SOIL MECHANICS

UNIT-1

SOIL FORMATION AND COMPOSITION

WHAT IS SOIL?

The term *Soil* was originated from the Latin word "*SOLUM*" meaning upper layer of earth

"*Soil* " is an assemblage of discrete solid particles of organic or inorganic composition with the voids filled up with water only or air only or a combination of both water and air

Soils thus can have three phases namely, solids, water and air present in it, and is called partially saturated soil

If there is no air present in a soil then, it is a saturated one.

If there is no water present in a soil then, it is a dry soil.

- ***Soil Mechanics*** deals with the strength and deformation behavior of soil due to application of load. It is one of the youngest disciplines of Civil Engineering involving the study of soil, its behavior and application as an engineering material.
- **According to Terzaghi** (1948): "Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles produced by the mechanical and chemical disintegration of rocks regardless of whether or not they contain an admixture of organic constituent."
- ***Foundation Engineering*** deals with the design and construction of foundations of structures using the principles of mechanics of soil.

APPLICATIONS OF SOIL MECHANICS

Design and construction of:

- Foundations (shallow and deep)
- Earth retaining structures
- Stability of slopes
- Earth dam
- Formation of Pavement
- Under ground structures .. tunnels, conduits and shafts

SOME COMMONLY USED SOILS

- Bentonite: Decomposed volcanic ash containing high percentage of clay mineral such as montmorillonite. It exhibits high degree of shrinkage and swelling.

- Black Cotton Soil: Black soil containing high percentage of montmorillonite and colloidal material exhibits high shrinkage and swelling.

- Glacial Till or Boulder Clay: Glacial clay containing all sizes of rocks fragments from boulders down to clay materials.

- Calche: Soil conglomerate of gravel, sand and clay cemented by calcium carbonate.

- Hard Pan: Densely cemented soil which remains hard when wet (Glacial Till)

- Laterite Soils: Deep brown soil of cellular structure, easy to excavate but gets hardened on exposure to air owing to the formation of hydrated iron oxides.

- Loam: It is a mixture of silt, sand and clay size particles in equal proportions.

- Loess: Uniform wind blown yellowish brown silt or silty clay exhibits cohesion in dug conditions which is lost on wetting.

- Marl: Mixtures of calcareous sands or clays or loam; clay content not more than 75 % and lime content not less than 15 %.

- Moorum: Gravel mixed with red clay.

- Top-Soil: Surface material which supports plant life.

MAJOR SOIL DEPOSITS OF INDIA

- Alluvial deposits
- Black cotton soil
- Lateritic soil
- Desert soil
- Marine clay

PARTICLE SIZE

I. S. Classification of soil

Clay size	Silt size	Sand size			Gravel size		Cobble size
		Fine	Medium	Coarse	Fine	Coarse	

0.002 0.075 0.425 2 4.75 20 80

Diameter of particles in mm

Not to scale

PARTICLE SHAPE

1. Spherical
2. Flaky
3. Needle shaped

- Bulky or spherical grains are described in terms of sphericity. Sphericity is denoted by ‘S’ and given as S = D_e/L

- In flaky grains or plate shaped grains thickness of the grains is very small as compared to the other two lateral dimensions. It will look like sheet of paper, a leaf or a platelet (Clays)

- Needle shaped grains are those in which one dimension is fully developed and is much larger compared to the other two dimensions. (Kaolinite)

INTER-PARTICLE FORCES IN A SOIL MASS

1. Gravitational forces are proportional to the mass and is important to coarse grained soil.

2. Surface forces are important for fine-grained soil as the specific surface area is large in the colloids. Surface forces are divided into two:
    1) Attractive forces
    2) Repulsive forces

SOIL STRUCTURE

Structure of a soil may be defined as the arrangement of soil grains. In the study of structure of soils we study the following:

1. Mineralogical Composition
2. Electrical Properties
3. Orientation and shape of soil grains
4. Nature and properties of soil water
5. Interaction of soil water and soil grains

Structural composition of soil influences many engineering properties such as permeability, compressibility and shear strength.

PRINCIPAL CLAY MINERALS

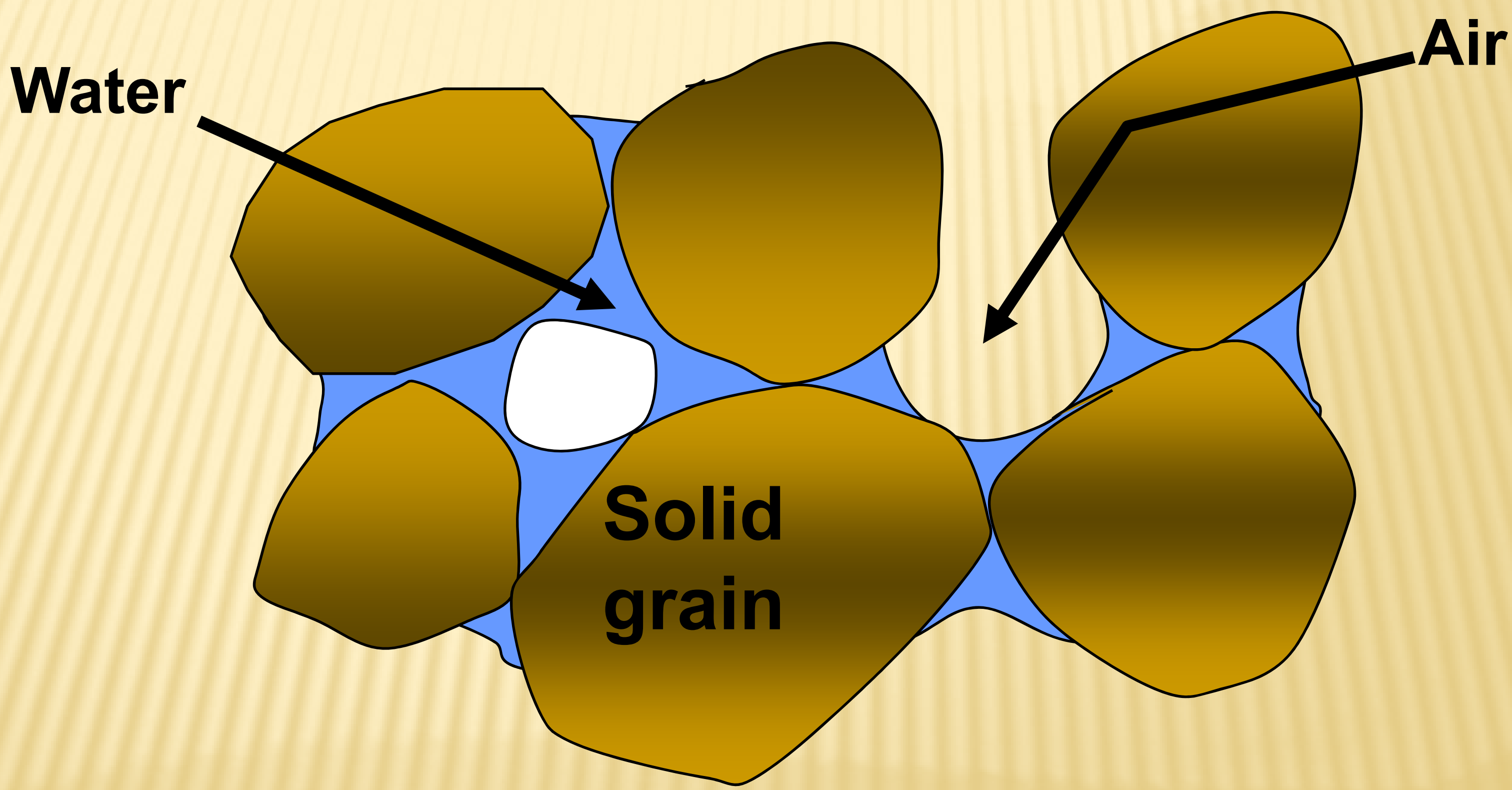
Clay minerals are tiny crystalline substances of one or more members of small groups of minerals . The principal clay minerals are as follows:

1. Montmorillonite
2. Illite
3. Kaolinite

UNIT –II &III

BASIC SOIL PROPERTIES And CLASSIFICATION OF SOILS

SOIL: A 3-PHASE MATERIAL



PROPERTIES OF SOIL

- Porosity
- Void ratio
- Degree of saturation
- Water content

Porosity (n)

The ratio between volume of voids to that of total volume of soil. It is expressed in percentage (%)

$$n = \frac{V_v}{V} \times 100$$

Void ratio (e)

The ratio between volume of voids to that of total volume of soil solids.

$$e = \frac{V_v}{V_s}$$

Degree of saturation (S)

The ratio between volume of water to the volume of voids. It is expressed in percentage (%)

$$S = \frac{V_w}{V_v} \times 100$$

Water content (w)

It is the amount of water present in the soil which is expressed in %age. It is the ratio between the mass of water to the mass of soil solids.

UNIT WEIGHTS

- The bulk unit weight $$\gamma_{bulk} = \frac{W}{V} = \frac{\gamma_w G_s V_s + \gamma_w e S V_s}{V_s + eV_s} = \frac{\gamma_w (G_s + eS)}{1 + e}$$

- The saturated unit weight $$\gamma_{sat} = \frac{\gamma_w (G_s + e)}{1 + e}$$
(S = 1)

- The dry unit weight (S = 0) $$\gamma_{dry} = \frac{\gamma_w G_s}{1 + e}$$

- The submerged unit weight $$\gamma' = \gamma_{sat} - \gamma_w$$

SPECIFIC GRAVITY OF SOIL

- Specific gravity of soil is defined as the ratio between mass or weight of a given volume of soil to that of mass or weight of equal volume of water
- The symbol to denote specific gravity is "***G***"
- Specific gravity of soil solids is denoted by "G_s"
- In general specific gravity of soil is $\cong 2.65$

GRAIN SIZE ANALYSIS

- The grain size analysis is used universally in the engineering classification of soils.
- The distribution of different grain sizes affects the engineering properties of soil.
- Grain size classification is used in partially establishing the suitability criteria for road, airfield and embankment
- constructions.
- Soil-water movement can be predicted using the grain size information.
- The susceptibility to frost action an extremely important consideration in cold climate is dependent on grain size of soil.
- The proper gradation of filter materials in earth dam construction is usually established from gradation tests of soils.

GRAIN SIZE ANALYSIS

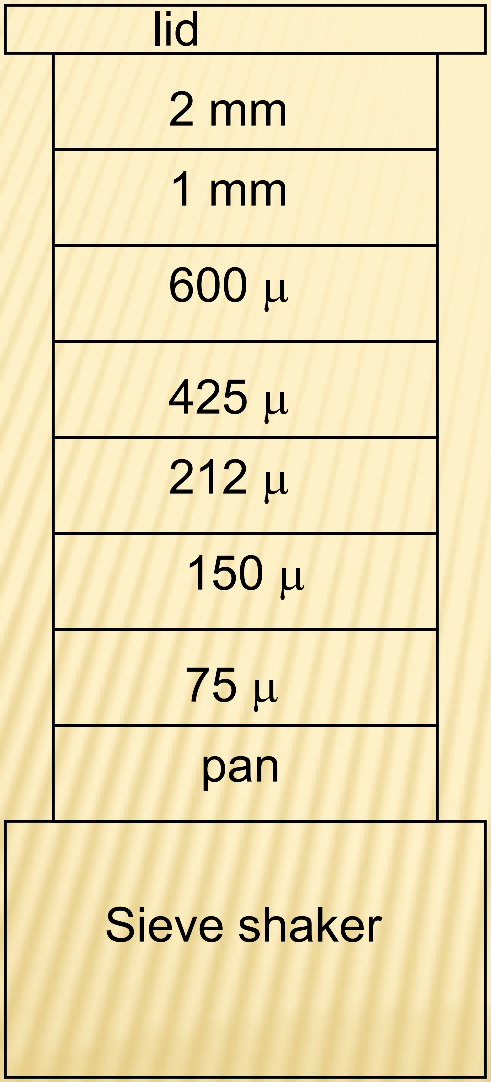
The mechanical analysis or particle size analysis is a method of separation of soil into different fractions based on the particle size. It is represented graphically by particle size distribution curve

TYPES

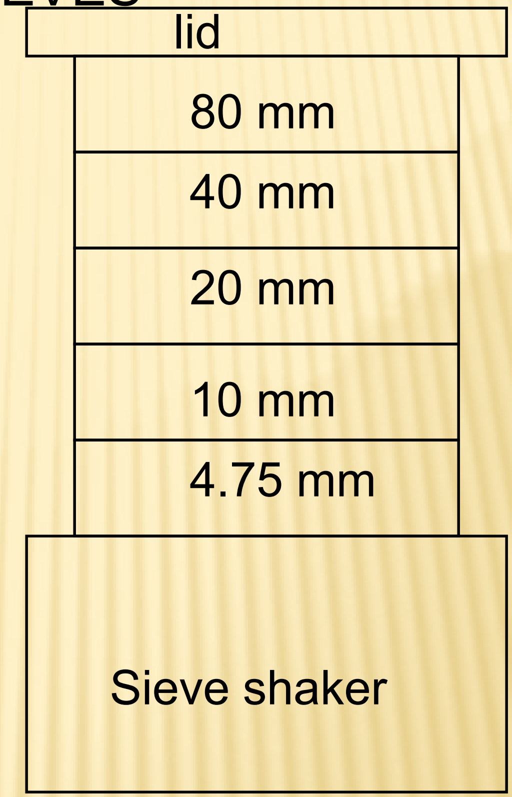
Sieve analysis ≥ 75 μm (Suitable for coarse grained soil)

Sedimentation analysis ≤ 75 μm (Suitable for fine grained soil)

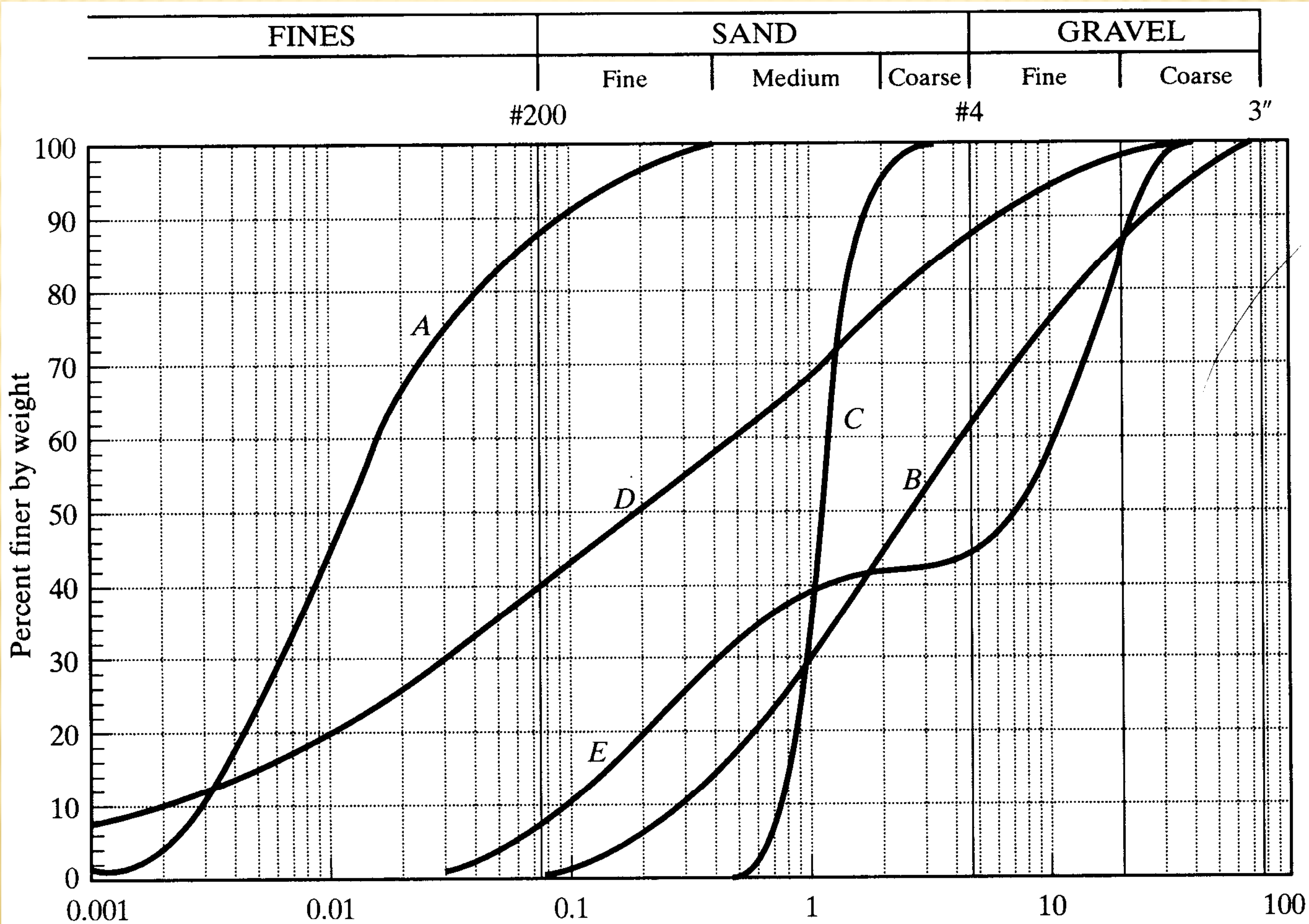
ARRANGEMENT OF FINE SIEVES



ARRANGEMENT OF COARSE SIEVES



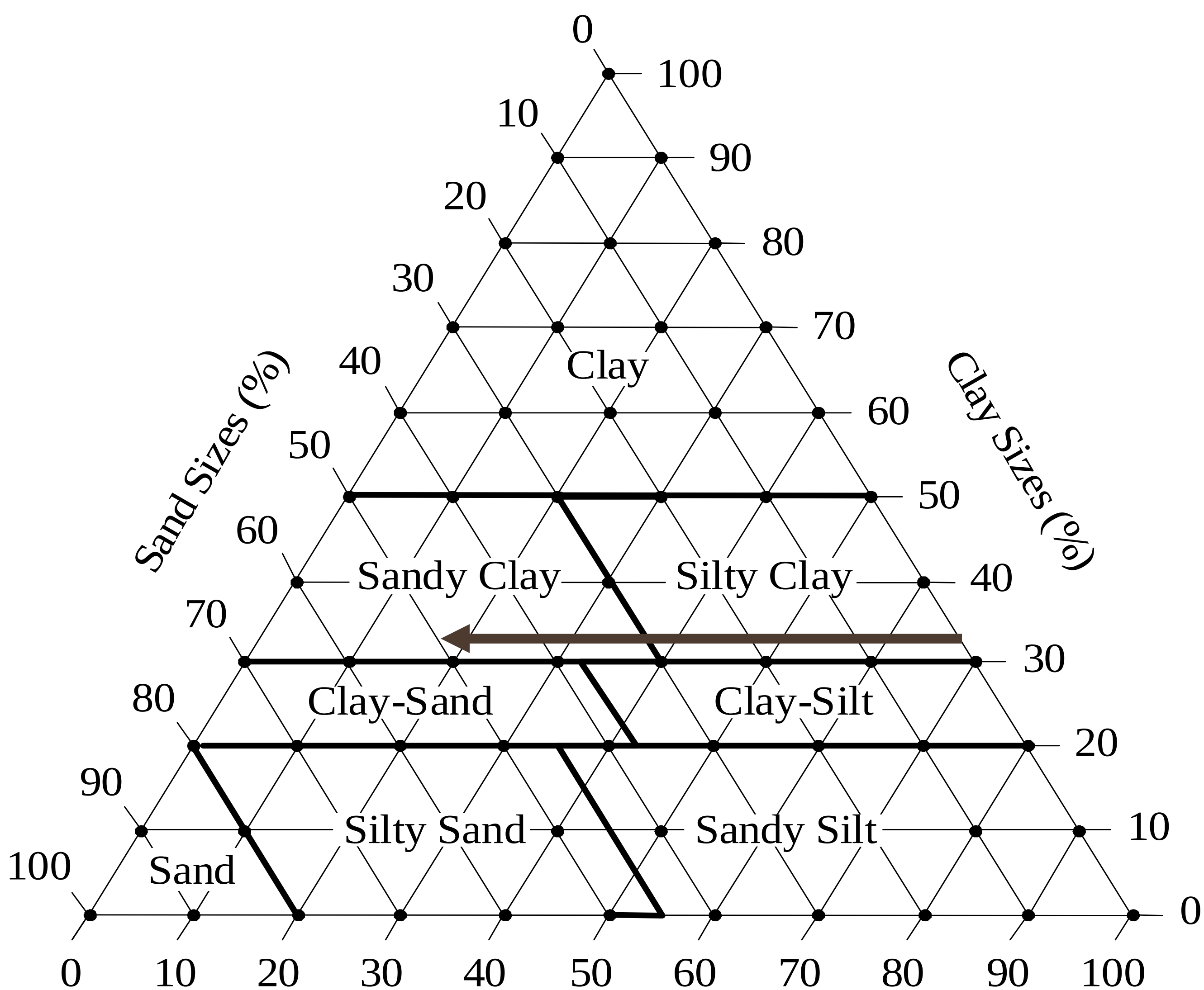
GRAIN SIZE DISTRIBUTION CURVES



SIMPLE CLASSIFICATION

- In general soils contain a wide range of particle sizes
- Some means of describing the characteristics of soils with different proportions of sand/silt/clay is required.

Example: EQUAL AMOUNTS SAND/SILT/CLAY



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Diameter of particles in mm

Not to scale

CLASSIFICATION SYSTEMS

- Used to determine the suitability of different soils
- Used to develop correlations with useful soil properties
- Special Purpose (Local) Systems
  - E.g. PRA system of AASHO
    - 1. Well graded sand or gravel: may include fines
    - 2. Sands and Gravels with excess fines
    - 3. Fine sands
    - 4. Low compressibility silts
    - 5. High compressibility silts
    - 6. Low to medium compressibility clays
    - 7. High compressibility clays
    - 8. Peat and organic soils

UNIFIED SOIL CLASSIFICATION

- Each soil is given a 2 letter classification (e.g. SW). The following procedure is used.
- Coarse grained (>50% larger than 75 μm)
    - Prefix S if > 50% of coarse is Sand
    - Prefix G if > 50% of coarse is Gravel

    - Suffix depends on %fines
    - if %fines < 5% suffix is either W or P
    - if %fines > 12% suffix is either M or C
    - if 5% < %fines < 12% Dual symbols are used

UNIFIED SOIL CLASSIFICATION

To determine W or P, calculate C_u and C_c

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

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

If prefix is G then suffix is W if $C_u > 4$ and C_c is between 1 and 3

otherwise use P

If prefix is S then suffix is W if $C_u > 6$ and C_c is between 1 and 3

otherwise use P

CONSISTENCY OF SOILS

- The consistency of a fine-grained soil refers to its firmness, and it varies with the water content of the soil.

- A gradual increase in water content causes the soil to change from solid to semi-solid to plastic to liquid states.

- The water contents at which the consistency changes from one state to the other are called consistency limits (or Atterberg limits).

- The three limits are known as the shrinkage limit (W_S), plastic limit (W_P), and liquid limit (W_L).

USCS Classification Chart

UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM DESIGNATION D-2487)

SOIL CLASSIFICATION CHART

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification: Group Symbol	Soil Classification: Group Name[B]
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve	Gravels More than 50% of coarse fraction retained on No. 4 sieve	Cleans Gravels Less than 5% fines[C]	$C_u \geq 4$ and $1 \leq C_c \leq 3$[E]	GW	Well-graded gravel[F]
			$C_u < 4$ and/or $C_c > 3$[E]	GP	Poorly graded gravel[F]
		Gravels with Fines More than 12% fines[C]	Fines classify as ML or MH	GM	Silty gravel[F,G,H]
			Fines classify as CL or CH	GC	Clayey gravel[F,G,H]
	Sands 50% or more of coarse fraction passes No. 4 sieve	Cleans Sands Less than 5% fines[D]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[E]	SW	Well-graded sand[I]
			$C_u < 6$ and/or $1 > C_c > 3$[E]	SP	Poorly graded sand[I]
		Sands with Fines More than 12% fines[D]	Fines classify as ML or MH	SM	Silty sand[G,H,I]
			Fines classify as CL or CH	SC	Clayey sand[G,H,I]
FINE-GRAINED SOILS 50% or more pass the No. 200 sieve	Silts and Clays Liquid limit less than 50	inorganic	PI > 7 and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
			PI < 4 or plots below "A" line[J]	ML	Silt[K,L,M]
		organic	Liquid Limit - oven dried / Liquid Limit - not dried < 0.75	OL	Organic clay[K,L,M,N] Organic silt[K,L,M,O]
	Silts and Clays Liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
			PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	Liquid Limit - oven dried / Liquid Limit - not dried < 0.75	OH	Organic clay[K,L,M,P] Organic silt[K,L,M,O]
HIGHLY ORGANIC SOILS		Primarily organic matter, dark in color, and organic odor		PT	Peat

ACTIVITY OF CLAYS

It is a measure of water holding capacity of clayey soil. The changes in the volume of clayey soil during swelling or shrinking depends upon the activity. It is the ratio of plasticity index to clay fraction (-2 μ size) of soil

Activity A = I_p / F

Classification of soil based on activity

S. No	Activity	Soil type
1.	A < 0.75	Inactive
2.	A = 0.75-1.25	Normal
3.	A > 1.25	Active

UNIT-4

PERMEABILITY

PERMEABILITY

- Permeability is the passage or seepage of water into the soil through its interconnecting voids
- The flow of water can be laminar or turbulent but the flow of water into soil is mostly laminar
- The unit of Permeability is “cm/s”
- It has a dominating influence on the total engg. behavior of soil

COEFFICIENT OF PERMEABILITY (k)

It is defined as the average velocity of flow through the total cross sectional area of soil under unit hydraulic gradient

Coefficient of permeability (*k*) of a soil is proportional to square of the particle size (D)

The value of coefficient of permeability of coarse grained soil may be one million times more than that of clay

$$k = \frac{QL}{Aht}$$

Where

Q = total volume of water

t = time period

h = head causing flow

L = length of the specimen

A = cross sectional area of soil

Darcy's law

For laminar flow conditions in a saturated soil the rate of flow or discharge per unit time (q) is proportional to hydraulic gradient (i)

$q = k\, i\, A$ where,

q = discharge per unit time

A= Total cross sectional area of soil perpendicular to the direction of flow

k = coefficient of permeability

i = hydraulic gradient

Validity of Darcy's law

Darcy's law is valid only for laminar flow conditions of flow of water through soil.

Reynolds found that the flow is laminar as long the velocity of flow is less than lower critical velocity (v_c) expressed in terms of Reynold's number.

$$\frac{v_c d \rho_w}{\eta g} = 2000$$

Discharge velocity and seepage velocity

Actual velocity of flow through the soil takes place only through voids of the soil is also known as seepage velocity.

Seepage velocity (v_s)is defined as the rate of discharge of percolating water per unit cross sectional area of voids perpendicular to the direction of flow.

Hence the actual velocity of flow will be more than the discharge velocity.

Methods of determination of permeability of soil

LABORATORY METHODS

- Constant head permeability test
- Variable or Falling head permeability test

The constant head test method is used for relatively more permeable soil ($k>10^{-4}$ cm/s) and

Variable or falling head test is used for less permeable soils ($k<10^{-4}$ cm/s)

FIELD METHODS (To measure in situ permeability)

- Pumping out tests
- Pumping in tests

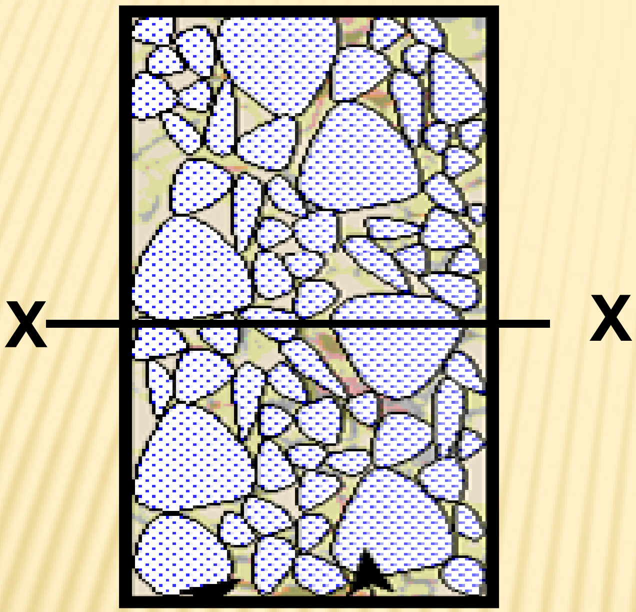
<u>Pumping out test</u> influences large area around the well and give an overall value of coefficient of permeability

<u>Pumping in tests</u> influences small area surrounding the hole and gives the value of coefficient of permeability of the soil surrounding the hole

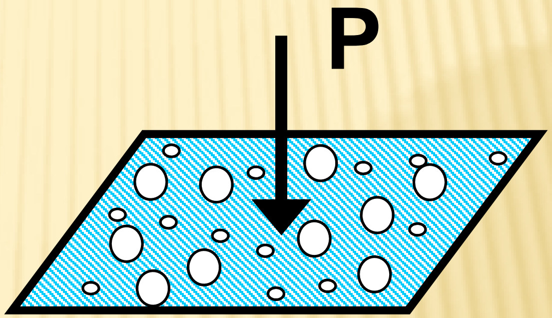
UNIT-5

FFECTIVE STESS CONCE

Stresses in Soil Masses



Soil Unit



Area = A

$$\sigma = P/A$$

Assume the soil is fully saturated, all voids are filled with water.

Effective Stress

- From the standpoint of the soil skeleton, the water carries some of the load. This has the *effect* of lowering the stress level for the soil.
- *Therefore, we may define*

effective stress = total stress minus pore pressure

$\sigma' = \sigma - u$ where,

σ' = effective stress
σ = total stress
u = pore pressure

Effective Stress

$$\sigma' = \sigma - u$$

- The effective stress is the force carried by the soil skeleton divided by the total area of the surface.
- The effective stress controls certain aspects of soil behavior, notably, compression & strength.

Effective Stress Calculations

$$\sigma'_z = \Sigma\, \gamma_i H_i - u$$

where,

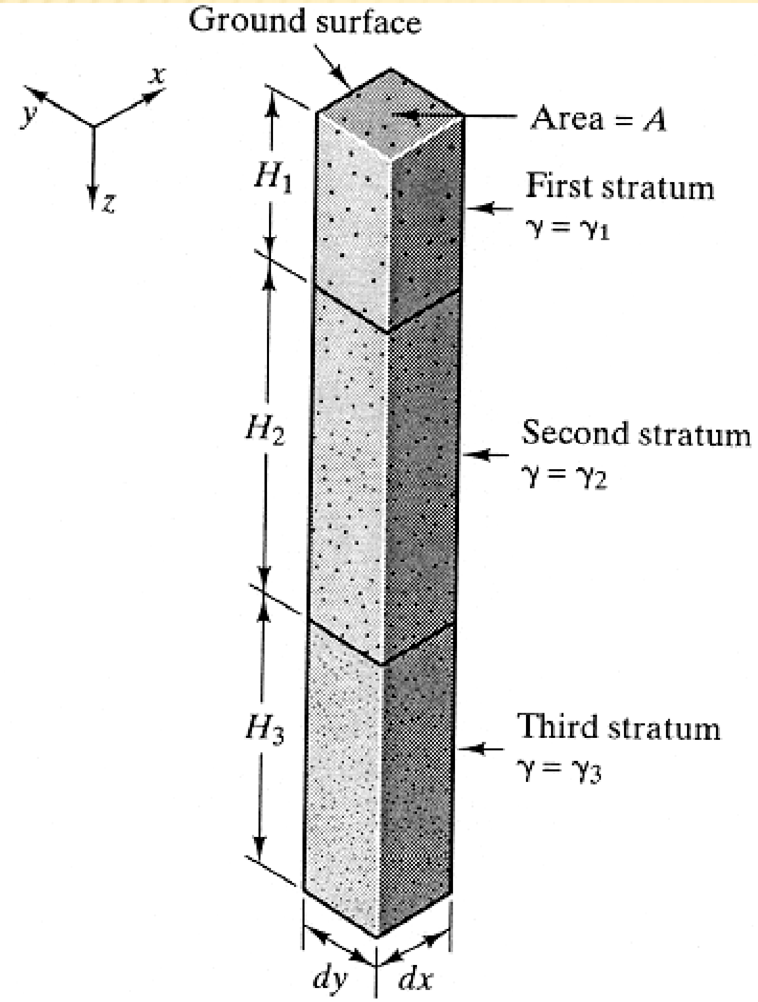
H = layer thickness

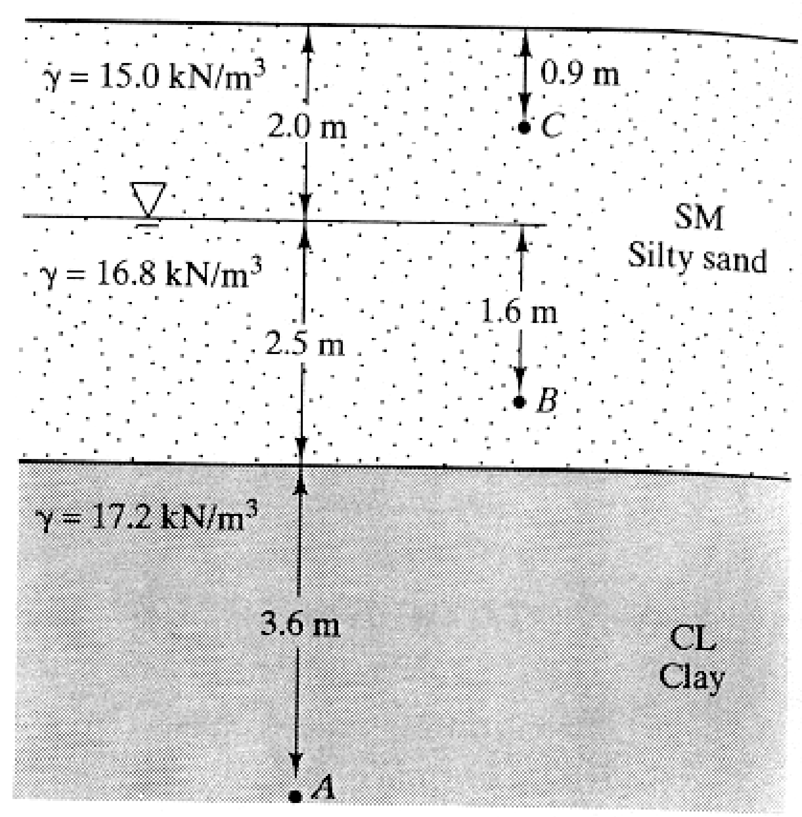
γ_{sat} = saturated unit weight

U = pore pressure = $\gamma_w Z_w$

When you encounter a groundwater table, you must use effective stress principles; i.e., subtract the pore pressure from the total stress.

Geostatic Stresses





USES OF FLOW NETS

The graphical properties of a flow net can be used in obtaining solutions for many seepage problems such as:

1. *Estimation of seepage losses from reservoirs:* It is possible to use the flow net in the transformed space to calculate the flow underneath the dam.

2. *Determination of uplift pressures below dams:* From the flow net, the pressure head at any point at the base of the dam can be determined. The uplift pressure distribution along the base can be drawn and then summed up.

3. *Checking the possibility of piping beneath dams:* At the toe of a dam when the upward exit hydraulic gradient approaches unity, boiling condition can occur leading to erosion in soil and consequent piping. Many dams on soil foundations have failed because of a sudden formation of a piped shaped discharge channel. As the stored water rushes out, the channel widens and catastrophic failure results. This is also often

UNIT-6

COMPACTION

Compaction is the application of mechanical energy to a soil so as to rearrange its particles and reduce the void ratio. It is applied to improve the properties of an existing soil or in the process of placing fill such as in the construction of embankments, road bases, runways, earth dams, and reinforced earth walls. Compaction is also used to prepare a level surface during construction of buildings. There is usually no change in the water content and in the size of the individual soil particles.

The objectives of compaction are:

To increase soil shear strength and therefore its bearing capacity.

To reduce subsequent settlement under working loads.

To reduce soil permeability making it more difficult for water to flow through.

LABORATORY COMPACTION

The variation in compaction with water content and compactive effort is first determined in the laboratory. There are several tests with standard procedures such as:

Indian Standard Light Compaction Test (similar to Standard Proctor Test)

Indian Standard Heavy Compaction Test (similar to Modified Proctor Test)

Indian Standard Light Compaction Test

Soil is compacted into a 1000 cm^3 mould in 3 equal layers, each layer receiving 25 blows of a 2.6 kg rammer dropped from a height of 310 mm above the soil. The compaction is repeated at various moisture contents.

Indian Standard Heavy Compaction Test

It was found that the Light Compaction Test (Standard Test) could not reproduce the densities measured in the field under heavier loading conditions, and this led to the development of the Heavy Compaction Test (Modified Test). The equipment and procedure are essentially the same as that used for the Standard Test except that the soil is compacted in 5 layers, each layer also receiving 25 blows. The same mould is also used. To provide the increased compactive effort, a heavier rammer of 4.9 kg and a greater drop height of 450 mm are used

COMPACTION OF COHESIONLESS SOILS

For **cohesionless soils** (or soils without any fines), the standard compaction tests are difficult to perform. For compaction, application of vibrations is the most effective method. Watering is another method. The seepage force of water percolating through a cohesionless soil makes the soil grains occupy a more stable position. However a large quantity of water is required in this method. To achieve maximum dry density, they can be compacted either in a dry state or in a saturated state.

RELATIVE DENSITY

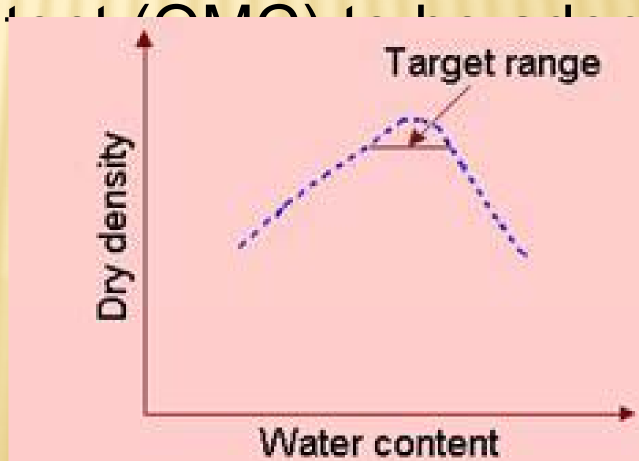
For these soil types, it is usual to specify a magnitude of **relative density (I_D)** that must be achieved. If ***e*** is the current void ratio or γ_d is the current dry density, the relative density is usually defined in percentage as

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

$$I_D = \frac{\gamma_{dmax}(\gamma_d - \gamma_{dmin})}{\gamma_d(\gamma_{dmax} - \gamma_{dmin})} \times 100$$

FIELD COMPACTION

To control soil properties in the field during earthwork construction, it is usual to specify the **degree of compaction**(also known as the **relative compaction**). This specification is usually that a certain percentage of the maximum dry density, as found from a laboratory test (Light or Heavy Compaction), must be achieved. For example, it could be specified that field dry densities must be greater than 95% of the maximum dry density (MDD) as determined from a laboratory test. Target values for the range of water content near the optimum moisture con[illegible]ted at the site can then be decided



Field Compaction Equipment

There is a wide range of compaction equipment. The compaction achieved will depend on the thickness of lift (or layer), the type of roller, the no. of passes of the roller, and the intensity of pressure on the soil. The selection of equipment depends on the soil type as indicated.

Equipment	Most suitable soils	Least suitable soils
Smooth steel drum rollers(static or vibratory)	Well-graded sand-gravel, crushed rock, asphalt	Uniform sands, silty sands, soft clays
Pneumatic tyred rollers	Most coarse and fine soils	Very soft clays
Sheepsfoot rollers	Fine grained soils, sands and gravels with > 20% fines	Uniform gravels, very coarse soils
Grid rollers	Weathered rock, well-graded coarse soils	Uniform materials, silty clays, clays
Vibrating plates	Coarse soils with 4 to 8% fines	
Tampers and rammers	All soil types	

UNIT-8

COMPRESSIBILITY AND CONSOLIDATION

INTRODUCTION

When a soil layer is subjected to vertical stress, volume change can take place through rearrangement of soil grains, and some amount of grain fracture may also take place. The volume of soil grains remains constant, so change in total volume is due to change in volume of water. In saturated soils, this can happen only if water is pushed out of the voids. The movement of water takes time and is controlled by the **permeability** of the soil and the locations of free draining boundary surfaces.

It is necessary to determine both the magnitude of volume change (or the settlement) and the time required for the volume change to occur. The magnitude of settlement is dependent on the magnitude of applied stress, thickness of the soil layer, and the **compressibility** of the soil.

When soil is loaded undrained, the pore pressure increases. As the excess pore pressure dissipates and water leaves the soil, settlement takes place. This process takes time, and the rate of settlement decreases over time. In coarse soils (sands and gravels), volume change occurs immediately as pore pressures are dissipated rapidly due to high permeability. In fine soils (silts and clays), slow seepage occurs due to low permeability.

COMPONENTS OF TOTAL SETTLEMENT

The total settlement of a loaded soil has three components: Elastic settlement, primary consolidation, and secondary compression.

Elastic settlement is on account of change in shape at constant volume, i.e. due to vertical compression and lateral expansion. **Primary consolidation (**or simply **consolidation)** is on account of flow of water from the voids, and is a function of the permeability and compressibility of soil. **Secondary compression** is on account of creep-like behaviour.

Primary consolidation is the major component and it can be reasonably estimated. A general theory for consolidation, incorporating three-dimensional flow is complicated and only applicable to a very limited range of problems in geotechnical engineering. For the vast majority of practical settlement problems, it is sufficient to consider that both seepage and strain take place in one direction only, as **one-dimensional**

NORMAL AND OVER CONSOLIDATED CLAY

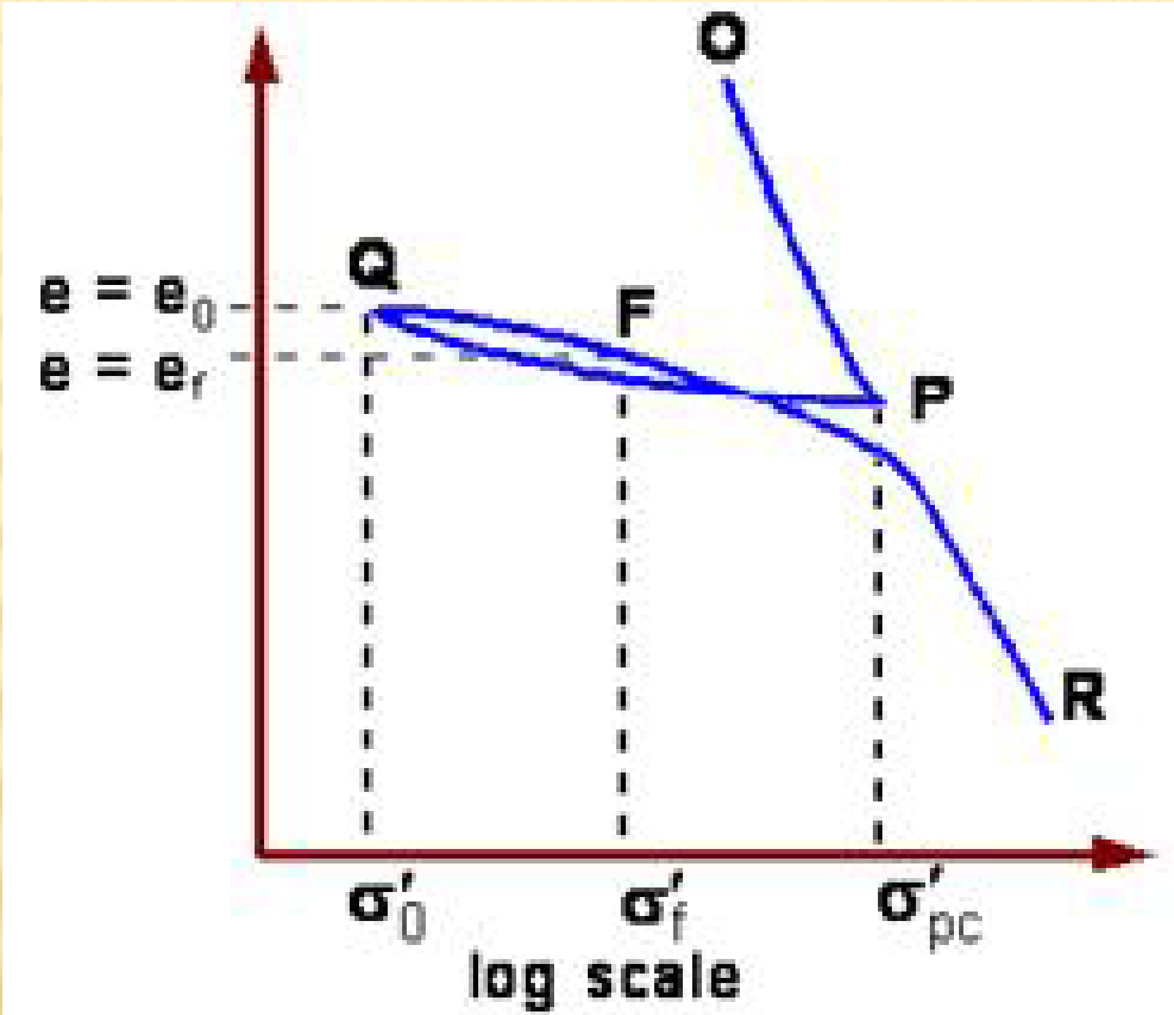
OP corresponds to initial loading of the soil. **PQ** corresponds to unloading of the soil. **QFR** corresponds to a reloading of the soil. Upon reloading beyond **P,** the soil continues along the path that it would have followed if loaded from **O to R**continuously.

The **preconsolidation stress, s'$_{pc}$**, is defined to be the maximum effective stress experienced by the soil. This stress is identified in comparison with the effective stress in its present state. For soil at state **Q or F,** this would correspond to the effective stress at point **P.**

If the current effective stress, **s'**, is equal (note that it cannot be greater than) to the preconsolidation stress, then the deposit is said to be **normally consolidated (NC).** If the current effective stress is less than the preconsolidation stress, then the soil is said to be **over-consolidated (OC).**

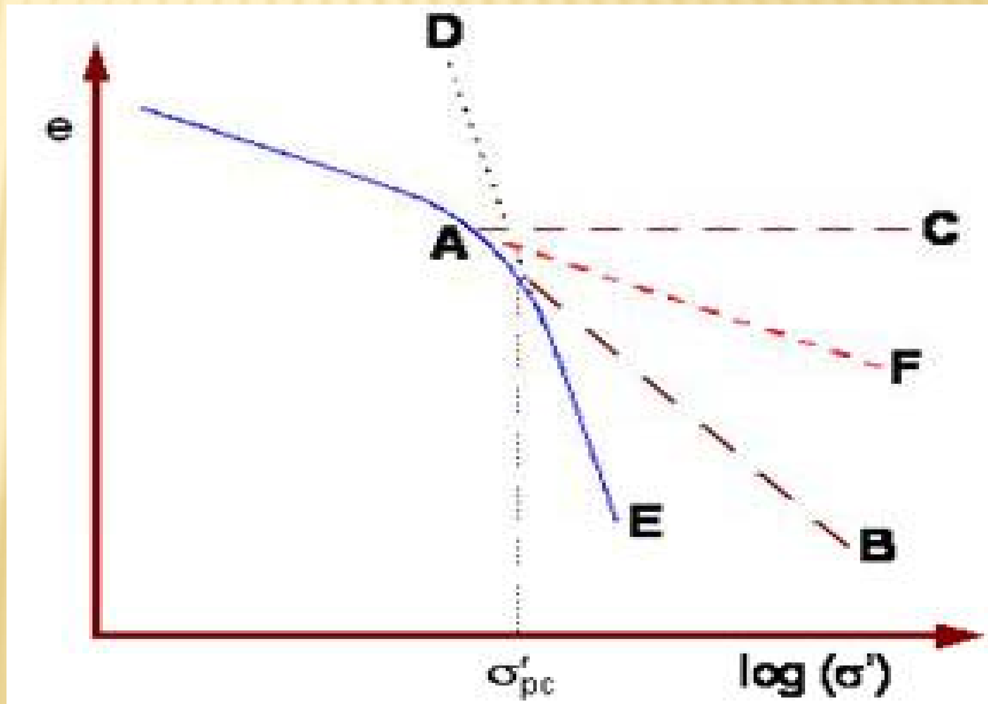
It may be seen that for the same increase in effective stress, the change in void ratio is much less for an overconsolidated soil **(from e_0 to e_f)**, than it would have been for a normally consolidated soil as in path **OP.** In unloading, the soil swells but the increase in volume is much less than the initial decrease in volume for the same stress difference.

The distance from the normal consolidation line has an important influence on soil behaviour. This is described numerically by the **overconsolidation ratio (OCR)**, which is defined as the ratio of the preconsolidation stress to the current effective


O
Q
F
P
R
e = e0
e = ef
σ'0
σ'f
σ'pc
log scale

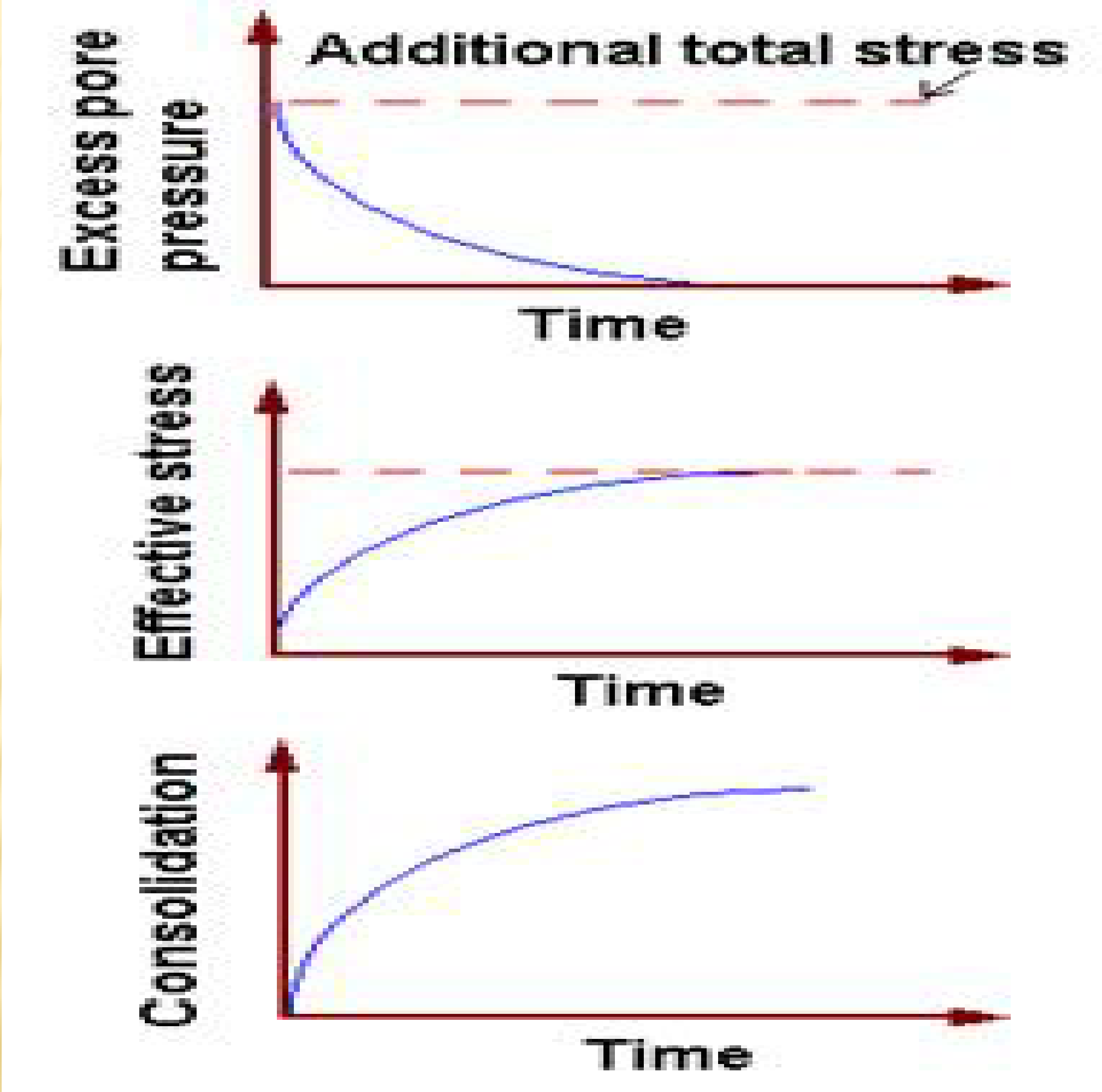
ESTIMATION OF PRECONSOLIDATION STRESS

It is possible to determine the preconsolidation stress that the soil had experienced. The soil sample is to be loaded in the laboratory so as to obtain the void ratio - effective stress relationship. Empirical procedures are used to estimate the preconsolidation stress, the most widely used being Casagrande's construction which is illustrated.



The steps in the construction are:

- Draw the graph using an appropriate scale.
- Determine the point of maximum curvature **A.**
- At **A,** draw a tangent **AB** to the curve.
- At **A,** draw a horizontal line **AC.**
- Draw the extension **ED** of the straight line portion of the curve.
- Where the line **ED** cuts the bisector **AF** of angle **CAB**, that point corresponds to the preconsolidation stress.



Additional total stress
Excess pore pressure
Time
Effective stress
Time
Consolidation
Time

UNIT-9

SHEAR STRENGTH

INTRODUCTION

Soils consist of individual particles that can slide and roll relative to one another. Shear strength of a soil is equal to the maximum value of shear stress that can be mobilized within a soil mass without failure taking place.

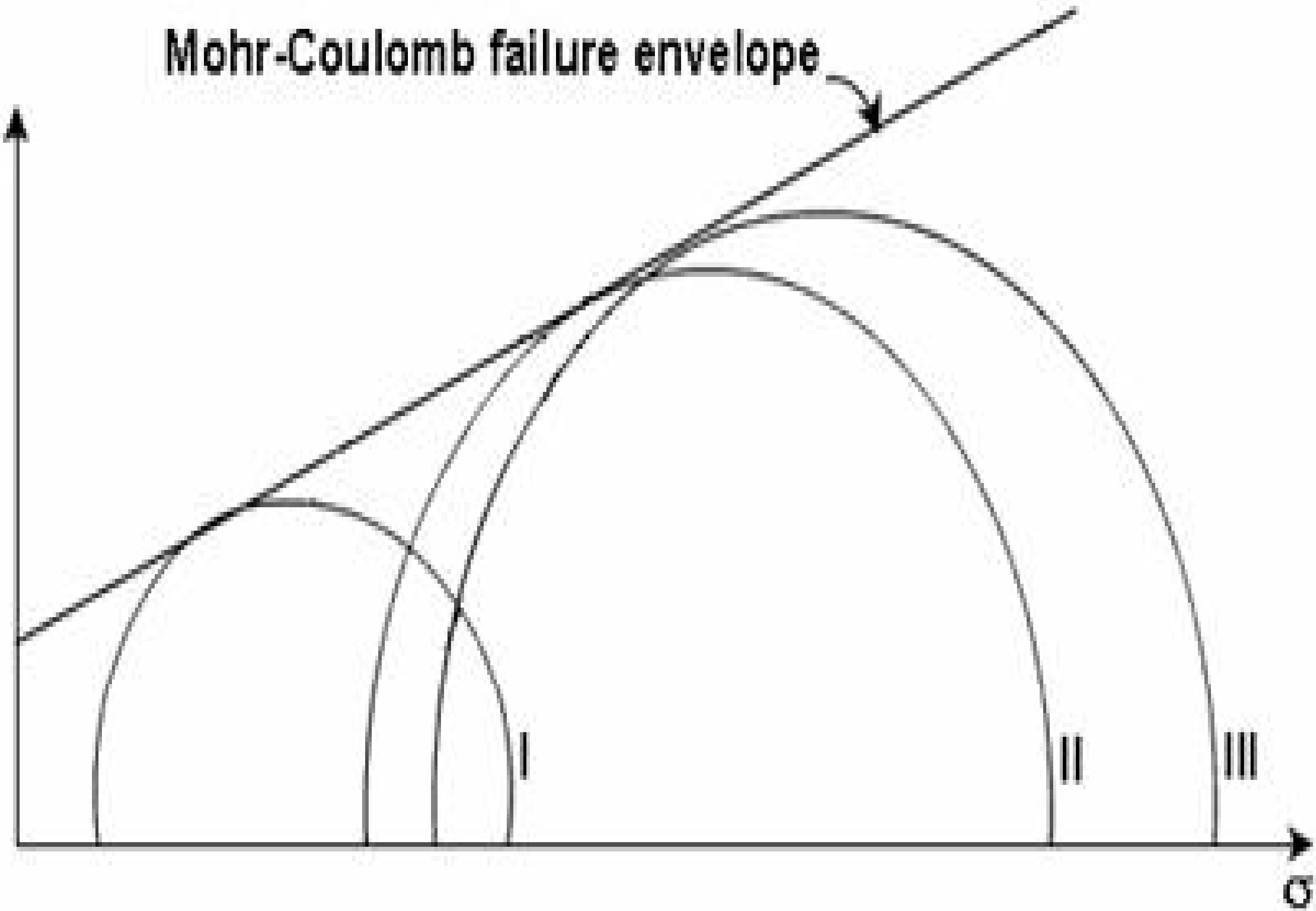
The shear strength of a soil is a function of the stresses applied to it as well as the manner in which these stresses are applied. A knowledge of shear strength of soils is necessary to determine the bearing capacity of foundations, the lateral pressure exerted on retaining walls, and the stability of slopes.

MOHR-COULUMB FAILURE

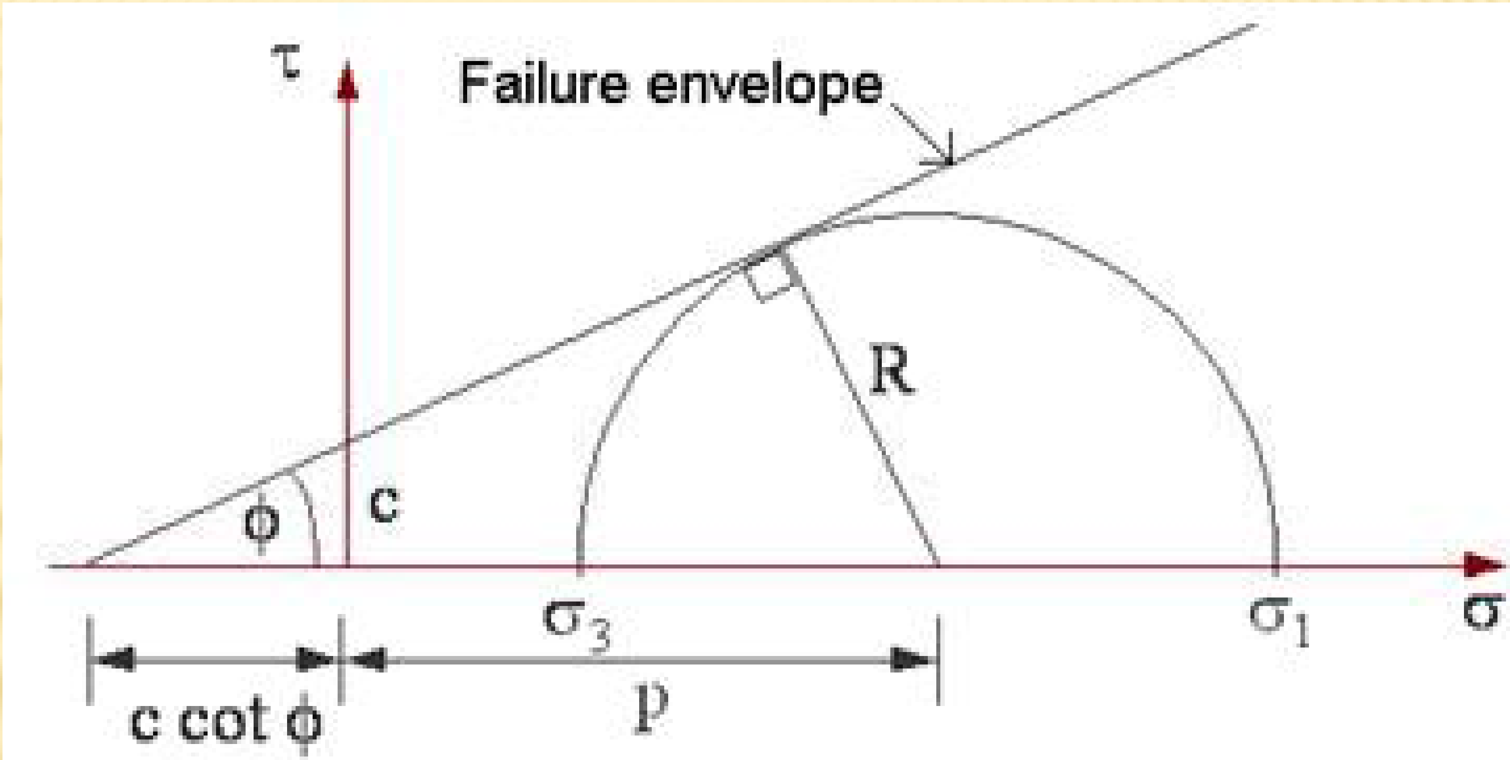
When the soil sample has failed, the shear stress on the failure plane defines the shear strength of the soil. Thus, it is necessary to identify the failure plane. Is it the plane on which the maximum shear stress acts, or is it the plane where the ratio of shear stress to normal stress is the maximum?

For the present, it can be assumed that a failure plane exists and it is possible to apply principal stresses and measure them in the laboratory by conducting a triaxial test. Then, the Mohr circle of stress at failure for the sample can be drawn using the known values of the principal stresses.

If data from several tests, carried out on different samples upto failure is available, a series of Mohr circles can be plotted. It is convenient to show only the upper half of the Mohr circle. A line tangential to the Mohr circles can be drawn, and is called the Mohr-Coulomb failure envelope.


Mohr-Coulomb failure envelope
τ
I
II
III
σ

If the stress condition for any other soil sample is represented by a Mohr circle that lies below the failure envelope, every plane within the sample experiences a shear stress which is smaller than the shear strength of the sample. Thus, the point of tangency of the envelope to the Mohr circle at failure gives a clue to the determination of the inclination of the failure plane. The orientation of the failure plane can be finally determined by the pole method.



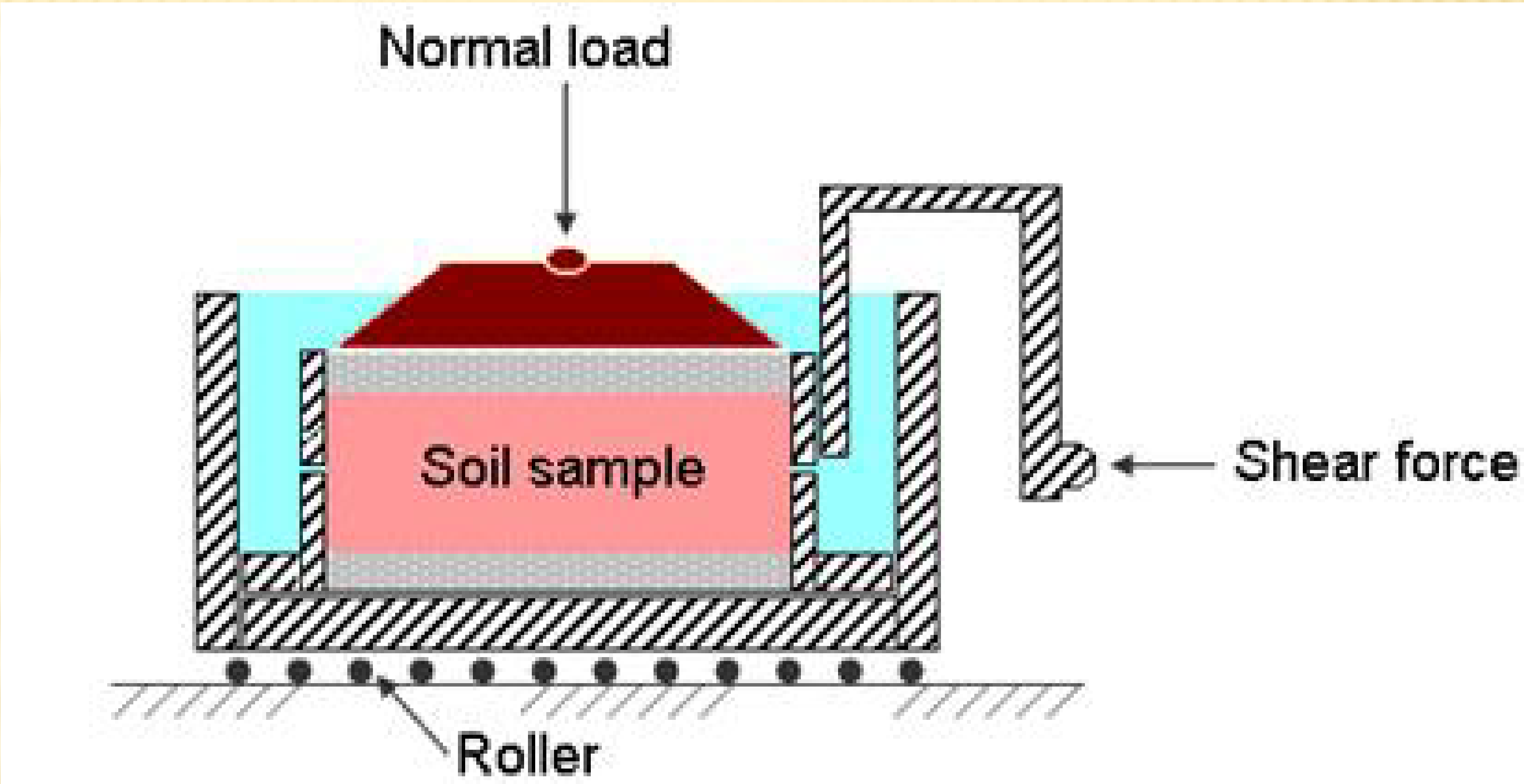
τ
Failure envelope
R
c
φ
σ3
σ1
σ
c cot φ
p

DIRECT SHEAR TEST

The test is carried out on a soil sample confined in a metal box of square cross-section which is split horizontally at mid-height. A small clearance is maintained between the two halves of the box.The soil is sheared along a predetermined plane by moving the top half of the box relative to the bottom half. The box is usually square in plan of size 60 mm x 60 mm.

If the soil sample is fully or partially saturated, perforated metal plates and porous stones are placed below and above the sample to allow free drainage. If the sample is dry, solid metal plates are used. A load normal to the plane of shearing can be applied to the soil sample through the lid of the box.

Tests on sands and gravels can be performed quickly, and are usually performed dry as it is found that water does not significantly affect the drained strength. For clays, the rate of shearing must be chosen to prevent excess pore pressures building up.


Normal load
Soil sample
Shear force
Roller

The test has several **advantages:**

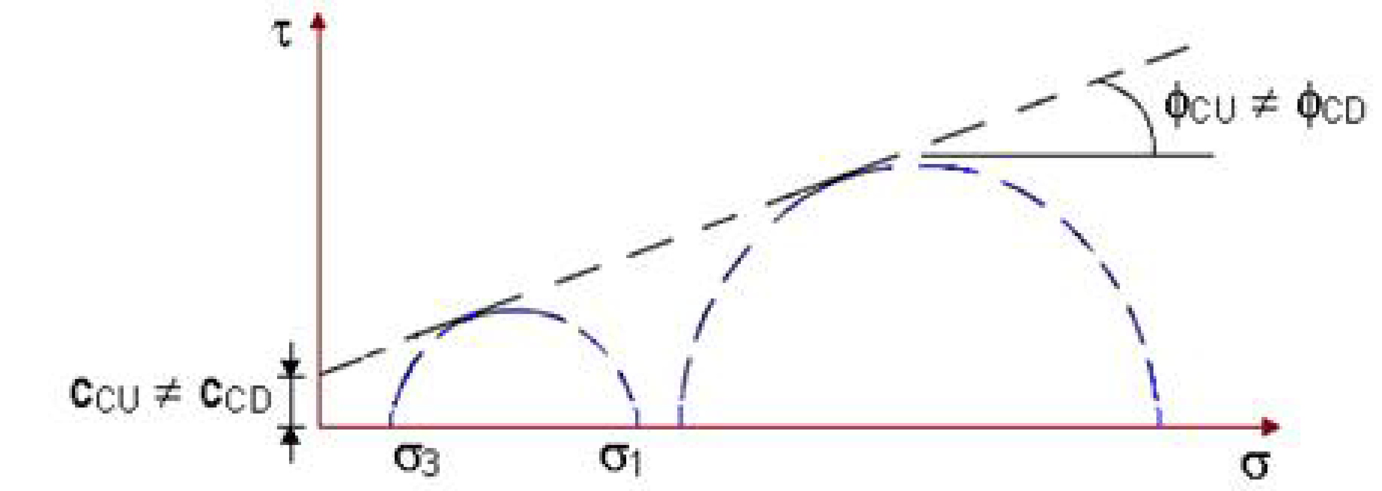
- It is easy to test sands and gravels.
- Large samples can be tested in large shear boxes, as small samples can give misleading results due to imperfections such as fractures and fissures, or may not be truly representative.
- Samples can be sheared along predetermined planes, when the shear strength along fissures or other selected planes are needed.

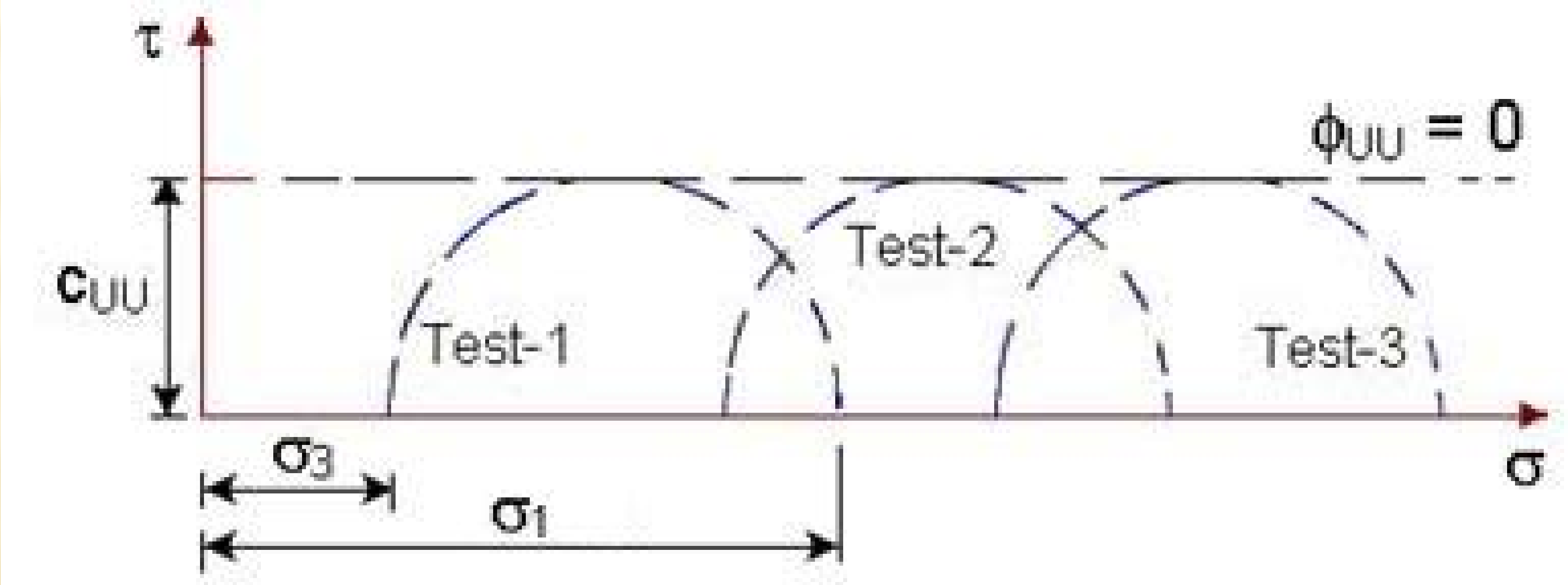
The **disadvantages** of the test include:

- The failure plane is always horizontal in the test, and this may not be the weakest plane in the sample. Failure of the soil occurs progressively from the edges towards the centre of the sample.
- There is no provision for measuring pore water pressure in the shear box and so it is not possible to determine effective stresses from undrained tests.
- The shear box apparatus cannot give reliable undrained strengths because it is impossible to prevent localised drainage away from the shear plane.

TOTAL STRESS PARAMETERS

1) UU test
2) CU & CD tests





PORE WATER PRESSURE

The difference between the total and effective stresses is simply the pore water pressure **u.** Consequently, the total and effective stress Mohr circles have the same diameter and are only separated along the **s - axis** by the magnitude of the pore water pressure.

It is easy to construct a series of total stress Mohr Circles but the inferred total stress parameters have no relevance to actual soil behaviour. In principle, the effective strength parameters are necessary to check the stability against failure for any soil construction in the field. To do this, the pore water pressure in the ground under the changed loading conditions must be known and in general they are not.

In an undrained triaxial test with pore pressure measurement, this is possible and the effective stresses can then be determined. Alternatively, in drained tests, the loading rate can be made sufficiently slow so as to allow the dissipation of all excess pore