

UNIT-5

Shear strength of soils

Importance of shear strength:-

- * In the design of foundations the evaluation of bearing capacity is dependent on the shear strength.
- * For the design of embankments for dams, roads, pavements, excavations, etc. The analysis of the stability of the slope is done using shear strength.
- * In the design of earth retaining structures like retaining walls, sheetpile, coffer dams, bulk heads, and other underground structures.

Mohr's - Coulomb failure theories:-

- * Of the many theories of failure that have been proposed, only that formulated by Mohr (1900) has been useful in case of soils.
 - 1) Material fails essentially by shear. The critical shear stress causing failure depends upon the properties of the material.
 - 2) The ultimate material is subjected to three dimensional principal stresses (i.e., $\sigma_1, \sigma_2, \sigma_3$) the intermediate principal stress does not have any influence on the strength of material.
 - 3) The ultimate strength of material is determined by stresses on potential failure plane.

* The theory was first expressed by Coulomb (1776) and later generalised by Mohr. The theory can be expressed algebraically by the equation.

$$\gamma_f = s = F(\sigma)$$

$\gamma_f = s$ = shear stress on failure plane, at failure
= shear resistance of material

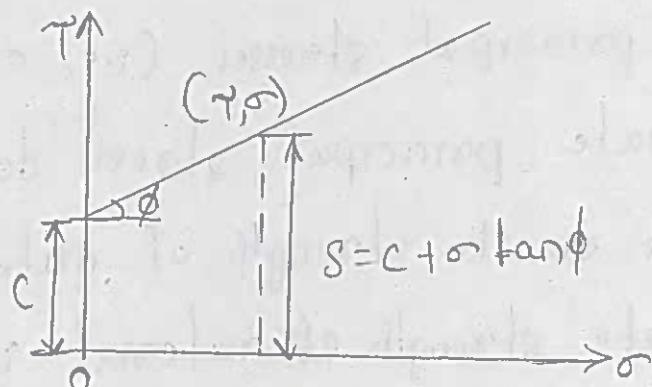
$F(\sigma)$ = function of normal stress

* If the normal and shear stress corresponding to failure are plotted, then a curve is obtained. The plot or the curve is called the strength envelope.

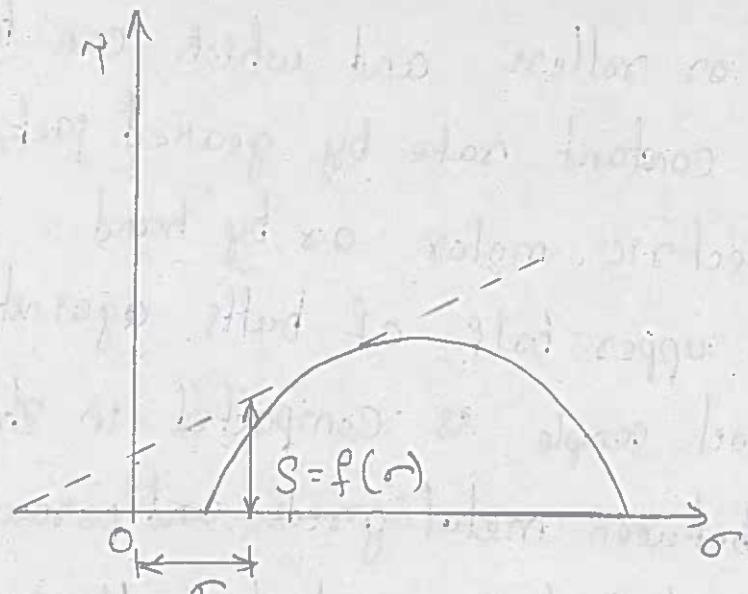
* Coulomb defined the function $F(\sigma)$ as a linear function of σ and gave the following strength equation.

$$s = c + \sigma \tan \phi$$

where the empirical constants c and ϕ represent respectively, the intercept on the shear axis and the slope of straight line of equation. These parameters are usually termed as cohesion and angle of internal friction or net shearing resistance respectively.



a) Coulomb envelope



b) Mohr's envelope

* Mohr envelope can be considered to be straight if the angle of internal friction ϕ is assumed to be constant. Depending upon the properties of a material the failure envelope may be straight or curved, and it may pass through the origin of stress or it may intersect the shear stress axes.

Types of laboratory tests for strength parameters:-

1) Direct shear test

2) Triaxial compression test

3) Vane shear test

1) Direct shear test:-

→ This is a simple and commonly used test and is performed in a shear-box apparatus.

→ The apparatus consists of a two piece shear box of square or circular cross-section.

→ The lower half of the box is rigidly held in

position in a container which rests over slides or rollers and which can be pushed forward at a constant rate by geared jack, driven either by electric motor or by hand.

- The upper half of butts against a proving ring.
- The soil sample is compacted in shear box, and is held between metal grids and porous stones.
- Normal load is applied on the specimen from a loading yoke bearing upon steel of pressure pad.
- When a shearing force is applied on lower box through geared jack.
- The volume change during the consolidation and during shearing process is measured by mounting a dial gauge at the top of the box.

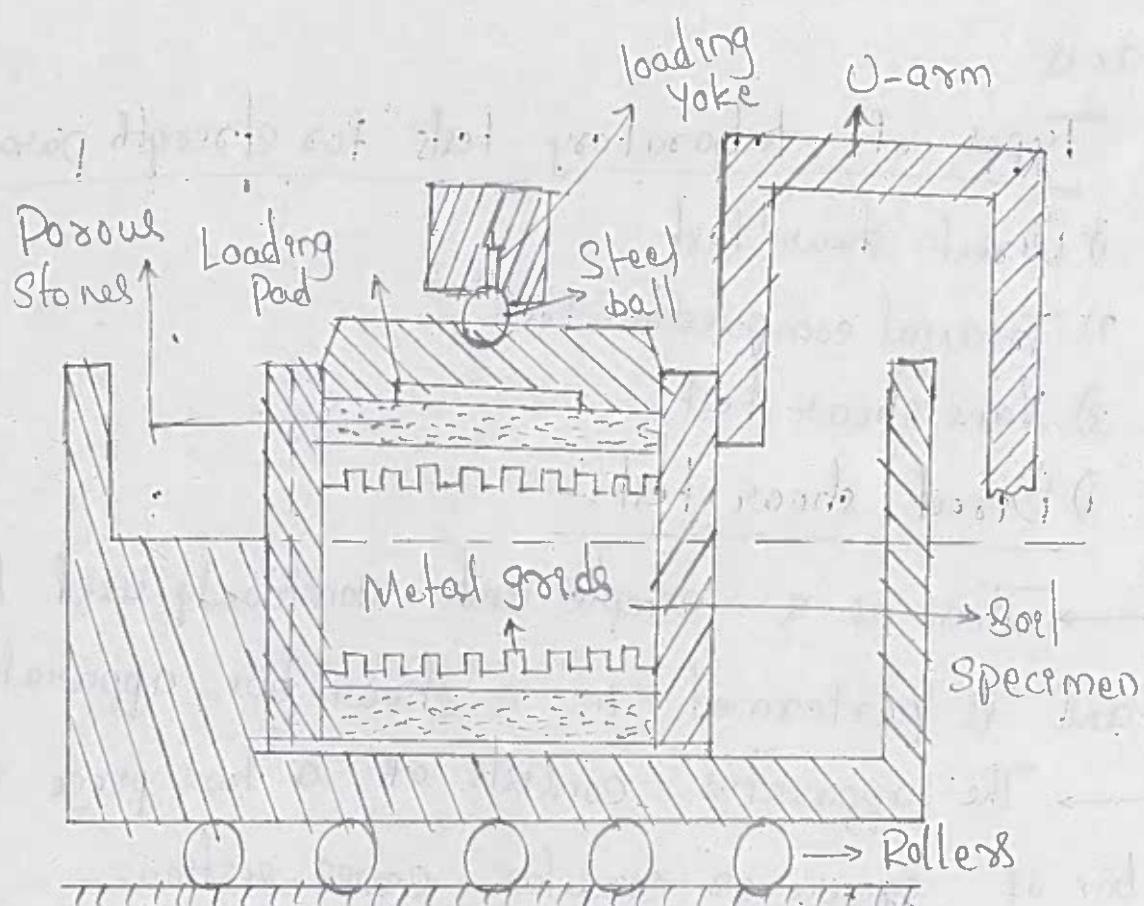


Fig:- Parts of direct shear box

2) Triaxial compression test:-

- Triaxial tests are performed on cylindrical soil samples. The samples have normally a height to diameter ratio of 2:1.
- The test equipment specially consists of a high pressure cylindrical cell made of perspex, fitted between the base and the top cap.
- The sample is fitted between rigid end caps and covered with a rubber membrane. It is then placed in perspex cell, which is filled with water.
- The soil specimen is subjected to three compressive stresses in mutually perpendicular directions, one of the three stresses being increased until the specimen falls in shear.
- The desired three-dimensional stress system is achieved by an initial application of all-round fluid pressure or confining pressure through water. While this confining pressure is kept constant throughout the test, only vertical loading is increased gradually at uniform rate.
- The axial stress thus constitute the major principal stress and confining pressure acts in the other two principal stresses being equal to confining pressure.
 - i) Consolidation stage
 - ii) Shear stage.

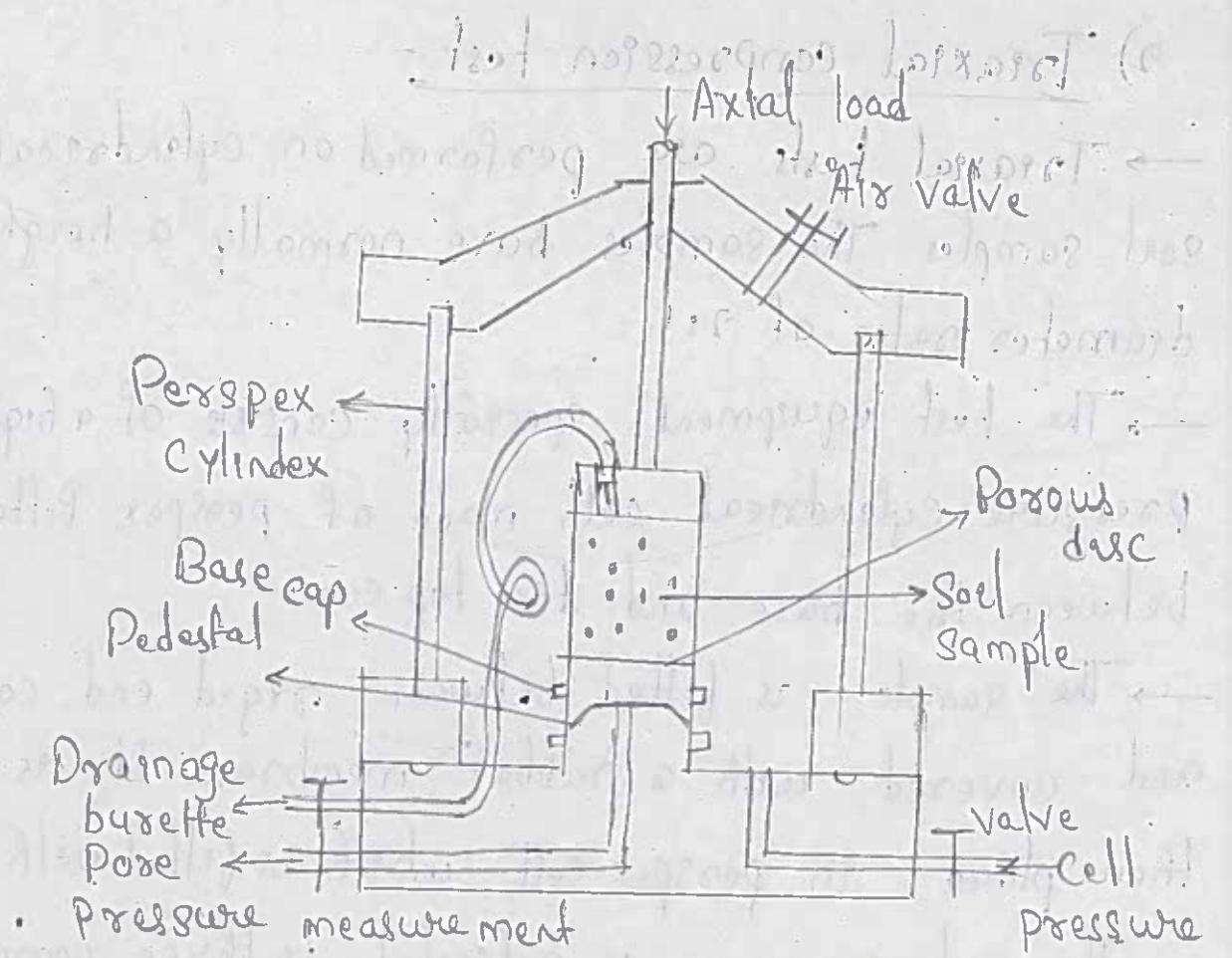


Fig:- Triaxial test equipment

3) Vane shear test :-

- The vane shear test is essentially a quick test used either in the laboratory or in the field.
- In this test, there is no mechanism to measure pore pressure, hence it is essentially an undrained test. So, it is used to determine the undrained shear strength of soils.
- This test is suitable for soft saturated clays and silts.
- The mechanism of test in lab and field is same, the only difference is in the size.
- The vane is pushed gently into the soil and torque is applied gradually to the upper end of the rod until soil fails in shear, due to rotation of

of the vane.

→ The torque is imparted to the vane by means of a disc at the top of rod. The disc is calibrated to measure the applied torque.

→ The vane and shear stress distributions are as shown in fig.

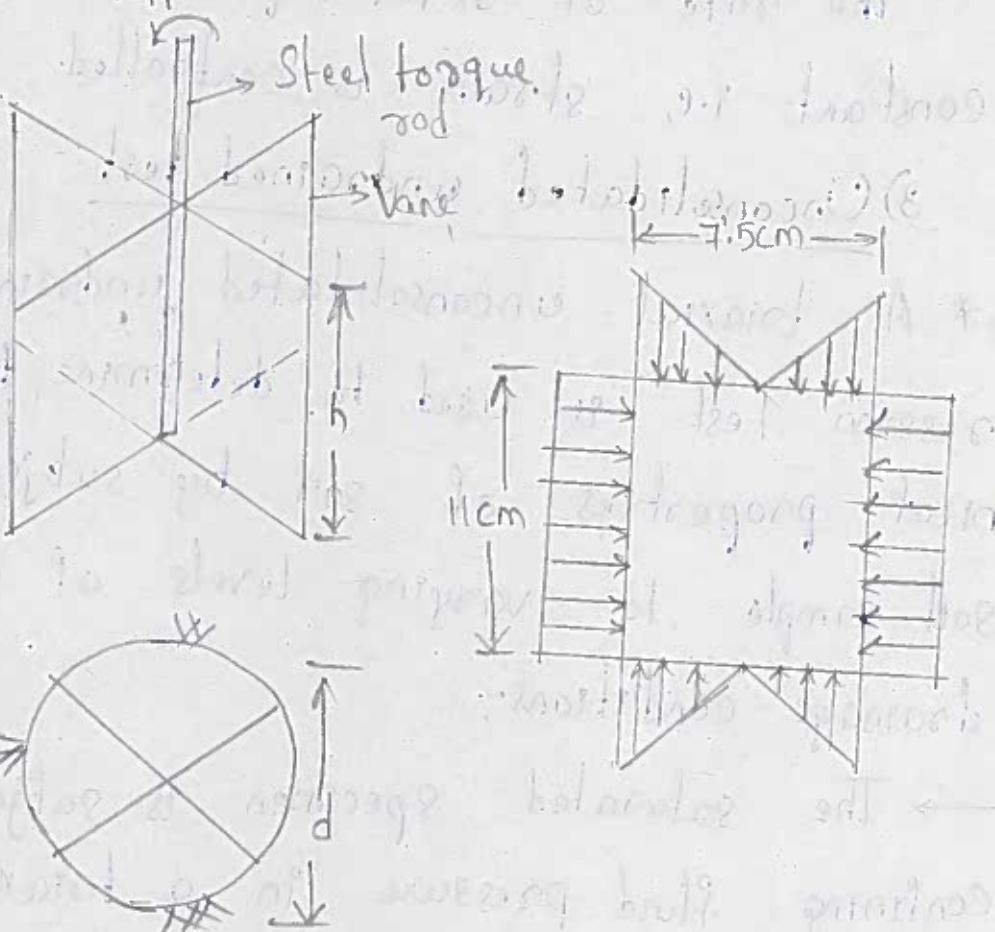
→ Assuming that the shear stress acting along the surface, top and bottom of the shear cylinder.

→ Total shearing resistance of soil at failure,

$$= \pi dh s + 2 \int_{d/2}^{dh/2} (2\pi r dr) s$$

$$s = \frac{T}{\pi d^2 \left(\frac{h}{2} + \frac{d}{6} \right)}$$

Applied torque



Strength tests, based on drainage conditions:-

1) Consolidated undrained test:-

* The standard consolidated undrained test is compression test, in which the soil specimen is first consolidated under all round pressure in the triaxial cell before failure is brought about by increasing the major principal stress.

2) Consolidated drained test:-

* In a consolidated drained test the sample is consolidated and sheared in compression slowly to allow pore pressure built up by the shearing to dissipate.

→ The rate of axial deformation is kept constant, i.e., strain is controlled

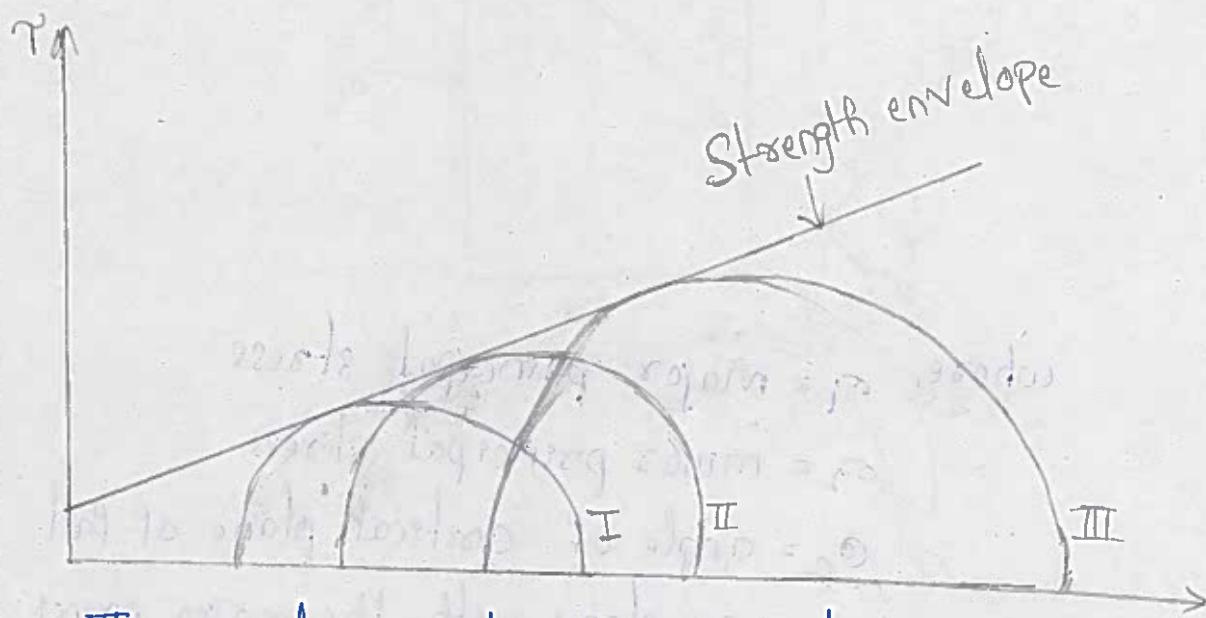
3) Unconsolidated undrained test:-

* A triaxial unconsolidated undrained compression test is used to determine the mechanical properties of soil by subjecting the soil sample to varying levels of stress and drainage conditions.

→ The saturated specimen is subjected to confining fluid pressure in a triaxial cell.

Strength Envelope:

- * The soil strength is evaluated from the shear strength.
- * It is done with the soil sample for estimating the shear strength.
- * When the vane shear test is done using the soil sample, the soil sample will fail.
- * The failed sample will determine when the vane shear test is done using the soil sample, the soil sample will fail.



- * The circle numbers I, II and III represents the number of samples.
- * The equation of the strength envelope is written as below

$$\tau_f = C + \sigma_f \tan \phi$$

where,

τ_f = shear stress

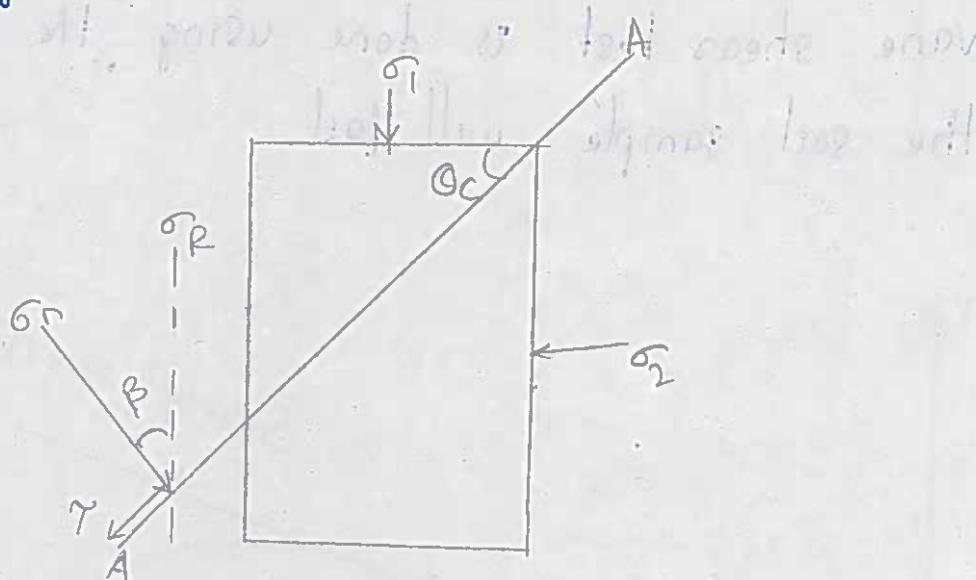
C = apparent cohesion

ϕ = internal friction angle

Shear strength of soil:-

* Shear strength is the resistance offered by soil against shear deformation, its value is equal to the shear stress on critical plane (Plane A-A)

* The critical plane is that plane on which resultant stress has maximum angle of obliquity with the normal of the plane.



where, σ_1 = major principal stress

σ_2 = minor principal stress

θ_c = angle of critical plane of failure plane with the major principal plane.

On the plane of θ_c (critical plane), θ_p is most inclined $\beta = \beta_{\max}$ for frictional soils
 $\beta_{\max} \approx$ internal frictional angle of soil (ϕ)

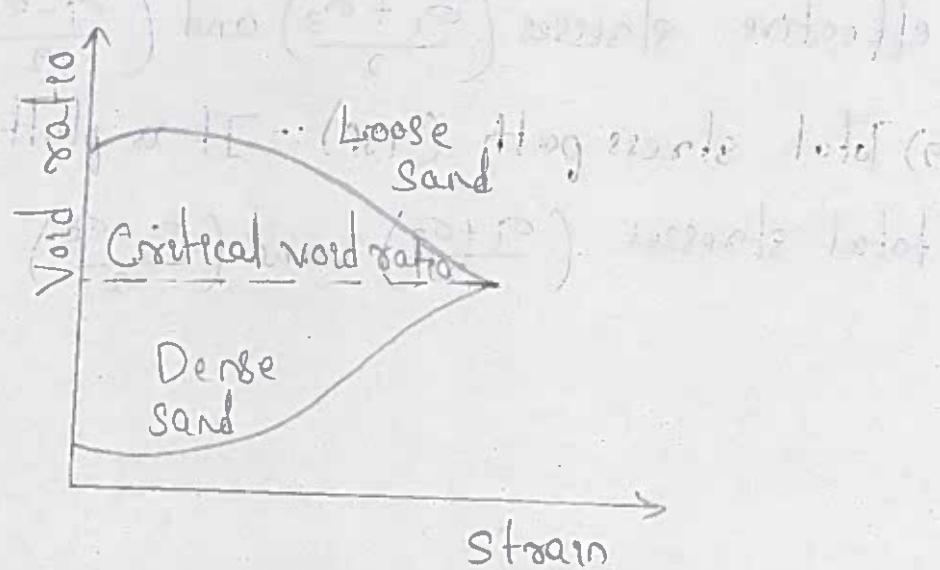
When angle β is maximum, then the shear stress on plane A-A will be equal to the shear strength of soil.

Dilatancy:-

- Dilatancy is a common feature of soils and sands.
- Its effect can be seen when the wet sand around the foot of a person walking on the beach appears to dry up.
- The deformation caused by the foot expands the sand under it and the water in the sand moves to fill the new space between the grains.

Critical void ratio:-

- The critical void ratio is defined as the void ratio at which failure will occur at zero volume change.
- The concept was first established by Casagrande.
- It represents the final void ratio of a soil sample, at ultimate strength.



Introduction to stress path method:-

- Progressive change in the state of a particular load application can be represented by a series of Mohr circles.
- The figure represents successive states as σ_1 is increased with σ_3 constant.
- Thus, the locus of points on the Mohr diagram whose coordinates represent with maximum shear stress and associated stress for the entire stress history is defined as stress path.

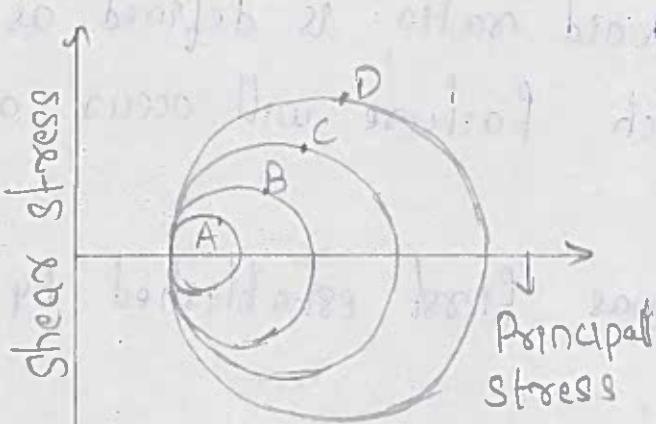


Fig :- Stress paths

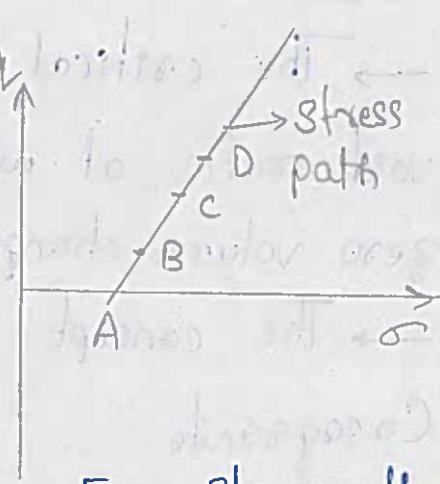


Fig :- Stress path

- 1) Effective stress path (ESP):- It is plotted between effective stresses $(\frac{\sigma_1 + \sigma_3}{2})$ and $(\frac{\sigma_1 - \sigma_3}{2})$
- 2) Total stress path (TSP):- It is plotted between total stresses $(\frac{\sigma_1 + \sigma_3}{2})$ and $(\frac{\sigma_1 - \sigma_3}{2})$