Geotechnical Engineering (18CV54)

Module – 3: Shear Strength of Soil

Introduction:

- When soil is loaded, shearing stresses are induced in it.
- When the shearing stresses reach a limiting value, shear deformation takes place, leading to the failure of the soil mass.
- The failure may be in the form of sinking of a footing, or movement of a wedge of soil behind a retaining wall forcing it to move out, or slide in an earth embankment.

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Module – 3: Shear Strength of Soil

Introduction:

- The shear strength of soil is the resistance to deformation by continuous shear displacement of soil particles or on masses upon the action of a shear stress.
- All stability analysis in soil mechanics involve a basic knowledge of the shearing properties and shearing resistance of soil.
- The shearing resistance of soil is constituted basically of the following components:

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Module – 3: Shear Strength of Soil

Introduction:

- The structural resistance to displacement of soil because of the interlocking of the particles.
- The frictional resistance to translocation between the individual soil particles at their contact points.
- Cohesion or adhesion between the surface of the soil particles.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Through a point in a loaded soil mass, innumerable planes pass and stress components on each plane depends upon the direction of the plane.
- It can be shown that there exists three typical planes, mutually orthogonal to each other, on which the stress is wholly normal and no shear stress acts.
- These planes are called the principal planes and the normal stresses acting on these planes are called the principal stresses.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- In the order of decreasing magnitude of the normal stress, these planes are called major, intermediate and minor principal planes and the corresponding normal stresses on them are called major principal stress $\sigma 1$, intermediate principal stress $\sigma 2$ and minor principal stress $\sigma 3$.
- Many problems in soil engineering can be approximated by considering two dimensional stress conditions.

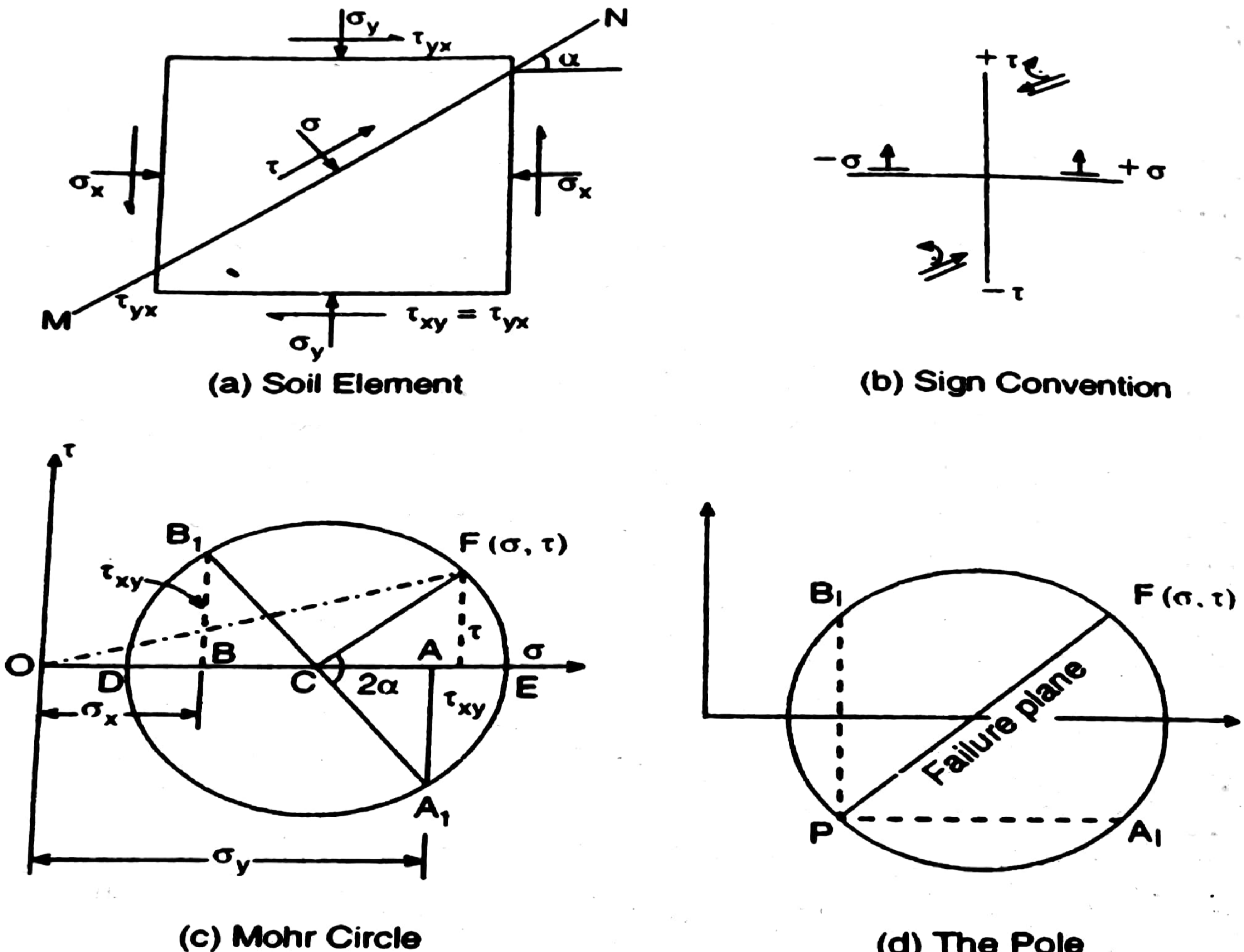

FIG. 18.1 MOHR'S STRESS CIRCLE.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Figure 18.1 (a) shows a soil element subjected to two dimensional stress system.
- From the consideration of the equilibrium of the element, one gets the following expression for the normal stress σ and shearing stress τ on the plane MN inclined at an angle α with the x direction:

$$\sigma = (\sigma_y + \sigma_x) / 2 + ((\sigma_y - \sigma_x) / 2) \cos 2\alpha + \tau_{xy} \sin 2\alpha$$

$$\tau = ((\sigma_y - \sigma_x) / 2) \sin 2\alpha - \tau_{xy} \cos 2\alpha$$

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Where σ_y and σ_x = normal stresses on planes perpendicular to y and x axes, respectively ($\sigma_y > \sigma_x$).
- Squaring the above two equations and adding, we get the following results:

$$(\sigma - ((\sigma_y + \sigma_x) / 2)^2 + \tau^2 = ((\sigma_y - \sigma_x) / 2)^2 + \tau^2_{xy}$$

- The co-ordinates of point on the circle represent the normal and shearing stresses on inclined planes at a given point. This circle is known as Mohr's circle.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- To draw the Mohr circle, the normal stresses σ_x and σ_y are marked on the abscissa, at points B and A and a circle is drawn with point C, mid-way between A and B, as the centre, with radius equal to CB1 = CA1 where BB1 and AA1 are the perpendicular drawn at B and A of magnitude equal to τ_{xy}.
- The sign conventions are shown in figure 18.1 (b).
- Figure 18.1 (c) shows the Mohr's circle so drawn.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- The co-ordinates of point F(σ , τ) represent the stress conditions on plane which makes and angle of α with the x direction.
- If from a point B1 [figure 18.1 (d)] on a circle representing the state of stress on vertical plane, a line is drawn parallel to this plane (i.e., vertical), it intersect the circle at a point P.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Also, if from the point A1 on the circle representing the stresses on the horizontal plane, a line is drawn parallel to this latter plane (i.e., horizontal) it will also intersect the circle in the same point P.
- In general, if through a point F representing the stresses on a given plane, a line is drawn parallel to that plane, it will also intersect the circle in the point P.
- The point P is therefore, a unique point called the origin of planes of the pole.

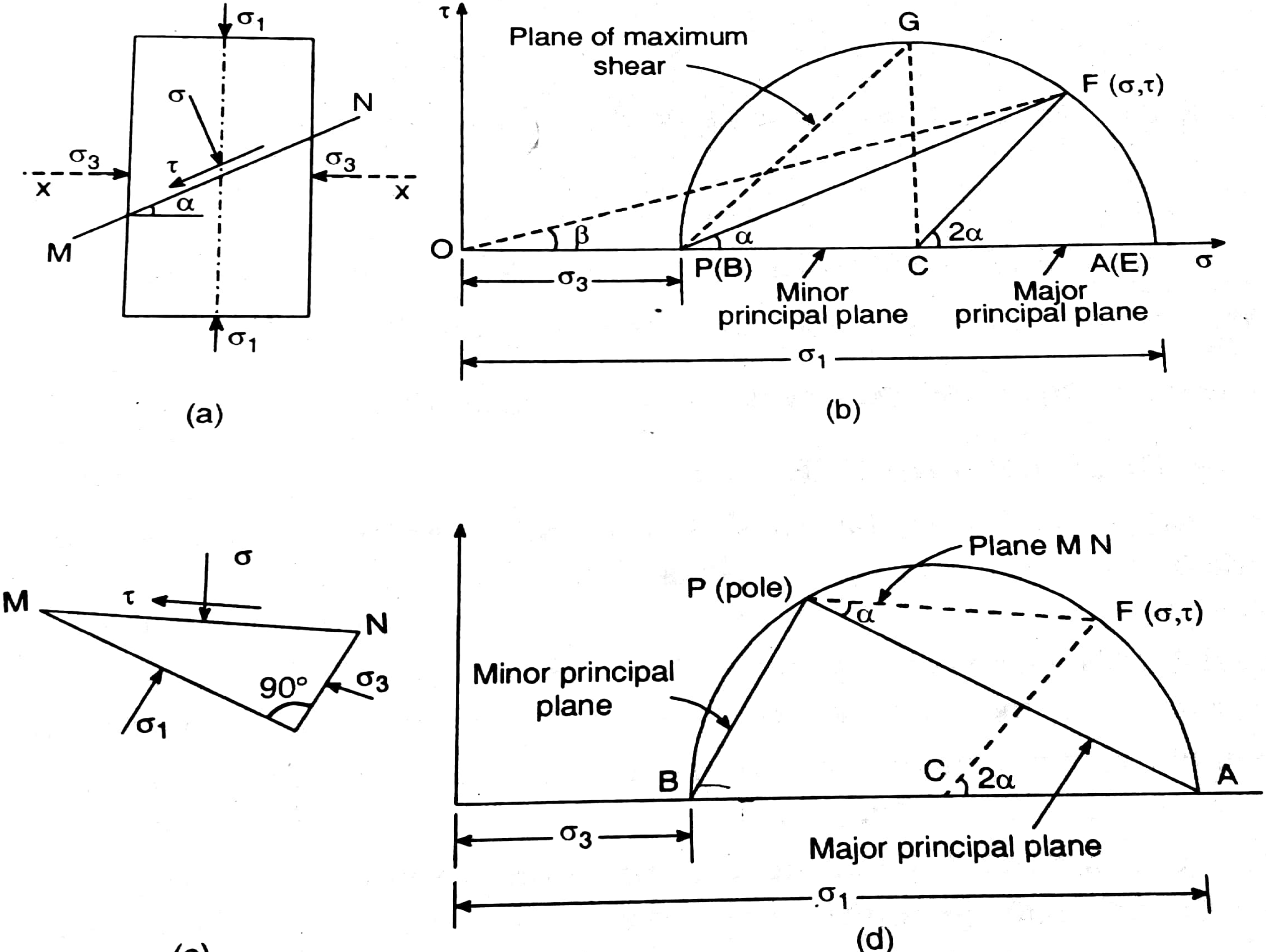

FIG. 18.2 MOHR CIRCLE OF STRESSES.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Let us now take the case of soil element whose sides are the principal planes, i.e., consider the state of stress where only normal stresses are acting on the faces of the element.
- Figure 18.2 (a) shows the element, and figure 18.2 (b) shows the Mohr circle.
- In figure 18.2 (a) the major principal plane is horizontal.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Hence the pole P is located by drawing a horizontal line through point A representing the major principal stress σ1.
- This intersects the circle at B.
- If a line PF drawn through P at an angle α with the horizontal, it will intersect the circle at F which represents the stress conditions on a plane inclined at an angle α with the direction of the major principal plane.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Figure 18.2 (c) shows an element in which the principal planes are not horizontal and vertical, but inclined to y and x directions.
- Figure 18.2 (d) shows the corresponding stress circle.
- Point A represents the major principal stress ($\sigma 1$, 0) and B represents the minor principal stress ($\sigma 3$, 0).
- Hence to get the position of the pole, a line is drawn through A, parallel to the major principal plane, to intersect the circle in P.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Evidently, PB gives the direction of minor principal plane.
- To find the stress components on any plane MN inclined at an angle α with the major principal plane, a line is drawn through P, at an angle α with PA, to intersect the circle at F.
- The co-ordinates of point F give the stress components on the plane MN.

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Module – 3: Shear Strength of Soil

Theoretical Considerations: Mohr's Stress Circle

- Analytical expression for σ , τ are:

  $\sigma = ((\sigma_1 + \sigma_3) /2) + ((\sigma_1 - \sigma_3) / 2) \cos 2\alpha$ (18.4)

  $\tau = ((\sigma_1 - \sigma_3) /2) \sin 2\alpha$ (18.5)

- The resultant stress on any plane is $\sqrt{\sigma^2 + \tau^2}$ and its angle of obliquity β is equal to $\tan^{-1} (\tau / \sigma)$.
- The maximum shear stress is equal to $(\sigma_1 - \sigma_3) /2$ and it occurs on planes with $\alpha = 45°$
- The normal stress on this plane will be $(\sigma_1 + \sigma_3) /2$

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Module – 3: Shear Strength of Soil

Mohr Coulomb Failure Theory:

The following are the essential points of Mohr's strength theory:

- Material fails essentially by shear. The critical shear stress causing failure depends upon the properties of the material as well as on normal stress on the failure plane.
- The ultimate strength of the material is determined by the stresses on the potential failure plane.

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Module – 3: Shear Strength of Soil

Mohr Coulomb Failure Theory:

The following are the essential points of Mohr's strength theory:

- When the material is subjected to three dimensional principal stress the intermediate principal stress does not have any influence on the strength of material. In other words, the failure criterion is independent of the intermediate principal stress.

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Module – 3: Shear Strength of Soil

Mohr Coulomb Failure Theory:

- The theory was first expressed by Coulomb and later generalised by Mohr.
- The theory can be expressed algebraically by the equation.

$$\tau_f = s = F(\sigma) \quad (18.6)$$

Where, $\tau_f = s$ = shear stress on failure plane, at failure

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

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Module – 3: Shear Strength of Soil

Mohr Coulomb Failure Theory:

- 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(σ) as a linear function of σ and gave the following strength equation:

$$s = c + \sigma \tan\Phi \quad (18.7)$$

- Where the empirical constants c and Φ represent the intercepts on the shear axis, and the slope of the straight line of Eq. 18.7. [fig 18.3 (a)].

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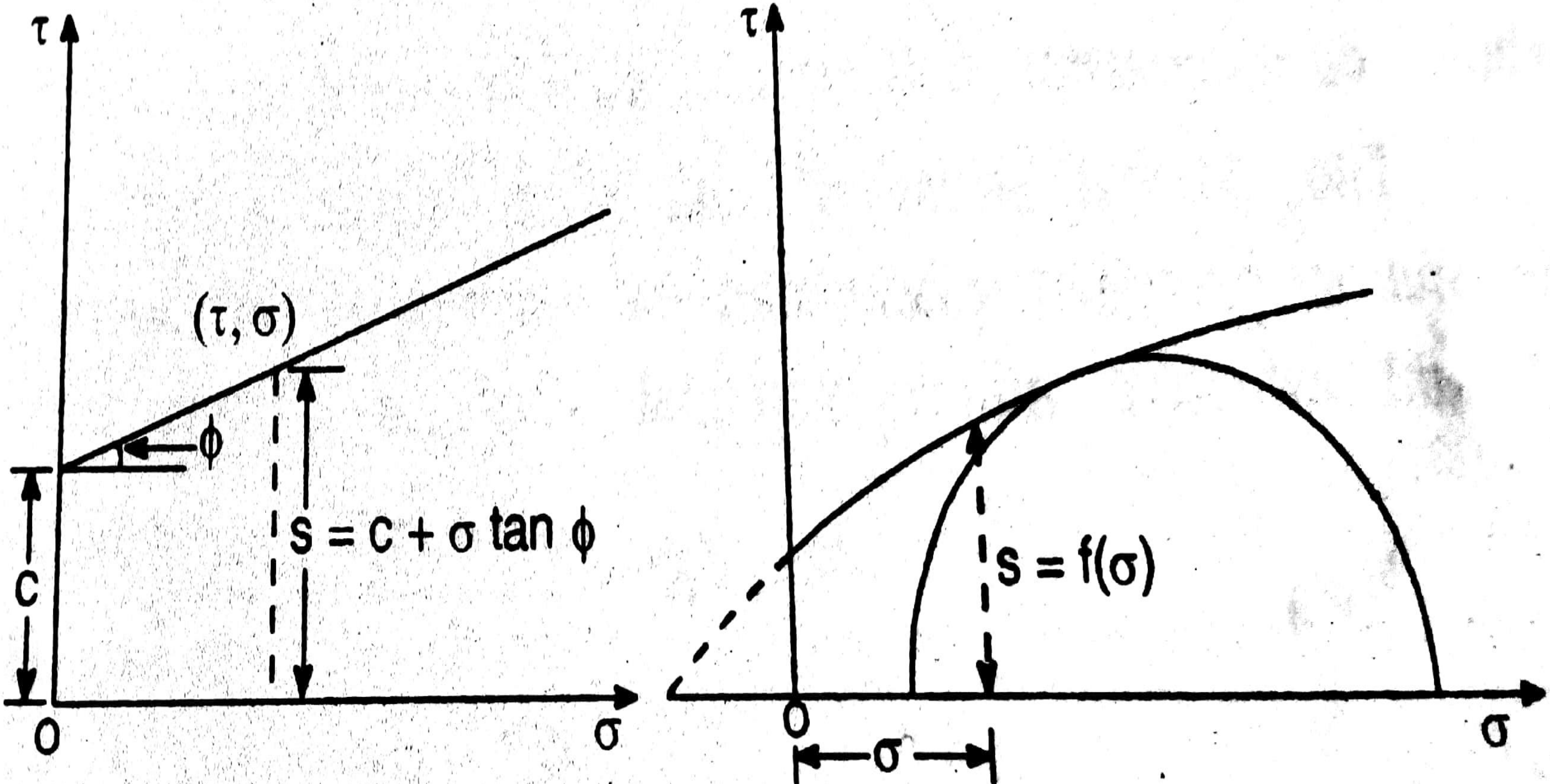
Module – 3: Shear Strength of Soil

Mohr Coulomb Failure Theory:

- These parameters are usually termed as cohesion and angle of internal friction.
- Fig 18.3 (b) shows the Mohr's envelope, which is the graphical representation of Eq. 18.6.
- Coulomb considered that the relationship between shear strength and normal stress could be adequately represented by the straight line.



(a) Coulomb Envelope

(b) Mohr's Envelope

FIG. 18.3. FAILURE ENVELOPES.

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Module – 3: Shear Strength of Soil

Mohr Coulomb Failure Theory:

- The generalised Mohr theory also recognises that the shear strength depends on the normal stress, but indicates that the relation is not linear.
- The strength theory indicates that definite relationship exists among the principal stresses, the angle of internal friction and the inclination of the failure plane.
- The curved failure envelope of Mohr is often referred to as a straight line for most of the calculations regarding the stability of soil mass.

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Module – 3: Shear Strength of Soil

Mohr Coulomb Failure Theory:

- For an ideal pure friction material, such as straight line passes through the origin [Fig 18.4 (a)].
- However, dense sands exhibit a slightly curved strength line, indicated by dashed line [Fig 18.4 (b)], represents purely cohesive material, for which the straight line is parallel to the axis.
- The strength of such a material is independent of the normal stress acting on the plane of failure.

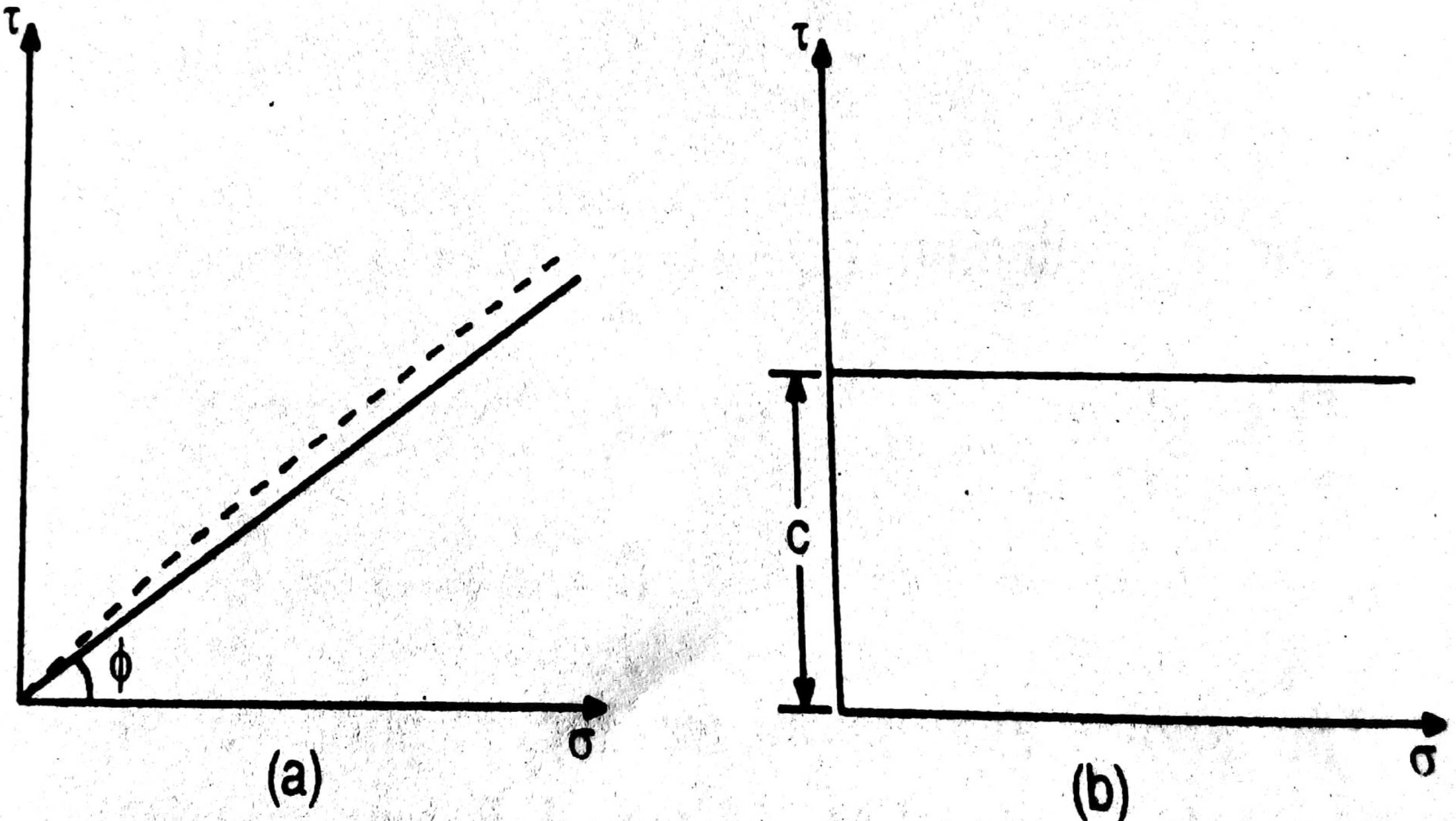

FIG. 18.4. STRAIGHT FAILURE ENVELOPE.

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Module – 3: Shear Strength of Soil

Mohr Coulomb Failure Theory:

- It can, therefore, be concluded that the Mohr envelope can be considered to be straight if the angle of internal friction 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.

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Module – 3: Shear Strength of Soil

The Effective Stress Principle:

- In Eq. 18.7, it is assumed that the total normal stress governs the shear strength of the soil.
- This assumption is not always correct.
- Extensive tests on remoulded clays have sustained beyond doubt Terzaghi's early concept that the effective normal stresses control the shearing resistance of soils.

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Module – 3: Shear Strength of Soil

The Effective Stress Principle:

- Therefore, a failure criterion of greater general applicability is obtained by expressing the shear strength as a function of the effective normal stress σ', given by the equation:

$$\tau_f = c' + \sigma' \tan \Phi'$$

or

$$\tau_f = c' + (\sigma - u) \tan \Phi'$$

- Where c'= effective cohesion intercept & Φ'= effective angle of shearing resistance

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Module – 3: Shear Strength of Soil

The Effective Stress Principle:

- In terms of total stresses, the equation takes the form:

$$\tau_f = c_u + \sigma \tan \Phi_u$$

- Where c_u = apparent cohesion and Φ_u= apparent angle of shearing resistance.
- The normal stress σ' and shear stress τ on any plane inclined at an angle α to the major principal plane can be expressed in terms of effective major principal stress σ_1' and effective minor principal stress σ_3‘ from Eqs. 18.4 and 18.5 as under:

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Module – 3: Shear Strength of Soil

The Effective Stress Principle:

$$\sigma' = ((\sigma_1' + \sigma_3') / 2) + ((\sigma_1' - \sigma_3') / 2) \times \cos 2\alpha \quad (18.11)$$

$$\tau = ((\sigma_1' - \sigma_3') / 2) \times \sin 2\alpha \quad (18.12)$$

Substituting the values of σ' in Eq. 18.8, we get

$$\tau_f = c' + \tan \Phi' \left[((\sigma_1' + \sigma_3') /2) + ((\sigma_1' - \sigma_3') /2) \times \cos 2\alpha \right]$$

- The most dangerous plane i.e., the plane on which failure will take place is the one on which the difference between the τ_f and τ is minimum.

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Module – 3: Shear Strength of Soil

The Effective Stress Principle:

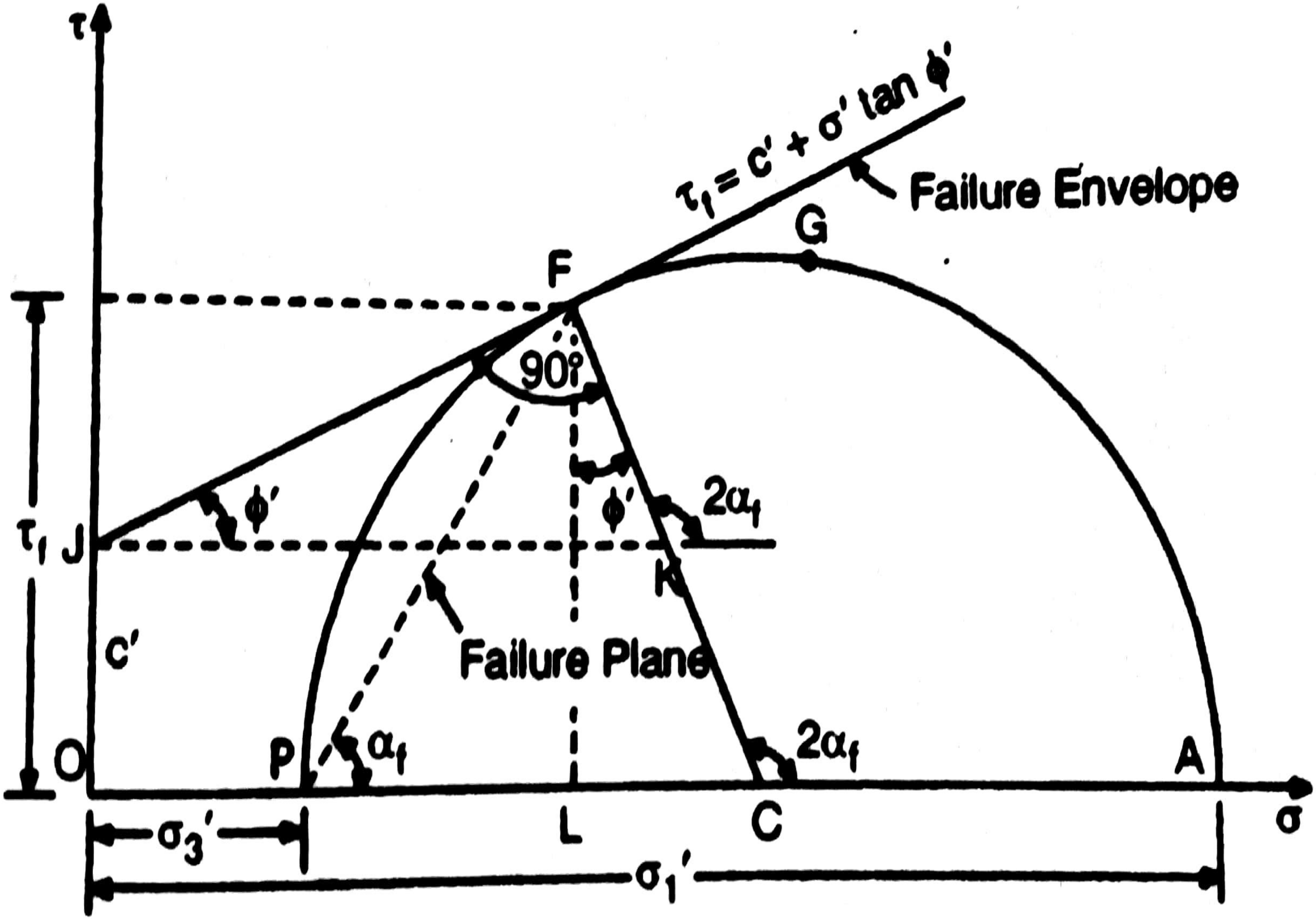
$$(\tau_f - \tau) = c' + ((\sigma_1' + \sigma_3')/2) \tan \Phi' + ((\sigma_1' - \sigma_3')/2) \times \cos 2\alpha \times \tan \Phi' - ((\sigma_1' - \sigma_3')/2) \times \sin 2\alpha$$

- Differentiating this with respect to α, we get

$$d/d\alpha\,(\tau_f - \tau) = -(\sigma_1' - \sigma_3') \sin 2\alpha \times \tan \Phi' - (\sigma_1' - \sigma_3') \cos 2\alpha$$

- For a minimum $(\tau_f - \tau)$, $d/d\alpha\,(\tau_f - \tau) = 0$
- This gives $\cos 2\alpha = -\sin 2\alpha \times \tan \Phi'$

$$\alpha = \alpha_f = 45° + (\Phi'/2) \quad (18.14)$$



τ
$\tau_f = c' + \sigma' \tan\phi'$
Failure Envelope
G
F
90°
φ'
φ'
2α_f
τ_f
J
K
c'
Failure Plane
O
P
α_f
2α_f
A
L
C
σ
σ₃'
σ₁'

FIG. 18.5

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Module – 3: Shear Strength of Soil

The Effective Stress Principle:

- The above expression for the location of the failure plane can be directly derived from the Mohr circle fig 18.5.
- J F represents the failure envelope given by the straight line.
- The pole P will be the point with stress co-ordinates as (σ_3' , 0).
- The Mohr circle is tangential to the Mohr envelope at the point F.

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Module – 3: Shear Strength of Soil

The Effective Stress Principle:

- PF represents the direction of the failure plane, inclined at an angle α_f with the direction of the major principal plane.
- From the geometry of fig. 18.5, we get from triangle JFK $2\alpha_f = 90° + \Phi'$ or $\alpha_f = 45° + (\Phi' / 2)$.
- It should be noted that for any combination of the applied principle effective stress σ_1' and σ_3', failure will occur only if the stress circle touches the failure envelope.

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Module – 3: Shear Strength of Soil

The Effective Stress Principle:

- Also, the co-ordinates of the failure point F represent the stress components σ' and τ at failure.
- As it is evident from fig 18.5, the τ_f at failure is less than the maximum shear stress, corresponding to the point G, acting on the plane PG.
- Thus, the failure plane does not carry maximum shear stress, and the plane which has the maximum shear stress is not the failure plane.

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Module – 3: Shear Strength of Soil

Measurement of Shear Strength Parameters :

- The measurement of shear strength of soil involves certain test observations at failure with the help of which the failure envelope or strength envelope can be plotted corresponding to a given set of conditions.

Shearing resistance can be determined in the laboratory by the following four methods:

- Direct shear test
- Triaxial shear test
- Unconfined compression test
- Vane shear test

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Module – 3: Shear Strength of Soil

Measurement of Shear Strength Parameters :

Again depending upon the drainage conditions, three types of shear tests have been developed:

- Undrained test or quick test
- Consolidated undrained test
- Drained test

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Module – 3: Shear Strength of Soil

Measurement of Shear Strength Parameters :

- In the undrained or quick test, no drainage of water is permitted.
- Hence there is no dissipation of pore pressure during the entire test.
- In the drained test, drainage is permitted throughout the test during the application of both normal and shear stresses, so that full consolidation occurs and no excess pore pressure is set up at any stage of the test.

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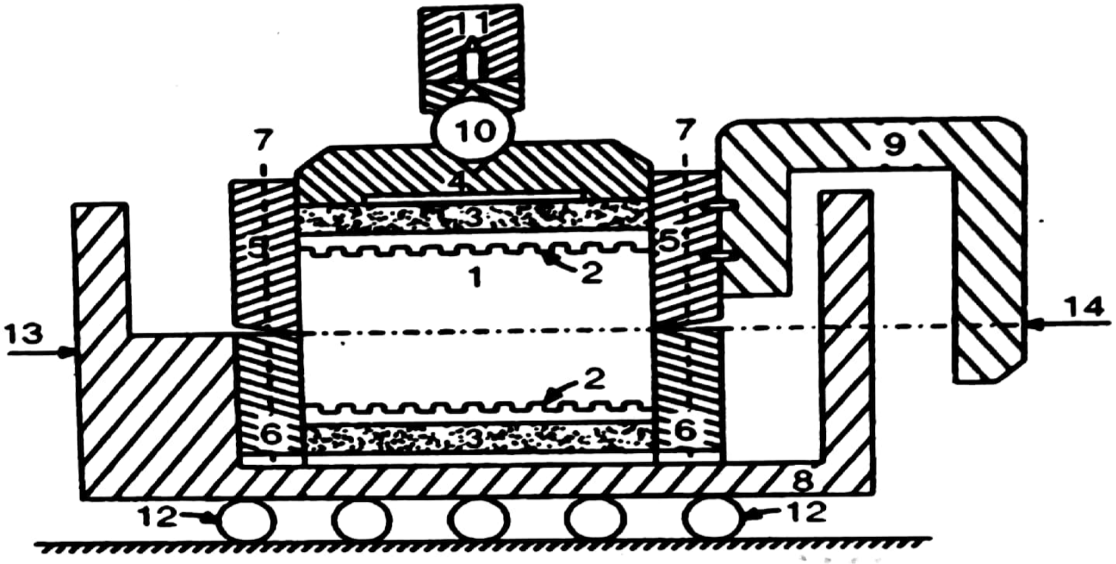
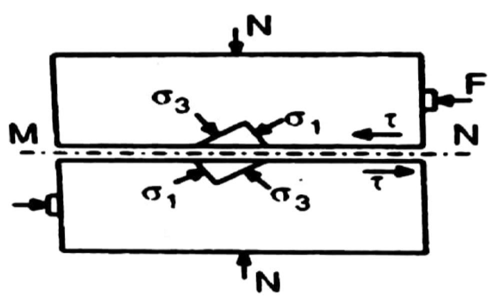
Module – 3: Shear Strength of Soil

Measurement of Shear Strength Parameters :

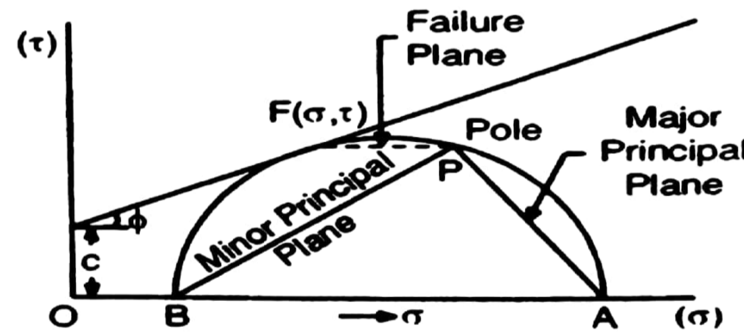
- In consolidated undrained test, drainage is permitted under the initially applied normal stress only and full primary consolidation is allowed to take place.
- No drainage is allowed afterwards.
- The parameters c and Φ are not fundamental properties of the soil, they may simply be considered merely coefficients derived from the geometry of the graph obtained by the plotting shear stress at failure against normal stress.



(a) Parts of direct shear box.



(b) Principle of direct shear box



(c) Mohr's envelope and principal stresses during the test

1.	SOIL SPECIMEN	6.	LOWER PART	11.	LOADING YOKE
2.	METAL GRIDS	7.	SCREWS TO FIX TWO HALVES OF SHEAR BOX	12.	ROLLERS
3.	POROUS STONES	8.	CONTAINER FOR SHEAR BOX	13.	SHEAR FORCE APPLIED BY JACK
4.	LOADING PAD	9.	U-ARM	14.	SHEAR RESISTANCE MEASURED BY PROVING RING
5.	UPPER PART	10.	STEEL BALL		

FIG. 18.6. SHEAR BOX TEST.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- This is a simple and commonly used test and is performed in a shear-box apparatus (fig 18.6).
- The apparatus consist 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.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- The upper half of the box butts against a proving ring.
- The soil sample is compacted in the shear box, and is held between metal grids and porous stones.
- As shown in fig 18.6 (a), the upper half of the specimen is held in the upper box and the lower half in the lower box, and the joint between the two parts of the box is at the level of the center of the specimen.
- Normal load is applied on the specimen from a loading yoke bearing upon steel ball of pressure pad.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- When a shearing force is applied to the lower box through the geared jack, the movement of the lower part of the box is transmitted through the specimen to the upper part of the box and hence on proving ring.
- The deforming of proving ring indicates the shear force.
- The volume change during the consolidation and during the shearing process is measured by mounting a dial gauge at the top of the box.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- The soil specimen can be compacted in the shear box by clamping both the parts together with the help of two screws.
- These screws are, however, removed before the shearing force is applied.
- Metal grids, placed above the top and below the bottom of the specimen may be perforated if drained test is required, or plain if undrained test is required.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- The metal grids have linear slots to have proper grip with the soil specimen, and are so oriented that the slots are perpendicular to the direction of the shearing force.
- The specimen of the shear box is sheared under a normal load N.
- The shearing strain is made increase at a constant rate, and hence the test is called the strain controlled shear box test.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- The other type of test is the stress controlled shear box test, in which there is and arrangement to increase the shear stress at a desired rate and measure the shearing strain.
- Fig 18.6 (a) shows the strain controlled shear box.
- The shear force, F, at failure, corresponding to the normal load N is measured with the help of proving ring.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- A number of identical specimens are tested under increasing normal loads and the required maximum shear force is recorded.
- A graph is plotted between the shear force F as the ordinate and the normal load N as the abscissa.
- Such a plot gives the failure envelope for the soil under the given test conditions.
- Fig 18.6 (c) shows such a failure envelope plotted as a function of the shear stress and the normal stress.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- The scales of both shearing stress and normal stress are kept equal so that the angle of shearing resistance can be measured directly from the plot.
- Any point F(σ,τ) on the failure envelope represents the state of stress in the material during failure, under a given normal stress.
- In the direct shear test, the failure plane MN is predetermined, and is horizontal.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- Fig 18.6 (b) shows the stress conditions during failure.
- In order to find the direction of principal planes at failure, we first locate the position of the pole on the Mohr circle [Fig 18.6 (c)] on the principle that the line joining any point on the circle to the pole P gives the direction of the plane on which the stresses are those given by the co-ordinates of that point.
- Hence, through point F a horizontal line is drawn to intersect the circle at the point P which is the pole.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- Since points A and B represent respectively, the major and minor principal stresses, PA and PB give the directions of major and minor principal planes.
- Test can be performed under all the three conditions of drainage.
- To conduct undrained test, plain grids are used.
- For the drained test, perforated grids are used.

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Module – 3: Shear Strength of Soil

Direct Shear Test:

- The same is first consolidated under the normal load, and then sheared sufficiently slowly so that complete dissipation of pore pressure takes place.
- The drained test is therefore also known as the slow test, and the shearing of cohesive soil may sometimes require 2 to 5 days.
- Cohesionless soils are sheared in relatively less time.
- For the consolidated undrained test, perforated girds are used.

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Module – 3: Shear Strength of Soil

Disadvantages of Direct Shear Test:

- The stress conditions across the soil sample are very complex.
- The distribution of normal and shearing stresses over the potential surface of sliding is not uniform.
- The stress is more at the edges and less in the centre.
- Due to this there is a progressive failure of the specimen, the entire strength of the soil is not mobilised simultaneously.

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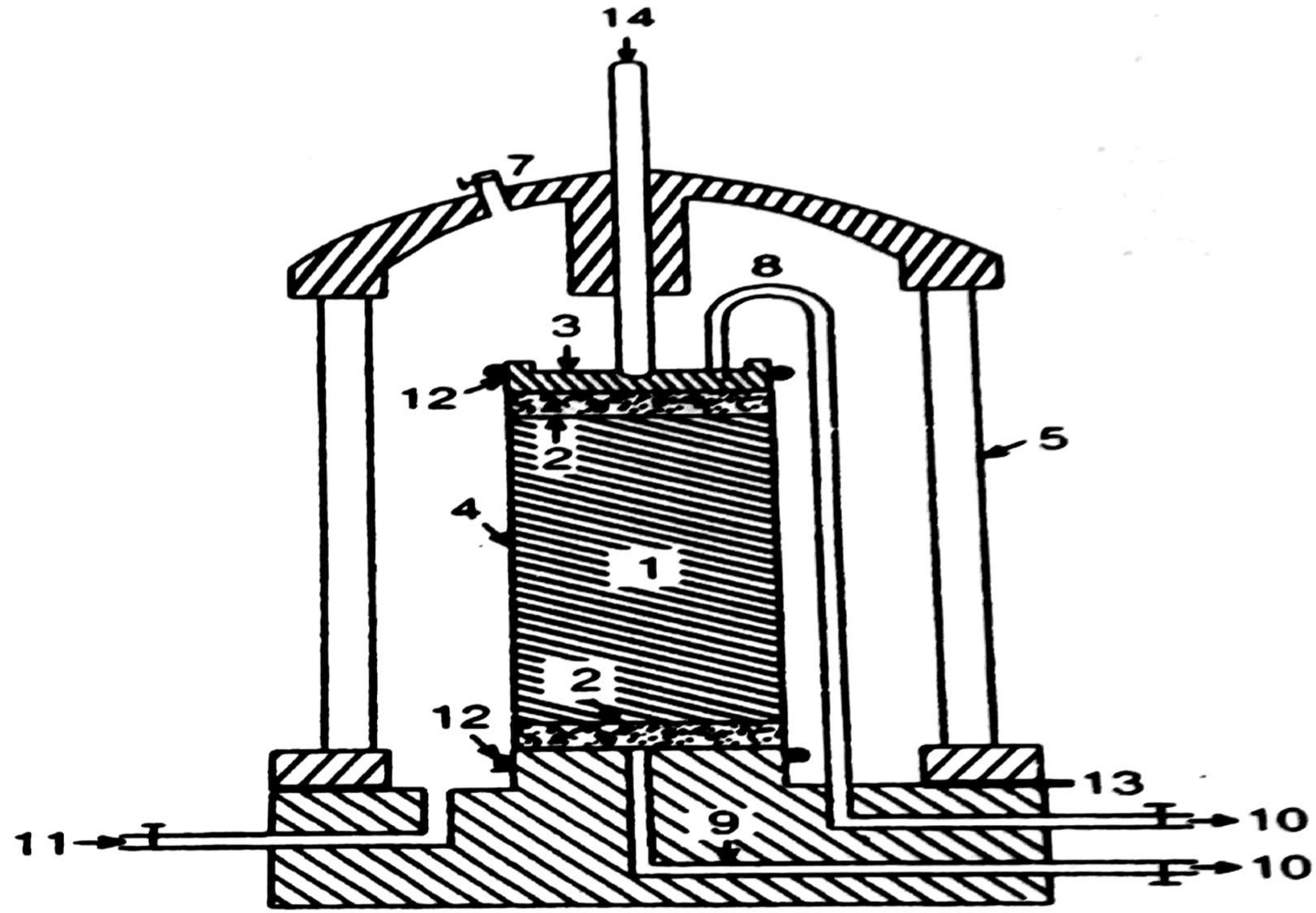
Module – 3: Shear Strength of Soil

Disadvantages of Direct Shear Test:

- As the test progresses, the area under shear gradually decreases.
- As compared to the triaxial test, there is little control on the drainage of soil.
- The plane of shear failure is predetermined, which may not be the weakest one.
- There is effect of lateral restraint by the side walls of the shear box.



1. SOIL SPECIMEN
2. POROUS DISC
3. TOP CAP
4. RUBBER MEMBRANE
5. PERSPEX CYLINDER
6. LOADING RAM
7. AIR RELEASE VALVE
8. TOP DRAINAGE TUBE
9. BOTTOM DRAINAGE TUBE
10. CONNECTIONS FOR DRAINAGE OR PORE PRESSURE MEASUREMENT
11. CELL FLUID INLET
12. RUBBER RINGS
13. SEALING RING
14. AXIAL LOAD THROUGH PROVING RING

FIG. 18.7. THE TRIAXIAL CELL.

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Module – 3: Shear Strength of Soil

Triaxial Shear Test:

- The strength test more commonly used in research laboratory today is the triaxial compression test, first introduced in the USA by A Casagrande and Karl Von Terzaghi in 1936-37.
- The solid specimen, cylindrical in shape, is subjected to direct stress acting in three mutually perpendicular directions.

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Module – 3: Shear Strength of Soil

Triaxial Shear Test:

- In the common solid cylindrical specimen test, the major principal stress σ_1 is applied in the vertical direction, and other two principal stresses σ_2 and σ_3 ($\sigma_2 = \sigma_3$) are applied in the horizontal direction by the fluid pressure round the specimen.
- The test equipment consist of a high pressure cylindrical cell, made of transparent material, fitted between the base and the top cap.

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Triaxial Shear Test:

- Three outlet connections are generally provided through the base: cell fluid inlet, pore water out let from the bottom of the specimen and the drainage outlet from the top of the specimen.
- A separate compressor is used to apply fluid pressure in the cell.
- Pore pressure developed in the specimen during the test can be measured with the help of a separate pore pressure measuring equipment.

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Triaxial Shear Test:

- The cylindrical specimen is enclosed in a rubber membrane.
- A stainless steel piston running through the centre of the top cap applies the vertical compressive load (called the deviator stress) on the specimen under test.
- The load is applied through a proving ring, with the help of a mechanically operated load frame.

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Module – 3: Shear Strength of Soil

Triaxial Shear Test:

- Depending upon the drainage conditions of the test, solid nonporous discs are placed on the top and bottom of the specimen and the rubber membrane is sealed on to these end caps by rubber rings.
- The length of the specimen is kept about 2 to 2.5 times the diameter.
- The cell pressure σ_3 acts all round the specimen it acts also on the top of the specimen as well as the vertical piston meant for applying the deviator stress.

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Module – 3: Shear Strength of Soil

Triaxial Shear Test:

- The vertical stress applied by the loading frame, through the proving ring is equal to (σ_1 - σ_3), so that the total stress on the top of the specimen = (σ_1 - σ_3) + σ_3 = σ_1 = major principal stress.
- This principal stress difference (σ_1 - σ_3) is called the deviator stress recorded on the proving ring dial.
- Another dial measures the vertical deformation of the sample during testing.

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Module – 3: Shear Strength of Soil

Triaxial Shear Test:

- A particular confining pressure σ_3 is applied during one observation, giving the value of the other stress σ_1 at failure.
- A Mohr circle corresponding to this set of (σ_1, σ_3) can thus be plotted.
- Various sets of observations are taken for different confining pressures σ_3 and the corresponding values of σ_1 are obtained.

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Module – 3: Shear Strength of Soil

Triaxial Shear Test:

- Thus, a number of Mohr circles, corresponding to failure conditions are obtained.
- A curve, tangential to these stress circles, gives the failure envelope for the soil under given drainage conditions of the test.
- Fig 18.10 (a) shows the effective stresses acting on the soil specimen during triaxial testing.
- The minor principal stress and the intermediate principal stress are equal.

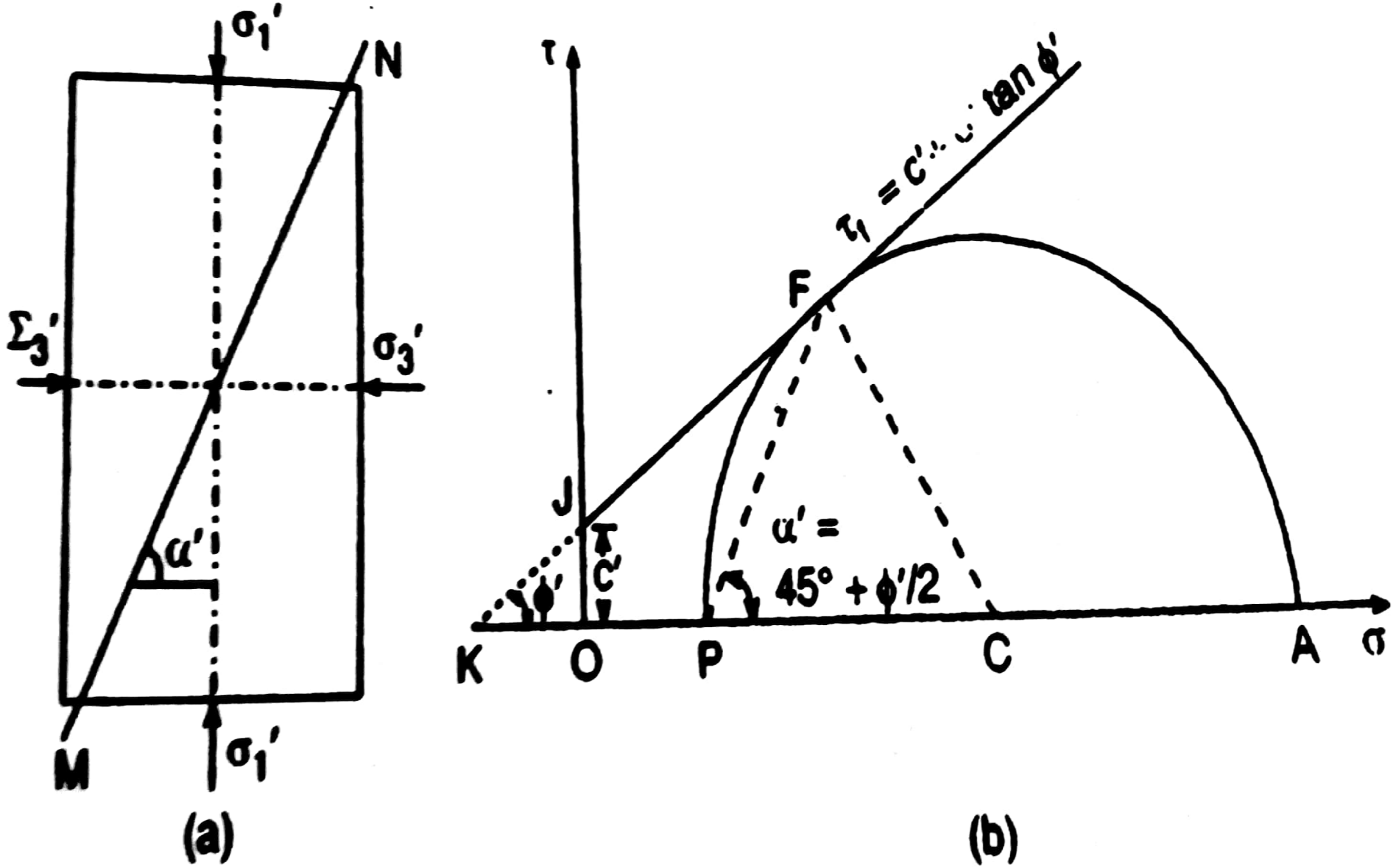

FIG. 18.10. STRESS CONDITIONS AND FAILURE ENVELOPE IN TRIAXIAL COMPRESSION TESTS.

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Module – 3: Shear Strength of Soil

Triaxial Shear Test:

- The effective minor principal stress is equal to the cell pressure minus the pore pressure.
- The major principal stress is equal to the deviator stress plus the cell pressure.
- The effective major principal stress is equal to the major principal stress minus the pore pressure.
- The stress components on the failure plane MN are normal stress and shear stress and the failure plane is inclined at an angle of α' to the major principal plane.

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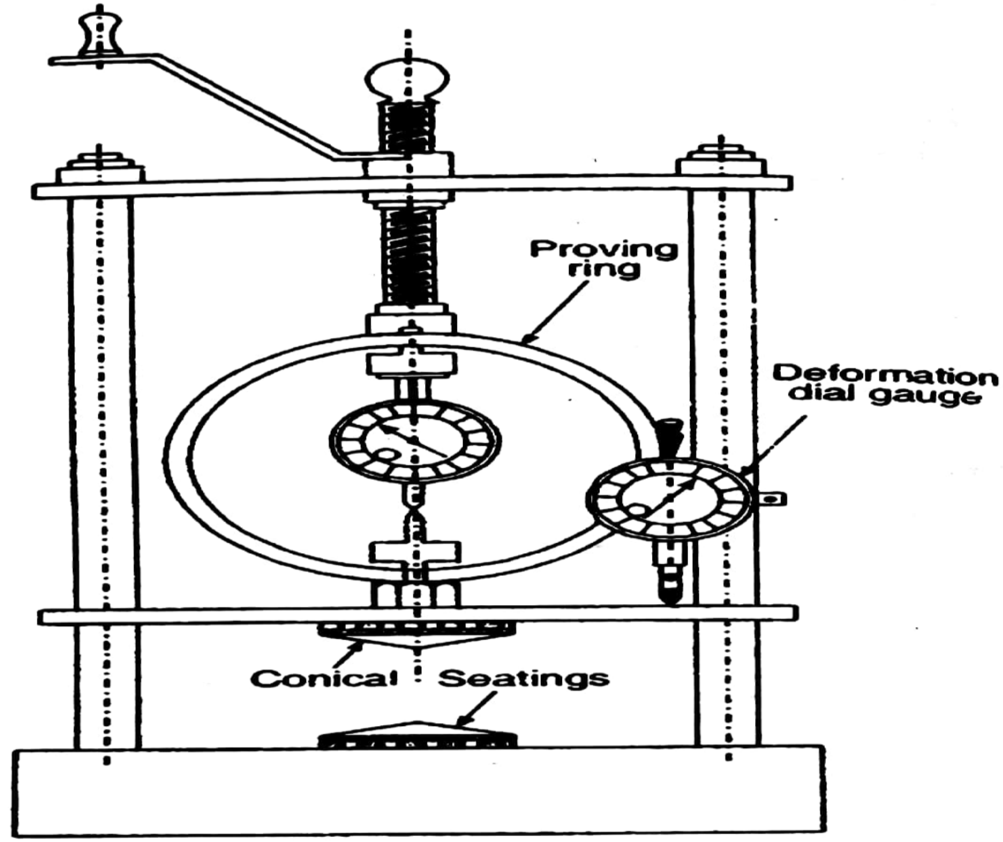
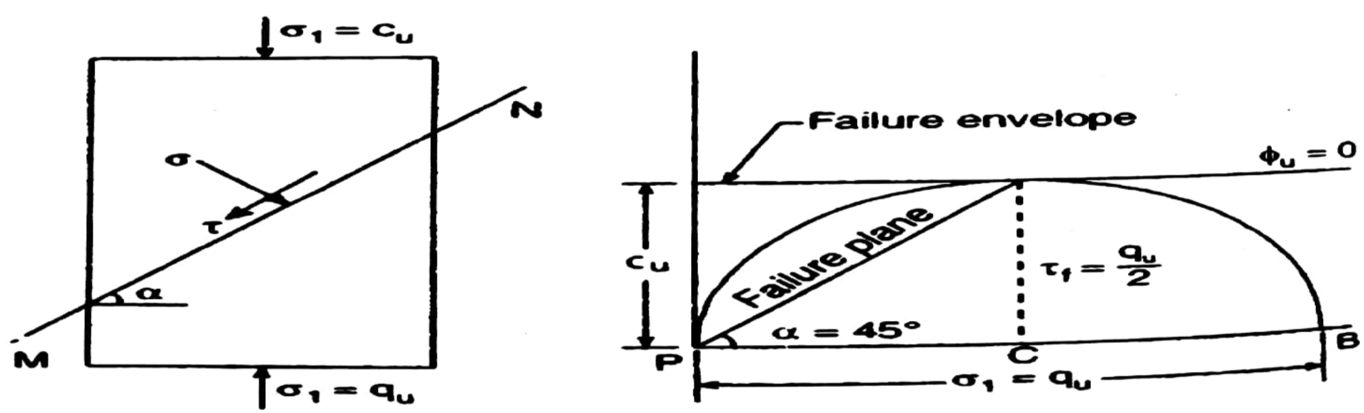
Module – 3: Shear Strength of Soil

Advantages of Triaxial Shear Test:

- The shear test under all the three drainage conditions can be performed with complete control.
- Precise measurement of the pore pressure and volume change during the test are possible.
- The stress distribution on the failure plane is uniform.
- The state of stress within the specimen during any stage of the test, as well as at failure is completely determinate.



(a) The unconfined compression tester



(b) (c)

FIG. 18.12. UNCONFINED COMPRESSION TEST.

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Module – 3: Shear Strength of Soil

Unconfined Compression Test:

- The unconfined compression test is a special case of triaxial compression test in which $\sigma_2 = \sigma_3 = 0$.
- The cell pressure in the triaxial cell is also called the confining pressure.
- Due to absence of such a confining pressure, the uniaxial test is called the unconfined compression test.
- The cylindrical specimen of soil is subjected to major principal stress σ_1 till the specimen fails due to shearing along a critical plane of failure.

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Module – 3: Shear Strength of Soil

Unconfined Compression Test:

- In this simplest form, the apparatus consists of a small load frame fitted with a proving ring to measure the vertical stress applied to the soil specimen.
- Fig 18.2 (a) shows an unconfined compression tester.
- The deformation of the sample is measured with the help of a separate dial gauge.
- The ends of the cylindrical specimen are hollowed in the from of cone.

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Module – 3: Shear Strength of Soil

Unconfined Compression Test:

- The cone seatings reduce the tendency of the specimen to become barrel shaped by reducing end-restraints.
- During the test, load versus deformation readings are taken and a graph is plotted.
- When a brittle failure occurs, the proving ring dial indicates a definite maximum load which drops rapidly with the further increase of strain.
- In the plastic failure, no definite maximum load is indicated.

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Module – 3: Shear Strength of Soil

Unconfined Compression Test:

- In such a case, the load corresponding to 20 percent strain is arbitrarily taken as the failure load.
- Fig 18.12 (b), (c) shows the stress conditions, at failure, in the unconfined compression test which is essentially an undrained test.
- Since $\sigma_3 = 0$, the Mohr circle passes through the origin which is also the pole.
- From Eq. 18.18, we get

$$\sigma_1 = 2c_u \tan \alpha = 2c_u \tan (45° + \Phi_u/2) \quad (18.22)$$

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Module – 3: Shear Strength of Soil

Unconfined Compression Test:

- In the above equation, there are two unknowns c_u and Φ_u, which cannot be determined by the unconfined test since a number of tests on the identical specimens give the same value of σ_1.
- Therefore, the unconfined compression test is generally applicable to saturated clays for which the apparent angle of shearing resistance is zero. Hence

$$\sigma_1 = 2c_u$$

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Module – 3: Shear Strength of Soil

Unconfined Compression Test:

- When the Mohr circle is drawn, its radius is equal to σ_1
  $\sigma_1 / 2 = c_u$.
- The failure envelope is horizontal.
- PF is the failure plane, and the stresses on the failure plane are

$$\sigma = \sigma_1 / 2 = q_u / 2 \quad \text{and} \quad \tau_f = \sigma_1 / 2 = q_u / 2 = c_u$$

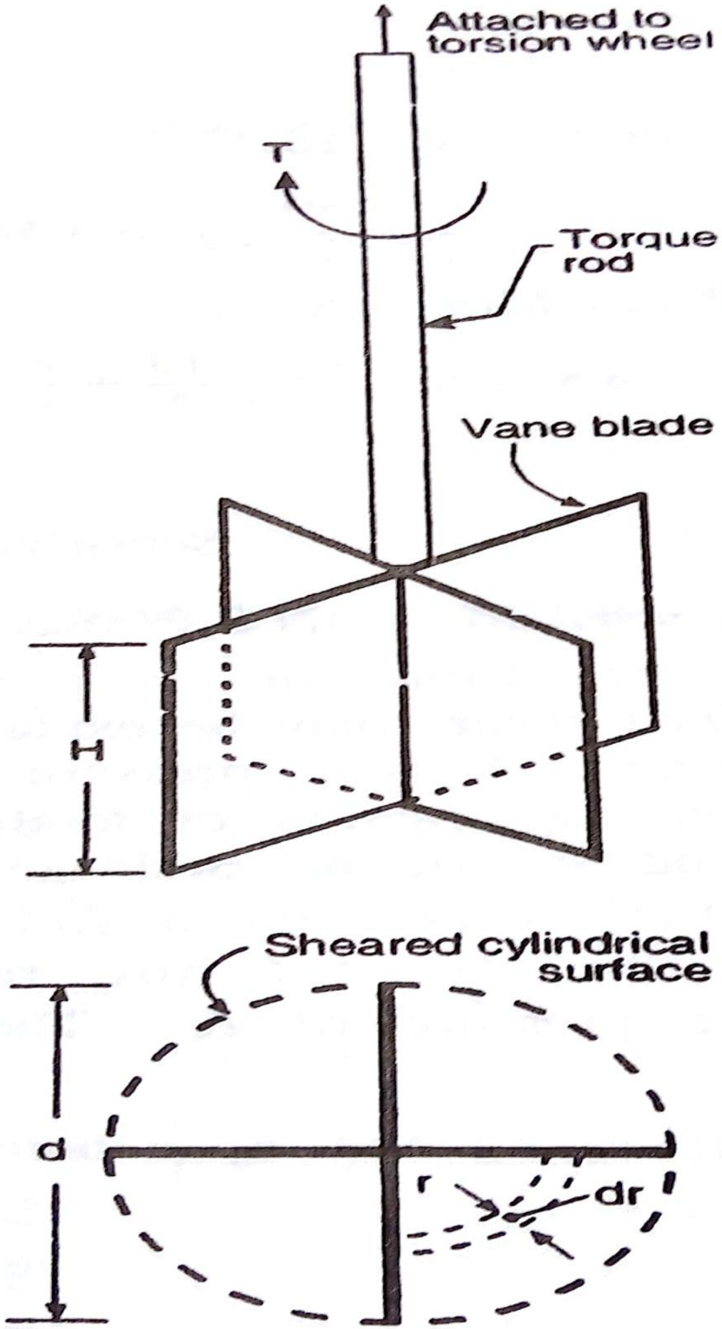

FIG. 18.22. VANE SHEAR TESTS.

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Module – 3: Shear Strength of Soil

Vane Shear Test:

- Is a quick test, used either in laboratory or in the field, to determine the undrained shear strength of cohesive soil.
- The vane shear tester consists of four thin steel plates, called vanes, welded orthogonally to a steel rod.
- A torque measuring arrangement, such as a calibrated torsion spring, is attached to the rod which is rotated by a worm gear and worm wheel arrangement.

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Module – 3: Shear Strength of Soil

Vane Shear Test:

- After pushing the vanes gently into the soil, the torque rod is rotated at a uniform speed.
- The rotation of the vane shears the soil along a cylindrical surface.
- The rotation of the spring in degrees is indicated by a pointer moving on a graduated dial attached to the worm wheel shaft.
- The torque T is then calculated by multiplying the dial reading with the spring constant.

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Module – 3: Shear Strength of Soil

Vane Shear Test:

- A typical laboratory vane is 20mm high and 12mm in diameter with blade thickness from 0.5 to 1mm, the blades being made of high tensile steel.
- The field shear vane is from 10 to 20 cm in height and from 5 to 10 cm in diameter, with blade thickness of about 2.5mm.
- The torque is calculated using the equation

$$T = \pi d^2 \tau_f \left(H/2 + d/12 \right)$$

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Module – 3: Shear Strength of Soil

Determination of Shear Parameter by Direct Shear Test:

The object of the test is to determine the shear parameters of soil with the help of shear box test.

Preparation of specimen:

- The undisturbed specimen is prepared by pushing a cutting ring of size 10cm in diameter and 2cm high, in the undisturbed soil sample obtained from the field. The square specimen of size 6cm x 6cm is then cut from the circular specimen so obtained.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Preparation of specimen:

- In order to obtain remoulded specimen of cohesive soil, the soil may be compacted to the required density and water content, in a separate bigger mould.
- The sample is then extracted and trimmed to the required size.
- Alternatively, the soil may be compacted at the required density and water content directly into the shear box after fixing two halves of the shear box together by means of the fixing screws.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Preparation of specimen:

- Non-cohesive soils may be tamped in the shear box itself with the base plate and grid plate or porous stone as required in place at the bottom of the box.
- In all the three cases mentioned above, water content and dry density of the soil compacted in the shear box should be determined.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Undrained Test:

- The shear box with the specimen plain grid plate over the base plate at the bottom of the specimen, and plain grid plate over the top of the specimen, should be fitted into position.
- The serrations of the grid plates should be placed at right angles to the direction of shear.

Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Undrained Test:

- As the porous stones are not used in the undrained tests, plain plates of equal thickness should be placed, one at the bottom and the other at the top of the two grids, so as to maintain the shear plane in the sample in the middle of its thickness.
- Place the loading pad on the top of the plain grid plate.
- Both the parts of the box should be tightened together by the fixing screws.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Undrained Test:

- Put water inside the water jacket so that the sample does not get dried during the test.
- Mount the shear box assembly on the load frame.
- Set the lower part of the shear box to bear against the load jack and the upper part of the box to bear against the proving ring. Set the dial of the proving ring to zero.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Undrained Test:

- Put the loading yoke on the top of the loading pad, and adjust the dial gauge to zero to measure the vertical displacement in the soil sample.
- Put proper normal weight on the hanger of the loading yoke, so that this weight plus the weight of the hanger equals the required normal load. Note the reading of the vertical displacement dial gauge.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Undrained Test:

- Remove the locking screws so that the parts are freed to move against each other. By turning the spacing screws, raise the upper part slightly above the lower part by about 1mm.
- Conduct the test by applying horizontal shear load to failure.
- The rate of strain may vary from 1 to 2.5mm per minute.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Undrained Test:

- Take the readings of proving ring dial gauge, longitudinal displacement gauge and vertical displacement gauge at regular time intervals.
- At the end of the test, remove specimen from the box and determine its final water content. Repeat the above steps on three or four indentical specimens, under laying normal loads.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Consolidated Undrained Test:

- Assemble the box in the similar manner as described above for the undrained test, except that instead of plain grid plates, perforated grid plates should be used, and saturated porous stones, should be used one at the top of the top perforated grid plate and the other at the bottom of the bottom perforated grid plate.
- Step 2, 3 and 4 same as in undrained test.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Consolidated Undrained Test:

- The shear test should be conducted only after complete consolidation has occurred under a particular normal stress. After the application of the normal load, the vertical compression of the soil with time should be recorded, as it done in the consolidation test.
- Apply the horizontal shear load. The rate of shear should be such that water does not drain from the specimen at the time of application of shear load.

Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Consolidated Undrained Test:

- Take the reading of the three dial gauges at constant interval of time.
- Remove the specimen from the box, at the end of the test, and determine its final water content.
- Repeat the test on three or four identical specimens, under varying normal loads.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Consolidated Drained Test:

- Assemble the shear box with sample, perforated grid plates and porous stones, as in consolidated undrained test.
- Allow the sample to consolidate under the normal load.
- After the application of the normal load, vertical compression of the soil with time should be recorded, as it done in the consolidation test.

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Module – 3: Shear Strength of Soil

Determination of shear parameter by Direct Shear Test:

Consolidated Drained Test:

- When consolidation has completely occurred, the shear test should be done at a slow rate so that complete drainage can occur and at least 95 percent pressure dissipation occurs during the test.
- At the end of the test, remove the specimen from the box and determine its final water content.
- Repeat the test on three or four samples, under varying normal loads.

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Module – 3: Shear Strength of Soil

Determination of Unconfined Compressive Strength:

The object of the experiment is to determine the unconfined compressive strength of clayey soil using controlled strain. The purpose of the test is to obtain a quantitative value of compressive and shearing strength of soils in an undrained state. The test may be performed on both undisturbed and remoulded soil sample.

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Module – 3: Shear Strength of Soil

Determination of Unconfined Compressive Strength:

Preparation of Test Specimen:

- Undisturbed cylindrical specimen may be cut from the bigger undisturbed sample obtained from the field.
- A wire saw may be used to trim the ends parallel to each other.
- A lathe or trimmer may be used to trim the specimen to circular cross-section.

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Module – 3: Shear Strength of Soil

Determination of Unconfined Compressive Strength:

Preparation of Test Specimen:

- Alternatively, field sample may be obtained directly in a thin sampling tube having the same diameter as the specimen to be tested.
- The split mould is oiled lightly from inside and the sample is then pushed out of the tube into the split mould.
- The split mould is opened carefully and sample is taken out.

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Module – 3: Shear Strength of Soil

Determination of Unconfined Compressive Strength:

Preparation of Test Specimen:

- Remoulded sample may be prepared by compacting the soil at the desired water content and dry density in a bigger mould, and then cut by the sampling tube.
- Alternatively, remoulded specimen may be prepared directly in the split mould.
- In both the cases, the density and water content of the specimen is determined.

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Module – 3: Shear Strength of Soil

Determination of Unconfined Compressive Strength:

Compression test:

- Measure the initial length and diameter of the specimen.
- Put the specimen on the bottom plate of the loading device. Adjust the upper plate to make contact with the specimen. Set the load dial gauge and the strain dial gauge to zero.

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Module – 3: Shear Strength of Soil

Determination of Unconfined Compressive Strength:

Compression test:

- Compress the specimen until cracks have definitely developed of the stress strain curve is well past its peak or until a vertical deformation of 20 percent is reached. Take the load dial readings approximately at every 1mm deformation of the specimen.
- Sketch the failure pattern, measure the angle between the cracks and the horizontal, if possible, and if the specimen is homogeneous.

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Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

The object of the experiment is to determine shear parameters of undisturbed or remoulded soil specimen in the triaxial compression apparatus by unconsolidated undrained test without the measurement of pore pressure.

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Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Undisturbed Specimen:

- If the undisturbed sample has been collected in a thin walled tube having the same internal diameter as that of the specimen required for testing, the sample may be extruded out with the help of sample extruder and pushed into the split mould.
- The sample should be extruded from the tube pushing from the cutting edge side.

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Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Undisturbed Specimen:

- The ends of the specimen are trimmed flat and normal to its axis.
- The split mould should be lightly oiled from inside.
- The specimen is then taken out, carefully, from the split mould, and its length, diameter, weight should be measured to an accuracy enabling the bulk density to be calculated.

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Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Undisturbed Specimen:

- A portion of the soil trimmings is placed for water content determination.
- The specimen is then placed on one of the end caps and the other end cap is put on the top of the specimen.
- The rubber membrane is then placed around the specimen using the membrane stretcher.
- The membrane is sealed to the end caps by means of rubber rings.

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Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Remoulded Specimen:

- Remoulded specimens may be prepared by compacting the soil, at required water content and dry density, in a big size mould by static or dynamic method, and then preparing the cylindrical specimen of required dimensions.

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Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Undrained Triaxial Compression Test:

- Cover the pedestal in the triaxial cell with a solid cap or keep drainage value closed.
- Place the specimen assembly centrally on the pedestal.
- Assemble the cell, with the loading ram initially clear of the top of the specimen, and place it in the loading machine.

Geotechnical Engineering (18CV54)

Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Undrained Triaxial Compression Test:

- Admit the operating fluid in the cell, and raise its pressure to the desired value.
- Adjust the loading machine to bring the loading ram a short distance away from the set on the top cap of the specimen.
- Read the initial reading to the load measuring gauge.

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Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Undrained Triaxial Compression Test:

- Adjust the loading machine further so that the loading ram comes just in contact with the seat on the top of the specimen.
- Note the initial reading of the dial measuring axial compression.
- Apply the compressive force at constant rate of axial compression, such that the failure is produced in a period of 5 to 15 minutes.

Geotechnical Engineering (18CV54)

Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Undrained Triaxial Compression Test:

- Take the simultaneous reading of load and deformation dials, define the stress-strain curve.
- Continue the test until the maximum value of stress had been passed or until an axial strain of 20 percent has been passed.
- Unload the specimen and drain off the cell fluid.
- Dismantle the cell and take out the specimen.

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Module – 3: Shear Strength of Soil

Determination of Shear Parameters by Triaxial Test:

Undrained Triaxial Compression Test:

- Remove the rubber membrane and note down the mode of failure.
- Weigh the specimen.
- Keep samples for water content determination.
- Repeat the test on three or more identical specimens under different cell pressure.