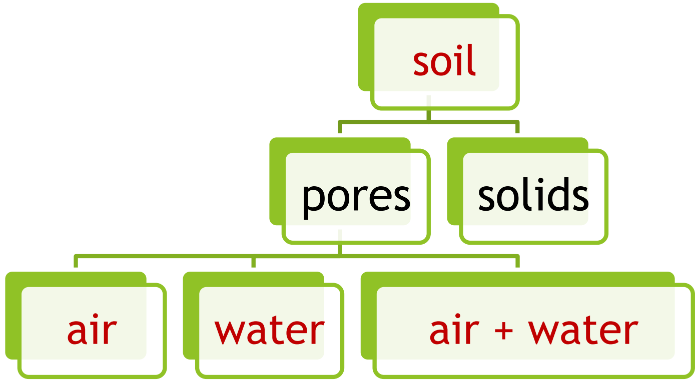
CONTENTS……..

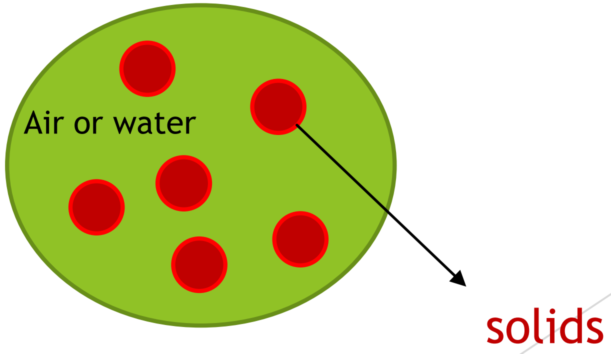
CHAPTER-1
INTRODUCTION

1.1 SOIL

from engineering point of view soil is an unconsolidated poros material composed of solid particles produced by disintegration of rocks.

- The pores present in soil mass are otherwise called voids.
- The pores may be partially filled with water and air or completely filled with water or completely filled with air.





SOIL MECHANICS

soil mechanics is a branch of mechanics which deals with the action of different forces acting on soil and flow of water through the soil.

SOIL ENGINEERING

soil engineering deals with application of principle of soil mechanics to solve practical problems.

GEOTECHNICAL ENGINEERING

geotechnical engineering is a broader term that includes soil engineering, rock mechanics and geology.

1.2 SCOPE OF SOIL MECHANICS

scope of soil mechanics says about vast application of soil mechanics for the construction of various civil engineering structures.

Few of the applications are listed below:

1.FOUNDATIONS

foundations are the most important things for every type of civil engineering structures.

They act as a medium to transfer the total load of structures to the soil.

2.RETANING STRUCTURES

When sufficient space is not space is not available for the soil mass to spread to form a safe slope a structure is require to retain the soil. Such structures are called retaining wall.

3.STABILITY OF SLOPES

If the soil surface is not horizontal there is a tendency of the soil to move in outward direction due to weight component of soil.

Soil engineering provides methods to check stability of slopes.

4.UNDERGROUND STRUCTURES

The design and construction of various engineering structures bears structural forces exerted by soil.

Using soil mechanics we evaluate such forces exerted by soil.

5.PAVEMENT DESIGN

the pavement consists of surfacing such as bitumen layer, base and sub-base course. The behaviour of sub-grade and sub-base are studied using soil mechanics.

6.EARTH DAM

Earth dams are created for creating resources. Major care is taken for the construction of earth dam as minimum negligence can create a disaster. It requires a thorough knowledge of civil engineering.

1.3 ORIGIN AND FORMATION OF SOIL

ORIGIN OF SOIL

- soils are formed by weathering of rocks by means of physical disintegration or chemical decomposition.
- When the rock is exposed to atmosphere for a longer period of time it disintegrates physically or decomposes chemically into smaller particles and in this way soil particle is formed.
- If the soil stays at the place of it's formation it is called residual soil or sedimentary soil and if it gets transported to other place via wind or water it is called transported soil.

FORMATION OF SOIL

soil is formed by two means i.e; either by physical disintegration or by chemical decomposition.

- Physical disintegration occurs due to following process;
  1. Temperature changes
  2. Wedging action of ice
  3. Spreading of root plants
  4. Abrasion
- Chemical decomposition occurs due to following process;
  1. Hydration
  2. Carbonation
  3. Oxidation
  4. Solution
  5. Hydrolysis

CHAPTER-2
PRELIMINARY DEFINITIONS AND RELATIONSHIP

2.1 SOIL AS A THREE PHASE SYSTEM

A phase diagram in geotechnical engineering is the diagrammatic representation of proportions of various components present in the soil mass.

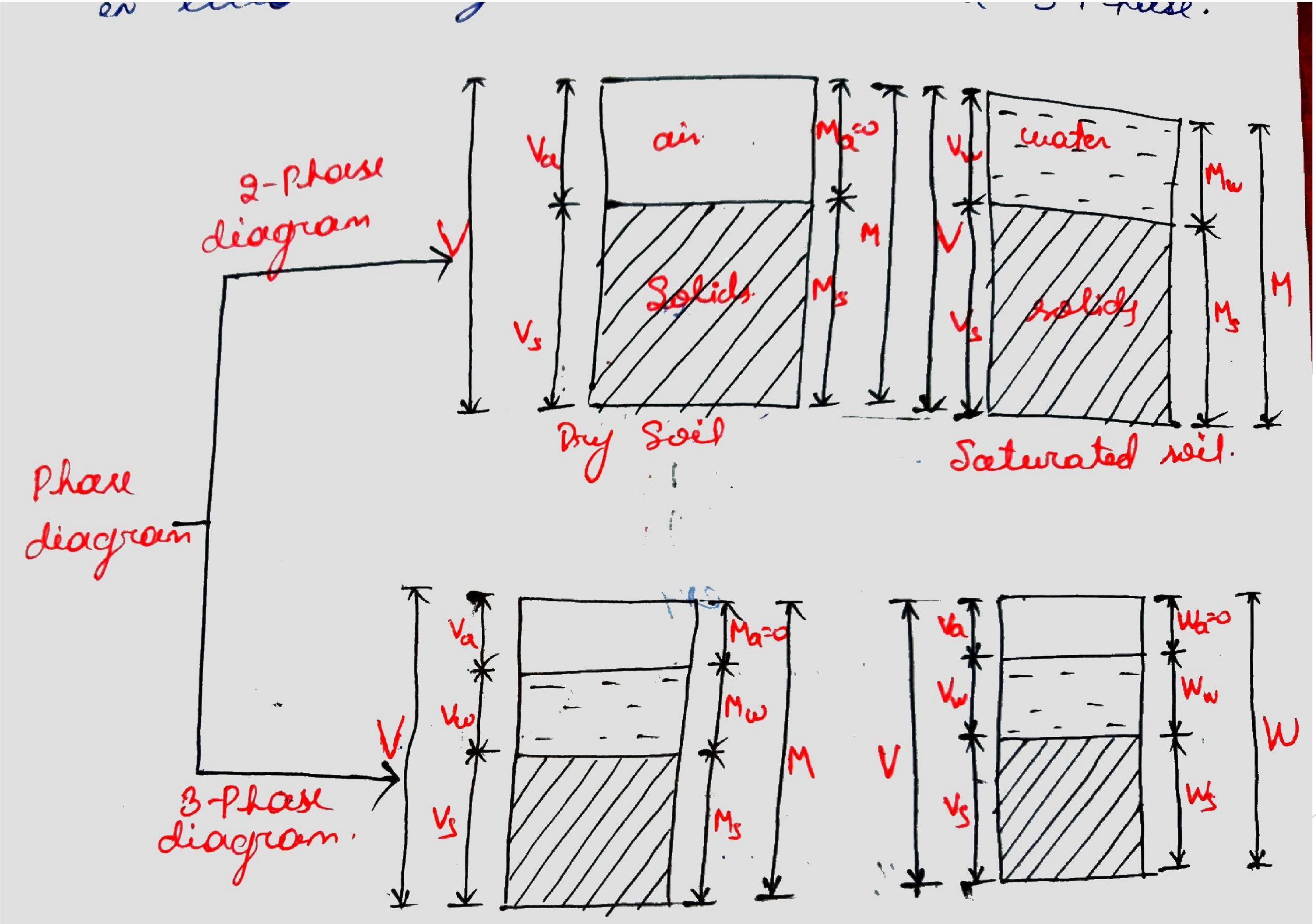
- A phase diagram in soil can be drawn in two ways i.e; 2-phase and 3-phase.

In the given phase diagram

V_A=volume of air V_w=volume of water V_s=volume of solids

W_A=weight of Air W_W=weight of water W_S=weight of solids

$V=V_V + V_S$ $V_V = V_A + V_W$ $W = W_W + W_S$ (as $W_A = 0$)



Phase diagram
2-Phase diagram
3-Phase diagram.
Dry Soil
Saturated soil.
air
Solids
water
solids
V
Va
Vs
Vw
Ma=0
M
Ms
Mw
Wa=0
Ww
Ws
W

2.2 IMPORTANT TERMS AND RELATION BETWEEN THEM

WARER CONTENT(W%)

It is otherwise called moisture content of soil.

- It is defined as the ratio between the weight of water to the weight of soil solids.

$$w\% = (w_w / W_S) X100$$

VOID RATIO(e)

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

$$e = V_V / V_S$$

- It is generally expressed in decimal fraction.
- No. of voids , volume of voids , size of voids and void ratio can vary for two different soils of same volume.

POROSITY(n%)

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

- It is otherwise called percentage of air voids.

$$n\% = (V_V / V)X100$$

NOTE

* Both porosity and void ratios are used to indicate denseness and looseness of the soil.

* Since total volume is a variable quantity and volume of solid is a constant parameter engineering significance of void ratio is more than porosity.

$n = V_V / V$

$= V_V / (V_V + V_S) = (V_V / V_S) / ((V_V / V_S)+(V_S / V_S)) = (V_V / V_S)/((V_V / V_S)+ 1)$

$n = e /(1+e)$

$e = n/(1-n)$

DEGREE OF SATURATION(S%)

It is defined as volume of voids to the volume of water to the volume of voids.

$S\% = (V_W / V_V)X100$

AIR CONTENT(a_c)

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

$a_c = V_a / V_V$

$a_c + S\% = (V_a / V_V) + (V_W / V_V)$

$= (V_a + V_W)/V_V$

$= V_V / V_V$

$= 1$

$a_c + s\% = 1$

PERCENTAGE AIR VOIDS($n_a\%$)

It is defined as the ratio of volume of air to the total volume of soil.

$$n_a\% = (Va/V)X100$$

$$n_a\% = V_a / V = (V_a / V_v) \times (V_v / V) = a_c \times n$$

$$n_a\% = a_c \times n\%$$

DENSITY OF SOIL

Density of soil is defined as the total mass of the soil to the total volume of the soil.

$$\rho = M/V$$

UNIT WEIGHT OF THE SOIL

Unit weight of the soil is defined as weight of soil to the total volume of the soil.

$$\gamma = W/V = (mg)/V$$

1.BULK UNIT WEIGHT OF THE SOIL

This defined as the total weight of the soil mass to the total volume of the soil mass under field condition.

$$\gamma_{bulk} = \text{(weight of the soil)/(volume of the soil)} = W/V$$

* Bulk density (ρ_{bulk}) = M/V

$$\gamma_{bulk} = \rho_{bulk} X g$$

2. DRY UNIT WEIGHT OF THE SOIL(γ_{dry} or γ_d)

It is defined as ratio of dry unit weight to the volume of the soil.

γ_d = (dry weight of soil)/(volume of soil) = W_s/V

NOTE

* Dry unit weight of soil means weight of soil when water void is not present in it.
* Dry unit weight should be taken after oven drying of soil.
* γ_d is the indication of denseness or looseness of the soil.

3. SATURATED UNIT WEIGHT(γ_{sat})

It is defined as weight of saturated soil mass to the total volume of soil mass.

γ_{sat} = (saturated weight of soil)/volume of the soil = W_{sat} / V

4. SUBMERGED OR EFFECTIVE UNIT WEIGHT(γ_{sub} or γ')

Submerged unit weight of the soil is the ratio of effective weight of the soil to the volume of the soil.

$\gamma_{sub} = \gamma_{sat} - \gamma_w$ $\gamma_{sub} \approx \gamma_{sat} / 2$

* Unit weight of soil solids ;

γ_s = weight of soil solids / volume of soil solids

$\gamma_s = W_S/V_S$

$\gamma_s > \gamma_{sat} > \gamma_{bulk} > \gamma_{dry} > \gamma_{sub}$

INTER RELATIONSHIP BETWEEN VARIOUS SOIL PARAMETERS

1. $n = e/(1+e)$
2. $e = n/(1-n)$
3. $n_a \% = a_c \times n\%$
4. $G_m \approx G_s/(1+e) \approx G_s (1-n)$
5. $Se = WG$
6. $\gamma_{bulk} = ((G + Se) x \gamma_w) / (1+e)$
7. at S=1 , $\gamma_{sat} = ((G + e) x \gamma_w) / (1+e)$
8. at S=0 , $\gamma_{sat} = (G\gamma_w) / (1+e)$
9. $\gamma_{bulk} = ((G-1) x \gamma_w) / (1+e)$
10. $\gamma_d = \gamma_{bulk} / (1+W)$

SPECIFIC GRAVITY(G)

1. TRUE/ABSOLUTE SPECIFIC GRAVITY

It is defined as the weight of solids of particular volume to the weight of same volume of standard fluid.

G = weight of solids of particular volume / weight of standard fluid of same volume

$G = W_S/W_W$

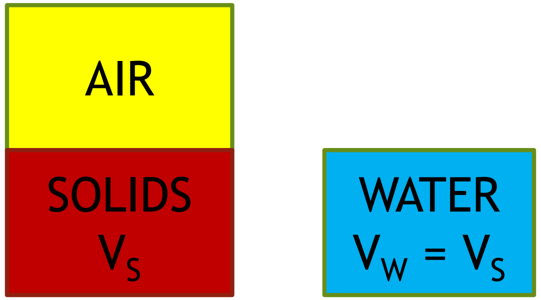
$G = W_S/W_W = (W_S/V_S)\ /(W_W/V_S)$

$= (W_S/V_S)\ /(W_W/V_W)$ (as $V_S=V_W$)

So $G = \gamma_S\ /\ \gamma_w$

$G = \gamma_S\ /\ \gamma_w = (\rho_s x g)\ /(\rho_w x g)$

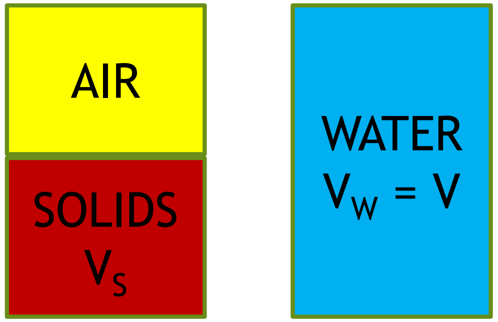
$G = \rho_s\ /\ \rho_w$



2. MASS OR APPERENT SPECIFIC GRAVITY (G_m)

It is defined as the ratio of weight of soil of particular volume to the weight of standard fluids of same volume.

G_m = weight of soil of particular volume / weight of standard fluid of same volume



CHAPTER-3

INDEX PROPERTIES OF SOIL

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Index properties of soil are those which helps in classification and identification of soil like water content, specific gravity, unit weight of soil, particle size distribution, consistency, sensitivity, thixotrophy, activity etc. .

3.1 WATER CONTENT

The water content of soil is a quantitative measurement of wetness of soil mass.

- The water content can be deter mined in the following methods;
  a) Oven drying method
  b) Sand bath method
  c) Alcohol method
  d) Calcium carbide method
  e) Infrared torsional balance method
  f) Radiation method
  g) Pycnometer method

A. OVEN DRYING METHOD

- **Oven drying method is a standard laboratory method** and gives most accurate result.
- In this method moist soil sample is placed in a container of known weight W_1 .
- Then container with moist soil sample is placed in a temperature controlled oven for oven drying.
- For inorganic soil, temperature is mentioned between 105°c - 110°c for sufficient duration.
- Generally for all type of soils drying period is continued for 24 hrs. in order to ensure the removal of complete moisture.
- Fro organic soils drying temperature is limited to 60 °c in order to avoid oxidation of organic matter present in it.
- However in no case temperature is increased beyond 110 °c as it may results in destruction of soil solids.

- In oven drying all type of soil water like ground water, capillary water, hygroscopic water, film water is removed except structural water and water of crystallization if present.

$$W\% = [(W_2 - W_3)/(W_3 - W_1)] \times 100$$

W_1 = weight of the empty container

W_2 = weight of container and moist soil

W_3 = weight of container and dry soil

B. SAND BATH METHOD

- It is a field method.
- In this method container with moist soil is placed in sand bath and heated over kerosene stove.
- As in this method there is no control over temperature, it is generally not suitable for organic soil.
- The procedure for sand bath method is same as oven drying method but the result of this method but the result of this method is not accurate.

C. ALCOHOL METHOD

- In this method methylated sprit is added in soil sample to increase the rate of evaporation during drying.
- Since alcohol (methylated sprit) is an oxidizing agent, therefore it result in oxidation of calcium compounds and organic matter hence it is not suitable for such soils.

D. CALCIUM CARBIDE METHOD

- It is one of the quickest method to find out water content of the soil and it gives result within 5-7 minutes.
- The instrument used in this method is called moisture tester.
- This method is also called as rapid moisture tester method.
- In this method 4-6 gm of moist soil is placed in closed moisture tester, then calcium carbide powder (CaC_2) is added in the moist soil.
- CaC_2 reacts with the water present in the soil resulting in formation of acetylene gas ($C_2 H_2$) which exerts pressure on the diaphragm of the moisture tester and this pressure is further calibrated from standard results to find water content of the soil.

E. INFRARED TORSIONAL BALANCE METHOD

- In this method infrared rays are used for drying the soil sample which are generated by standard bulb.
- In this method drying and weighing of sample is done simultaneously. Hence it is generally suitable for those soils which quickly absorbes moisture from atmosphere.
- In this, moist sample of soil and infrared rays are placed in different arms of torsional balance.
- Moist soil gets dry with the help of infrared rays produced by bulb. Hence weight of the soil sample decreases, resulting in decrease in torque on soil sample arm. This decrease in torque is further calibrated to find water content of the soil.
- More the reduction in torque of soil arm, more will be the water content.

F. RADIATION METHOD

- It is a field method used in large areas like reservoirs and dams.
- In this method two steel casings are inserted in moist soil at a specific distance.
- In first casing radioactive material and in second casing detector is placed.
- When radioactive material is active it emits neutrons. These neutron strike with hydrogen atoms of water which is present in soil and loose its energy.
- This loss in energy of neutrons is detected by the detector of second casing and is further calibrated to find water content of the soil.

CONT…

- Loss of Energy = Amount of Water Content in the Soil.
- Detector Device is Calibrated to give directly the Water content of the Sub-Soil, at that Level of Emission.
- Shielding Precaution required – Radiation Problems.

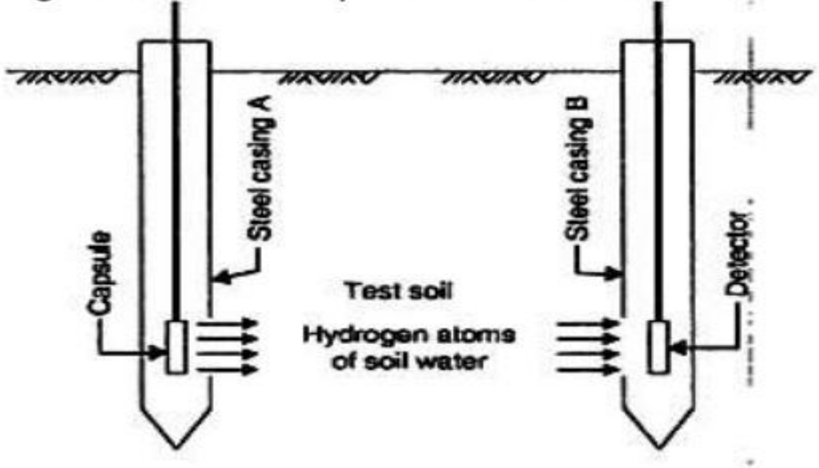


FIG. 3.2 RADIATION METHOD

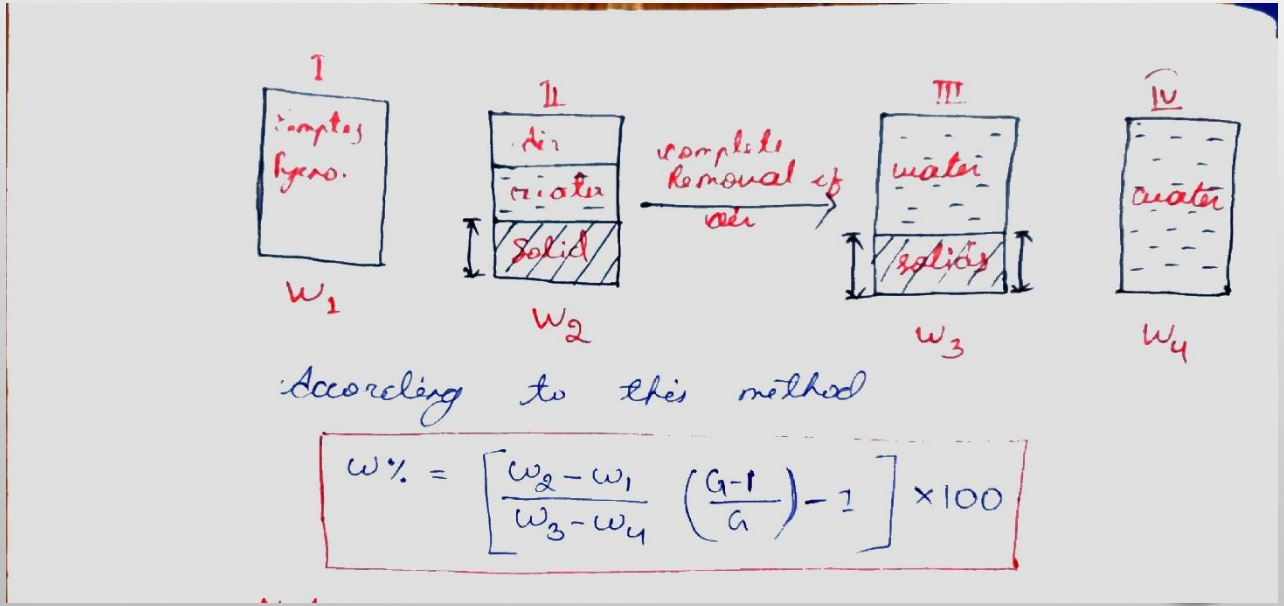
G. PYCNOMETER METHOD

- Pycnometer is a glass bottle of 900ml. Volume having a conical brass top with 6mm dia. Circular hole at the center.
- This method is one of the quickest method to find out water content of the soil which gives the result within 10 to 20 mins.
- This method can only be used for those soils whose specific gravity is known.

PROCEDURE

- Let the weight of empty pycnometer is W_1 .
- Moist soil is placed in the pycnometer for which water content is required. Let the weight of soil and pycnometer is W_2 .
- Empty volume of pycnometer is completely filled with water so that complete removal of air will take place.

  let now the total weight is W_3
- Now the pycnometer is completely emptied and again filled with water after it's proper cleaning and now let it's weight be W_4 .



NOTE

- this method is suitable only when there is complete removal of air takes place in stage III.
- Therefore this method is generally suitable for the coarse grained soil.

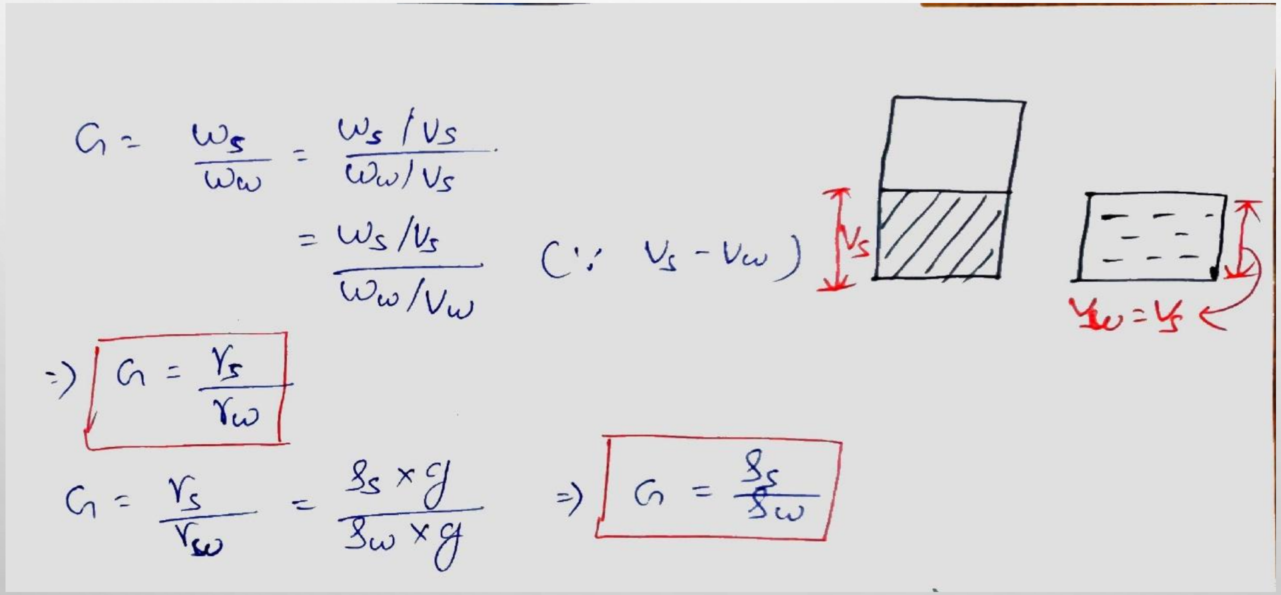
3.2 SPECEFIC GRAVITY

1. True /Absolute specific gravity

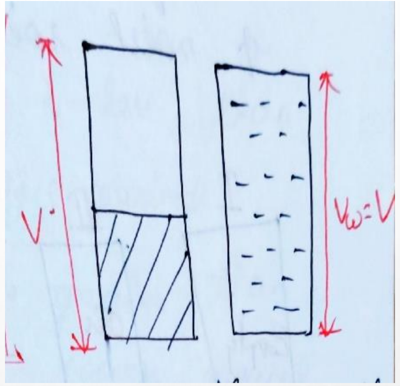
it is defined as the ratio of weight of solids of particular volume to the weight of same volume of standard fluid.

G = (weight of soil solids of particular volume)/(weight of standard fluid of same volume)

$G = W_S / W_W$



2. MASS OR APPERENT SPECIFIC GRAVITY



it is defined as the ratio of weight of soil of particular volume to weight of standard fluid of same volume.

G_m = weight of soil of particular volume / weight of standard fluid of same volume

METHODS TO DETERMINE SPECIFIC GRAVITY OF SOIL

The specific gravity of the solid particles is determined in the laboratory using the following methods:

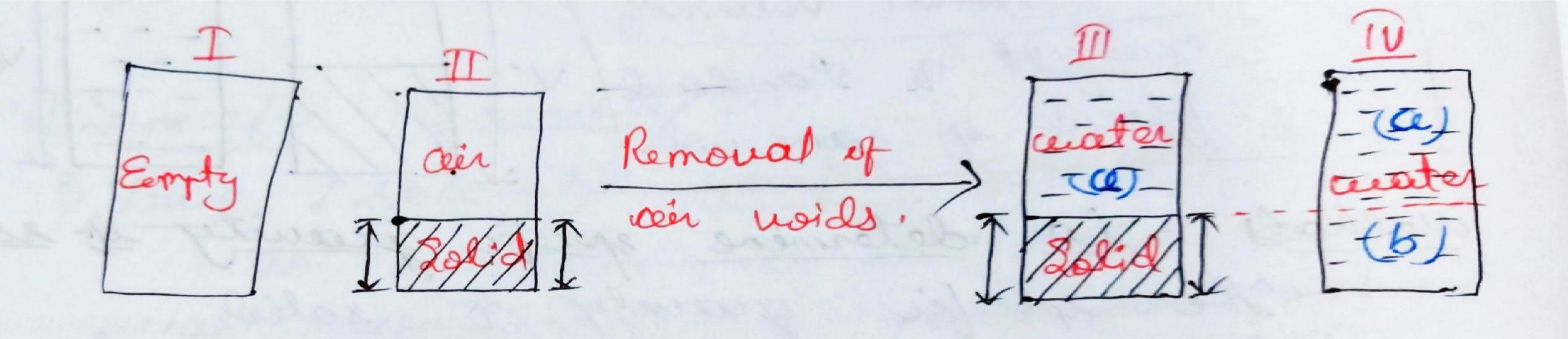
1. Density bottle method
2. Pycnometer method
3. Measuring flask method
4. Glass jar method
5. Shrinkage limit method

Specific gravity can be determined either by using 50ml density bottle or by using 500ml flask or by 900ml pycnometer.

- Generally density bottle is suitable for all type of soil where as flask and pycnometer are used for coarse grained soil.

PROCEDURE

- This method is same as the pycnometer method to determine water content of the soil.
- The only difference in this case is in stage III dry soil is used instead of moist soil.



G = weight of soil of given volume / weight of water of same volume of soil

G = (W_2 - W_1) / weight of water pf same volume

Weight of water in stage III (a) = $W_3 - W_2$

Weight of water in stage IV (a + b) = $W_4 - W_1$

Weight of water whose volume is same as weight of solid = $(W_4 - W_1) - (W_3 - W_2)$

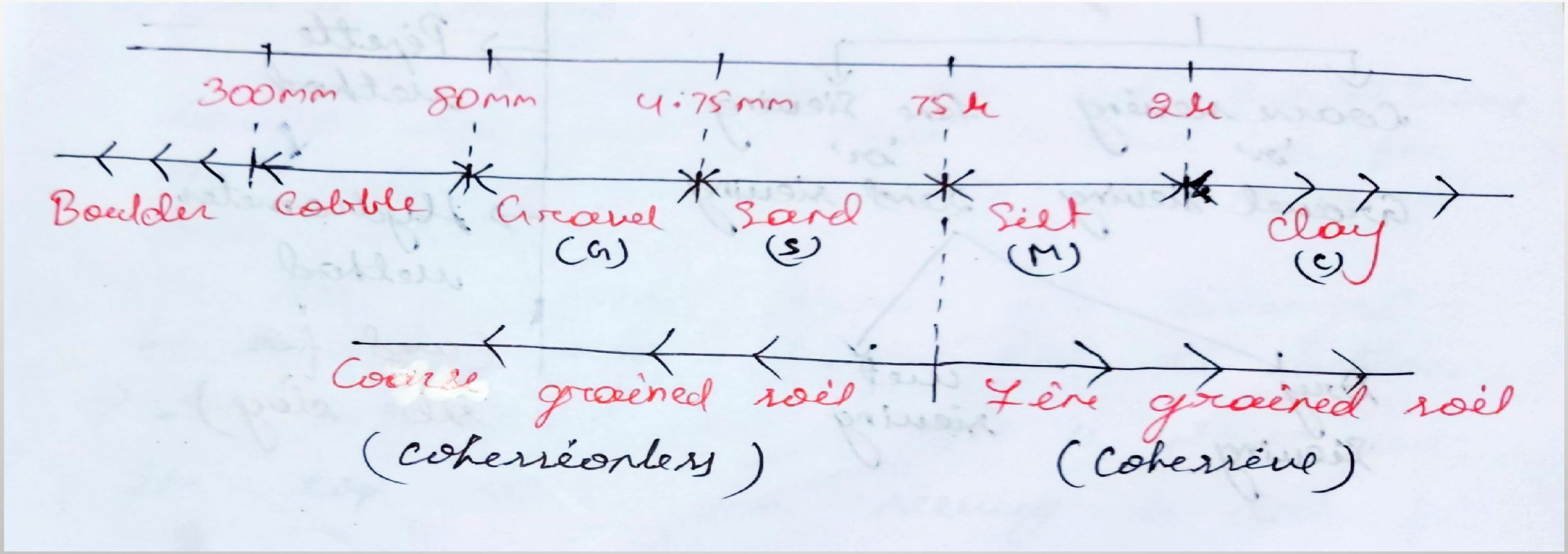
= (b + a) – a = b

$$G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

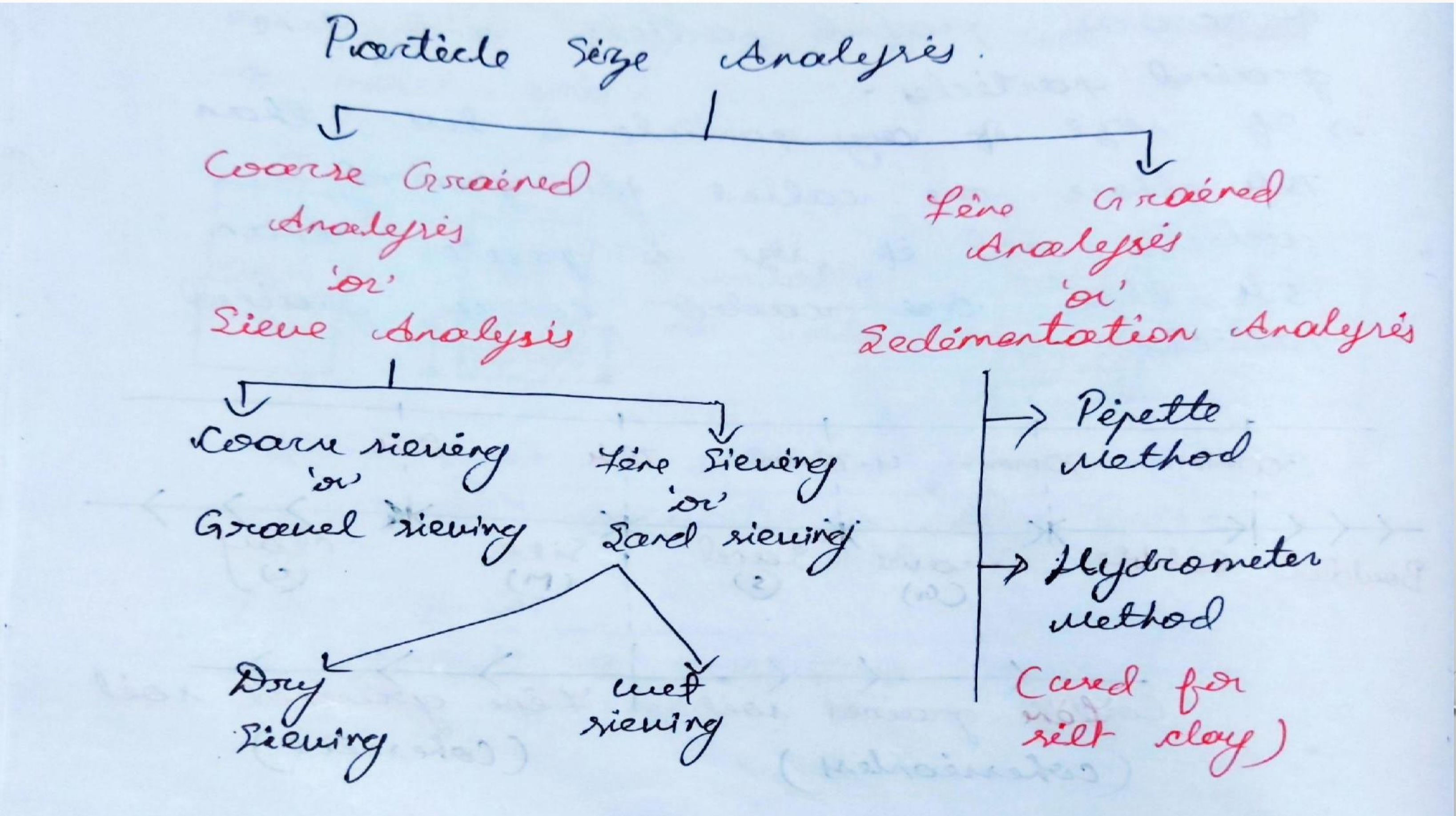
3.3 PARTICLE SIZE DISTRIBUTION

A soil mass basically coarse grained particles and fine grained particles.

- If the size of any particle is less than 75μ , those soils are called fine grained particles and if size is greater than 75μ those are called coarse grained particles.



- If soil has a fineness of 30% , then it means 30% particles by weight are fine grained soil (silt and clay) i.e ; are finer than 75μ (0.75 mm).
- Percentage of different size of particles present in the given dry sample of soil is found using particle size analysis , which is generally carried out in 2 stages:
  a) Sieve analysis
  b) Sedimentation analysis



SIEVE ANALYSIS

- Sieves are generally made of spun brass phosphor bronze sieve cloth.
- Sieves are designed either by it's size (mm or μm) or by it's number.
- According to IS:1498-1970, the sieves are designed by the size of square opening, in mm or microns. (1 μ = 10^{-6} mm).
- Various sizes of sieves are available ranging from 80mm to 75 μ.
- Sieve no. represents square opening per inches of length.
- E . G ; IS sieve no. 6 means, there 6 openings of equal size in 1inch of length.
- Greater is the sieve no. smaller will be the size of sieve opening.

A. Coarse sieving

- It is done for the soil fractions having size greater than 4.75mm or for the soils fractions which are retained over 4.75mm.
- In sieving sieves are arranged in decreasing order from top to bottom.
- An oven dried soil sample is placed over top sieve and sieving is done for at least 10mins, either mechanically or manually by sieve shaker.
- Weight of soil retained is noted after sieving which is further used to find percentage finer corresponding to given size of particle.

COMPUTATION OF PERCENTAGE FINER

let us consider total soil of mass M is taken for sieving

- The soil is sieved through 7 nos. of sieves.
- Let us mass of soil retained on these sieves are M1, M2…..M7 respectively and mass retained on PAN is M8.

Now,

the percentage of material retained on each sieve and PAN can be expressed as;

$$P1 = \frac{M1}{M} X100$$

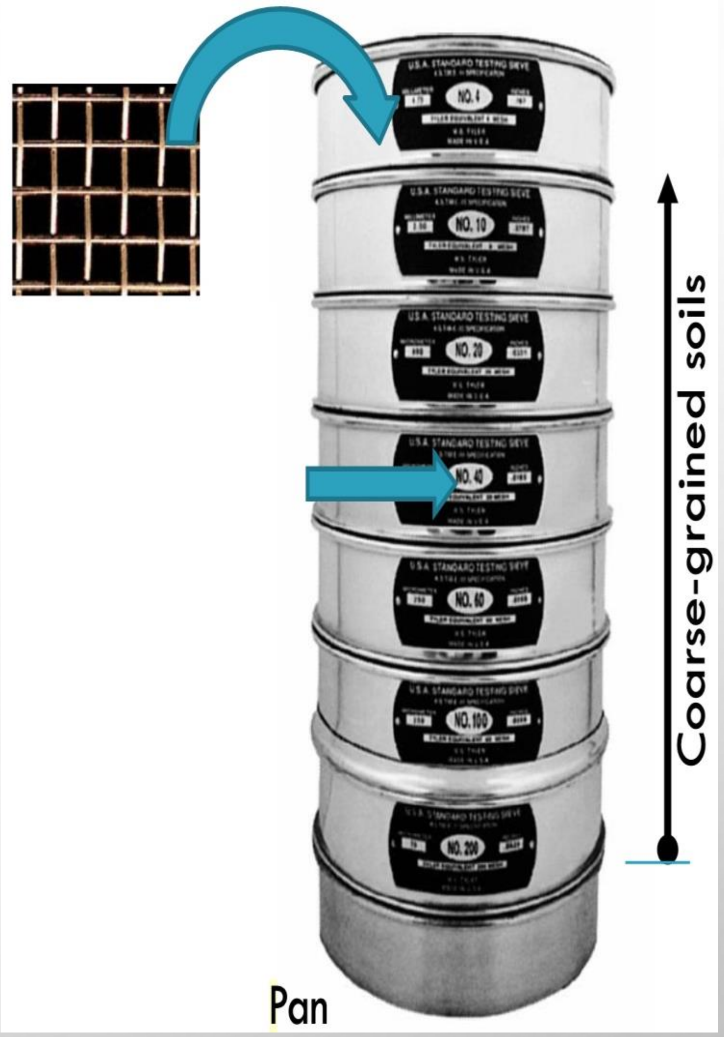
$$P2 = \frac{M2}{M} X100$$

.

.

.

$$P8 = \frac{M8}{M} X100$$



So , the cumulative percentage retained on each sieve can be calculated as,

$C1 = P1$

$C2 = P1 + P2$

.

.

$C7 = P1 + P2 + \ldots\ldots\ldots\ldots\ldots\ldots + P7$

Now, the percentage finer for any sieve can be calculated by substituting the cumulative percentage retained on each sieve from 100%

Thus, $N1 = 100 - C1$

$N2 = 100 - C2$

.

.

$N7 = 100 - C7$

- Before sieving the soil, it should be oven dried properly to avoid the lumps.

WET AND DRY SAND SIEVING

- If silt and clay are present in sand then wet sieving should be done, in which sand is washed so that fine particles (clay and silt) get removed.
- Where as if fine particles are not present in sand then dry sieving is done.
- In case pf wet sieving for washing of silt and clay from sand 2gm of Sodium hexameta phosphate $(NaPO3)_6$ is used in 1lit of water.
- $(NaPO3)_6$ is used as deflocculating or dispersing agent.

SEDIMENTATION ANALYSIS

- Sedimentation analysis is done for silt and clay having size less than 75 micron.
- Sedimentation analysis is based on stokes law.

STOKE'S LAW

according to stoke's law if a spherical particle falls through infinitely large medium of fluid, then it achieves constant terminal velocity also called settling velocity (V_S).

$$V_s = \frac{(G-1)\gamma_w d^2}{18\mu}$$

G = Specific gravity of solid

γ_w = unit weight of water

d = diameter of the particle

μ = dynamic viscosity of fluid in which settling of particles occurs

V_s = settling or terminal velocity

LIMITATIONS OF STOKE'S LAW

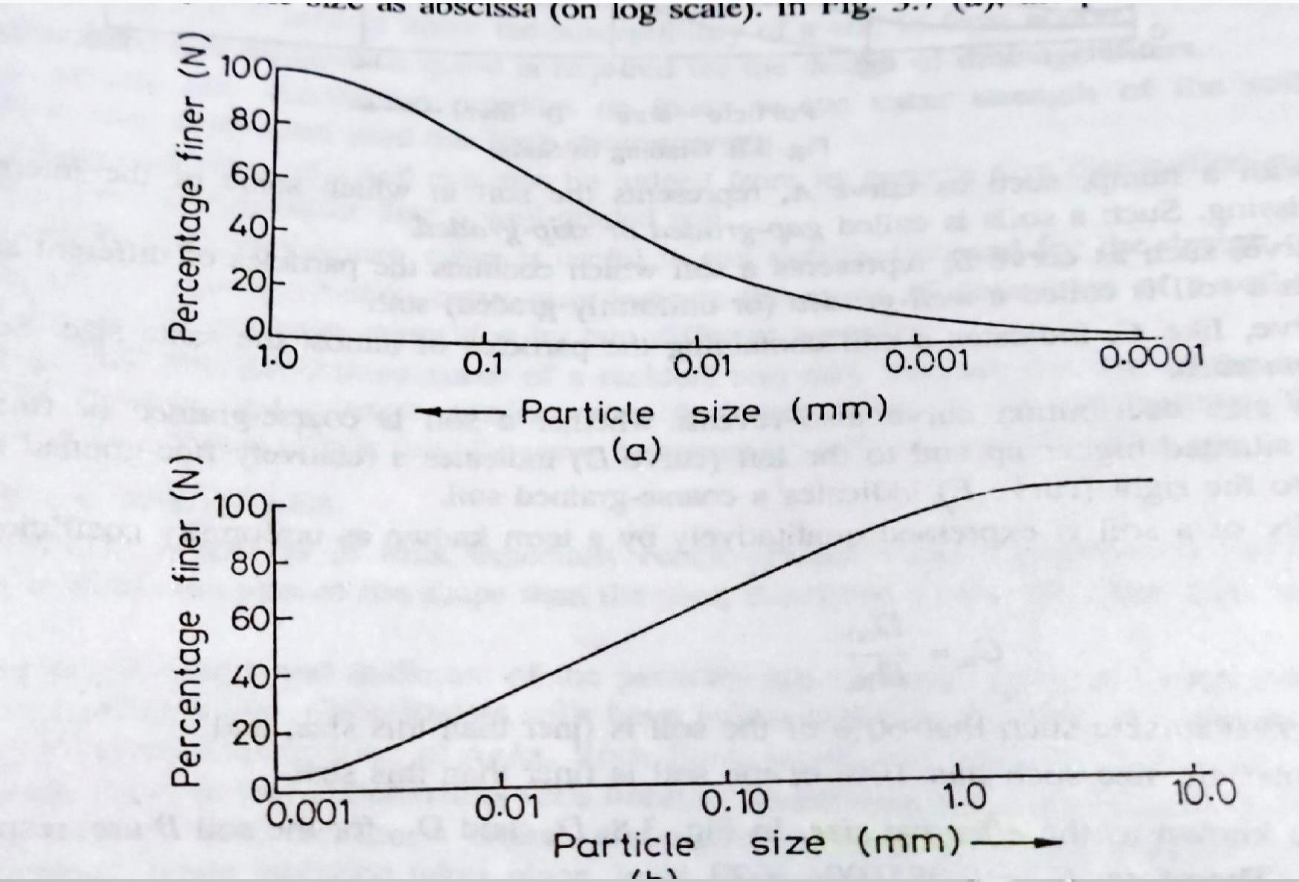
- Particles should be spherical but in actual fine grained particles are flaky in nature.
- Medium is assumed to be infinite but sedimentation jar have fine dimension.
- This law is valid when flow around the particle is laminar and the laminar flow can be maintained when particle size is in between 0.2μ to 200 μ.

NOTE

- If size of particle is greater than 0.2μ, then due to gravity acceleration occurs through out the settlement.
- If size of particle is less than 0.2μ, then Brownian (zig-zag) motion of particles occure that doesn't allow particles to settle.
- Soil particles having size less than 0.2μ can not be analyzed by sedimentation.

PARTICLE SIZE DISTRIBUTION CURVE

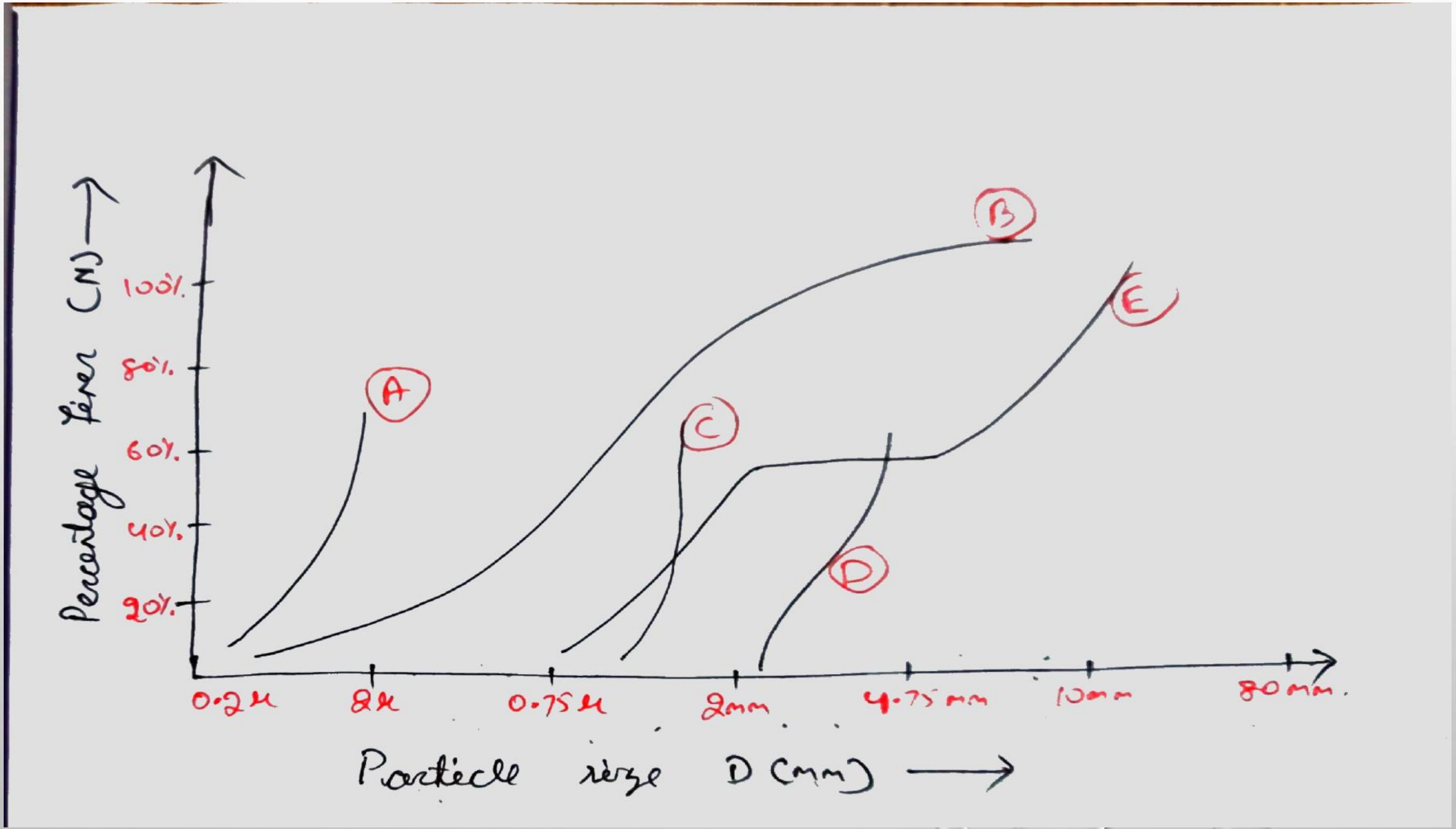
- Particle size distribution curve is also called "gradation curve", that represents the distribution of particles of different size in the soil mass.
- Semi-log graph is used to plot particle size distribution curve of any soil.
- In particle size distribution curve percentage finer is plotted on Y-axis where as particle size in mm is plotted in x-axis.



GRADING OF SOILS

the distribution of different particles of different sizes in a soil mass is called grading.

- Different grades of soil creeats different curves in particle size distribution curve.



A = poorly graded clay

B = well graded coarse grained soil

C = uniformly graded sand

D = poorly graded sand

E = gap graded soil

NOTE

CURVE	SOIL
position	type
shape	gradation
Vertical line	Uniformly graded
Horizontal line	Gap graded

- For coarse grained soil certain size of particles like D_{10} , D_{30} ,D_{60} assumes highest significance than other size of particles as they helps in representing the characteristics of particle size distribution curve in terms of a parameter known as shape factor.
- D_{10} is called effective size of particle.

*Effective size means it is the particle size which if present alone will cause almost same effect as it is caused by all size of particle.

- D10 means size of particle in mm such that 10% particles are finer than that size .

SHAPE FACTOR

1. Coefficient of uniformity

it represents the particle size range(position) of the distribution curve along with gradation.

$C_U = D_{60} / D_{10}$

Where , D_{60} = size of particle such that 60% of soil is finer than this size

D_{10} = particle size such that 10% of the soil is finer than that size

- Larger the numerical value of C_U , the more is the range of particles.

$C_U \approx 1$ uniformly graded

$C_U > 6$ well graded sand

$C_U > 4$ well grade gravel

- But C_U is not sufficient condition to say that a soil is well graded. Hence another shape factor coefficient of curvature is used to define a soil as well graded or poorly graded.

2. COEFFICIENT OF CURVATURE (C_C)

It represents the shape (gradation) of the particle size distribution curve.

$C_C = (D_{30})^2 / (D_{60} \times D_{10})$

if, C_C = (1-3) IT IS WELL GRADED SOIL

$C_C < 1$ OR $C_C > 3$ IT IS POORLY GRADED SOIL

- For well graded soil both Cu and Cc should satisfy. If any of these doesn't satisfies then it is called poorly graded soil.

USES OF PARTICLE SIZE DISTRIBUTION CURVE

Particle size distribution curve is used in classification of coarse grained soil.

- The particle size distribution curve is used for drainage filter.
- 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.
- The compressibility of soil can also be determined by using particle size distribution curve. A uniform soil is more compressible than a well graded soil.
- The particle size distribution curve is useful in soil stabilisation for the design of pavement.
- The particle size distribution of a residual soil may indicate the age of soil deposit. With increasing age, the average particle size decrease because of weathering. Then particle size distribution curve which is initially wavy becomes smooth and regular with age.

RELATIE DENSITY(I_D)

Relative density is one of the most important property of the cohesionless soil.

$I_D\% = (e_{max} - e) / (e_{max} - e_{min})$

$$I_d = \frac{\frac{1}{(\gamma_d)_{min}} - \frac{1}{\gamma_d}}{\frac{1}{(\gamma_d)_{min}} - \frac{1}{(\gamma_d)_{max}}}$$

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

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

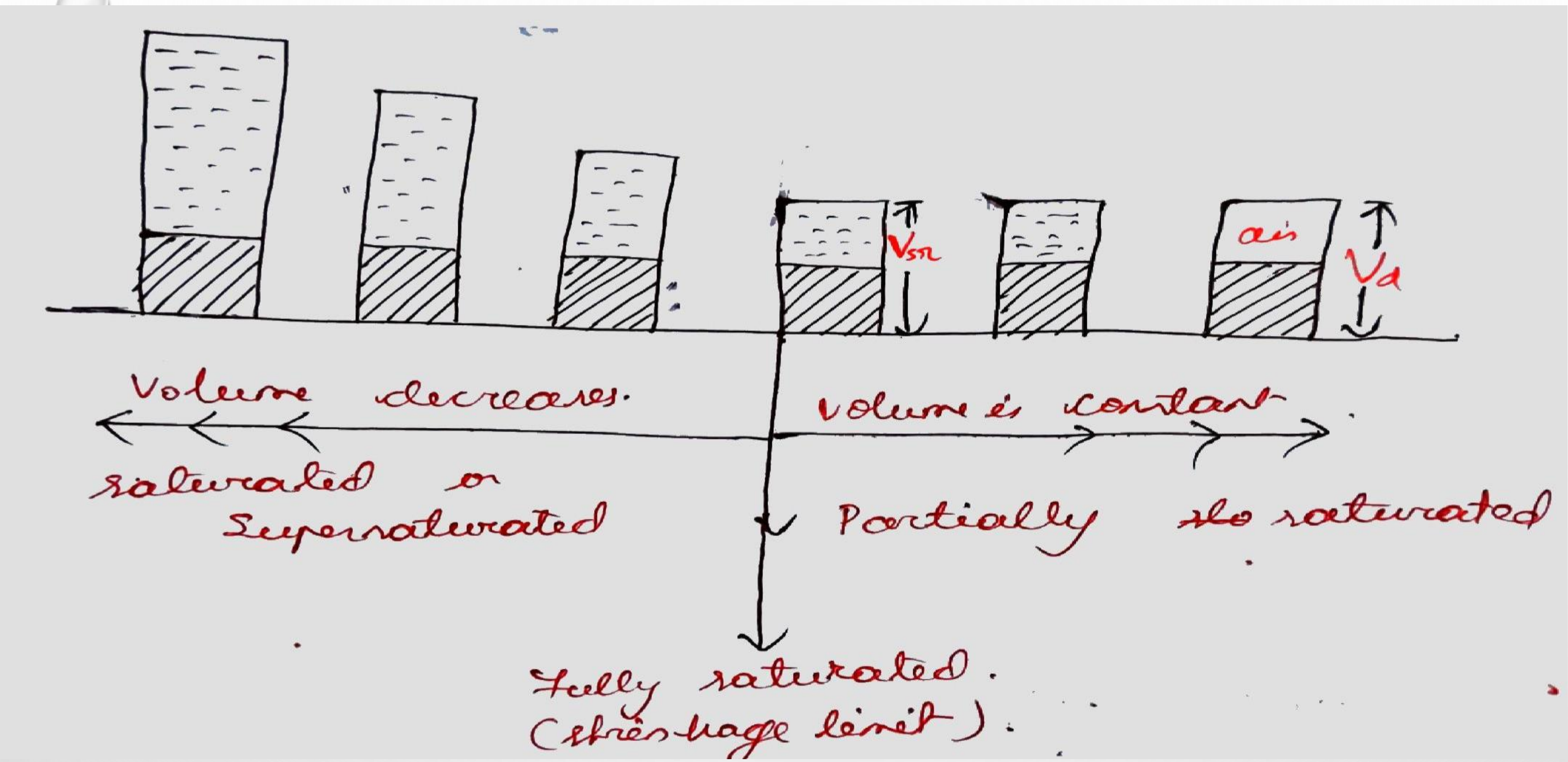
e = void ratio of the soil in its natural state

3.4 CONSISTENCY

Consistency refers to degree of deformation which may be recorded in a soil due to change in water content.

- Consistency term is used for fine grained soil.
- According to Atterberg consistency of soil may be classified in 4 stages and behaviour of soil is different in different stages.

i. liquid state ii. Plastic state iii. Semisolid state iv. Solid state



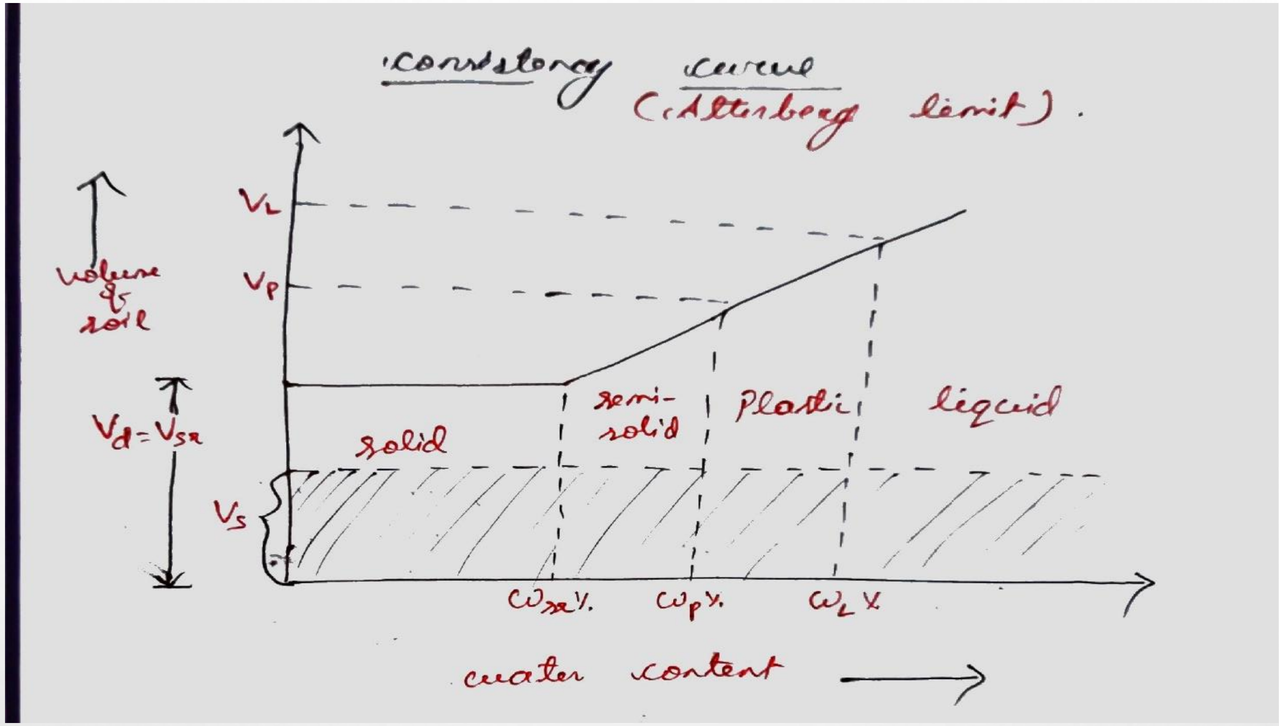
CONSISTENCY LIMITS

The water content between any two stages at which consistency of soil changes is called consistency limits.

V_L = volume of soil at liquid limit liquid limit = V_L

V_L = volume of soil at plastic limit plastic limit = V_L

V_L = volume of soil at shrinkage limit shrinkage limit = V_L



LIQUID LIMIT (W_L %)

It is the water content at which soil passes from liquid state to plastic state and vice versa.

➢ It may also be defined as the minimum water content at which soil is in liquid state and have a tendency to flow.

*Higher the liquid limit of the soil higher the will be the compressibility of the soil.

PLASTIC LIMIT(W_P %)

It is the minimum water content at which soil is in plastic state.

➢ At plastic limit soil passes from plastic state to semisolid state and vice versa.

NOTE

Liquid limit and plastic limit of gravel and sand are very close to each other and it is of no significance because they are non-plastic.

SHRINKAGE LIMIT(W_{sr} %)

It is defined as the maximum water content beyond which if water of soil is reduced then then is no change in the volume of the soil.

- As below shrinkage limit replacement of water by air takes place such that volume of void and volume of soil remain constant.
- Shrinkage limit may be define das the minimum water content at which the soil is fully saturated.

CONSISTENCY INDEXES

Consistency index indicates consistency and firmness of the soil.

A. Plasticity index (I_P %)

It is the range of water content in which soil is in plastic state and exhibits plasticity.

- Plasticity index is the difference between liquid limit and plastic limit.
- Plasticity depends on the type of clay minerals and it's magnitude present in soil and also on the amount of adsorbed water.

$$I_P \% = W_L \% - W_P \%$$

- The property of soil by virtue of which it under go deformation without cracking and fracturing is called plasticity.

B. CONSISTENCY INDEX (I_C)

It represents the effect of consistency on shear strength of soil.

- Greater the consistency index greater will be the shear strength of the soil.

$$I_C = (W_L \% - W \%) / (W_L \% - W_P \%)$$

W = natural water content

C. LIQUIDITY INDEX (I_L)

It is the inverse of consistency index.

- It also represents consistency of soil in terms of it’s strength.

$$I_C = (W \% - W_P \%) / (W_L \% - W_P \%)$$

CHAPTER 3
CLASSIFICATION OF SOIL

Soil classification is the process of arranging the soil into different groups such that the soil in a particular group have similar behaviour.

For a soil classification system to be useful to the geotechnical engineers, it should have following basic requirements:

1. It should have limited number of groups.
2. It should be based on engineering properties which are most relevant for the purpose for which classification has been made.
3. It should be simple and should use the terms which are easily understood.

CLASSIFICATION OF SOIL CAN BE DONE BY ANY OF THE FOLLOWING METHODS:

1. Particle size classification
2. Textural classification
3. AASTHO classification
4. Unified soil classification system
5. Indian standard soil classification system

A. PARTICLE SIZE CLASSIFICATION:

The size of individual particle present in soil has an important influence on the behaviour of soil. In this method soils are classified on the basis of their sizes(dia.).

CLASSIFICATION OF SOIL BASED ON PARTICLE SIZE

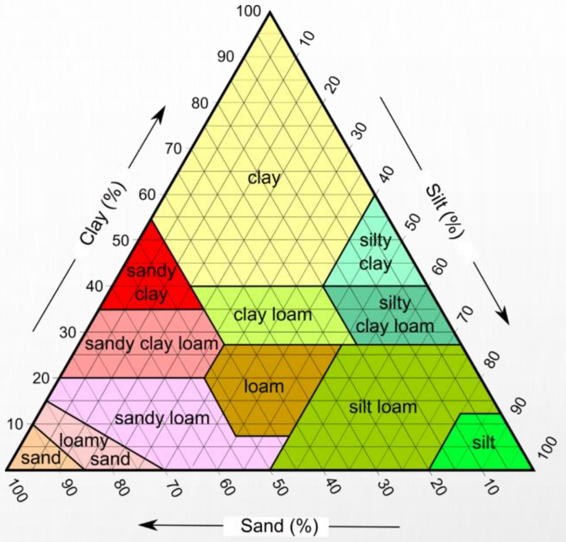
- CLAY <0.002MM
- SILT (0.002-0.075)MM
- SAND (0.075-4.75)MM
  - FINE SAND (0.075-0.425)MM
  - MEDIUM SAND (0.425-2)MM
  - COARSE SAND (2-4.75)MM
- GRAVEL (4.75-80)MM
  - FINE GRAVEL (4.75-20)MM
  - COARSE GRAVEL (20-80)MM
- COBBLE (80-300)MM
- BOULDAR >300MM

B. TEXTURAL CLASSIFICATION

- Texture means visual appearance. The visual appearance of soil is called soil texture.
- The texture depends on the particle size, shape of the particles and gradation of the particles.
- In this method the classification of soil is done on the basis of relative percentage of clay, silt sand present in it.
- In this method standard texture chart is used to classify the soi'.
- Modified textural chart come into existence to eliminate the term loam present in the chart.

  * LOAM: Loam is a mixture of clay, silt and sand in different proportion.

- The term loam is replaced by soil engineering terms as silty clay, clayey silt etc. .
- In this case major component of soil is used as noun and less prominent component is used as adjective.



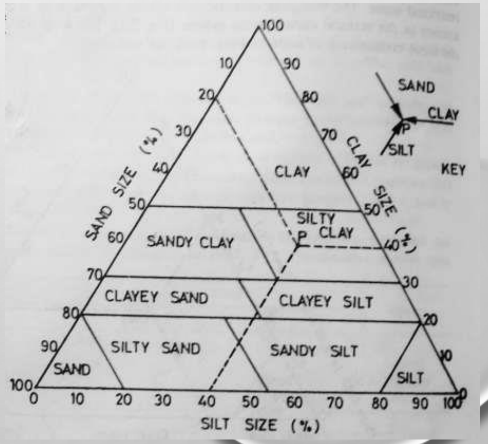
(Textural Classification Chart)

C. AASTHO CLASSIFICATION SYSTEM(AMERICAN ASSOCIATION OF STATE HIGHWAYS AND TRANSPORTATION OFFICIAL CLASSIFICATION)

- This method is generally used for classifying the soil used in construction of highways.
- In this method particle size, plasticity of soil, compressibility of soil are used to classify the soil.
- Performance of the soil when used in pavement construction is described on the basis of an index known as "group index".

$$GI = 0.2a + 0.005ac + 0.01bd$$

- GI Value ranges between 0-20.
- As the GI Value increases the quality of soil gradually decreases.



(MODIFIED TEXTURAL CLASSIFICATION CHART)

GI	QUALITY OF SOIL
0-2	Good
2-5	Fair
5-10	Poor
10-20	Very poor

a = portion of percentage passing through 75µ sieve greater than 35% but not exceeding 75%

$a = (\%\text{ passing through } 75\mu \text{ sieve} - 35\%) \quad \ngeq 40\%$

b = Portion of percentage passing through 75µ sieve greater than 15% but not exceeding 55%

$b = (\%\text{ passing through } 75\mu \text{ sieve} - 15\%) \quad \ngeq 40\%$

c = it is the part of liquid limit which is greater than 40%

$c = (W_L\ \% - 40\%) \quad \ngeq 20\%$

d = it is the part of plasticity index

$d = (I_P\ \% - 10\%) \quad \ngeq 20\%$

* while calculating a, b, c, d if any value comes negative then it will be taken as zero.

D. UNIFIED SOIL CLASSIFICATION SYSTEM

In this method soil is broadly classified into two groups, coarse grained soil and fine grained soil.

E. INDIAN STANDARD SOIL CLASSIFICATION SYSTEM

- In this method soil is broadly divided into two groups, coarse grained soil and fine grained soil.
- Classification of coarse grained soil is done on the basis of particle size, coefficient of uniformity, coefficient of curvature, fineness.
- Fine grained soil is classified on the basis of particle size, plasticity of soil and compressibility of soil.
- A soil is termed as coarse grained soil if 50% or more than 50% soil mass retains over 75μ sieve, otherwise it is called fine grained soil.

* FINENESS- It is the percentage of soil fraction smaller than 75μ in the soil mass.

SYMBOLS USED TO IDENTIFY THE TYPE OF SOIL:

G = Gravel S = SAND M = Silt C = Clay O = Organic soil

PT = Peat soil(highly organic) W = Well graded P = Poorly graded

L = Low compressible($w_l < 35\%$) I = Medium compressible($35\% < W_L < 50\%$) H = Highly compressible($W_L > 50\%$)

CLASSIFICATION OF COARSE GRAINED SOIL

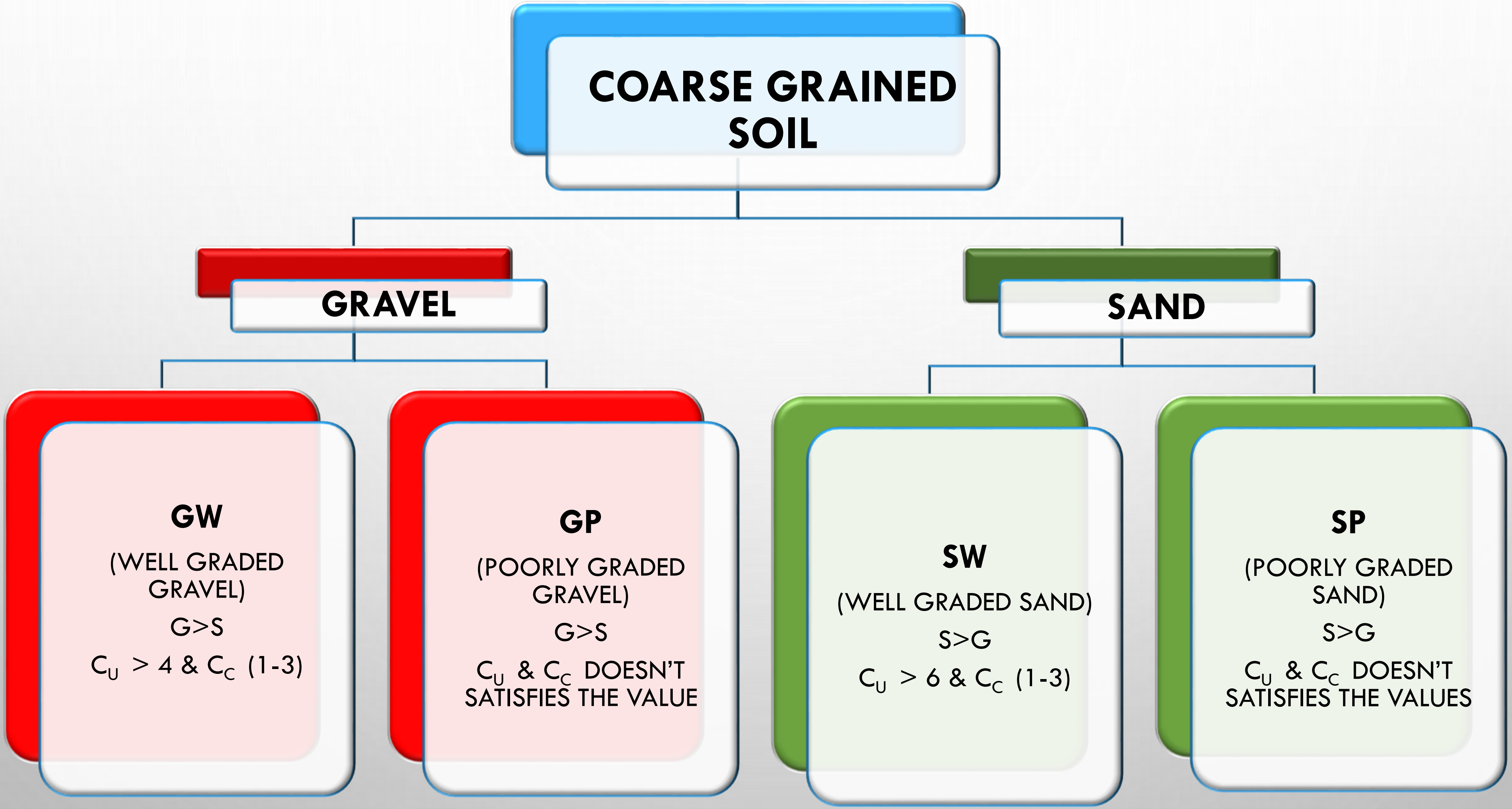
When fineness is < 5% (gradation is important but silt and clay content is not important)

When 5% < fineness < 12% (gradation along with silt and clay content is important)

When fineness is > 12% (gradation is not important but silt and clay content is not important)

1. WHEN FINENESS IS < 5%

Only gradation is important but silt and clay content is not important.

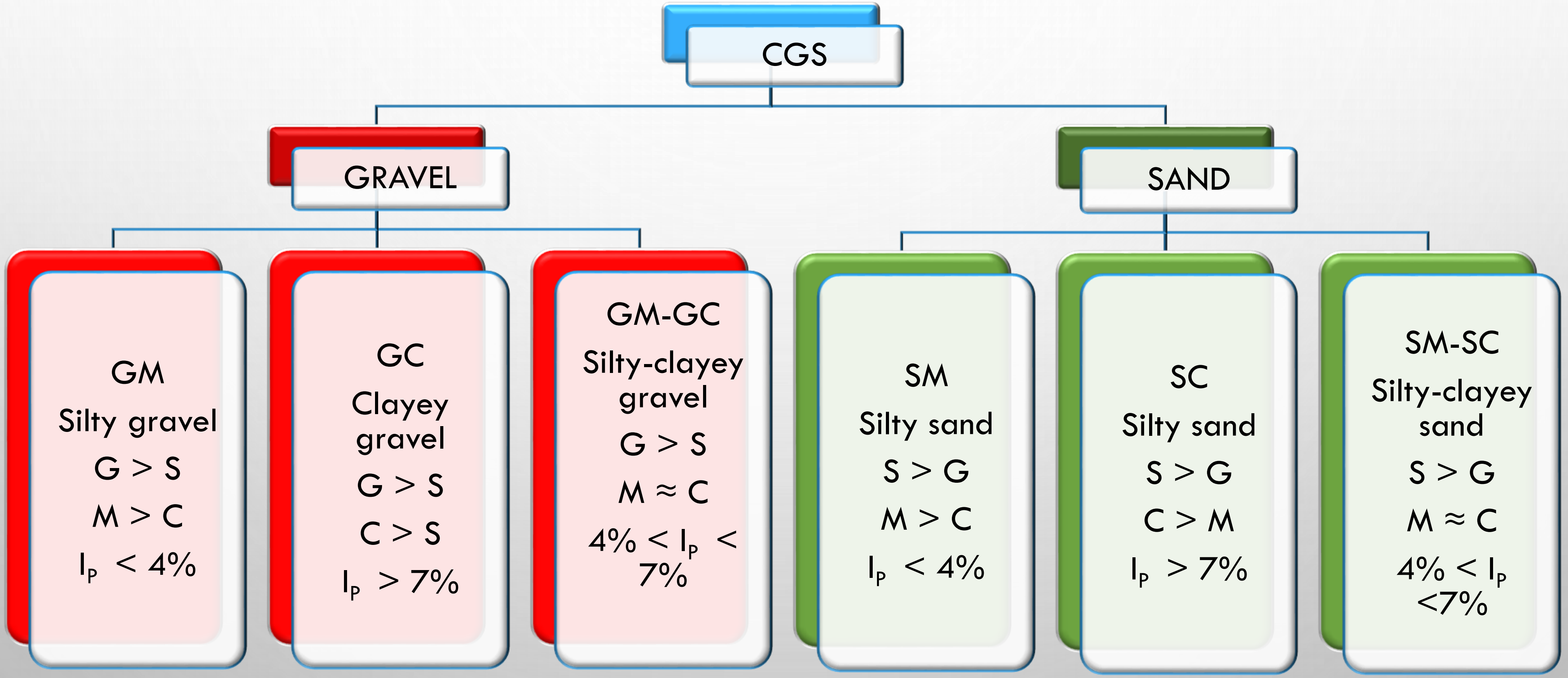


* Gradation means weather a soil is well graded or poorly graded.

1. WHEN FINENESS IS > 12%:

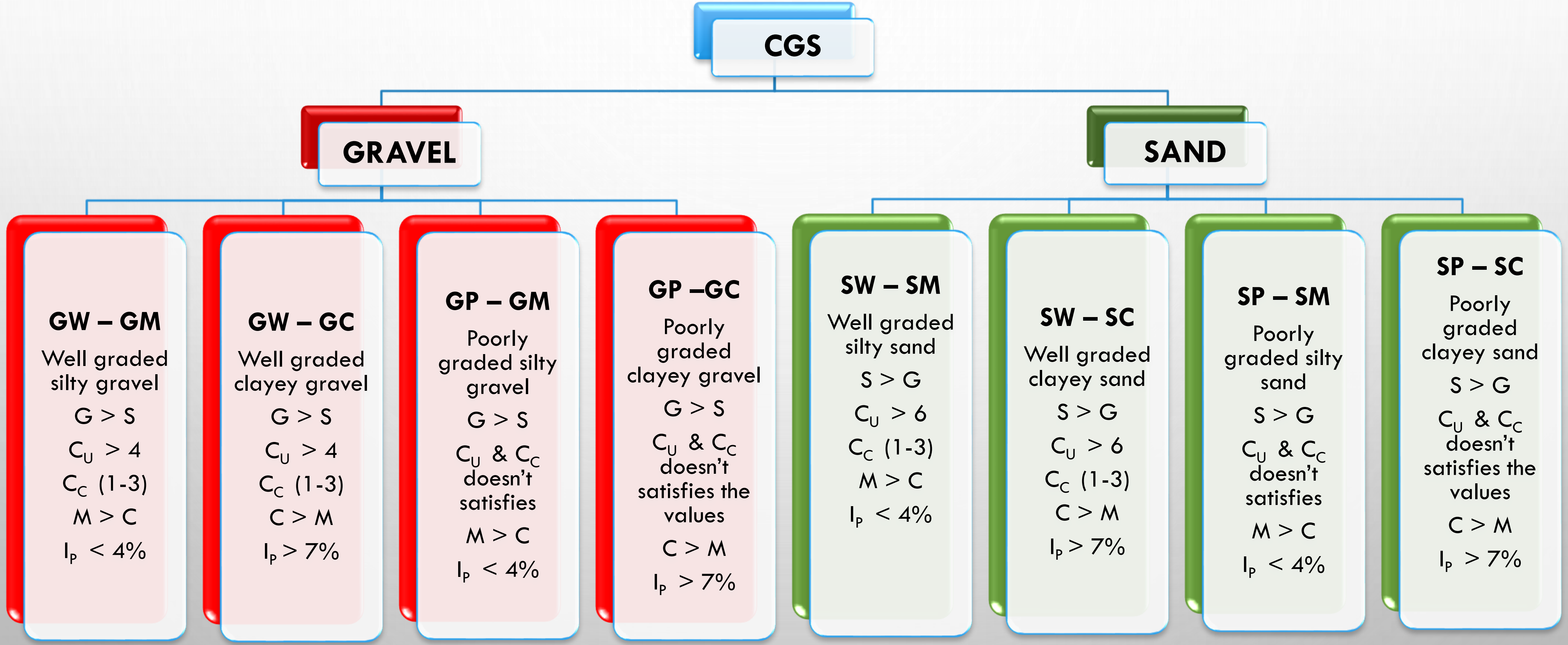
In this case gradation is not important but silt and clay content is important.

- As in this case portion of fine grained soil is significant, so plasticity chart is used to classify the soil.



3. WHEN FINENESS IS BETWEEN (5 – 12)%:

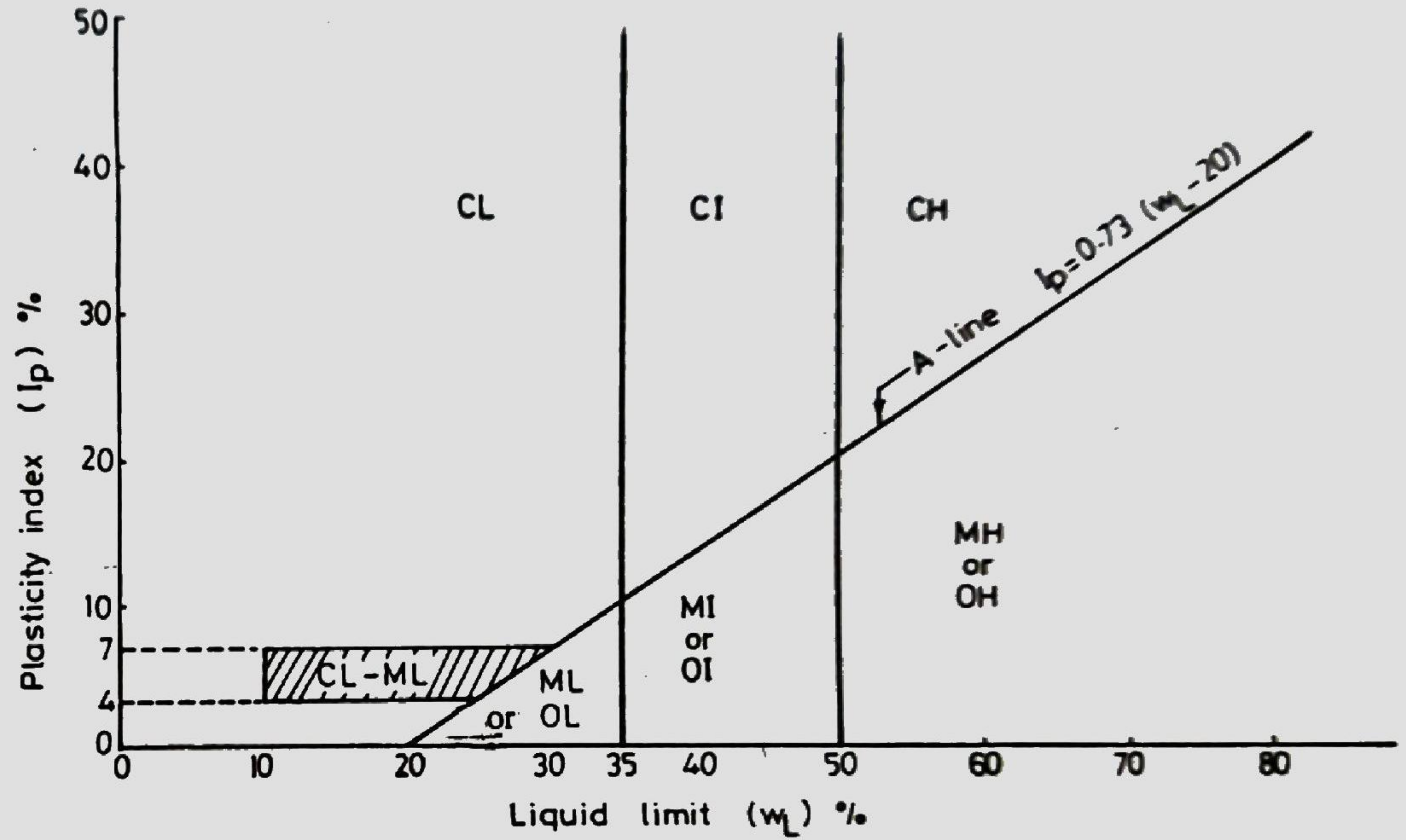
In this case both gradation as well as silt and clay content is important.



CLASSIFICATION OF FINE GRAINED SOIL

When more than 50% of the total soil sample passes through 75µ sieve, that soil is called fine grained soil.

- Fine grained soil are classified on the basis of particle size, compressibility and plasticity.
- Plasticity chart is used to classify fine grained soils.
- Plasticity chart consists plasticity index and liquid limit.
- In order to separate inorganic clay from inorganic silt and organic soil , casagrande defined a line termed as a – line, which represents the relation between w_l & i_p .
- Soil above A – line are clay and soil below A – line is silt or organic soil.



CL
CI
CH
A-line
$I_p = 0.73 (w_L - 20)$
CL-ML
ML or OL
MI or OI
MH or OH
Plasticity index (I_p) %
Liquid limit (w_L) %
0
4
7
10
20
30
40
50
0
10
20
30
35
40
50
60
70
80

CHAPTER – 5

PERMEABILITY AND SEEPAGE

5.1 Permeability (k)

It is the ability of the medium to permit the flow of fluid through its inter connecting voids. It is also known as hydraulic gradient.

- Permeability of coarse grained soil is grater than permeability of fine grained soil.
- When a soil is pervious water can flow through it but when the soil is impervious water can not flow through the soil.
- A completely impervious soil is practically impossible but a soil is assumed to be impervious when it has a very low value of permeability.
- Flow of free water depends upon the permeability of soil and the head causing flow.

SOIL	K (cm/sec)
Gravel	>1
Sand	$1 - 10^{-3}$
Silt	$10^{-3} - 10^{-6}$
Clay	$< 10^{-6}$

Darcy's law

The flow of free water through the soil is governed by darcy's law.

As per darcy's law for laminar flow condition in homogeneous saturated soil mass, velocity of flow through soil (v_f) is directly proportional to the hydraulic gradient.

$$V \propto I$$

$$V = KI$$

$$i = (H_1 - H_2) / L = H / L$$

i=Hydraulic gradient (head loss per unit length)

K = Coefficient of permeability (in cm/sec or m/sec)

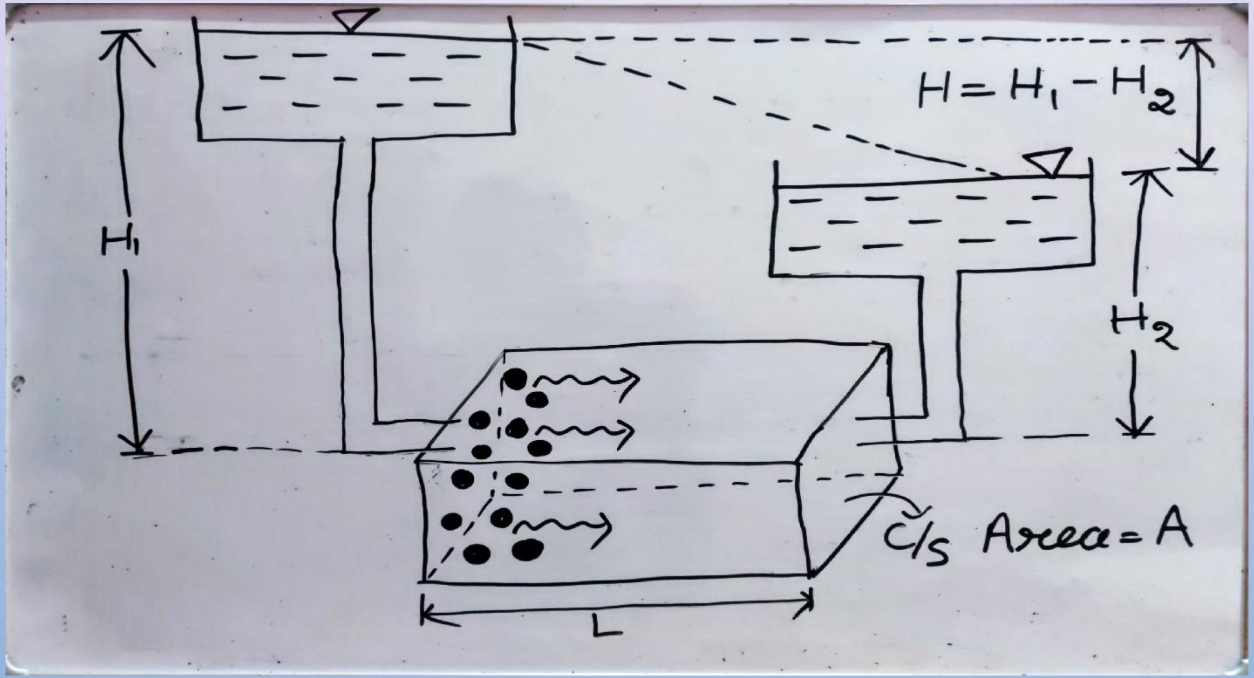
V = Velocity of flow / flow velocity / discharge velocity / superficial velocity / average velocity

According to darcy's law the discharge q is obtained by multiplying the velocity of flow (V) by the total cross sectional area of the soil (A) normal to the direction of flow.

$$Q = VA = k\,i\,A$$

* Darcy's law is valid only when the soil is homogeneous, saturated and flow through the soil is laminar.

Darcy's law is not valid in case of gravels, as flow through gravels is turbulent.



The velocity of flow considered above is the average velocity or discharge velocity and it is considered that the flow of water tales place through the total area of the section.

But in actual the flow takes place through the voids present in the soil and the area of the voids is comparatively smaller than the total area of the soil. Hence the velocity of flow is more than the average velocity. Hence seepage velocity is considered as the true velocity.

Total discharge is same incase of both seepage velocity and average velocity.

$$Q = V_{AVG} \times A_{SOIL} = V_{SEEPAGE} \times A_{VOID}$$

There is a relation between actual velocity or seepage velocity and average velocity or discharge velocity as given below

$$V_S = V_{AVG} / n$$ (as $0 < n < 1$ hence $V_S > V_{avg}$)

Where;

V_S = Seepage velocity V_{AVG} = Average velocity N = Porosity

According to darcy's law $V_S = K_P\ i$ where, K_P = coefficient of percolation

$$K_P = K / n$$

K_P indicates seepage velocity of flow through the voids

K indicates average velocity of flow through the soil

5.2 factors affecting the coefficient of permeability

Coefficient of permeability is the function of medium properties and flow properties.

$$k = C \left(\frac{\gamma_w}{\mu}\right)\left(\frac{e^3}{1+e}\right) D^2$$

Following are the factors affecting the coefficient of permeability

1. Particle size

As it is clear from the above equation that permeability is directly proportional to the size of the particle. Hence permeability of coarse grained soil is grater than the permeability of fine grained soil.

2. Structure of the soil mass

Shape of the flow passage affects the permeability of the soil. Size of the passage depends on the structural arrangement of the soil particles. For same value of void ratio permeability in case of flocculated structure is more than in case of dispersed structure.

3. Shape of the particles

The permeability of the soil depends on the shape of the soil particles. For a given value of void ratio soil with angular particles is less permeable than soil with rounded particles because specific surface area of angular particle is greater than in case of rounded particles.

4. Void ratio

For a given soil sample greater the value of void ratio higher is the permeability of the soil. The permeability of the soil at a given void ratio has no relationship with permeability of another soil with same void ratio. But it is observed that soil with highest void ratio are least pervious. Because the size of the voids in such type of soil are very small through which water can't flow easily.

5. Degree of saturation

If the soil is not fully saturated then air pockets are presents in the soil mass which provides a resistance to the flow of fluid through the soil mass. Hence, as the degree of saturation of soil increases air content in soil decreases which decreases the resistance developed towards the flow of the fluid and permeability increases. Darcy's law is not strictly applied to such soils.

6. Adsorbed water

In case of fine grained soils there is a layer of adsorbed water strongly attached to the surface which doesn't under gravitational force. More the quantity of adsorbed water present in the soil there is less place available for the fluid to flow due to which permeability decreases.

7. Impurities in water

Any foreign impurities in water has a tendency to block the passage. Hence more is the impurities present in water less is the permeability of the soil.

8. Viscosity of the fluid

More is the viscosity of the fluid , the more it provides resistance against flow hence permeability of the soil decreases.

9. Density of the fluid

As the density of the fluid increases the permeability of the soil decreases.

10. Texture of the solids

As the roughness of the soil solids increases the resistance against flow increases hence permeability decreases. But as the smoothness of the soil solids increases the resistance against flow decreases and permeability increases.

5.2. A. Constant head permeabilith test

- This method is suitable for coarse grained soil for which substantial discharge can be obtained in the given time during the test.
- In thus method water is allowed to flow through the soil sample under constant head in order to analyze its permeability by noting the amount of water collected flowing through it.
- Constant head permeability test is conducted in an instrument known as permeameter. Constant head permeameter consists of a metallic mould of 100mm internal diameter, 127.3mm effective height and 1000ml capacity.
- The mould is also provide with a detachable collar of 100 mm dia. And 60 mm height which is required during compaction of soil.
- The mould is also provided with a drainage valve and an air release valve.
- Procedure:

Before conducting the constant head permeability test make sure that the soil is fully saturated condition.

Place the soil sample inside the mould in between two porous discs. Make sure that the porous discs are properly deaired before placing them inside the mould.

- If the sample is not saturated before conducting the test first of all fully saturate the soil sample. After the sample is saturated the constant head is connected to the drainage cap and water is allowed to flow through the drainage base still a steady-state of flow is achieved.
- The water level in the constant head chamber in which the mould is kept constant and before starting the experiment the water is filled upto the berm.
- The water which overflows after entering through the chamber is collected in a graduated jar for a convinient period.
- The difference in head between the constant head reservoir and the constant head chamber is the head that is responsible for the flow of water through the soil.

As we know $Q = K\,i\,A$ and $i = H / L$

So, $Q = K \cdot (H/L) \cdot A$

$$\Longrightarrow K = \frac{V \, .L}{t \, .H \, .A}$$

H = head loss

L = length of the flow

T = time taken for the experiment

A = cross-sectional area of the soil sample

V = volume of the water collected in the graduated jar

B. Falling head permeability test

- As the water collected in the graduated jar of the constant head permeability test is very less hence, falling head permeability test is done for the fine grained soil or less permeable soil.
- In this test a stand pipe of known cross-sectional area(a) is placed in the top of the soil sample of cross-sectional area(a) and water is allowed to flow through it.
- The whole assembly is placed in a constant head chamber filled with water up to the brim. The porous discs and the water pipe should be deaired before starting the experiment. Before starting the experiment the soil sample should be in fully saturated state.
- The test is started by allowing the water to pass through the soil and the overflowing water is collected in a graduated jar.
- The time required for the water level to fall from h1 head to h2 head is noted down. The head is measured with reference to the water level in the constant head chamber.

According to the falling head permeability test coefficient of permeability can be defined as

$$K = 2.303 \times \frac{a\,L}{A\,\Delta t}\log\left(\frac{h1}{h2}\right)$$

a = cross-sectional area of the stand pipe

A = cross-sectional area of the soil sample taken

L = length of the soil sample

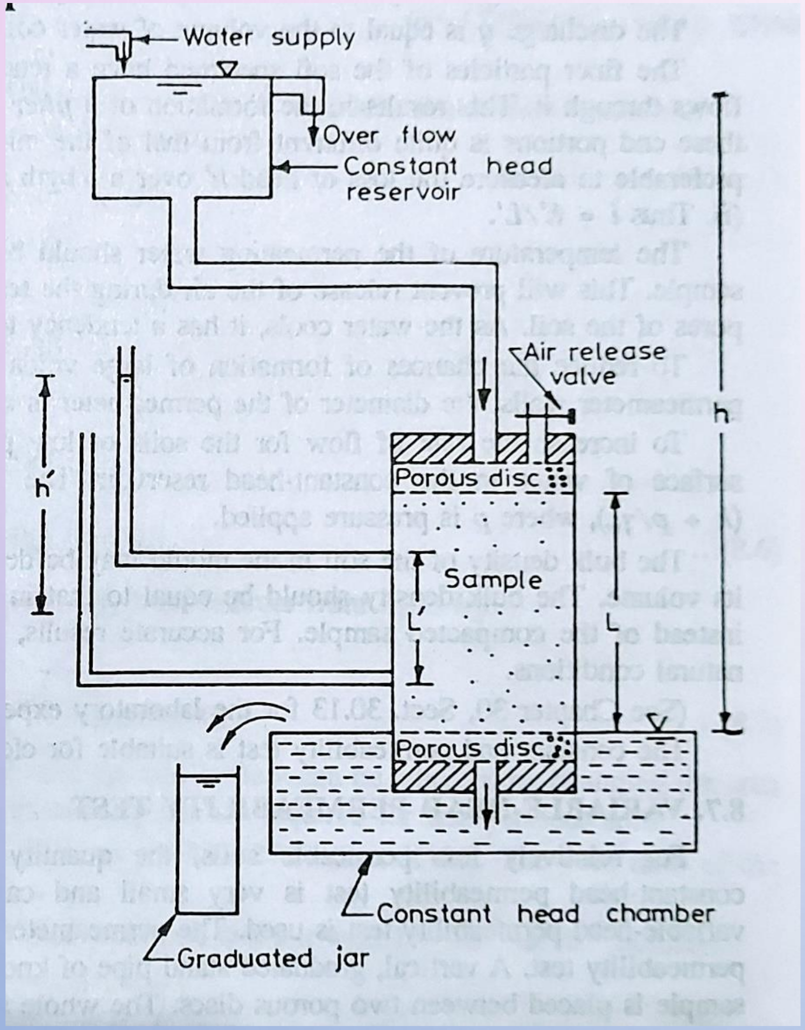
$\Delta t = time\ taken\ for\ the\ water\ to\ fall\ from\ h1\ head\ to\ h2\ head$

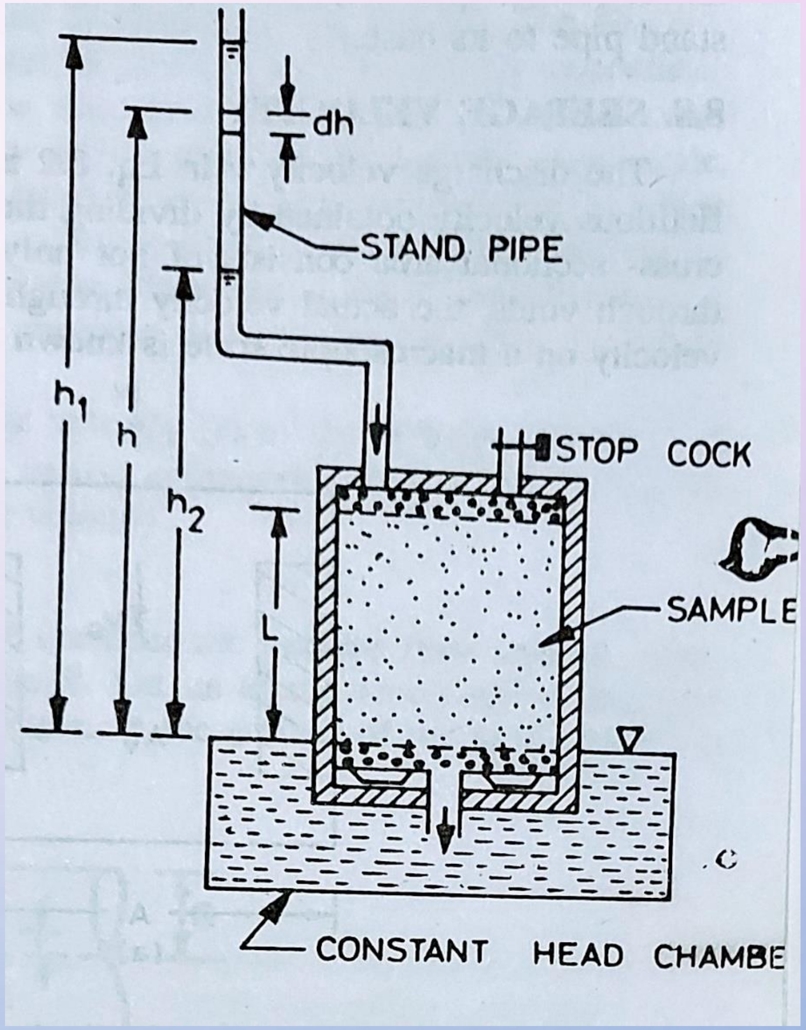
h1 = head of water at time t1

h2 = head of the water at time t2

NOTE : if time taken for the water to fall form head h1 to h2 is “t” sec. And from h2 to h3 is also “t” secs. The,

$$h2 = \sqrt{h1h3}$$


Water supply
Over flow
Constant head
reservoir
Air release
valve
h
h'
Porous disc
Sample
L'
L
Porous disc
Constant head chamber
Graduated jar


dh
STAND PIPE
h_1
h
h_2
STOP COCK
L
SAMPLE
CONSTANT HEAD CHAMBE

5.4 Seepage

Seepage is a process in which water flows from higher head to lower head in a porous medium under the effect of gravitational force.

- When water flows through the soil mass at every point in the soil mass there exists 3nos. Of heads named as pressure head, datum head and velocity head.
- Since seepage flow through the soil mass is laminar and velocity of flow is very less hence the velocity head van be neglected. So the total head at any point can be calculated as summation of pressure head and datum head.

Hydraulic head or seepage head

This can be defined as the difference of total head between two points in the soil mass under which flow occurs from one point to another.

Pressure head

It can be found either by observing the height of water table above the concerned section or by observing then rise of water in the peizometer if piezometer is inserted in the concerned section.

Pressure head = h

Datum head

It is the elevation of the concerned section above the datum line.

Datum head = Z

Total head = pressure head + datum head

NOTE : If datum is changed then there will be no change in pressure head and seepage head but total head and datum head will change at any point.

Seepage pressure and seepage head

When water seeps through the soil mass it exerts frictional drag on the soil particles in the direction of flow. This drag force results in seepage pressure on the soil mass in the direction of flow.

- If 'h' is the hydraulic head (seepage head) under which seepage takes place then seepage pressure can be defined as

$P_S = h \gamma_w$ where, h = seepage head p_s = seepage pressure

$I = \frac{h}{Z}$ $\Longrightarrow h = i\,Z$

$\therefore$ $P_S = i\, Z\, \gamma_w$

seepage force = seepage pressure x area

$F_S = i\, Z\, \gamma_w\, A$

Total stress (σ):

Total stress at any given plane section in a soil mass is due to two things, such as: 1. Self weight of the soil mass above the concerned section 2. Overburden pressure

- Total stress constitutes of two components i.e; efeective stress and pore water pressure

Total stress = effective stress + pore water pressure

$$\sigma = \sigma' + u$$

σ = Total stress σ' = effective stress u = pore water pressure

EFFECTIVE STRESS(σ'):

These are the stresses which are being transferred by grain to grain contact that's why it is also called intergranular pressure.

- Effective stress leads to decrease in void ratio and permeability of the soil and increases degree of denseness stability and bearing capacity of the soil.
- There is no method available to find the effective stress directly. The effective stress is calculated indirectly by the formula given below.

$$\sigma' = \sigma - U$$

PORE WATER PRESSURE(U):

It is the pressure caused by the pore water. It is equal to the weight of the water per unit area above the concerned section of the water. As this pressure acts all around the soil solids and it doesn't tend to force the soil solids to come in contact with each other hence this is also known as "neutral pressure".

$$U = h\,\gamma_w$$

NOTE

Pore water pressure at a point is calculated either by observing height of water table above concerned point or by observing rise of water level in the piezometer if it is inserted at any point.

- Seepage pressure always acts in the direction of flow.
- If seepage takes place in vertically downward direction then seepage pressure also acts in downward direction which force soil solids in downward direction that results soil solids come closer to each other hence effective stress increases.
- If flow takes place in upward direction then seepage pressure acts in upward direction which results in decrease in effective stress.

QUICKSAND CONDITION:

When flow takes place in upward direction, seepage pressure acts in upward direction due to which effective stress at each point in soil mass decreases.

- If seepage pressure is such that effective stress at most critical point reduces to zero , in such case cohesionless soil mass looses it's shear strength and has tendency to flow along with water.
- This phenomenon in which soil particles leave the soil mass and flow along with water is termed as quick sand condition or piping condition or sand boiling condition.
- The hydraulic condition at which quick sand condition occurs is called critical hydraulic gradient or piping gradient or floating gradient.

$$i_{cr} = \frac{G - 1}{1 + e} = (g - 1).(1 - n)$$

NOTE:

Quick sand is not a type of sand, it is a flow condition in cohesionless soil mass when effective stress reduces to zero due to upward flow.

- Quick sand condition generally occurs in fine sand and silt and not in gravels, coarse sand and clay.
- For fine sand and silt the value of critical hydraulic gradient is approximatly equal to 1.

CHAPTER6

COMPACTION AND CONSOLIDATION

PREPARED BY : LOPAMUDRA NAYAK

COMPACTION

COMPACTION

- Compaction is a process of increasing the unit weight of the soil (decreasing the volume of soil and voids of soil) by forcing the soil solids into a dense state by reducing the air voids.
- In this process the soil particles are rearranged artificially and packed together into a compacted state by mechanical process in order to decrease the void ratio, permeability and to increase the denseness and unit weight of the soil mass.
- Compaction can be done by using roller, rammer and vibrators.
- The more compacted the soil is more is the denseness and unit weight of the soil.

LIGHT AND HEAVY COMPACTION TEST

IS LIGHT COMPACTION TEST:

As per IS : 2720 (part VII) a standard mould of 100 mm diameter, 127.3 mm height and 100 ml capacity is used for the light compaction test. A rammer of 2.6 kg is used for the light compaction test with a free fall height of 310 mm and a face diameter of 50 mm.

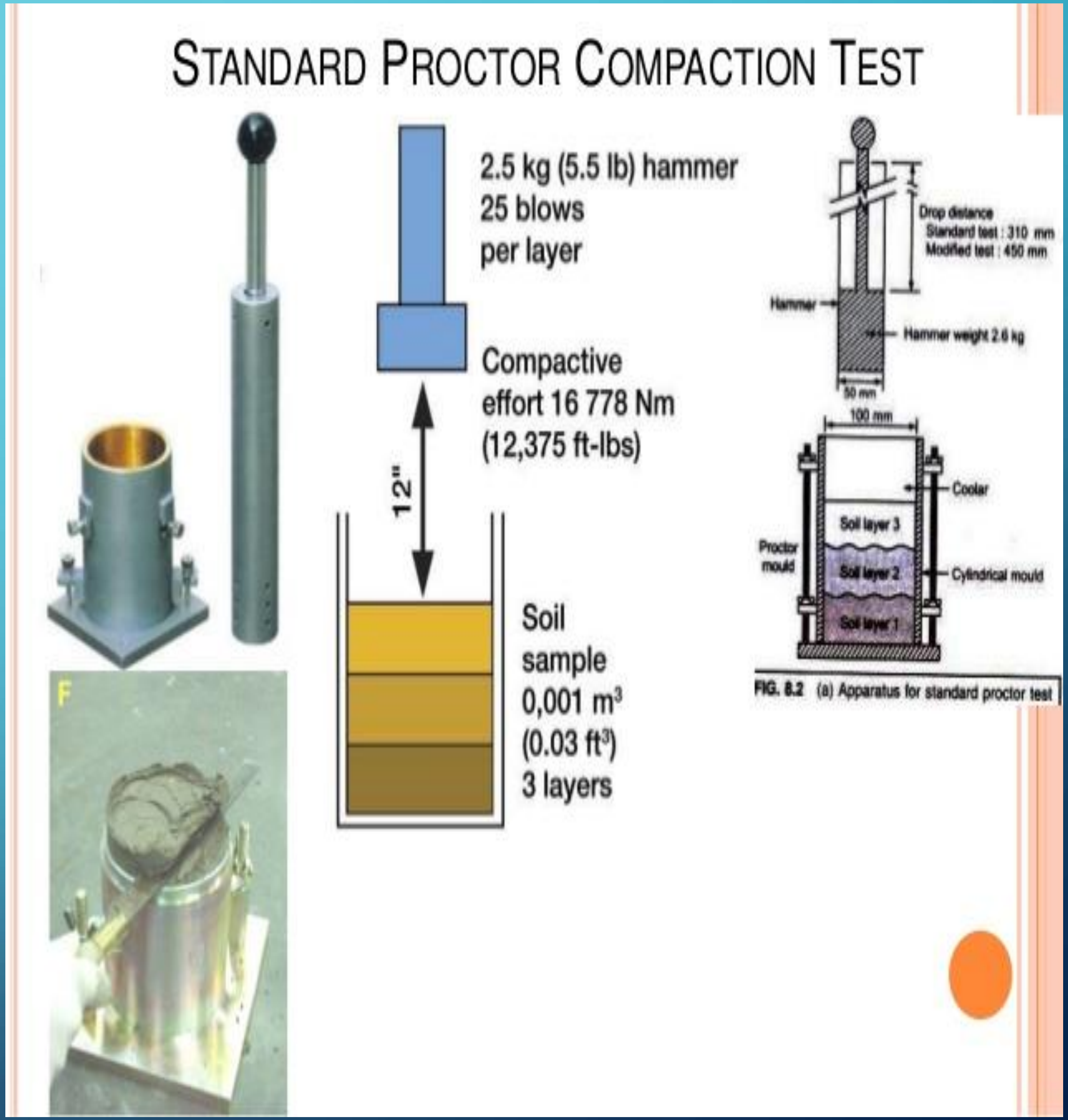
Procedure:

- About 3 kg of air-dried, pulverized soil passing through the 4.75 mm sieve is taken for the test. Water is added to the soil to bring the water content of the soil to about 4% if the soil is coarse grained and 8% if the soil is fine grained and the soil is covered with a wet cloth and left for maturing for about half an hour.
- The mould is cleaned, dried and greased properly and the weight of the empty mould with base plate is taken and then the mould is fitted to the base plate of the soil.
- Then the mould is filled with the matured soil up to one third the height of the mould. The soil is compacted by 25 nos. of blows using the rammer. While ramming the soil make sure that blows are evenly distributed over the surface of the soil.
- After this the surface of the soil is scratched a little and then the second layere is added and blows are given in same manner as in the first layer and likewise third layer compacted. The third layer is projected above the top of the mould into the collar by not more than 6 mm.
- Then the collar is removed and the surface is trimmed off and levelled properly.
- The mass of the mould, base plate and the compacted soil is taken, and thus the mass of compacted soil is determined.

- Representative soil samples are taken from the bottom, middle and top of the soil sample to determine the water content of the sample. Then the dry unit weight of the sample is calculated from the water content and bulk unit weight.

$$\gamma_{bulk} = \frac{W}{V}$$

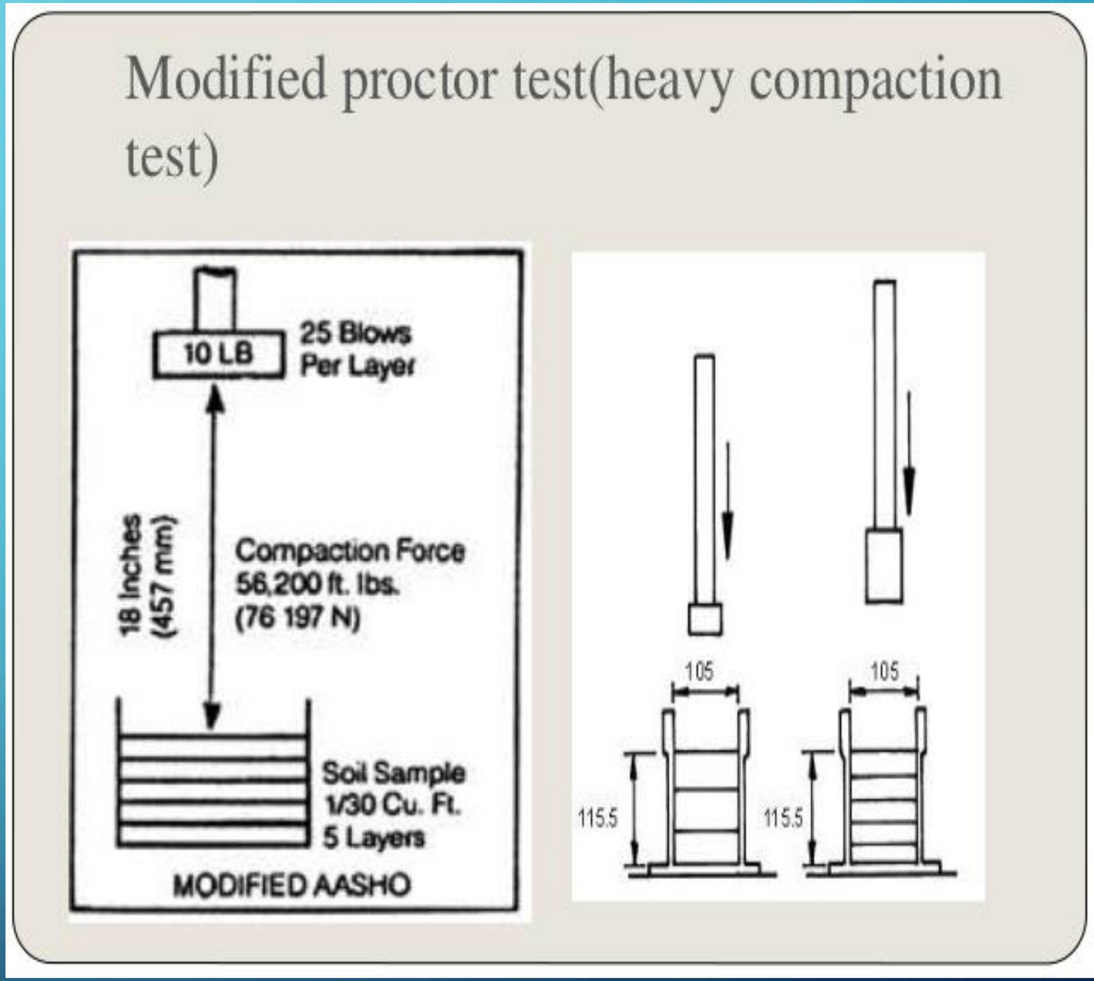
$$\gamma_{dry} = \frac{\gamma_{bulk}}{1+W}$$



IS HEAVY COMPACTION TEST:

IS heavy compaction test was developed to represent heavier compaction than that in light compaction test. This test is used to simulate the field conditions where heavy rollers are used.

- In heavy compaction test the mould used is same as in light compaction test but the rammer used is much heavier and the free fall height is more than light compaction test.
- The rammer used in heavy compaction test has a weight of 4.89 kg and a free fall height of 450 mm. in heavy compaction test the soil is compacted in three layers instead of five layers.
- The procedure of finding out dry unit weight and water content of the soil is same as in light compaction test.



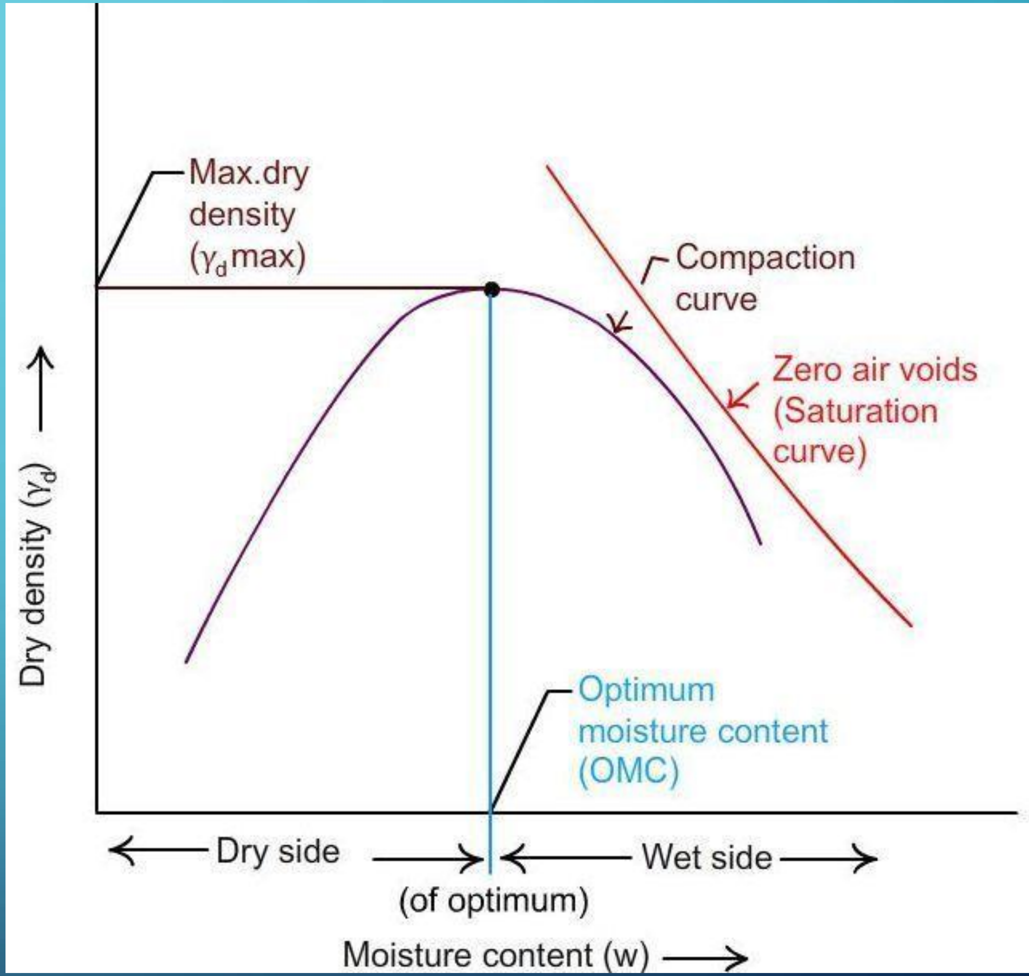
COMPACTION CURVE:

After performing the compaction on soil, sample of soil is collected in the containers and tested for the water content and dry unit weight of the soil.

- Dry unit weight on different water content is observed on same compactive effort.
- Result of the above experiment is plotted as a curve named as compaction curve. In compaction curve water content is taken in x-axis and dry unit weight is taken in y-axis.
- This compaction curve further used to find out the water content at which maximum dry unit weight is achieved and that water content is called "optimum moisture content".

NOTE: For a given value of water content maximum dry unit weight is achieved when there is complete removal of air from the soil takes place.

- For a given soil mass maximum dry unit weight is achieved when the degree of saturation is 100% or the air content is 0% and this dry unit weight is called theoretical dry unit weight. As the water content increases the theoretical maximum dry unit weight decreases.



AIR VOID LINE:

A line showing the relationship between water content and dry unit weight at a constant percentage of air voids is called air void line.

equation of air void line : $\frac{(1-n_a)G\Gamma_w}{1+wG}$

SATURATION LINE:

A line showing relationship between water content and dry unit weight at constant percentage of degree of saturation is termed as saturation line.

Equation of saturation line : $\frac{G\Gamma_w}{1+\frac{WG}{S}}$

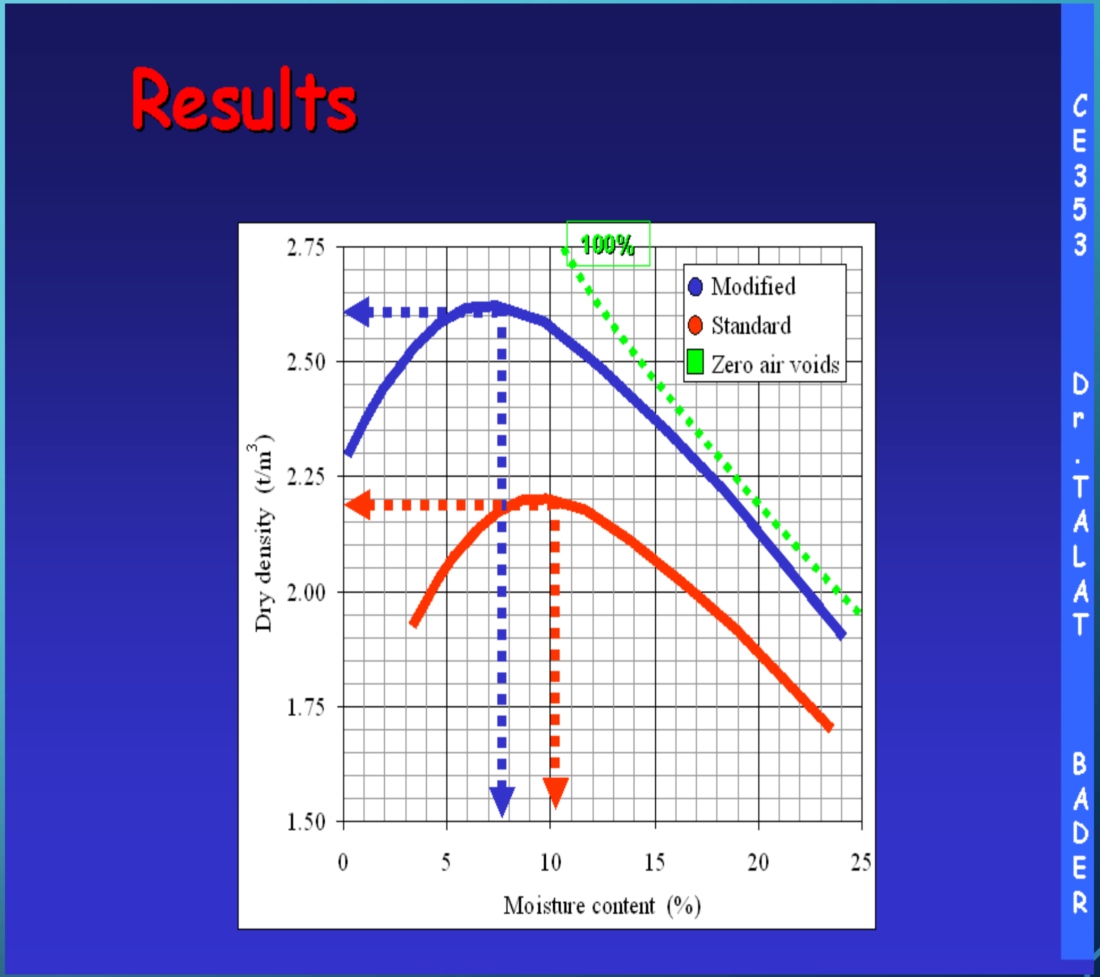
NOTE: 0% air void line is same as 100% saturation line but 90% saturation line is not same as 10% air void line.

LINE OF OPTIMUMS:

- For a particular soil mass and at a given value of water content if the compactive effort increases then the dyr unit weight also increases. With increasing the value of compactive effort on a given soil mass the maximum dry unit weight increases and corresponding OMC increases.
- A line showing the relationship between optimum moisture content and practical maximum dry unit weight for a particular soil is called "line of optimum".

FACTORS AFFECTING COMPACTION

1. Water content: At lower water content soil is relatively stiff hence offer higher resistance against compaction and doesn't pack into denser state of contact resulting in dry unit weight. As the water content increases more layers of water are added to the soil solids and soil particles becomes workable and come into denser state of packing which results in higher value of dry unit weight. This increases takes place up to a particular value of water content and that water content is termed as OMC. After OMC if we will increase the amount of water in soil there will be no change in the lubrication effect and the water gradually starts replacing the solids and the denseness of soil starts decreasing.
2. Degree of compaction: Degree of compaction means the amount of energy provided to the soil during compaction. This energy is provided in terms of number of blows. With increase in degree of compaction the dry unit weight increases and the OMC decreases but there is no direct relationship between degree of compaction and the OMC.



3. Method of compaction: Methods of compaction includes the weight of the compacting element, time and area of contact between the compacting element and the the soil. It also includes the nature of effect induced by the compacting element like weather the soil is compacted by means of impact, pressure, vibration or kneading. The compaction curve obtained in one method of compaction is different from the curve obtained from another method of compaction keeping the compacting effort constant.

4. Types of soil: The dry density achieved for different type of soil is different. Generally dry density of coarse grained soil is higher than the dry density achieved in the fine grained soil. Addition of fine grained particles to the coarse grained soil can increase the dry density of the soil to a certain extent. But after a certain amount i.e; the amount needed to fill the voids completely , it the amount of fine grained particles are further increased the maximum dry density starts decreasing.

5. Admixtures: The compaction characteristics of the soil is increased by adding the admixtures. The dry density achieved depends on the type and the amount of admixtures. The most commonly used admixtures are lime, cement and bitumen.

Example 6.1:

The following results were obtained from a standard compaction test on a sample of soil.

Water content	0.12	0.14	0.16	0.18	0.20	0.22
Mass of wet soil	1.68	1.85	1.91	187	1.87	1.85

The volume of mould used was 950ml. Make necessary calculations and plot the compaction curve and obtain the maximum dry density and the optimum water content. Also calculate the void ratio, the degree of saturation and the theoretical maximum dry density. (G = 2.70)

Solution:

Water content(W)	0.12	0.14	0.16	0.18	0.20	0.22
Mass of wet soil (M kg)	1.68	1.85	1.91	1.87	1.87	1.85
Bulk density $\rho = M/V = V/0.950$	1.77	1.95	2.01	1.97	1.97	1.95
Dry density $\rho_d = \rho/(1+W)$	1.58	1.71	1.73	1.67	1.64	1.60
Void ratio e = $((G\rho_w)/\rho_d) - 1$	0.71	0.58	0.56	0.62	0.65	0.69
Degree of saturation S = WG/e	0.46	0.65	0.77	0.78	0.83	0.86
Theoretical maximum dry density $(\rho_d)_{thmax} = G\rho_w/(1+GW)$	2.04	1.96	1.89	1.82	1.75	1.69

Plot the graph between maximum dry density and water content of the soil and from the graph find the value of maximum dry density and optimum water content of the soil.

VARIOUS METHODS USED IN FIELD FOR COMPACTION

In field most commonly used methods are use of rollers, rammers and vibrators.

1. Rollers: various types of rollers are used for the compaction of soil in the field. The compaction using rollers depends on the following factors:

- Contact pressure: in general the compaction increases with increase in contact pressure
- Number of passes: with increase in number of passes the compaction increases but after a certain limit there in no increase in the dry density with increase in number of passes. From economy point of view the number passes is restricted between 5 to 15.
- Thickness of the layer: thickness of the layer and compaction are inversely proportional to each other. The compaction increases with decrease in the thickness of the layer.
- Speed of the roller: the speed of the roller should be adjusted to get the maximum effect.

Types of rollers:

A-Smooth-wheeled roller:

- In this process compaction is achieved by application of pressure over soil.
- This process is suitable for coarse grained soil. This process is generally used in compaction of roads.
- Tandem roller is type of smooth-wheeled roller.

B-Sheep foot roller

- Compaction is done by kneading action.
- These rollers are generally used for cohesionless soils. These are generally used in construction of earth dams.

C-Pneumatic-tyred rollers:

- In these rollers compaction is done by the combined action of pressure and kneading.
- These rollers are suitable for all type of soils but generally used for cohesive soils.
- These rollers are generally provided with a weighing box which can be filled with ballast to increase the weight of the roller.

2. Rammers:

Rammers are instruments which consists of an iron block connected to a rod. The is lifted to a certain height provided and then it is dropped to give the blows to compact the soil.

- In case rammers the compaction is generally done by impact.
- Rammers are generally used in case of confined areas. These are generally used for all type of soils but these are generally used for cohesionless soils.

3. Vibrators:

In case of vibrators the soil is compacted by means of vibration. Vibrators are generally used to compact cohesionless soils. This technique is most suitable for compaction of sand. Vibrators are generally used in confined areas.

CONSOLIDATION

When soil is subjected to compressive force the it's volume decreases. This decrease in volume due to increase in load or effective stress is called compressibility of soil. When the soils is subjected to compressive force the following things occure;

1. Compression of air
2. Expulsion of air
3. Compression of water
4. Expulsion of water
5. Elastic compression of solids
6. Plastic compression of solids

Consolidation : Expulsion of water from voids from the soil mass due to compression of saturated soil under steady static pressure is called consolidation.

DIFFERENCE BETWEEN COMPACTION AND CONSOLIDATION

Compaction

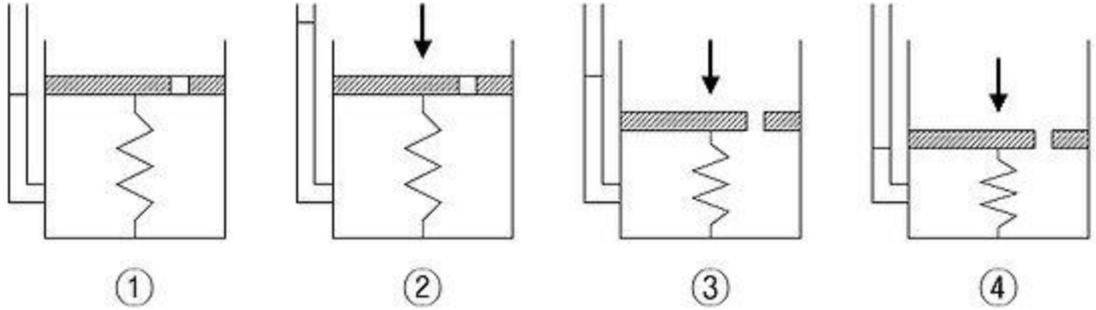
- Compaction is a process where a mechanical pressure is used to compress the soil mass for the purpose of soil improvement.
- Dynamic loads by rapid mechanical methods like tamping, rolling and vibration are applied for a small interval in soil compaction.
- In compaction process, soil volume is reduced by removing air void from the saturated and dry soil.
- Compaction of soil is mainly used for sandy soil.
- Compaction is intentionally done to produce a high unit weight of soil and consequently improve other soil properties.
- During compaction the dry density increases with the same value of water content.

Consolidation

- Consolidation is a process where steady and static pressure causes compression of saturated soil.
- Static and sustained loading is applied for a long interval in soil consolidation.
- In consolidation process, soil volume is reduced by squeezing out pore water from the saturated soil.
- Consolidation of soil is mainly used for clayey soil.
- Consolidation is a natural process where soil below the building and other structure compacted by the transferred load to the soil through the provided foundation system.
- During the consolidation process the dry density increases with decrease in the water content.

TERZAGHI'S SPRING ANALOGY METHOD:

- The process of consolidation is often explained with an idealized system composed of a container with a hole in its cover, and water. In this system, the spring represents the compressibility or the structure of the soil itself, and the water which fills the container represents the pore water in the soil.



1. The container is completely filled with water, and the hole is closed. (Fully saturated soil)
2. A load is applied onto the cover, while the hole is still unopened. At this stage, only the water resists the applied load. (Development of excess pore water pressure)
3. As soon as the hole is opened, water starts to drain out through the hole and the spring shortens. (Drainage of excess pore water pressure)
4. After some time, the drainage of water no longer occurs. Now, the spring alone resists the applied load. (Full dissipation of excess pore water pressure. End of consolidation)

THANK YOU

CHAPTER - 8

EARTH PRESSURE ON RETAINING STRUCTUE

Prepared By: Lopamudra Nayak

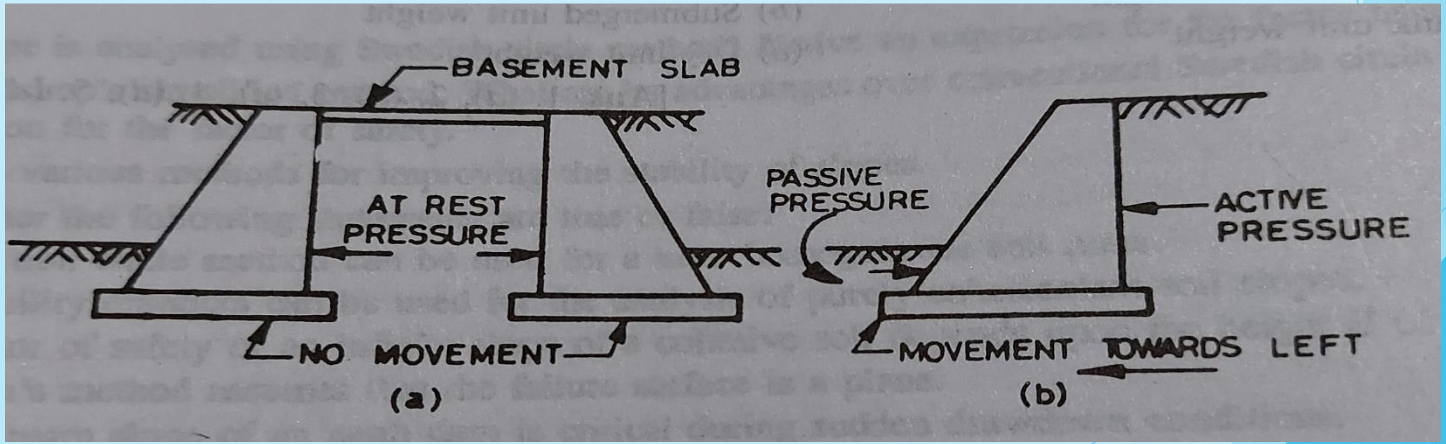
8.1 : EARTH PRESSURE

- To design all kind of earth retaining structure the pressure exerted by the material retained by the structure is also considered.
- The lateral pressure exerted by the retained material is termed as earth pressure.
- The material retained by such structures is called by backfill and it's top surface is either horizontal or inclined.
- The position of the backfill above the horizontal plane at the top elevation of the wall is termed as surcharge.

TYPES OF EARTH PRESSURE

Depending upon the movement of the wall with respect to the backfill there are three types of earth pressure

A. Earth pressure at rest
B. Active earth pressure
C. Passive earth pressure



A.EARTH PRESSURE AT REST

If the wall of any earth retaining structure is rigid then the soil retained by these structures is in rest condition. The pressure exerted by the soil in this state is called earth pressure at rest.

In rest condition the lateral strain in soil is zero i.e; $\varepsilon_h = 0$

$$\frac{-\sigma_h}{E} + \frac{\mu\sigma_h}{E} + \frac{\mu\sigma_v}{E} = 0 \quad \Longrightarrow \quad \frac{\sigma_h}{\sigma_v} = \frac{\mu}{1-\mu} = K_0$$

Where K_0 = coefficient of earth pressure at rest

DERIVATION:

$\sigma_V = \gamma Z$, $\sigma_h = p_0$, $\frac{\sigma_h}{\sigma_V} = K_0$

$\Longrightarrow \sigma_h = K_0 \sigma_V$

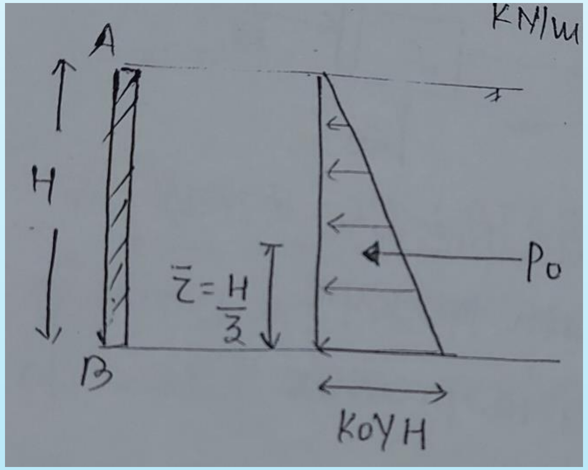
$\Longrightarrow p_0 = K_0 \sigma_V$

$\Rightarrow p_0 = K_0 \gamma Z$

When $z = 0$ $p_0 = 0$

When $z = H$ $p_0 = K_0 \gamma Z$

* 'z' is measured from top of the wall



Total thrust on the wall

F_0 = (Average pressure on the wall) x (Area of the wall where pressure is acting)

$$= \left(\frac{0+K_0\ \gamma\ H}{2}\right) \text{ x } (H \text{ x } 1)$$

$$F_0 = \frac{K_0\ \gamma H2}{2} \quad KN/m^2 \text{ per unit length of the wall}$$

Total thrust P_0 will act at CG of the pressure diagram

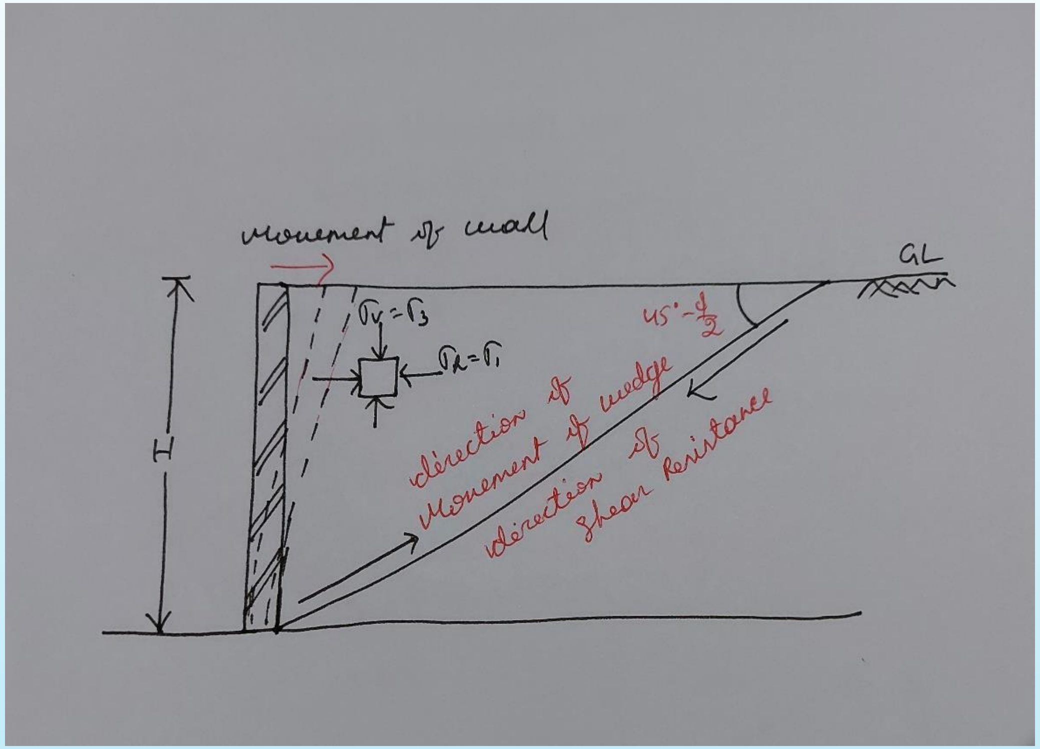
B. ACTIVE EARTH PRESSURE

During active state the wall moves away from the backfill and along with this, a portion of the retained material moves with the wall. This portion which moves away with the wall is called failure element.

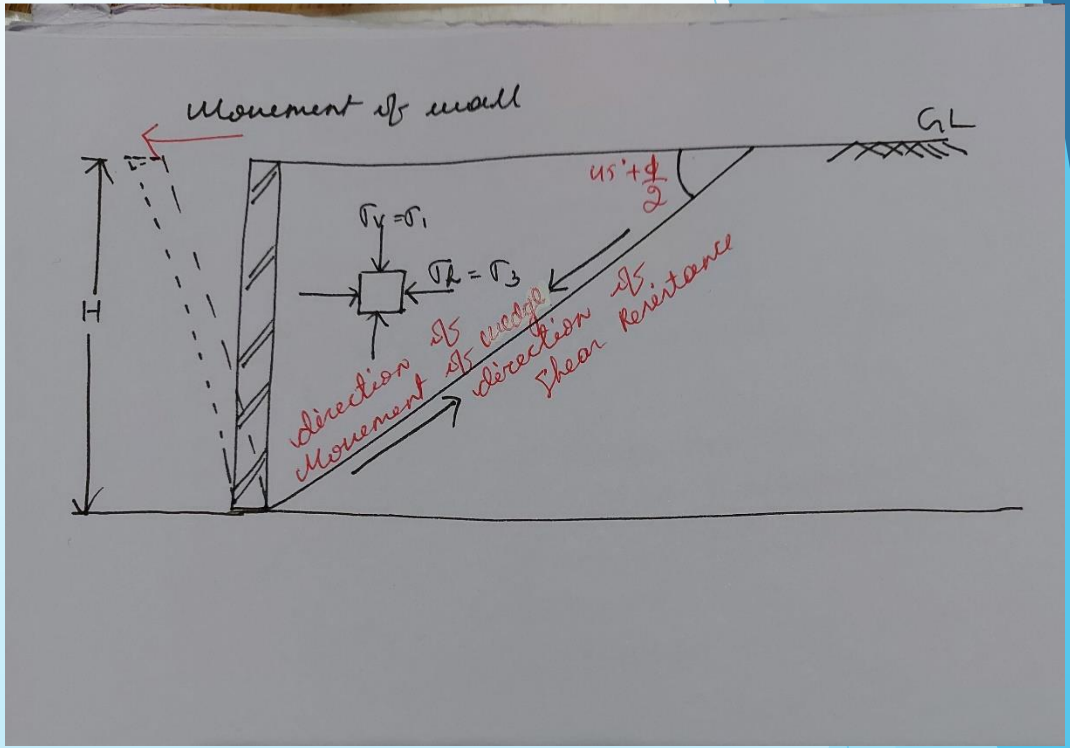
- As the wall starts sliding the shear strength starts decreasing. This decrease in shear strength keeps on decreasing upto a certain point till the complete shear resistance of the soil is mobilized. The minimum pressure acting on the wall at this state is called **active earth pressure**.

C. PASSIVE EARTH PRESSURE

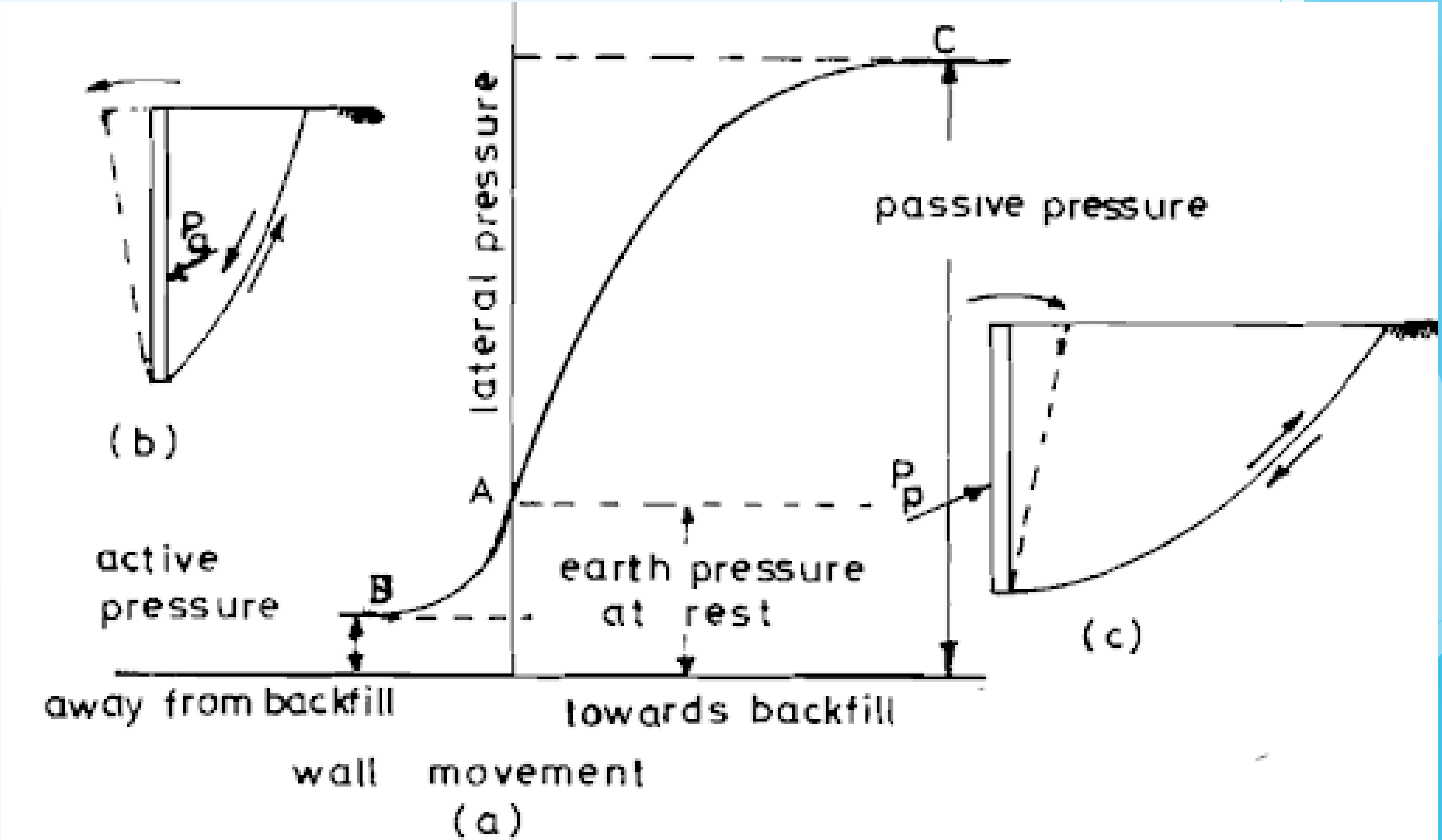
During passive state the wall moves towards the backfill. With movement of the wall the pressure on the wall keeps on increasing. It increase up to a certain extent till the total shear resistance is mobilized. The pressure on the wall at this state is called **passive earth pressure**.



PASSIVE EARTH PRESSURE



ACTIVE EARTH PRESSURE



lateral pressure
C
passive pressure
P_a
(b)
A
P_p
active pressure
B
earth pressure at rest
(c)
away from backfill
towards backfill
wall movement
(a)

8.2 : RANKINE'S EARTH PRESSURE THEORY

Assumptions in Rankine's earth pressure theory:

Soil is homogeneous, isotropic, semi-infinite, dry and cohesion less.

- The ground surface in always planner but it may be horizontal or inclined.
- The face of the wall in contact with the backfill is vertical and smooth.
- Soil is in plastic state of equilibrium both in case of active and passive state.
- The failure surface is planner.

Derivation of active and passive earth pressure:

Active earth pressure:

Coefficient of active earth pressure , $\mathbf{K_a} = \frac{\mathbf{1 - \sin \emptyset}}{\mathbf{1 + \mathit{sin}\ \emptyset}}$

$\sigma_h = P_a \qquad \sigma_v = \gamma\ z$

$\Rightarrow \frac{\sigma_h}{\sigma_v} = \mathbf{K_a}$

$\Rightarrow \mathbf{p_a} = \mathbf{K_a \gamma\ z}$

*With increase in value of ∅(angle of internal friction) the value of Active earth pressure coefficient decreases.

Passive earth pressure:

Coefficient of passive earth pressure , $\mathbf{K_p} = \frac{1+\sin\emptyset}{1-\sin\emptyset}$

$\sigma_h = p_a$ $\sigma_v = \gamma\ z$

$\Rightarrow \frac{\sigma_h}{\sigma_v} = \mathbf{K_P}$

$\Rightarrow \mathbf{p_p = K_p\, \gamma\ z}$

*With increase in value of ∅(angle of internal friction) the value of Passive earth pressure coefficient increases.

NOTE: 1. Both active and passive earth pressure are coefficient are function of ∅ only both in case of cohesive and cohesionless soil.

2. K_P x K_P = 1

DIFFERENT TYPES OF CASES TO DETREMINE EARTH PRESSURE THEORY

1. Retaining structure with dry or bulk backfill:

Active state: $p_a = K_a\, \gamma\ z$

@ A when $z = 0$, $p_a = 0$

@ B when $z = H$, $p_a = K_a\, \gamma\ H$

Thrust per unit wall length = (Average pressure on the wall) x (Area of the wall where pressure is acting)

Active thrust = $F_a = \frac{Ka\ \gamma\ H^2}{2}$ (acting at CG i.e; at H/3 distance from the base of the wall)

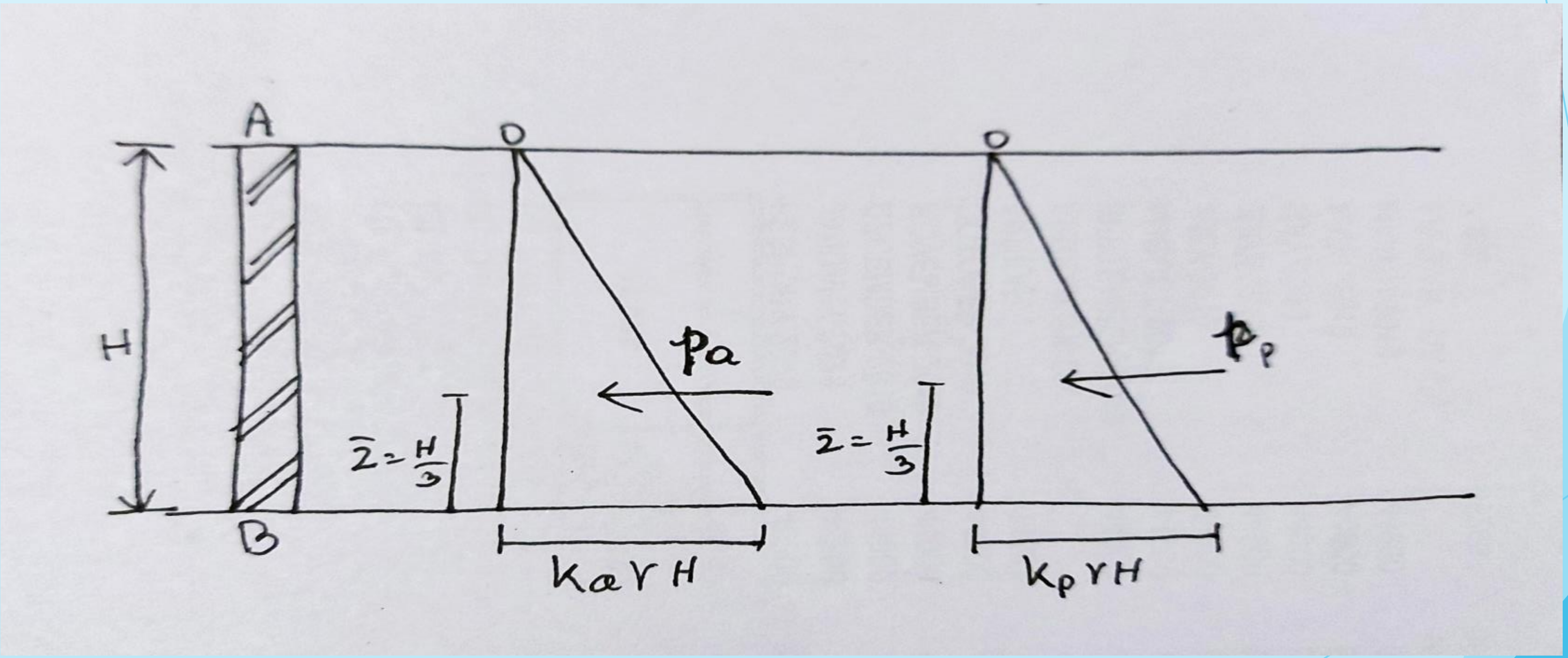
Passive state: $p_p = K_p \gamma z$

@ A when z = 0 , $p_p = 0$

@ B when z = H , $p_p = K_a \gamma H$

Thrust per unit wall length = (Average pressure on the wall) x (Area of the wall where pressure is acting)

Passive thrust = $F_p = \dfrac{Kp\ \gamma H^2}{2}$ (acting at CG i.e; at H/3 distance from the base of the wall)



2. Backfill with uniform surcharge(q KN/m^2):

Active state:

for surcharge $P_{a1} = K_a\ q$

@ A when $z = 0$, $p_{a1} = 0$

@ B when $z = H$, $p_{a1} = K_a\ q$

Active thrust $= F_{a1} = K_a\ q\ H$ will act at Z_1 from bottom

for backfill $p_a = K_a\ \gamma\ z$

@ A when $z = 0$, $p_{a2} = 0$

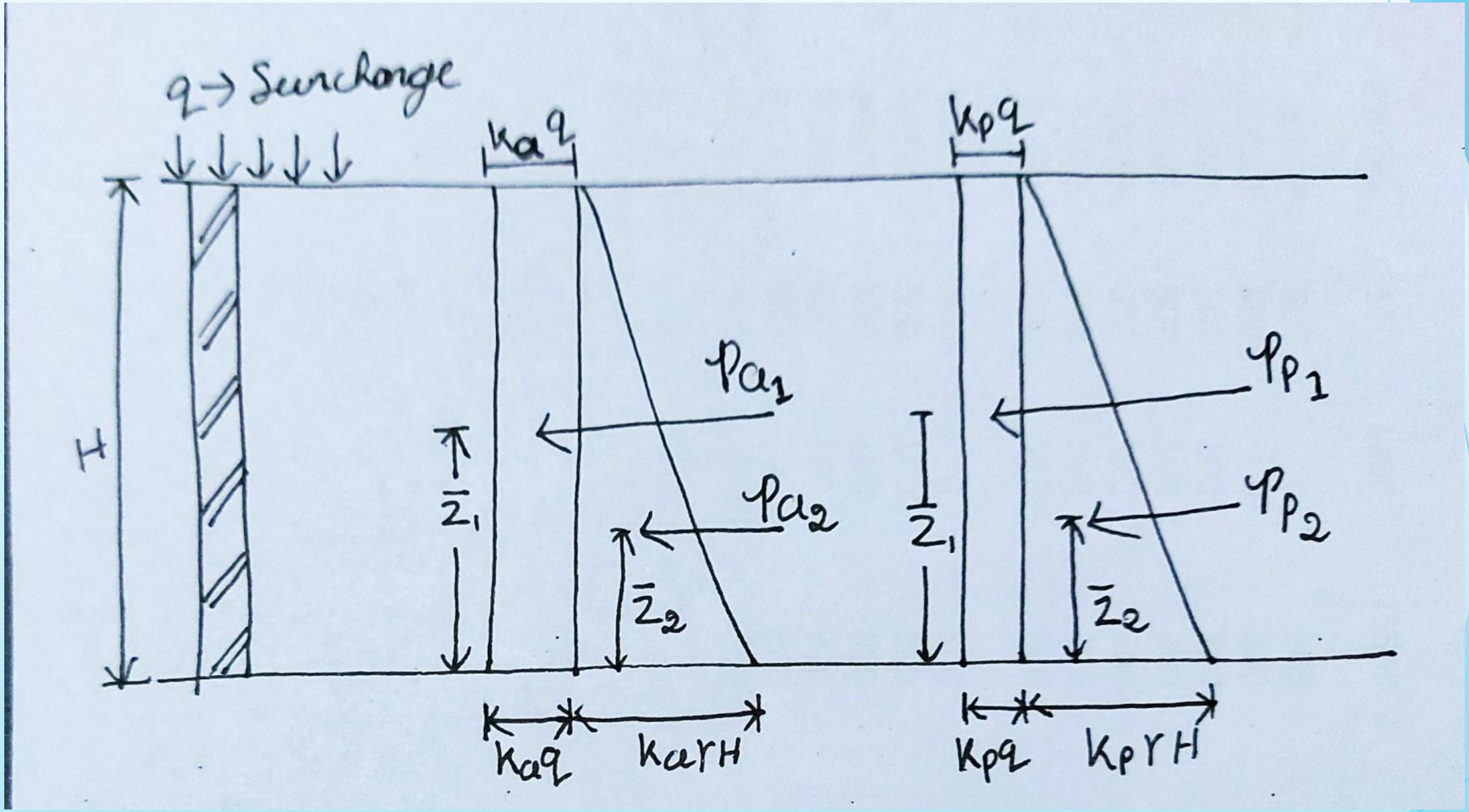
@ B when $z = H$, $p_{a2} = K_{a2}\ \gamma\ H$

Active thrust $= F_{a2} = \dfrac{Ka\ \gamma\ H^2}{2}$ will act at Z_2 from bottom

Total thrust $= F_{a1} + F_{a2}$

The total thrust will act at $Z = \dfrac{F_{a1}\ Z + Fa_2\ Z}{F_{a1} + F_{a2}}$ from base of the wall.

***Same procedure will be for passive case.**



q → Surcharge
$K_a q$
$K_p q$
H
P_{a1}
P_{a2}
$\bar{Z}_1$
$\bar{Z}_2$
P_{p1}
P_{p2}
$\bar{Z}_1$
$\bar{Z}_2$
$K_a q$
$K_a \gamma H$
$K_p q$
$K_p \gamma H$

3. Earth pressure in case of submerged backfill:

In this case the total earth pressure is due to the soil solids and the water.

Active state:

Due to the soil solids

$p_{a1} = K_a \gamma' z$

@ A when z = 0 , $p_{a1} = 0$

@ B when z = H , $p_{a1} = K_a \gamma' H$

Active thrust $F_{a1} = \frac{Ka\ \gamma' H^2}{2}$ **at H/3 from bottom**

Due to water(The hydrostatic pressure is same in all direction hence it is not multiplied by K_a & K_P)

$p_{a2} = \gamma_w z$

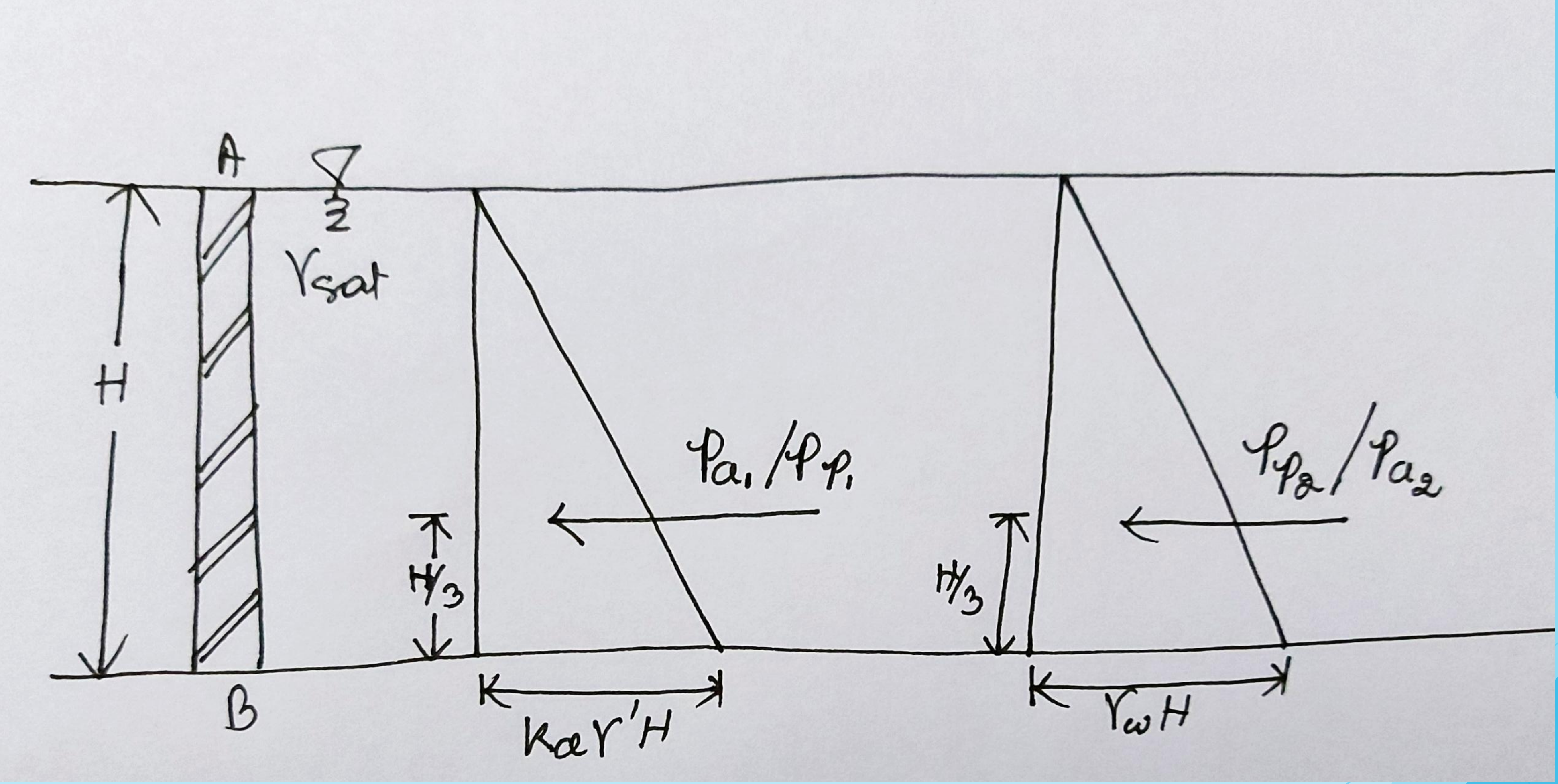
@ A when z = 0 , $p_{a2} = 0$

@ B when z = H , $p_{a2} = \gamma_w z$

Active thrust $F_{a2} = \frac{\gamma_w H^2}{2}$ **at H/3 from bottom**

Total thrust $F_a = F_{a1} + F_{a2}$

The total thrust will act at $Z = \frac{F_{a1} Z + Fa_2 Z}{F_{a1} + F_{a2}}$ **from base of the wall.**


A
γ_{sat}
H
B
P_{a_1}/P_{p_1}
H/3
$K_a\gamma'H$
P_{p_2}/P_{a_2}
H/3
$\gamma_w H$

4. Earth pressure in case of submerged backfill with water table at depth (H_1) from ground:

Active state:

a. Earth pressure due to the soil of height H1

$$F_{a1} = \frac{Ka\ \gamma\ (H1)^2}{2} \qquad \text{will act at } z1 = H2 + H1/3$$

b. Earth pressure when the soil of height H1 act as surcharge on the soil of height H2

$$F_{a2} = (K_a\,\gamma\ H1)\ H2 \qquad \text{will act at } z2 = H2 / 2$$

c. Earth pressure due to the saturated soil of height H2

$$F_{a3} = \frac{Ka\ \gamma'\ (H2)^2}{2} \qquad \text{will act at } z3\ H2 / 3$$

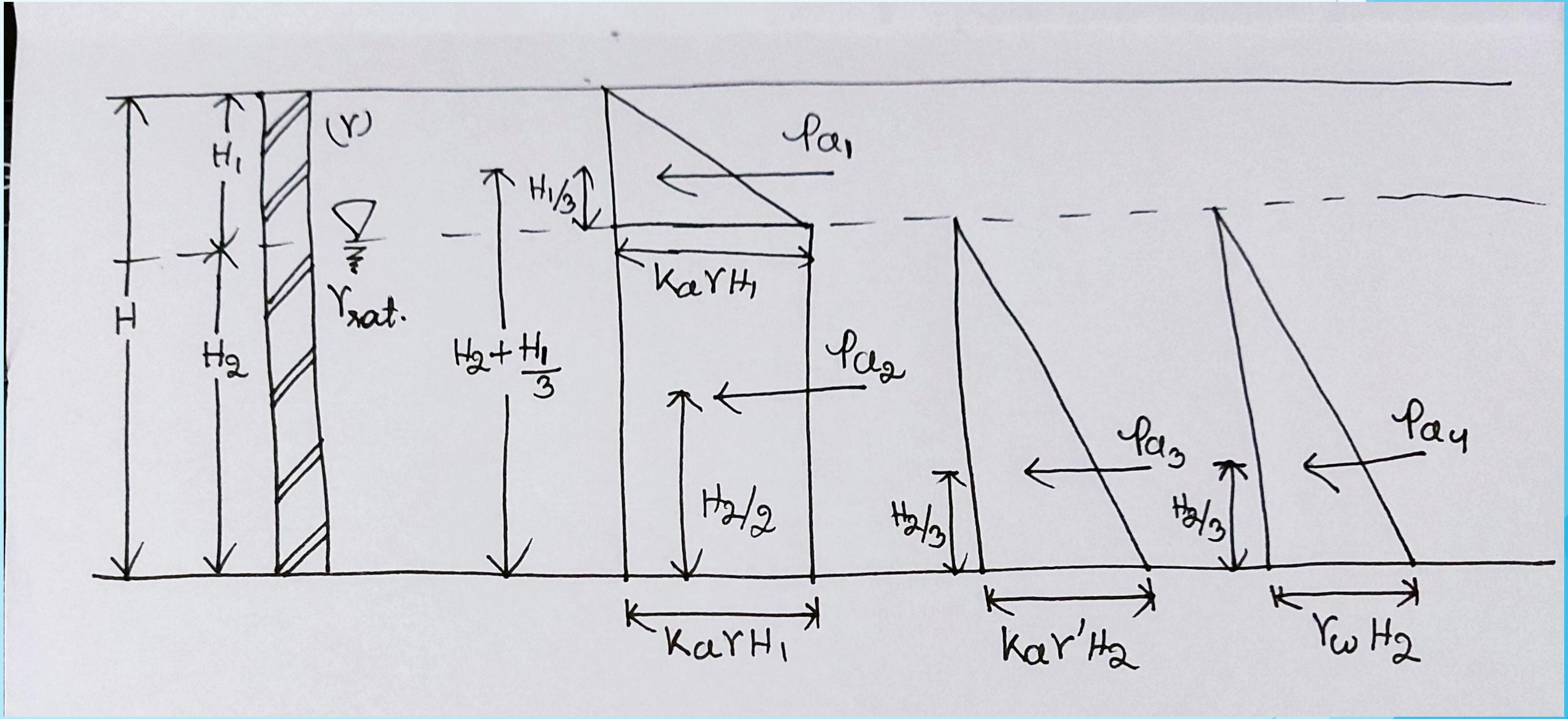
d. Earth pressure due to the water of depth H2

$$F_{a4} = \frac{\gamma_w\ H2^2}{2} \qquad \text{will act at } z4 = H2 / 3$$

Total thrust $Fa = F_{a1} + F_{a2} + F_{a3} + F_{a4}$

Total thrust will act at $Z = \dfrac{F_{a1}\ z1 + F_{a2}\ z2 + F_{a3}\ z3 + F_{a4} z4}{F_{a1} + F_{a2} + F_{a3} + F_{a4}}$

*Procedure will be same for the passive earth pressure.



(γ)
H₁
H
H₂
γsat.
H₂ + H₁/3
H₁/3
Pa₁
KaγH₁
Pa₂
H₂/2
KaγH₁
Pa₃
H₂/3
Kaγ'H₂
Pa₄
H₂/3
γω H₂

5. Backfill with different soils having different angle of friction:

*With increase in angle of friction active earth pressure coefficient decreases but passive earth pressure coefficient increases and vice versa.

If $\varphi 1 > \varphi 2$ then $Ka1 < Ka2$

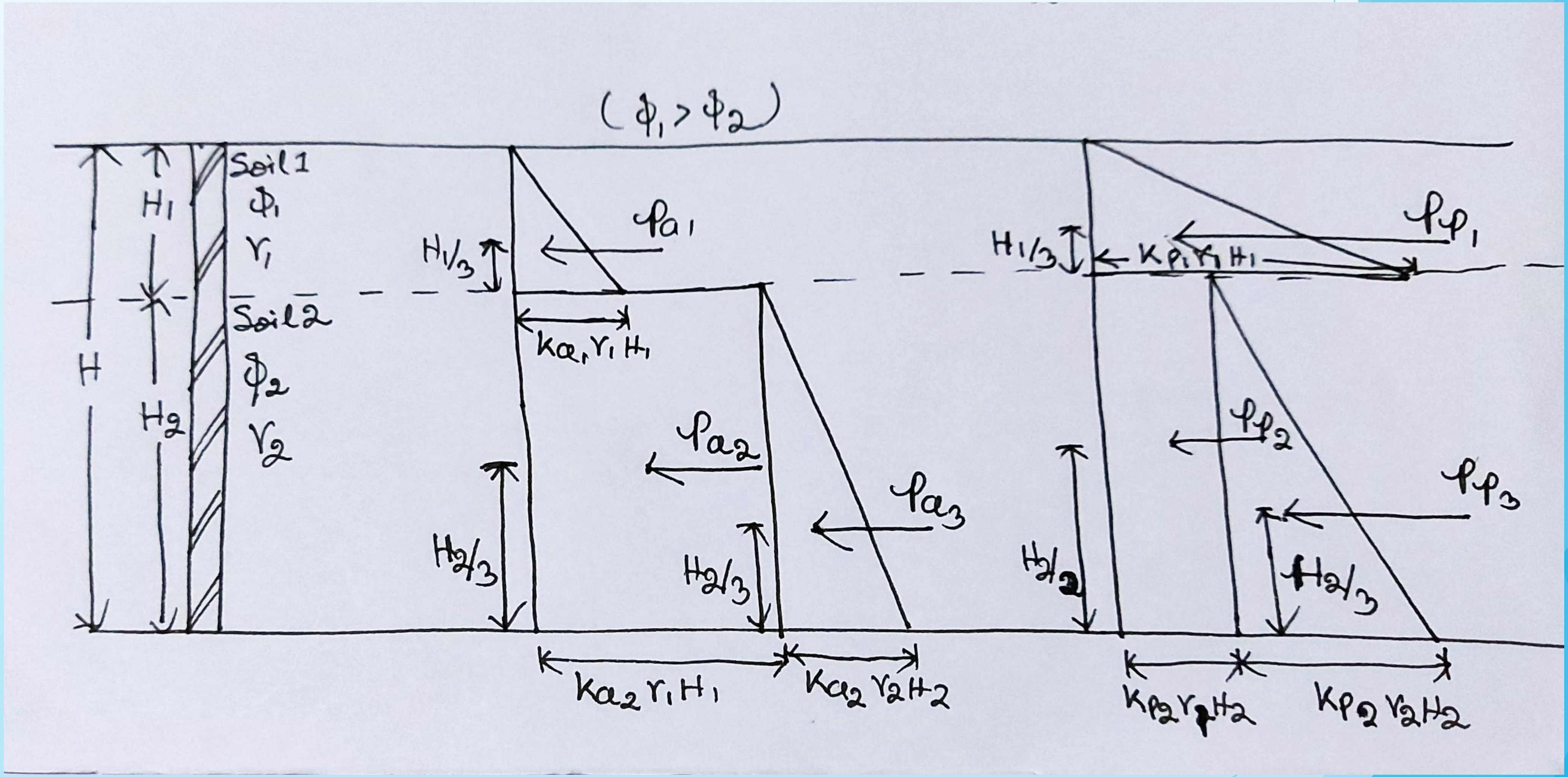
$$F_{a1} = \frac{Ka1\ \gamma 1\ H1^2}{2}$$ will act at $z1 = H_1/3 + H_2$

$$F_{a2} = (Ka2\ \gamma 1\ H1)H2$$ will act at $z2 = H_2/2$

$$F_{a3} = \frac{Ka2\ \gamma 2\ H2^2}{2}$$ will act at $z3 = H_2/3$

Total active thrust $F_a = F_{a1} + F_{a2} + F_{a3}$ will act at $Z = \frac{z1\, F_{a1} + z2\, F_{a2} + z3\, F_{a3}}{F_{a1} + F_{a2} + F_{a3}}$

Same procedure will be for the passive state.



(ϕ1 > ϕ2)
Soil 1
ϕ1
γ1
H1
H
Soil 2
ϕ2
γ2
H2
Pa1
H1/3
Ka1 γ1 H1
Pa2
Pa3
H2/3
H2/3
Ka2 γ1 H1
Ka2 γ2 H2
Pp1
H1/3
Kp1 γ1 H1
Pp2
Pp3
H2/2
H2/3
Kp2 γ1 H2
Kp2 γ2 H2

CHAPTER 9

FOUNDATION ENGINEERING

Prepared by : Lopamudra Nayak

9.1FOUNDATION

Foundation is that part of the structure through which total load is finally transmitted to the soil. To increase the stability of the structure foundations are generally kept below the ground level.

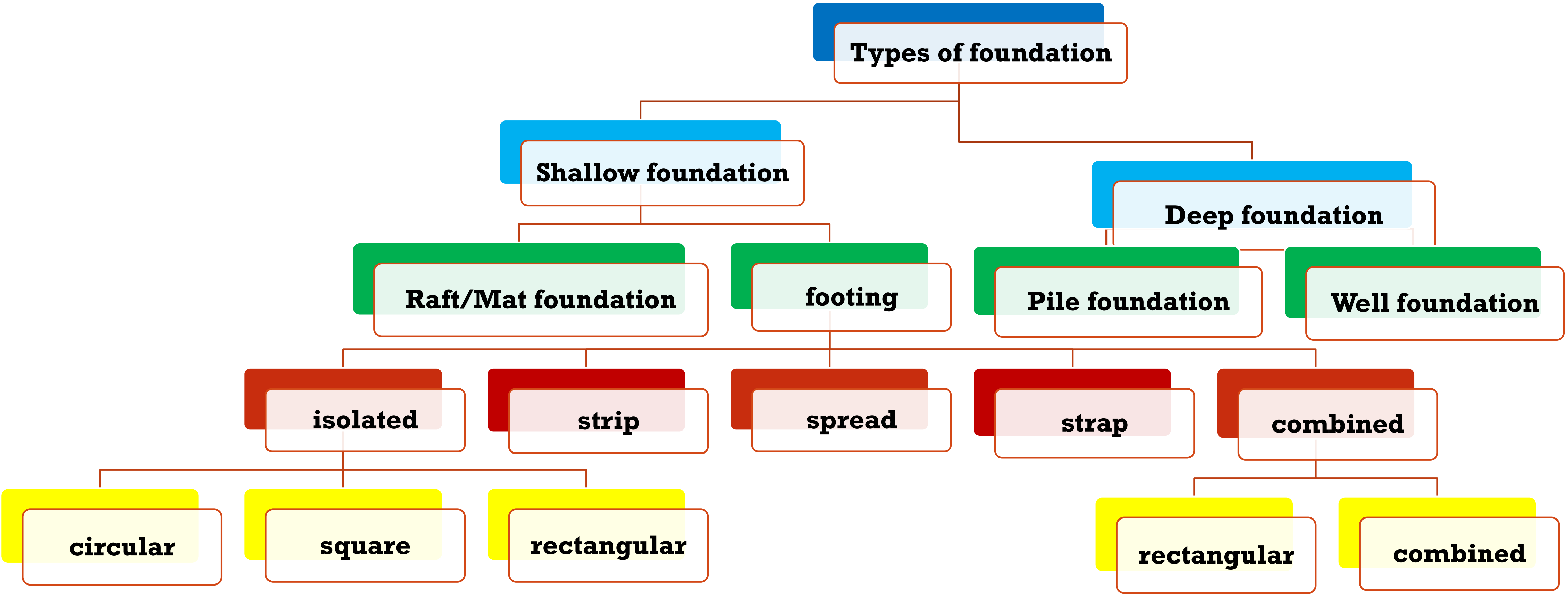
- A foundation is required for distributing the loads of the superstructure on a larger area. A foundation should be designed in such way that the soil below it doesn't fails in shear and the settlement is within the safe limits.

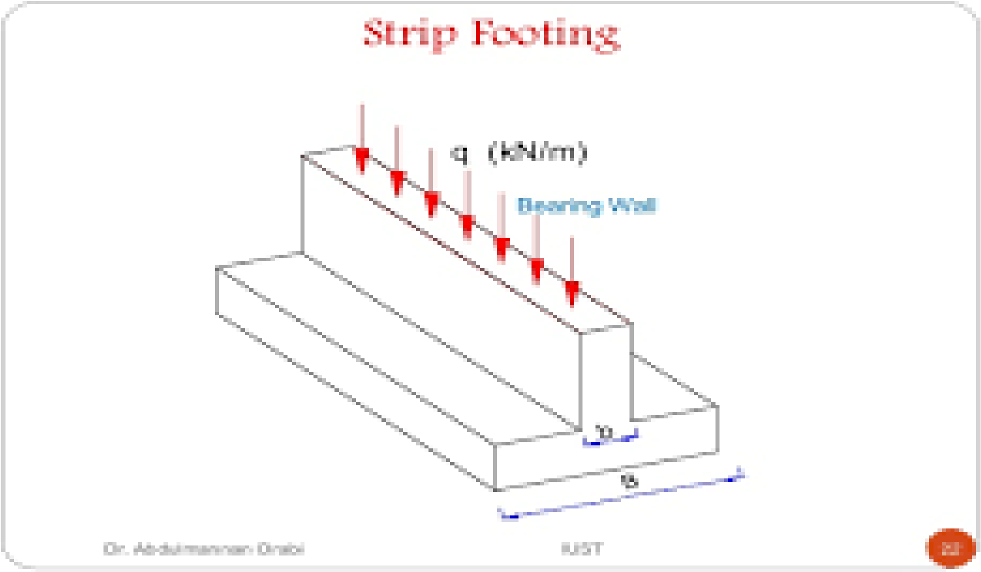
9.1.1 : Functions of foundation:

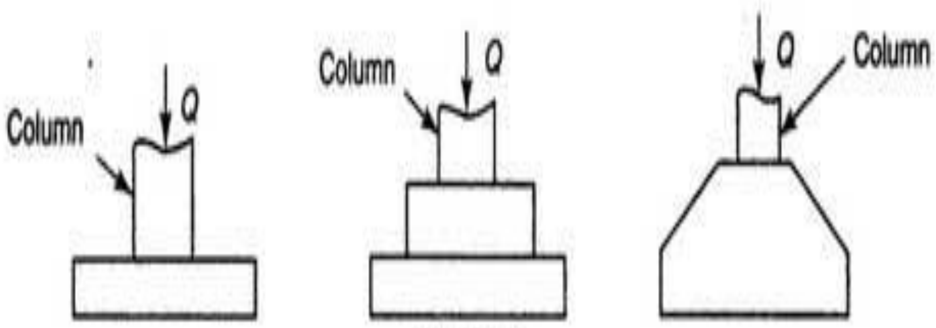
- Foundation reduces the load intensity. It distributes the load of super structure to a larger area so that the intensity of load at it's base doesn't exceeds the safe bearing capacity of the soil.
- Foundation distributes the non-uniform load of super structure evenly to the soil.
- Foundation provides a levelled and hard surface over which the super structure can be built.
- It provides the lateral stability to the structure. The stability of the building against sliding and overturning due to horizontal forces is increased due to foundation.

Foundations are broadly categorised into two categories as **shallow foundation** and **deep foundation.**

A shallow foundation transmits the load to the strata at a shallow depth but deep foundation transfers the load at considerable depth below the ground surface.

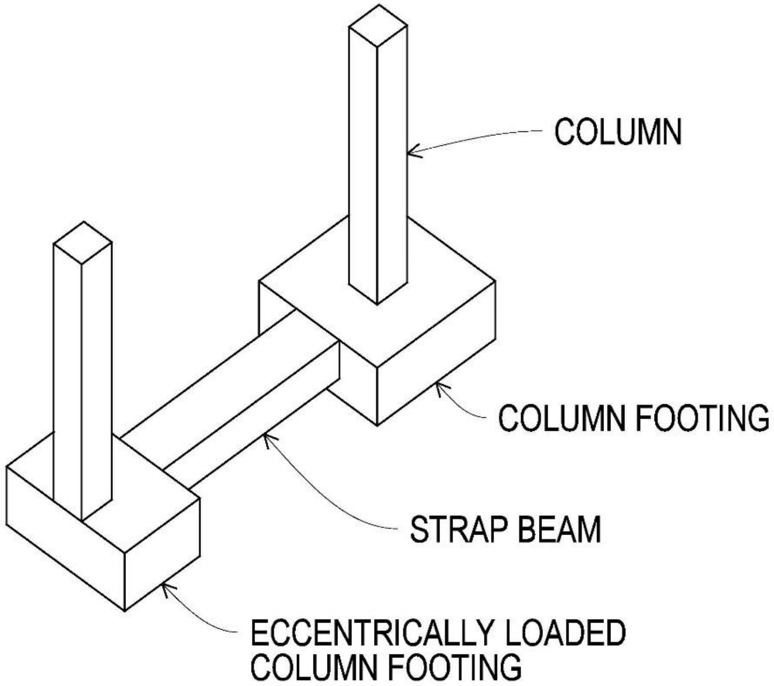

Types of foundation
Shallow foundation
Deep foundation
Raft/Mat foundation
footing
Pile foundation
Well foundation
isolated
strip
spread
strap
combined
circular
square
rectangular
rectangular
combined


Strip Footing
q (kN/m)
Bearing Wall
b
B
IUST



Elevations

(a) Spread footings



9.1.2 : Shallow and Deep Foundations

9.1.2a : Shallow foundations

Isolated footing:

Isolated footing are used for individual column in case of shallow foundation

Strip footing:

Strip footing are generally used for load-bearing wall. These are also provided for row of columns such that their spread footings overlap or nearly touches each other.

Spread footing:

Spread footing is a type of isolated footing of uniform thickness. Sometime it is stepped or haunched to spread the load over a large area.

Strap or cantilever footing:

In strap footing two individual footings are connected by a strap such that they will behave as a single footing. The strap simply acts as a connecting member and doesn't take any soil reaction. The strap is designed as a rigid beam.

Combined footing:

Combined footing is used when two columns are so close to each other that their individual footing will overlap. It is also used when a column is close to the property line such that a spread footing will loaded eccentrically.

Combined footing are of two types , rectangular footing and trapezoidal footing. Rectangular footing is used when two columns of same cross-sections are used and trapezoidal footing is used when two columns of different cross-sections are used.

9.1.2b : Deep foundations

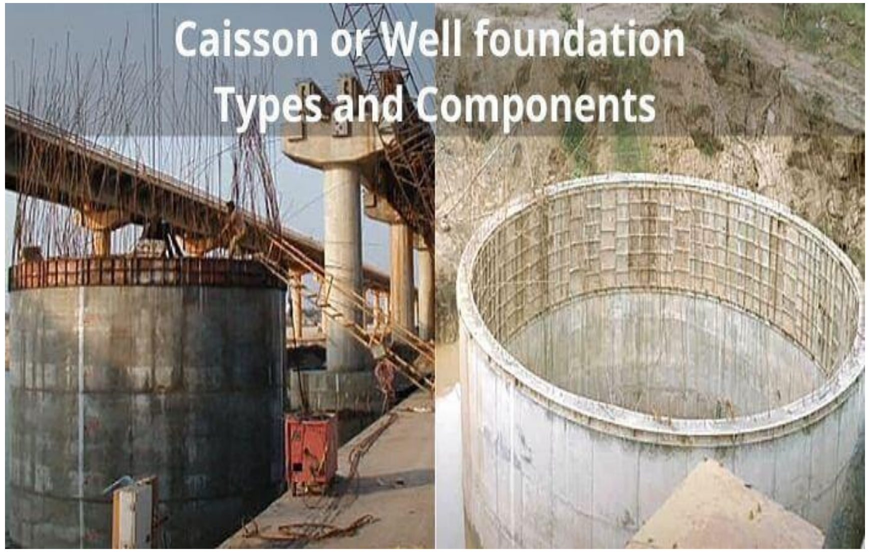
A foundation is called deep foundation when the ratio of depth to width of foundation exceeds 1(according to Terzaghi) and depth to width ratio is equal to or exceeds 2.5(according to skempton).

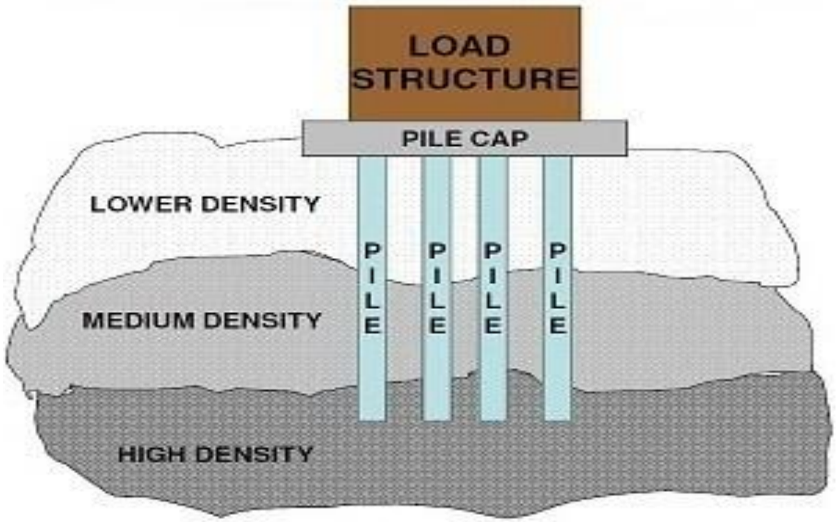
Pile foundation:

A pile is a slender structural member made of steel, concrete or wood. A pile is either driven into the soil or formed in-situ by excavating a hole and filling it with concrete.

Well foundation:

Well foundation is a type of deep foundation which is generally provided below the water level for bridges.





9.1.3 : Types of shear failure in foundation:

There are three types of shear failures in foundation;

1. General shear failure:

this type of failure generally occurs incase of low compressible soils. In such failures failure pattern is well defined and shear failure is experienced with the heaving of ground surface adjacent to foundation at both sides.

- As the pressure increases towards the ultimate value, the state of plastic equilibrium is reached initially in the soil around the edge of footing and gradually spreads downward, upward and outward and ultimately the state of plastic equilibrium is fully developed throughout the soil.
- Initially the settlement is less but after the clear failure there is a significant settlement of the foundation.

2. Local shear failure:

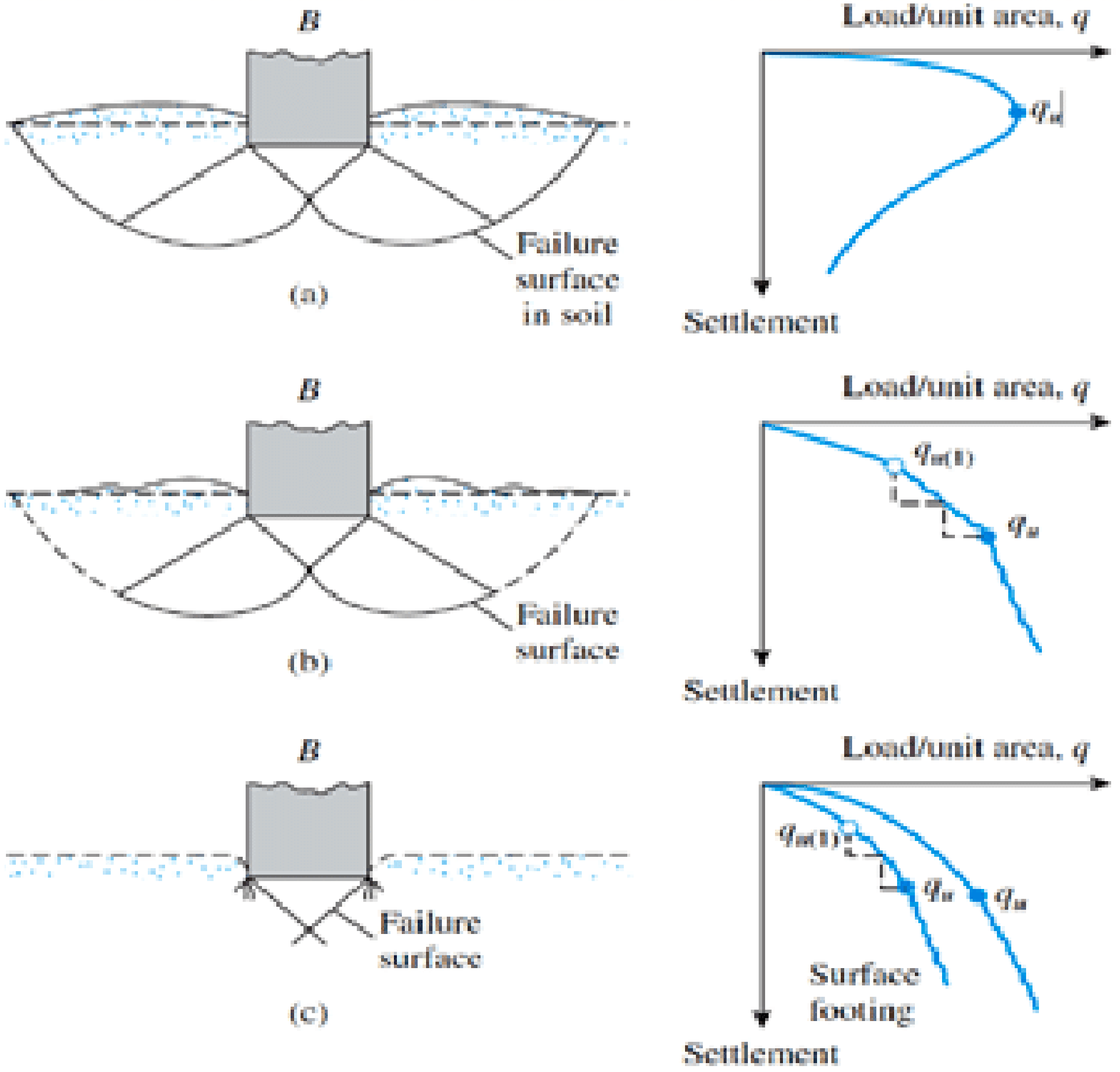
In case of local shear failure there is partial development of state of plastic equilibrium. Local shear failure generally occurs in lose sands.

- In this case the failure surface doesn't reach up to the ground surface and only slight heaving of foundation around the soil occurs.
- As in this case failure occurs gradually hence no clear failure is observed.

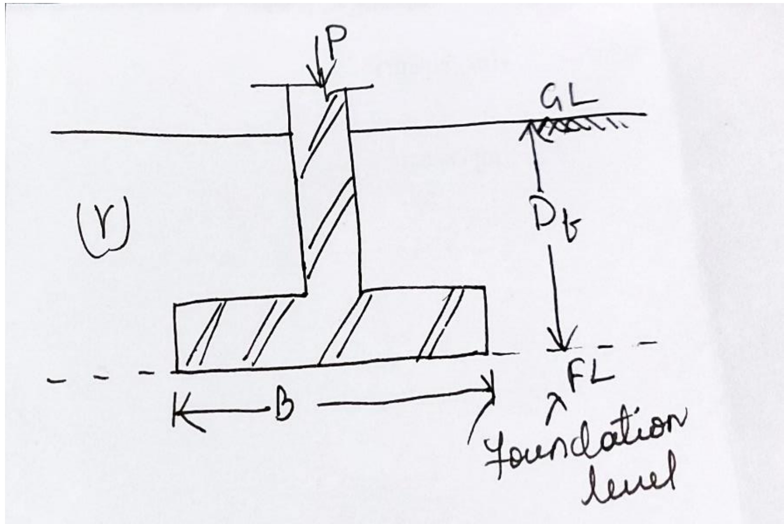
3. Punching shear failure:

Punching shear failure generally occurs in deep foundations when they are placed on very loose sands and soft clay and are not commonly seen in case of shallow foundation.

- In this case the soil exactly below the footing gets separated from the adjacent soil and excessive settlement occurs at less value of load and during this process the adjacent soil mass remains unstressed.
- No heaving of soil is observed in this case. In a very short span of time very large settlement is obtained. No clear failure occurs in this case.


B
Load/unit area, q
q_u
Failure surface in soil
(a)
Settlement
B
Load/unit area, q
$q_{u(1)}$
q_u
Failure surface
(b)
Settlement
B
Load/unit area, q
$q_{u(1)}$
q_u
q_u
Failure surface
Surface footing
(c)
Settlement

Basic definitions:



1. Gross loading intensity:

It is the total pressure acting at the base level of the foundation due to self weight of the loading, applied load due to the super structure and self weight of the soil above the foundation level.

2. Net loading intensity:

This pressure is due to the self weight of the footing and the externally applied load. In this case the load due to the soil above the foundation level is not included.

3. Ultimate bearing capacity(q_u):

It is the maximum gross pressure at the base of the foundation which can be applied without shear failure. OR

It is the minimum gross pressure at which the foundation just fails in shear.

4. Net ultimate bearing capacity(q_{nu}):

It is the maximum net pressure which can be applied at the base of the foundation without shear failure after deducting the overburden pressure on the soil.

$$q_{nu} = q_u - \gamma D_f$$ (use γ’ instead of γ when the soil is in submerged condition)

5. Net safe bearing capacity (q_{ns}):

It is defined as the ratio of net ultimate bearing capacity to factor of safety(F).

$$q_{ns} = \frac{q_{nu}}{F} = \frac{q_u - \gamma D_f}{F}$$ (use γ’ instead of γ when the soil is in submerged condition)

6. Safe bearing capacity of the soil(q_{safe}):

It is the maximum gross pressure which can be applied at the base of foundation safely without shear failure.

$$q_{safe} = \frac{q_u - \gamma D_f}{F} + \gamma D_f$$ (use γ’ instead of γ when the soil is in submerged condition)

7. Safe load (Q):

Safe load at the base of the foundation is obtained by multiplying the area of the base of the footing with the safe bearing capacity of the soil.

9.2 : Terzaghi's bearing capacity theory:

Assumptions in Terzaghi's bearing capacity theory:

Following are the assumptions made in Terzaghi's bearing capacity theory;

- He assumed that the foundation is laid at shallow depth.
- He assumed the base of the foundation to be rough.
- The assumed that the foundation fails in general shear failure.
- The loading on the foundation is vertical and symmetrical.
- He neglected the shear resistance of the soil above the foundation.
- He derived the equation for strip footing.
- For his derivation he removed the soil above the foundation and replaced it with the equivalent surcharge.

Zone I (zone of elastic equilibrium)

In this zone the soil remains in the state of elastic equilibrium and this soil behaves as a part of the footing.

This soil is prevented from lateral movement by adhesion between the base of the footing and soil.

Zone II (radial shear zone)

In this zone the soil remains in plastic equilibrium. The failure plane of this zone is spiral or log-spiral.

Zone III (Rankine's passive zone)

An over burden pressure q acts In Rankine's passive zone. It makes an angle of $(45 – \varphi/2)$ with the horizontal.

Terzaghi's equation of ultimate bearing capacity:

$$q_u = C\,N_c + \gamma D_f\,N_q + 0.5\,\gamma\,B\,N_\gamma$$

The net ultimate bearing capacity can be determined as

$$q_{nu} = q_u - \gamma D_f$$

$$q_{nu} = C\,N_c + \gamma D_f\,N_q + 0.5\,\gamma\,B\,N_\gamma - \gamma D_f$$

$$q_{nu} = C\,N_c + \gamma D_f\,(N_q - 1) + 0.5\,\gamma\,B\,N_\gamma$$

N_c , N_q , N_γ are called bearing capacity factors.

C = cohesion of the soil below the foundation

D_f = depth of the foundation

B = width of the foundation

γ = unit weight of the soil

The bearing capacity factors depends on the friction angle (φ)

$N\varphi = (1 + \sin\varphi) / (1 - \sin\varphi)$

$N_q = N\varphi \cdot e^{\tan\varphi}$

$N_\gamma = 1.8 \tan\varphi \, (N_q - 1)$

$N_c = \cot\varphi \, (N_q - 1)$

Terzaghi's equation for different shape of footing:

Square footing: $1.3\, C\, N_c + \gamma D_f\, N_q + 0.4\, \gamma\, B\, N_\gamma$

Circular footing: $1.3\, C\, N_c + \gamma D_f\, N_q + 0.3\, \gamma\, B\, N_\gamma$

Rectangular footing: $(1 + \frac{0.3B}{L})\, C\, N_c + \gamma D_f\, N_q + (1 - \frac{0.2B}{L})\, 0.5\, \gamma\, B\, N_\gamma$

NOTE: all the above equations are derived for general shear failure case. But if the foundation fails in loacal shear failure the value of cohesion (c) and angle of internal friction (φ) are to be modified. The modified values of c and φ are as given below:

modified value of cohesion (c_m) = $\frac{2C}{3}$

Modified value of angle of internal friction (φ_m) = $\tan^{-1}(\frac{2\tan\phi}{3})$

- If the modified value of angle of internal friction used then accordingly the values of bearing capacity factors are also modified.

9.2.1 : Effect of water table on bearing capacity of soil:

The effect of water table on soil can be determined by two methods, one is by using the effective unit weight of the soil and other is by using water table correction factor.

Effective unit weight concept:

According to this concept the soil below the water table is in submerged condition and the soil above the water table is in bulk condition.

- To study the effect of water table on soil the soil s divided into three zones. Zone –III extends upto the depth of foundation, zone-II extends up to the depth equal to the width of the foundation up to which the stress zone extends, zone-I includes the soil below the stress level.

Bearing capacity equation when the water table lies in zone-I

When the water table lies in zone-I the bearing capacity equation remains unchanged. All the terms in the bearing capacity equation remains unchanged.

$$q_u = C\,N_c + \gamma D_f\,N_q + 0.5\,\gamma\,B\,N_\gamma$$

Bearing capacity equation when the water table lies in zone-II

When the water table lies in zone-II only the 3rd term in the bearing capacity equation is affected and 1st and 2nd term remains unaffected. In this case the soil in the zone-II will have two different unit weight. The portion of the soil above the water table will have bulk unit weight and the soil below the water table will have submerged unit weight.

$$q_u = C\,N_c + \gamma D_f\,N_q + 0.5\,(\gamma x + \gamma'(B-x))B\,N_\gamma$$

Bearing capacity equation when the water table lies in zone-III

In this case all the three terms are affected but the effect of water table on cohesion is negligible hence the effect of water table on 1st term is neglected.

$$q_u = C\,N_c + (\gamma y + \gamma'(D_f - y))N_q + 0.5\,\gamma'\,B\,N_\gamma$$

Water table correction factor concept:

To apply the water table correction factor the soil is initially assumed to be saturated and then the water table correction is applied.

- $\mathbf{R_w}$ & $\mathbf{R'_w}$ are called water table correction factor for 2nd and 3rd terms in the bearing capacity equation.

$\mathbf{R_w = 0.5\,(1+ \frac{y}{D_f})}$ "y" is the depth of the water below the ground level ($0 < y < D_f$)

$\mathbf{R'_w = 0.5\,(1+ \frac{x}{B})}$ "x" is the depth of the water below the foundation level ($0 < x < B$)

IS code method:

In IS code method to find out net ultimate bearing capacity of soil shape factor, depth factor and inclination factors are included.

$$\mathbf{q_{nu} = C\,N_c\,s_c\,d_c\,i_c + \gamma D_f\,(N_q - 1)\,s_q\,d_q\,i_q + 0.5\,\gamma\,B\,N_\gamma\,s_\gamma\,d_\gamma\,i_\gamma}$$

s_c , s_q , s_γ = shape factors

d_c , d_q , d_γ = depth factors

i_c , i_q , i_γ = inclination factors

ϕ'	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°
N_c	5.14	6.49	8.35	10.98	14.83	20.72	30.14	46.12	75.31	133.88	266.89
N_q	1.0	1.57	2.47	3.94	6.40	10.66	18.40	33.30	64.20	134.88	319.07
N_γ	0.0	0.45	1.22	2.65	5.39	10.88	22.40	48.03	109.41	271.76	762.89

Shape of Footing	s_c	s_q	s_γ
Continuous Footing (strip)	1.0	1.0	1.0
Rectangular Footing	1 + 0.2 *B/L*	1 + 0.2 *B/L*	1 – 0.4 *B/L*
Square Footing	1.3	1.2	0.8
Circular Footing	1.3	1.2	0.6

$$i_c = i_q = (1 - \alpha°/90°)^2$$

and

$$i_\gamma = (1 - \alpha°/\phi')^2$$

where α° is the inclination of the load with vertical.

9.3 : PLATE LOAD TEST AND STANDARD PENETRATION TEST

9.3.1 : PLATE LOAD TEST:

Plate load test is a field test used to find out both the ultimate bearing capacity of the soil and the settlement of foundation.

Procedure:

To conduct the plate load test a pit of width 5 times the size of the plate is excavated whose depth is equal to the depth of the foundation.

- Then rigid circular or square plate is placed inside the pit having the size of 30, 45, 60 and 90 cm whichever is suitable for the experiment. For dense soil smaller size plate is preferred and for loose sand larger size plate is preferred.
- After placing the plate inside the pit three dial gauges are attached to the plate to measure the settlement of plate and average of the three readings is considered as the settlement of the foundation.
- First a sitting load of 7kn/m1 is applied then it is released after some time. Then the load is applied in increments of about 20% of the estimated safe load or one-tenth of the ultimate load.
- The settlement is recorded after 1, 5, 10, 20, 40, 60 mins and further after an interval of one hour. The test is carried out until the failure occurs or at least until the settlement of about 25 mm has occurred.

Calculation of bearing capacity as per plate load test:

- Incase of clayey soil the ultimate bearing capacity is independent of the size of the footing hence ultimate bearig capacity of the foundation is same as the ultimate bearing capacity of the plate.

$$\mathbf{q_{uf} = q_{up}}$$

- In case of sandy soil the ultimate bearing capacity increases with increase in size of the foundation.

$$q_{uf} = q_{up} \text{ x } (B_f / Bp)$$

Calculation of settlement of foundation according to plate load test;

- For sandy soil the settlement of foundation can be calculated as follows

$$\frac{sf}{sp} = \left[\frac{Bf\,.(Bp+0.3)}{Bp\,.(Bf+0.3)}\right]^2$$

S_f = settlement of the foundation

S_p = settlement of the plate

B_f = width of the foundation

B_p = width of the plate

- In case of clays the settlement of the foundation can be calculated as follows

$$\frac{\text{sf}}{\text{sp}} = \frac{\text{Bf}}{\text{Bp}}$$

9.3.2 : STANDARDD PENETRATION TEST:

Standard penetration test is also a field test used to determine the bearing capacity of soil.

Procedure;

To carry out standard penetration test first a split spoon sampler is inserted into the soil using hammer to make a bore hole. The bore hole continues up to the depth at which we need to find out the standard penetration value.

- The split spoon sampler is then allowed to penetrate into the soil by applying impact load with a hammer of weight 65 kg and having a free fall height of 75 cm.
- The penetration per blow of the hammer is called SET. The number blows required for 300 mm penetration is called SPT number (N). Number blows are counted for every 150 mm penetration. The first 150 mm penetration is not considered for the calculation of SPT no. but after that 300 mm penetration is considered as the SPT no.
- Few corrections are applied to the observed SPT value to get the final SPT value and they are overburden correction and water table correction or dilatancy correction.
- Overburden correction is applied considering the confining pressure of the soil where as dilatancy correction is applied considering the water table.

Overburden correction:

Overburden correction is applied only when the overburden pressure is less than 280 kn/m^2 .

If "N" is the observed value of SPT then corrected SPT no after application of overburden correction can be written as;

$$N_1 = N \times \frac{350}{\sigma+70}$$

where "σ" is the overburden pressure at the level of test

* If the value of overburden pressure is greater than 280 kn/m^2 then overburden correction is not applied.

Dilatancy Correction:

Dilatancy correction is applied only when the water table is present at or above the test level. If it is below the test level then dilatancy correction is not applied.

After applying dilatancy correction the corrected value of SPT can be written as;

$$N_2 = 15 + \frac{N1 - 15}{2}$$

* Dilatancy correction is required if N_1 is greater than 15.