Rajiv Gandhi University of Knowledge Technology-Nuzvid

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS

BY

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SHEAR STRENGTH OF SOIL

PART-1

Syllabus of Shear strength of soil

- Basic mechanism of shear strength
- Mohr – Coulomb Failure theories
- Stress-Strain behaviour of Sands – Critical Void Ratio
- Stress-Strain behaviour of clays
- Shear Strength determination- various drainage conditions.

INTRODUCTION

- ‘Shearing Strength’ of a soil is perhaps the most important of its engineering properties.
- This is because all stability analyses in the field of geotechnical engineering, whether they relate to foundation, slopes of cuts or earth dams, involve a basic knowledge of this engineering property of the soil.
- ‘Shearing strength’ or merely ‘Shear strength’, may be defined as the resistance to shearing stresses and a consequent tendency for shear deformation.
- Basically speaking, a soil derives its shearing strength from the following :
- (1) Resistance due to the interlocking of particles.
- (2) Frictional resistance between the individual soil grains, which may be sliding friction, rolling friction, or both.
- (3) Adhesion between soil particles or ‘cohesion’.

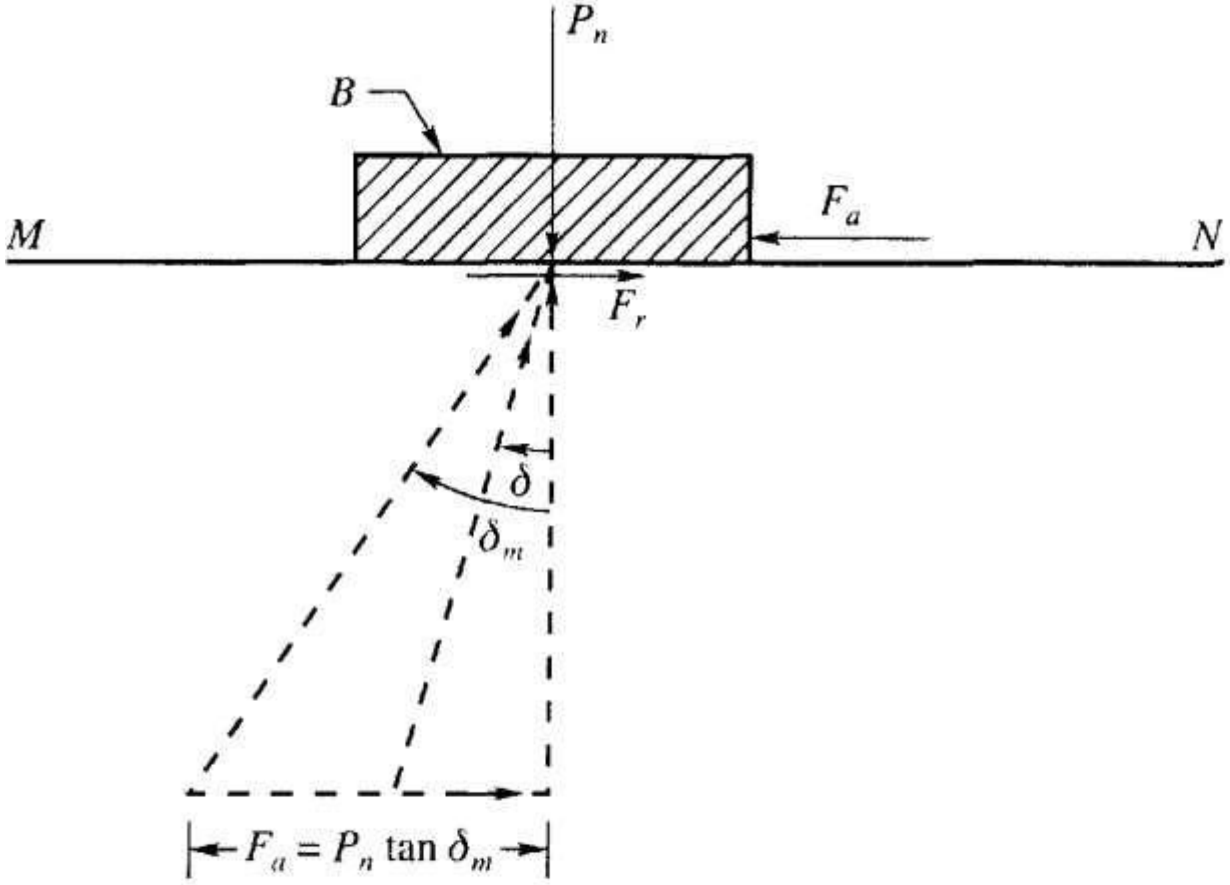
INTRODUCTION

- Granular soils of sands may derive their shear strength from the first two sources, while cohesive soils or clays may derive their shear strength from the second and third sources.
- Highly plastic clays, however, may exhibit the third source alone for their shearing strength.
- Most natural soil deposits are partly cohesive and partly granular and as such, may fall into the second of the three categories just mentioned, from the point of view of shearing strength.

BASIC CONCEPT OF SHEARING RESISTANCE AND SHEARING STRENGTH

- Consider a prismatic block *B* resting on a plane surface *MN* as shown in Fig.
- Block *B* is subjected to the force *Pn* which acts at right angles to the surface *MN*, and the force *Fa* that acts tangentially to the plane. The normal force *Pn* remains constant whereas *Fa* gradually increases from zero to a value which will produce sliding.
- If the tangential force *Fa* is relatively small, block *B* will remain at rest, and the applied horizontal force will be balanced by an equal and opposite force *Fr* on the plane of contact.
- This resisting force is developed as a result of roughness characteristics of the bottom of block *B* and plane surface *MN*.
- The angle δ formed by the resultant *R* of the two forces *Fr* and *Pn* with the normal to the plane *MN* is known as the *angle of obliquity*.
- If the applied horizontal force *Fa* is gradually increased, the resisting force *Fr* will likewise increase, always being equal in magnitude and opposite in direction to the applied force.

- Block *B* will start sliding along the plane when the force *Fa* reaches a value which will increase the angle of obliquity to a certain maximum value δ .
- If block *B* and plane surface *MN* are made of the same material, the angle δ_m is equal to ϕ which is termed the *angle of friction*, and the value tan ϕ is termed the *coefficient of friction.*



- If block *B* and plane surface *MN* are made of dissimilar materials, the angle *8* is termed the *angle of wall friction.*
- The applied horizontal force *Fa* on block *B* is a shearing force and the developed force is friction or *shearing resistance.*
- The maximum shearing resistance which the materials are capable of developing is called the *shearing strength.*
- If another experiment is conducted on the same block with a higher normal load *Pn* the shearing force *Fa* will correspondingly be greater. A series of such experiments would show that the shearing force *Fa* is proportional to the normal load *Pn*, that is

$$F_a = P_n \tan \phi$$

- If *A* is the overall contact area of block *B* on plane surface MN, the relationship may be written as

$$\text{shear strength, } s = \frac{F_a}{A} = \frac{P_n}{A} \tan \phi$$

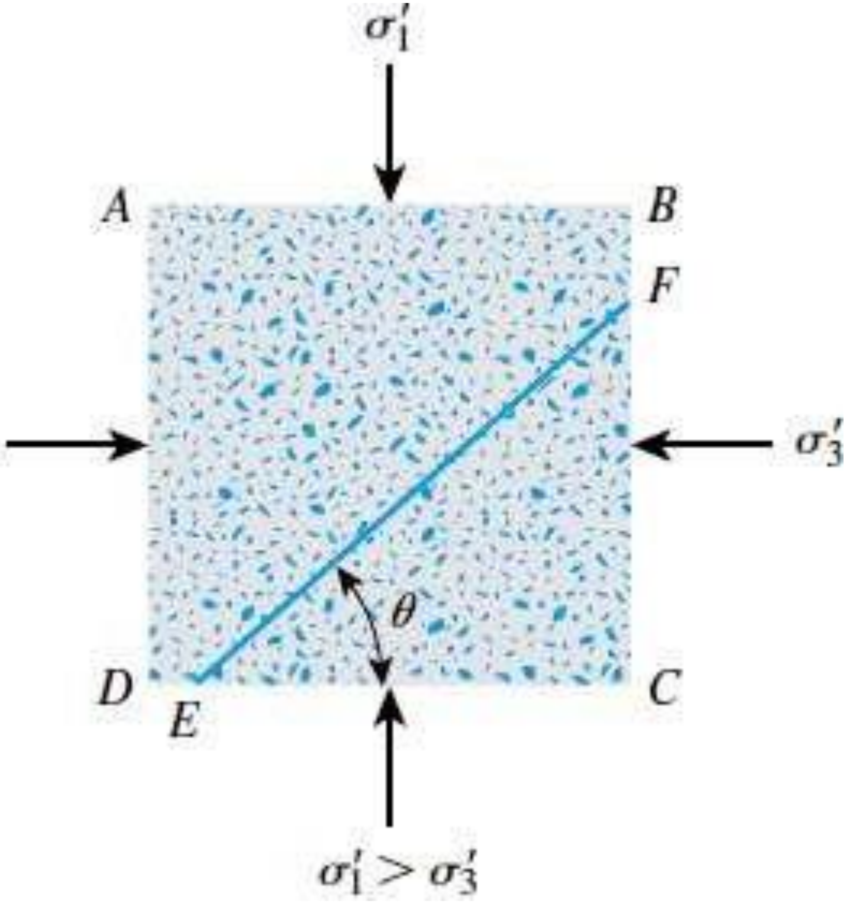
or

$$s = \sigma \tan \phi$$

PRINCIPAL PLANES AND PRINCIPAL STRESSES—MOHR'S CIRCLE

- A 'Principal plane' is defined as a plane on which the stress is wholly normal, or one which does not carry shearing stress.
- From mechanics, it is known that there exists three principal planes at any point in a stressed material.
- The normal stresses acting on these principal planes are known as the 'principal stresses'. The three principal planes are to be mutually perpendicular.
- In the order of decreasing magnitude the principal stresses are designated the 'major principal stress', the 'intermediate principal stress' and the 'minor principal stress', the corresponding principal planes being designated exactly in the same manner.

- Let us consider an element of soil whose sides are chosen as the principal planes, the major and the minor, as shown in Fig
- Considering the equilibrium of the element and resolving all forces in the directions parallel and perpendicular to *AB, the* following equations may be obtained:

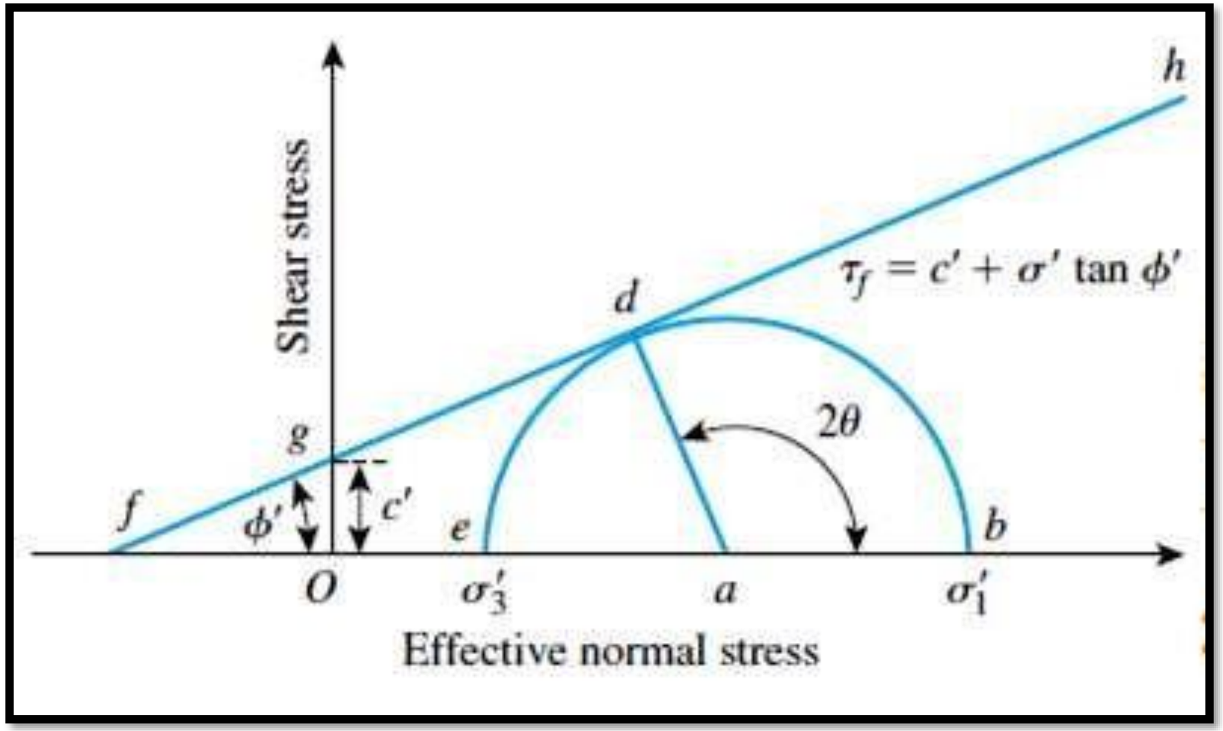


$$\sigma_\theta = \sigma_1 \cos^2\theta + \sigma_3 \sin^2\theta = \sigma_3 + (\sigma_1 - \sigma_3)\cos^2\theta$$

$$= \frac{(\sigma_1 + \sigma_3)}{2} + \frac{(\sigma_1 - \sigma_3)}{2} \,.\, \cos 2\theta$$

$$\tau_\theta = \frac{(\sigma_1 - \sigma_3)}{2} \,.\, \sin 2\theta$$

- Otto Mohr (1882) represented these results graphical in a circle diagram, which is called Mohr's circle.
- Normal stresses are represented as abscissa and shear stresses as ordinates.
- If the coordinates σ_θ and τ_θ are plotted for all possible values of θ, the locus is a circle as shown in Fig. This circle has its centre on the axis and cuts it at values σ_3 and σ_1. This circle is known as the Mohr's circle.

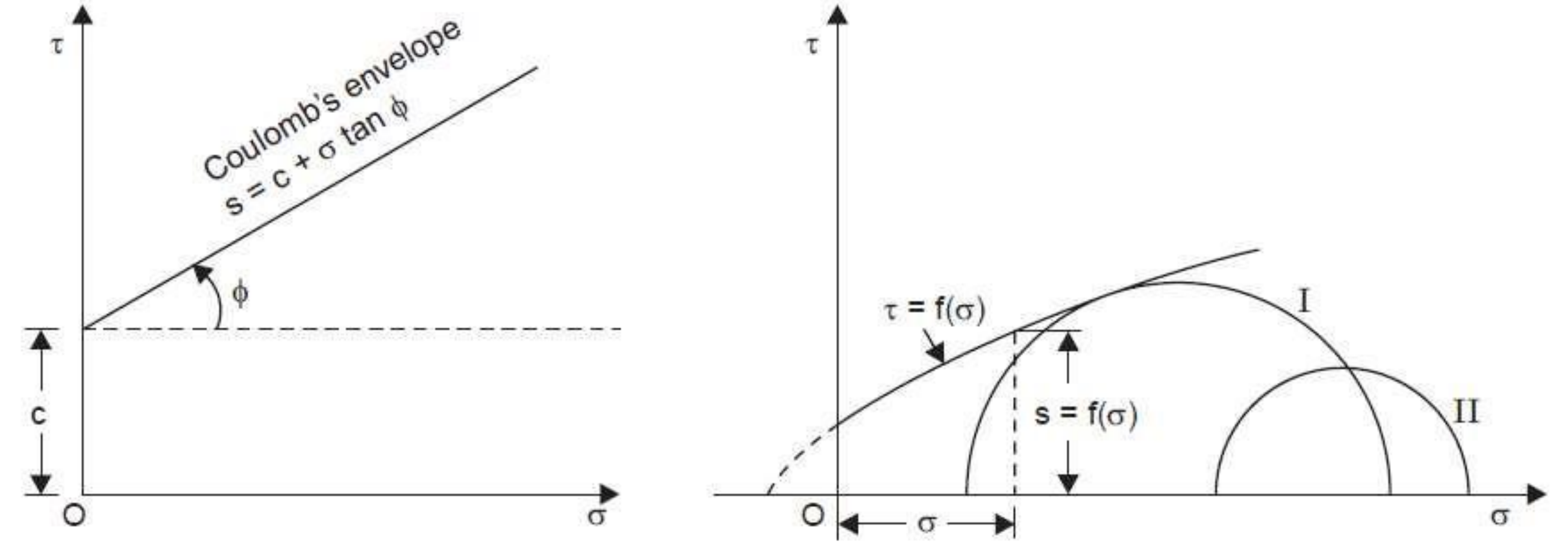


Mohr-Coulomb Theory

- The Mohr-Coulomb theory of shearing strength of a soil, first propounded by Coulomb (1976) and later generalised by Mohr, is the most commonly used concept.
- The functional relationship between the normal stress on any plane and the shearing strength available on that plane was assumed to be linear by Coulomb; thus the following is usually known as Coulomb's law:

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

- where *c and φ are empirical parameters, known as the 'apparent cohesion' and 'angle of shearing* resistance' (or angle of internal friction), respectively.
- These are better visualised as 'parameters' and not as absolute properties of a soil since they are known to vary with water content, conditions of testing such as speed of shear and drainage conditions, and a number of other factors besides the type of soil.

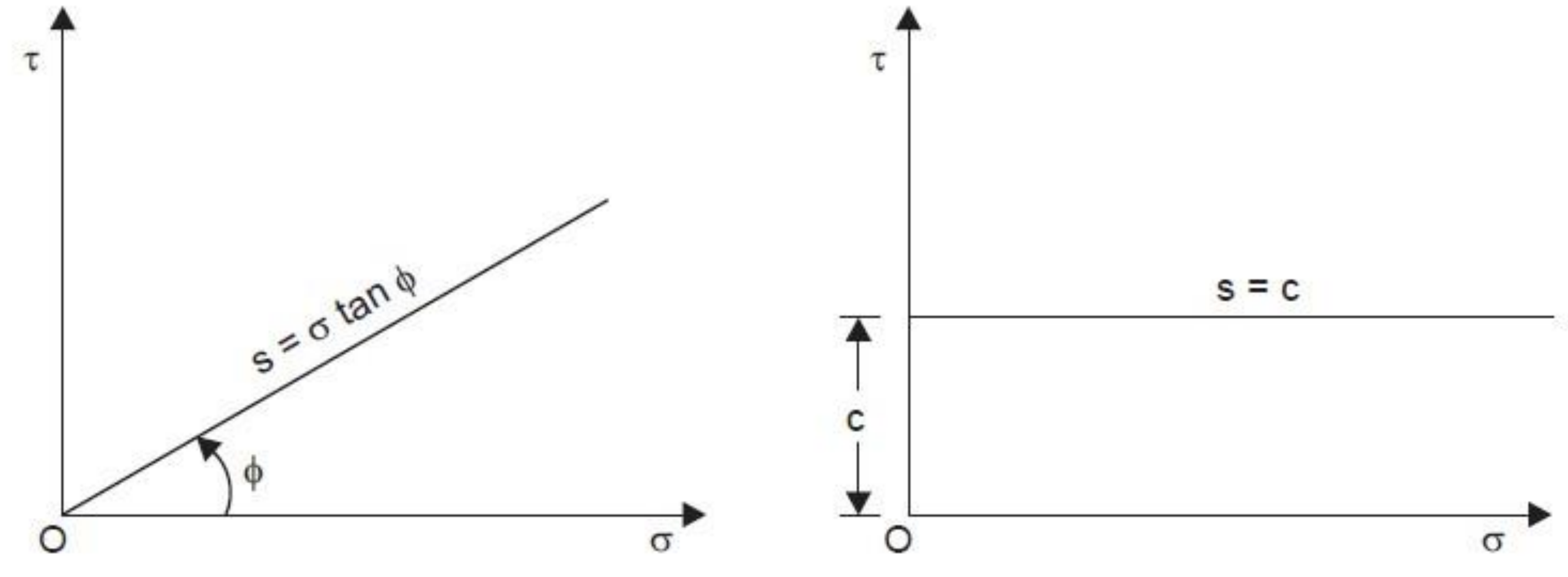


(a) Coulomb's envelope for a c-ϕ soil
(b) Mohr's generalized failure envelope

➢Coulomb's law is merely a mathematical equation of the failure envelope shown in Fig. (a); Mohr's generalisation of the failure envelope as a curve which becomes flatter with increasing normal stress is shown in Fig. (b).

➢The envelopes are called 'strength envelopes' or 'failure envelopes'.

➢It can be said that the Mohr's circle of stress relating to a given stress condition would represent, incipient failure condition if it just touches or is tangent to the strength or failure envelope (circle I); otherwise, it would wholly lie below the envelopes as shown in circle II, The Coulomb envelope in special cases may take different shapes. For a purely cohesionless or granular soil or a pure sand, it would be as shown in Fig. (*a)* and for a purely cohesive soil or a pure clay, it would be as shown in Fig. (*b).*



(a) Pure sand "c = 0" or "ϕ"-soil (b) Pure clay ("ϕ = 0" or "c"-soil)

Effective Shear Strength parameters

$$s = c' + \bar{\sigma}_f \tan \phi'$$

- according to Terzaghi, it is the effective stress on the failure plane that governs the shearing strength and not the total stress.
- the strength of a soil is a unique function of the effective stress acting on the failure plane
- where c' and φ' are called the effective cohesion and effective angle of internal friction, respectively, since they are based on the effective normal stress on the failure plane.
- Collectively, they are called 'effective stress parameters', while c and φ of Eq. 8.26 are called ''total stress parameters''.

TYPES OF SHEAR TESTS BASED ON DRAINAGE CONDITIONS

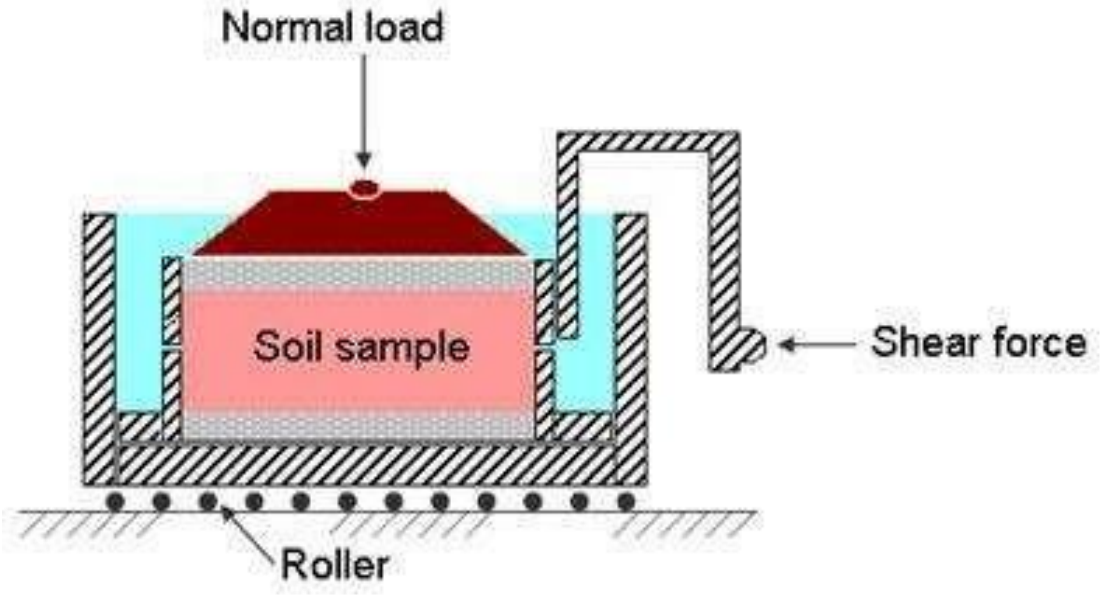
- A cohesionless or a coarse-grained soil may be tested for shearing strength either in the dry condition or in the saturated condition.
- A cohesive or fine-grained soil is usually tested in the saturated condition.
- Depending upon whether drainage is permitted before and during the test, shear tests on such saturated soils are classified as follows:

SHEARING STRENGTH TESTS

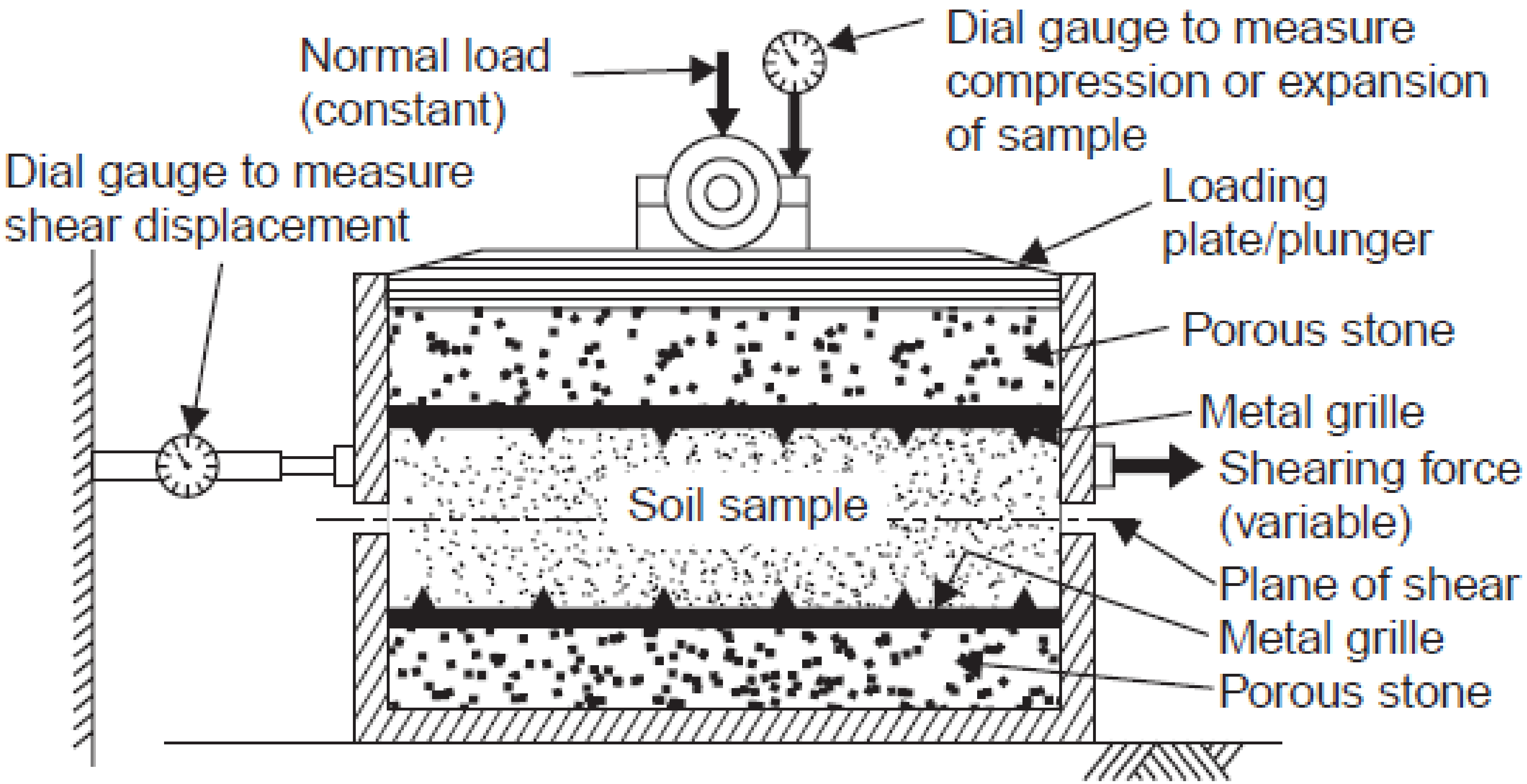
- ***Laboratory Tests***
- 1. Direct Shear Test
- 2. Triaxial Compression Test
- 3. Unconfined Compression Test
- 4. Laboratory Vane Shear Test
- 5. Torsion Test
- 6. Ring Shear Tests
- ***Field Tests***
- 1. Vane Shear Test
- 2. Penetration Test

1. Direct Shear Test

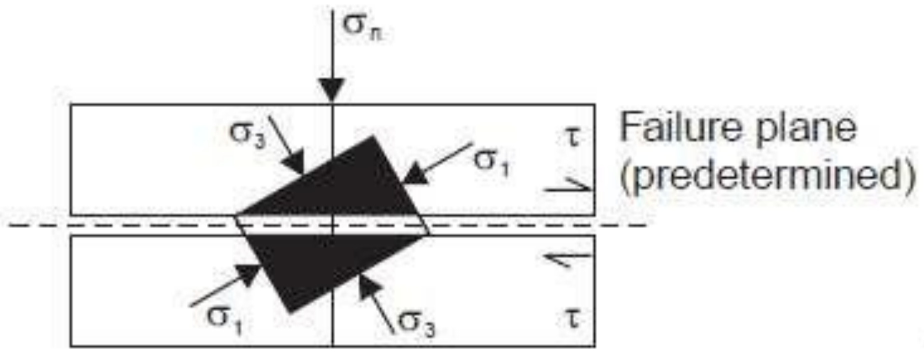
- The test is carried out on a soil sample confined in a metal box of square cross-section which is split horizontally at mid-height. A small clearance is maintained between the two halves of the box.
- The soil is sheared along a predetermined plane by moving the top half of the box relative to the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



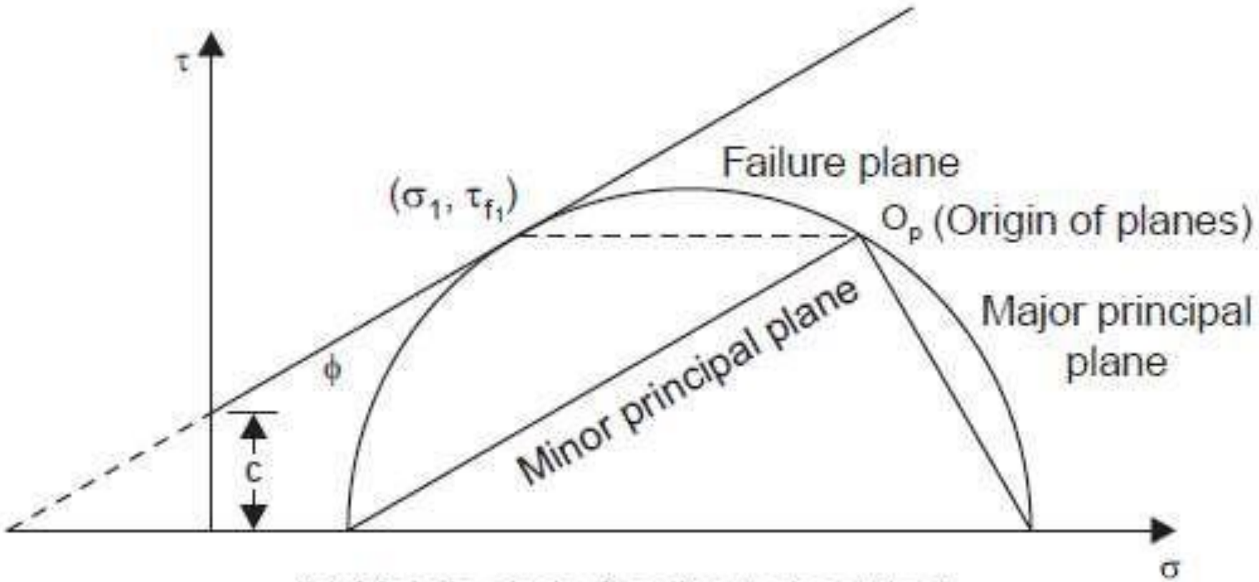
Direct Shear Test



Direct Shear Test



(a) Conditions of stress in the shear box



(b) Mohr's circle for direct shear test

Direct Shear Test

- 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.
- As a vertical normal load is applied to the sample, shear stress is gradually applied horizontally, by causing the two halves of the box to move relative to each other. The shear load is measured together with the corresponding shear displacement. The change of thickness of the sample is also measured.
- A number of samples of the soil are tested each under different vertical loads and the value of shear stress at failure is plotted against the normal stress for each test. Provided there is no excess pore water pressure in the soil, the total and effective stresses will be identical. From the stresses at failure, the failure envelope can be obtained.

Direct Shear Test

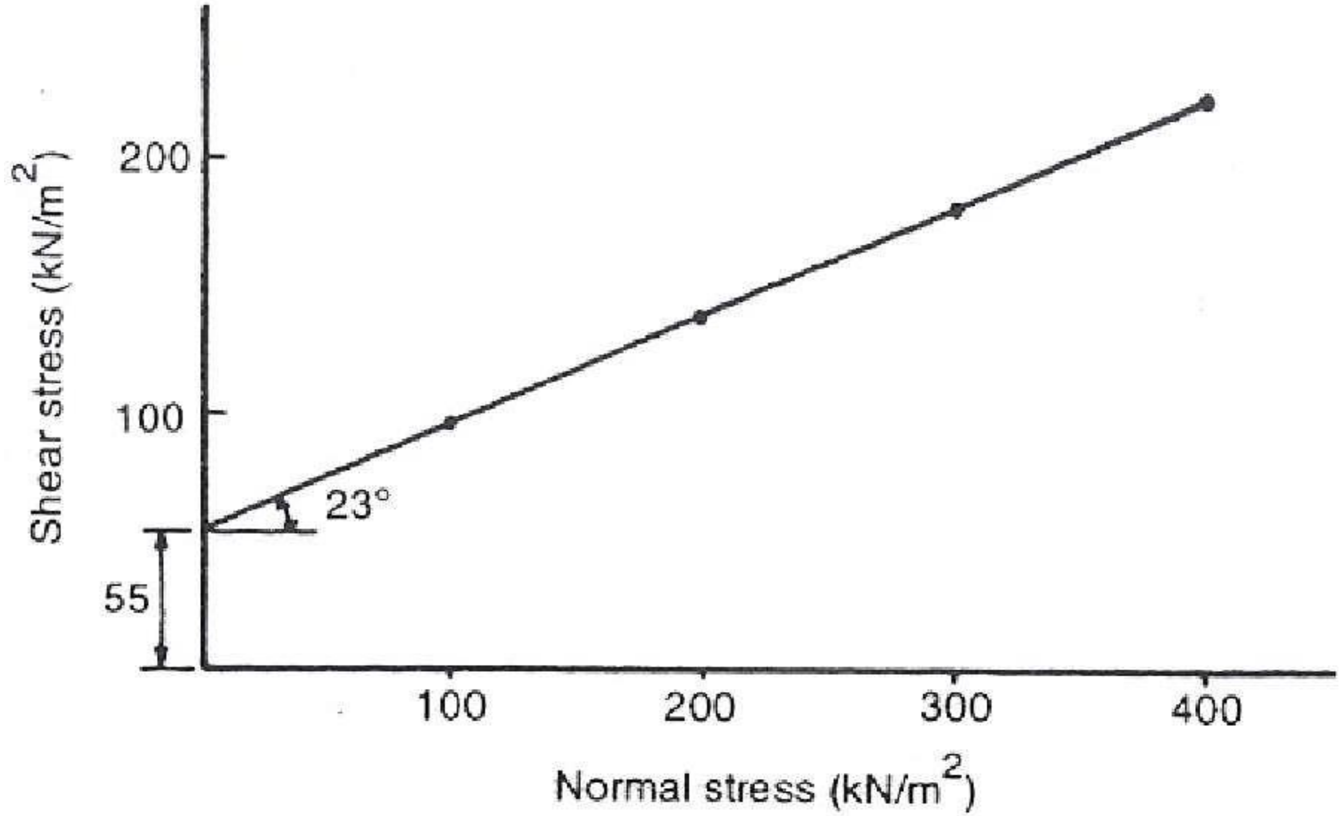
- **The test has several advantages:**
- It is easy to test sands and gravels.
- Large samples can be tested in large shear boxes, as small samples can give misleading results due to imperfections such as fractures and fissures, or may not be truly representative.
- Samples can be sheared along predetermined 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 localized drainage away from the shear plane.

Example

- Undrained shear box tests were carried out on a series of soil samples with the following results

Test No	Total Normal Stress (kN/m2)	Total Shear stress at Failure (kN/m2)
1	100	98
2	200	139
3	300	180
4	400	222

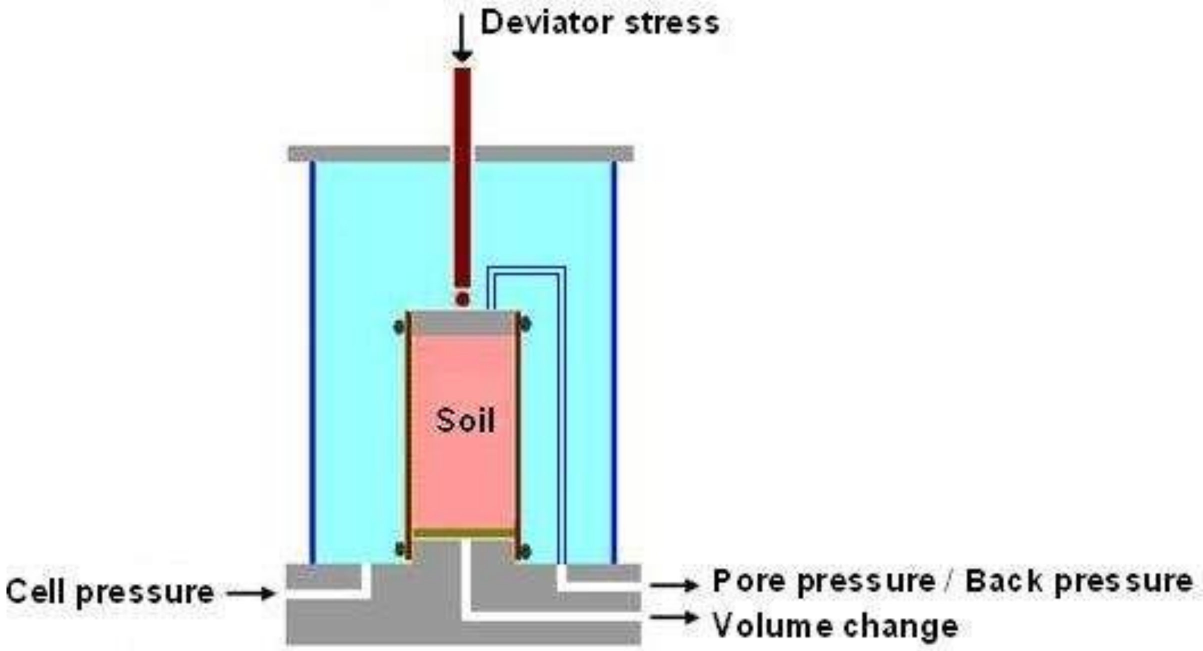
- Determine the cohesion and angle of internal friction of the soil, with respect to total stress

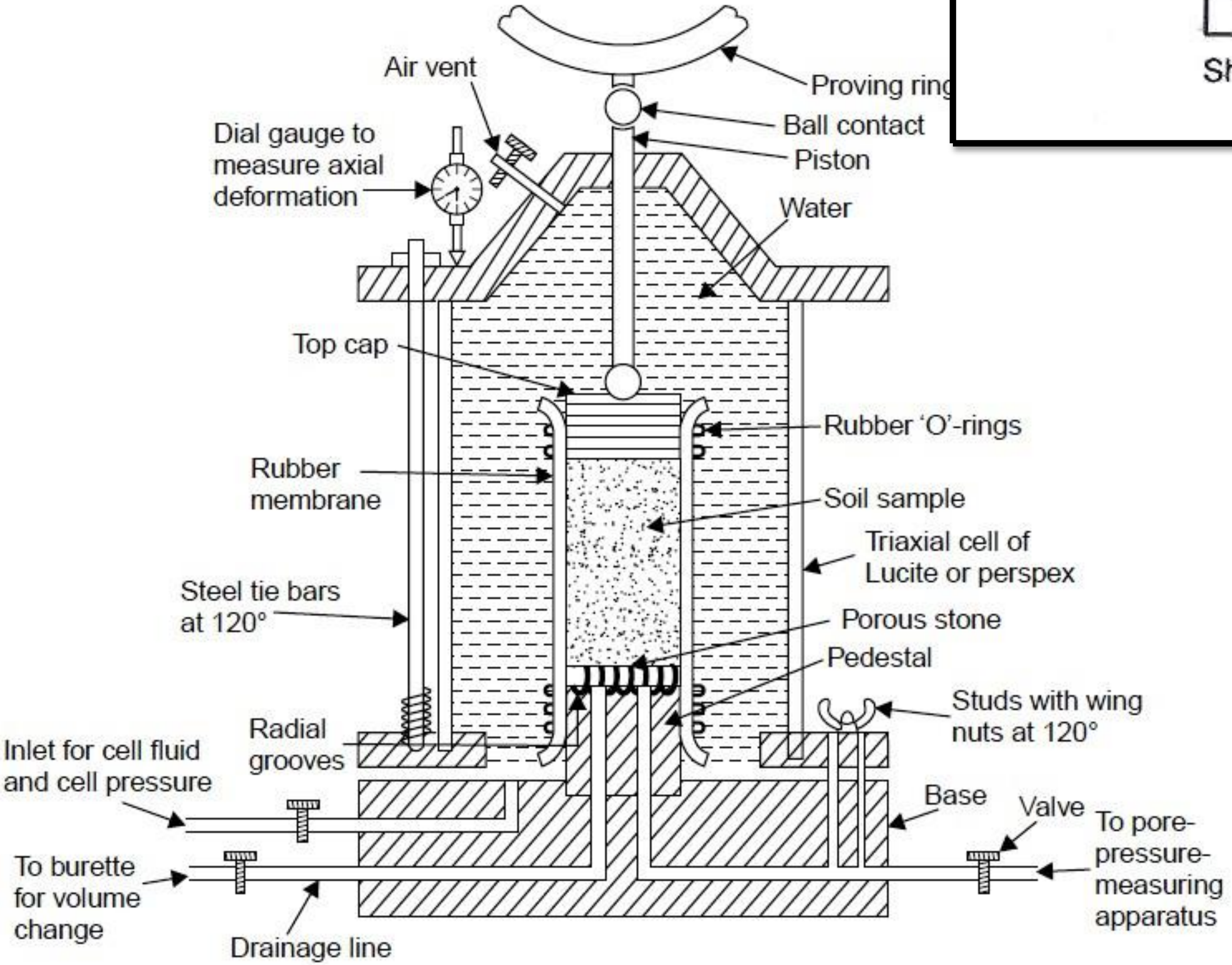


Shear stress (kN/m²)
200
100
55
23°
100
200
300
400
Normal stress (kN/m²)

2. Triaxial Test

- The triaxial test is carried out in a cell on a cylindrical soil sample having a length to diameter ratio of 2.
- The usual sizes are 76 mm x 38 mm and 100 mm x 50 mm.
- Three principal stresses are applied to the soil sample, out of which two are applied water pressure inside the confining cell and are equal.
- The third principal stress is applied by a loading ram through the top of the cell and is different to the other two principal stresses.
- A typical triaxial cell is shown.





Air vent
Proving ring
Ball contact
Piston
Dial gauge to
measure axial
deformation
Water
Top cap
Rubber 'O'-rings
Rubber
membrane
Soil sample
Triaxial cell of
Lucite or perspex
Steel tie bars
at 120°
Porous stone
Pedestal
Studs with wing
nuts at 120°
Radial
grooves
Inlet for cell fluid
and cell pressure
Base
Valve
To pore-
pressure-
measuring
apparatus
To burette
for volume
change
Drainage line

$(45^\circ + \frac{\phi}{2})$
Shear
Barrelling
Barrelling
and shear

- The soil sample is placed inside a rubber sheath which is sealed to a top cap and bottom pedestal by rubber O-rings.
- For tests with pore pressure measurement, porous discs are placed at the bottom, and sometimes at the top of the specimen.
- Filter paper drains may be provided around the outside of the specimen in order to speed up the consolidation process.
- Pore pressure generated inside the specimen during testing can be measured by means of pressure transducers.
- The triaxial compression test consists of two stages:

1. First stage: In this, a soil sample is set in the triaxial cell and confining pressure is then applied.
2. Second stage: In this, additional axial stress (also called deviator stress) is applied which induces shear stresses in the sample. The axial stress is continuously increased until the sample fails.

- During both the stages, the applied stresses, axial strain, and pore water pressure or change in sample volume can be measured.

- There are several test variations, and those used mostly in practice are:
- UU (unconsolidated undrained) test: In this, cell pressure is applied without allowing drainage. Then keeping cell Type equation here.pressure constant, deviator stress is increased to failure without drainage.
- CU (consolidated undrained) test: In this, drainage is allowed during cell pressure application. Then without allowing further drainage, deviator stress is increased keeping cell pressure constant.
- CD (consolidated drained) test: This is similar to CU test except that as deviator stress is increased, drainage is permitted. The rate of loading must be slow enough to ensure no excess pore water pressure develops.
- In the test, if pore water pressure is measured, the test is designated by $\overline{UU}$.
- In the CU test, if pore water pressure is measured in the second stage, the test is symbolized as .$\overline{CU}$

Unconsolidated Undrained Test

- Drainage is not permitted at any stage of the test, that is, either before the test during the application of the normal stress or during the test when the shear stress is applied.
- Hence no time is allowed for dissipation of pore water pressure and consequent consolidation of the soil; also, no significant volume changes are expected.
- Usually, 5 to 10 minutes may be adequate for the whole test, because of the shortness of drainage path.
- However, undrained tests are often performed only on soils of low permeability.
- This is the most unfavourable condition which might occur in geotechnical engineering practice and hence is simulated in shear testing.
- Since a relatively small time is allowed for the testing till failure, it is also called the 'Quick test.' It is designated *UU, Q, or* Q_u *test.*

Consolidated Undrained Test

- Drainage is permitted fully in this type of test during the application of the normal stress and no drainage is permitted during the application of the shear stress.
- Thus volume changes do not take place during shear and excess pore pressure develops.
- Usually, after the soil is consolidated under the applied normal stress to the desired degree, 5 to 10 minutes may be adequate for the test.
- This test is also called ‘consolidated quick test’ and is designated CU or Qc test,
- These conditions are also common in geotechnical engineering practice.

Consolidated Drained Test

- Drainage is permitted fully before and during the test, at every stage. The soil is consolidated under the applied normal stress and is tested for shear by applying the shear stress also very slowly while drainage is permitted at every stage.
- Practically no excess pore pressure develops at any stage and volume changes take place.
- It may require 4 to 6 weeks to complete a single test of this kind in the case of cohesive soils, although not so much time is required in the case of cohesionless soils as the latter drain off quickly.
- This test is seldom conducted on cohesive soils except for purposes of research.
- It is also called the ‘Slow Test’ or ‘consolidated slow test’ and is designated *CD, S, or Sc test.*

- The choice as to which of these tests is to be used depends upon the types of soil and the problem on hand.
- For problems of short-term stability of foundations, excavations and earth dams UU-tests are appropriate.
- For problems of long-term stability, either CU-test or CD tests are appropriate, depending upon the drainage conditions in the field.

- **Significance of Triaxial Testing**
- The first stage simulates in the laboratory the in-situ condition that soil at different depths is subjected to different effective stresses. Consolidation will occur if the pore water pressure which develops upon application of confining pressure is allowed to dissipate. Otherwise the effective stress on the soil is the confining pressure (or total stress) minus the pore water pressure which exists in the soil.
- During the shearing process, the soil sample experiences axial strain, and either volume change or development of pore water pressure occurs. The magnitude of shear stress acting on different planes in the soil sample is different. When at some strain the sample fails, this limiting shear stress on the failure plane is called the shear strength.

❑ The triaxial test has many advantages over the direct shear test:

- The soil samples are subjected to uniform stresses and strains.
- Different combinations of confining and axial stresses can be applied.
- Drained and undrained tests can be carried out.
- Pore water pressures can be measured in undrained tests.
- The complete stress-strain behavior can be determined.

- ***Area Correction for the Determination of Additional Axial Stress or Deviatoric Stress:***
- The additional axial load applied at any stage of the test can be determined from the proving ring reading. During the application of the load, the specimen undergoes axial compression and horizontal expansion to some extent. Little error is expected to creep in if the volume is supposed to remain constant, although the area of cross-section varies as axial strain increases.

If A_0, h_0 and V_0 are the initial area of cross-section, height and volume of the soil specimen respectively, and if A, h, and V are the corresponding values at any stage of the test, the corresponding changes in the values being designated ΔA, Δh, and ΔV, then

$$A(h_o + \Delta h) = V = V_0 + \Delta V$$

$$\therefore \qquad A = \frac{V_0 + \Delta V}{h_0 + \Delta h}$$

But, for axial compression, Δh is known to be negative.

$$\therefore \qquad A = \frac{V_0 + \Delta V}{h_0 - \Delta h} = \frac{V_0\left(1 + \dfrac{\Delta V}{V_0}\right)}{h_0\left(1 - \dfrac{\Delta h}{h_0}\right)} = \frac{A_0\left(1 + \dfrac{\Delta V}{V_0}\right)}{(1 - \varepsilon_a)},$$

since the axial strain, $\varepsilon_a = \Delta h / h_0$.

For an undrained test, $A = \dfrac{A_0}{(1 - \varepsilon_a)}$,

since $\Delta V = 0$.

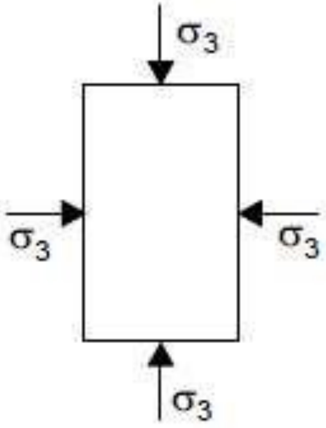
This is called the 'Area correction' and $\dfrac{1}{(1 - \varepsilon_a)}$ is the correction factor.

Once the corrected area is determined, the additional axial stress or the deviator stress, $\Delta\sigma$, is obtained as

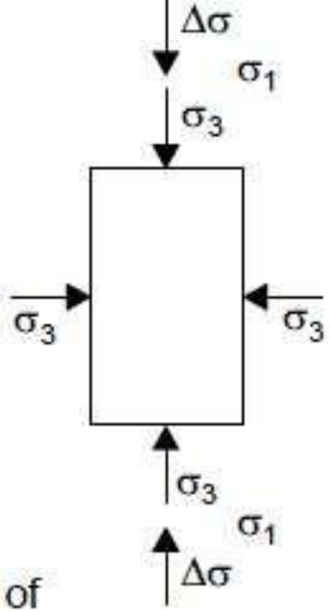
$$\Delta\sigma = \sigma_1 - \sigma_3 = \frac{\text{Axial load (from proving ring reading)}}{\text{Corrected area}}$$

The cell pressure or the confining pressure, σ_c, itself being the minor principal stress, σ_3, this is constant for one test; however, the major principal stress, σ_1, goes on increasing until failure.

$$\sigma_1 = \sigma_3 + \Delta\sigma$$



(a) Initially, upon application of all-round fluid pressure, or confining pressure



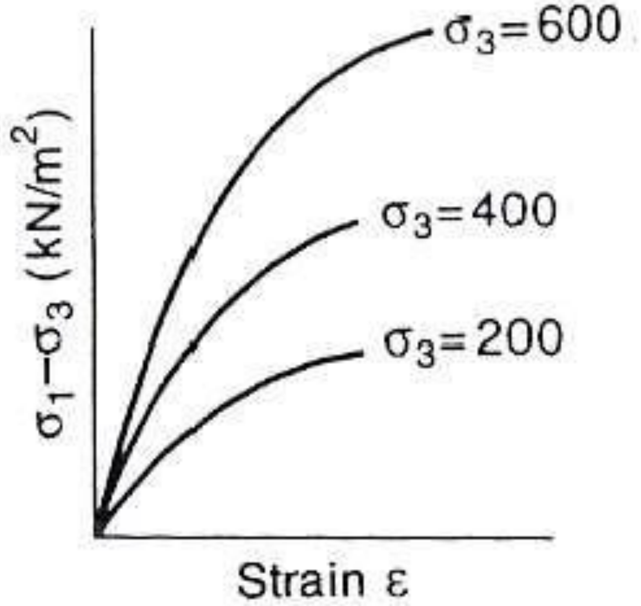
$\sigma_1 = \sigma_3 + \Delta\sigma$

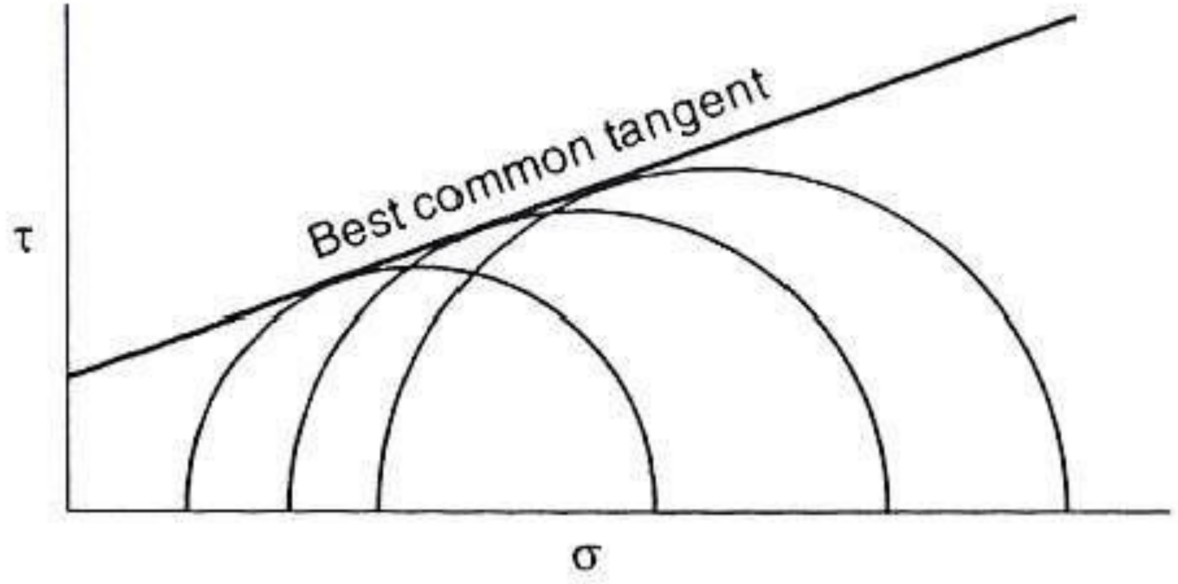
where $\Delta\sigma$ = externally applied axial stress

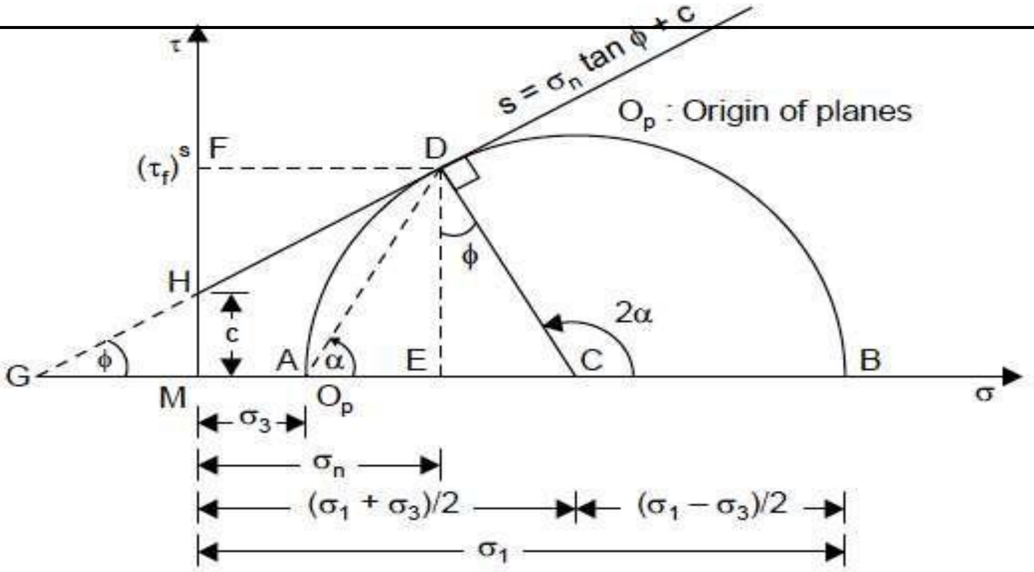
$\therefore$ $\Delta\sigma = (\sigma_1 - \sigma_3)$, or the principal stress difference, often called the "Deviatoric stress".

(b) After application of external axial stress in addition to the confining pressure, held constant until failure

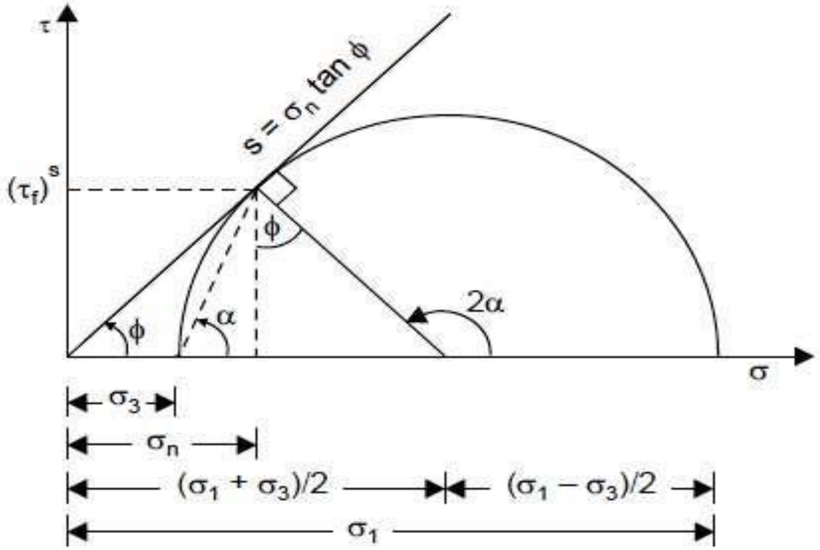
Mohr's Circle for Triaxial Test



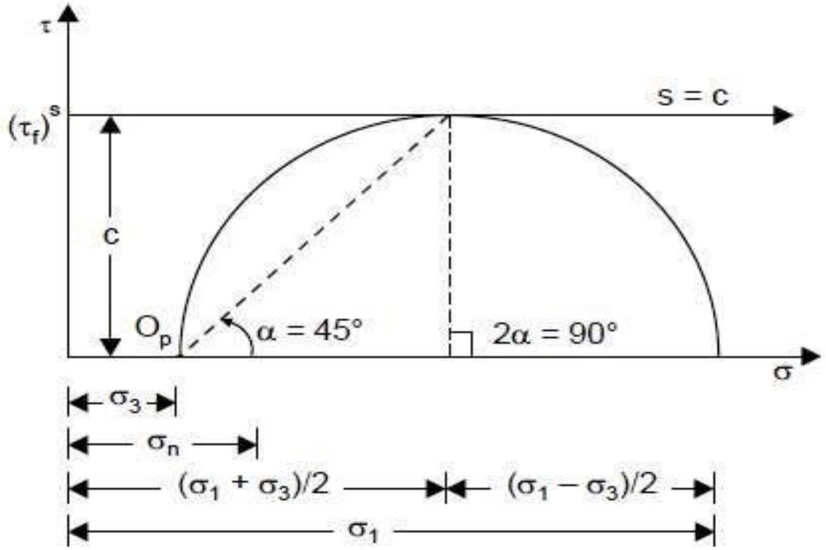




(a) Mohr's circle at failure for a general c-φ soil



(b) Mohr's circle at failure for a pure frictional or φ-soil



(c) Mohr's circle for a pure cohesive soil or c-soil at failure

With reference to Fig. (a), the relationship between the major and minor principal stresses at failure may be established from the geometry of the Mohr's circle, as follows:

From ΔDCG, $\quad 2\alpha = 90° + \phi$

$\therefore \quad \alpha = 45° + \phi/2$

Again from ΔDCG

$$\sin\phi = DC/GC = DC/(GM + MC) = \frac{(\sigma_1 - \sigma_3)/2}{c\cot\phi + (\sigma_1 + \sigma_3)/2}$$

$$= \frac{(\sigma_1 - \sigma_3)}{2c\cot\phi + (\sigma_1 + \sigma_3)}$$

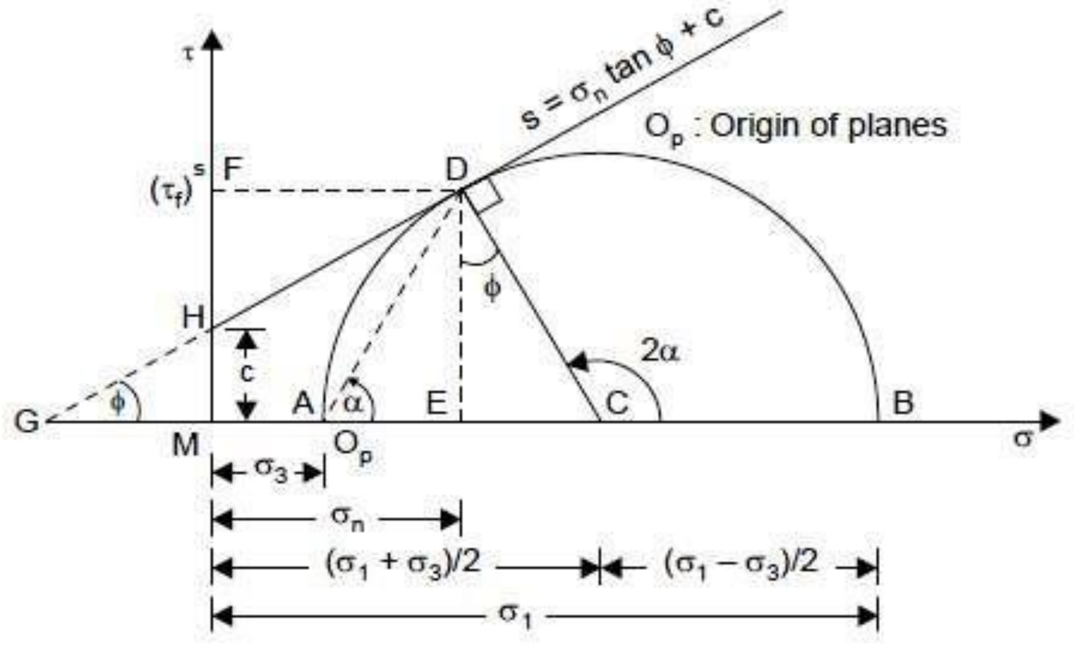
$$\therefore \quad (\sigma_1 - \sigma_3) = 2c\cos\phi + (\sigma_1 + \sigma_3)\sin\phi$$

$$\sigma_1(1 - \sin\phi) = \sigma_3(1 + \sin\phi) + 2c\,.\cos\phi$$

$$\therefore \quad \sigma_1 = \frac{\sigma_3(1 + \sin\phi)}{(1 - \sin\phi)} + \frac{2c\cos\phi}{(1 - \sin\phi)}$$

$$\sigma_1 = \sigma_3\tan^2(45° + \phi/2) + 2c\tan(45° + \phi/2)$$

$$\sigma_1 = \sigma_3\tan^2\alpha + 2c\tan\alpha$$



(a) Mohr's circle at failure for a general c-φ soil

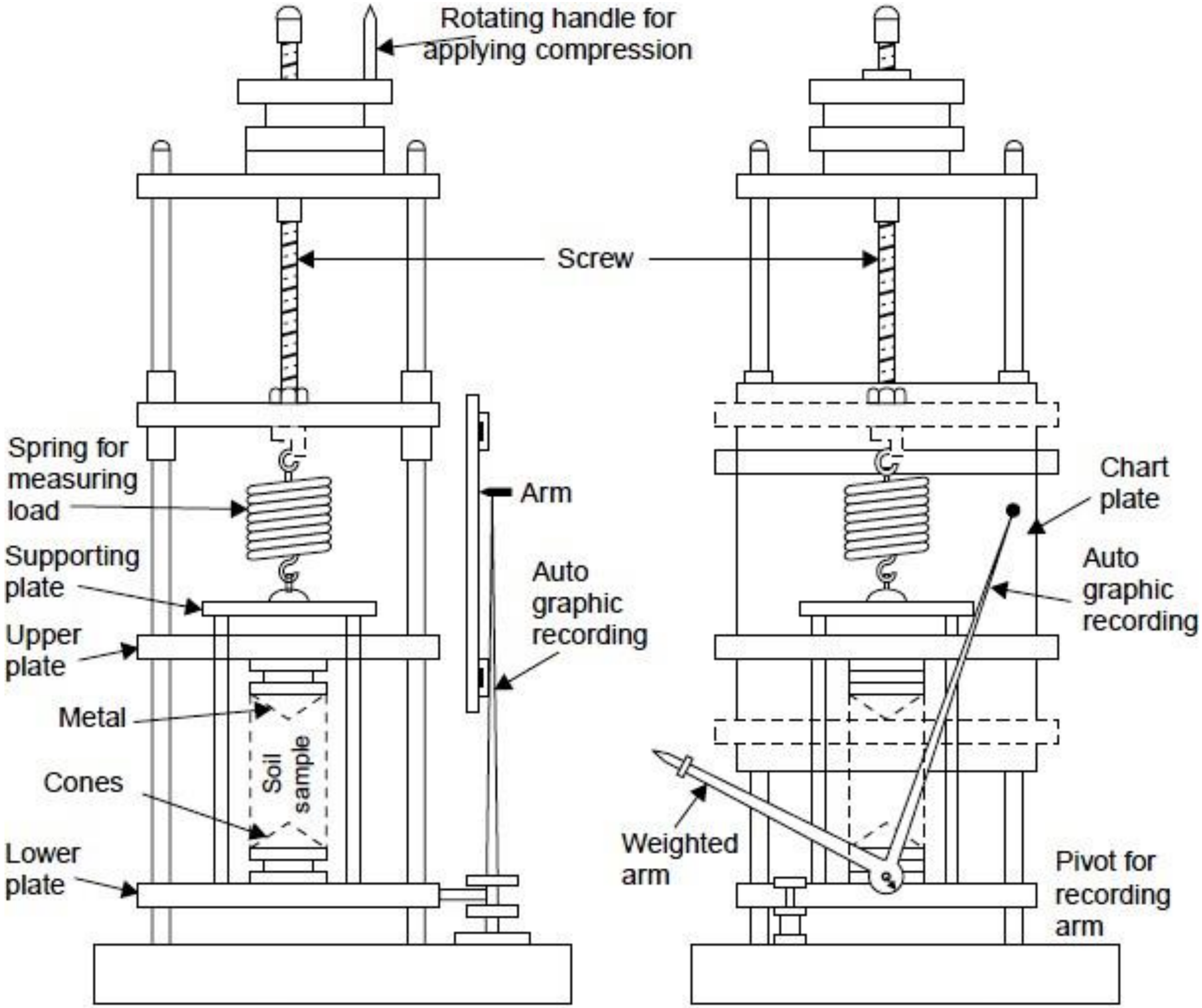
$$\boxed{\sigma_1 = \sigma_3 N_\phi + 2c\sqrt{N_\phi}}$$

$$\boxed{\text{where,} \quad N_\phi = \tan^2\alpha = \tan^2(45° + \phi/2)}$$

This Equation defines the relationship between the principal stresses at failure. This state of stress is defined as 'Plastic equilibrium condition', when failure is imminent.

3. Unconfined Compression Test

- This is a special case of a triaxial compression test; the confining pressure being zero. A cylindrical soil specimen, usually of the same standard size as that for the triaxial compression, is loaded axially by a compressive force until failure takes place. Since the specimen is laterally unconfined, the test is known as 'unconfined compression test'.
- The axial or vertical compressive stress is the major principal stress and the other two principal stresses are zero.
- This test may be conducted on undisturbed or remoulded cohesive soils. It cannot be conducted on coarse-grained soils such as sands and gravels as these cannot stand without lateral support. Also the test is essentially a quick or undrained one.
- Owing to its simplicity, it is often used as a field test, besides being used in the laboratory. The failure plane is not predetermined and failure takes place along the weakest plane.



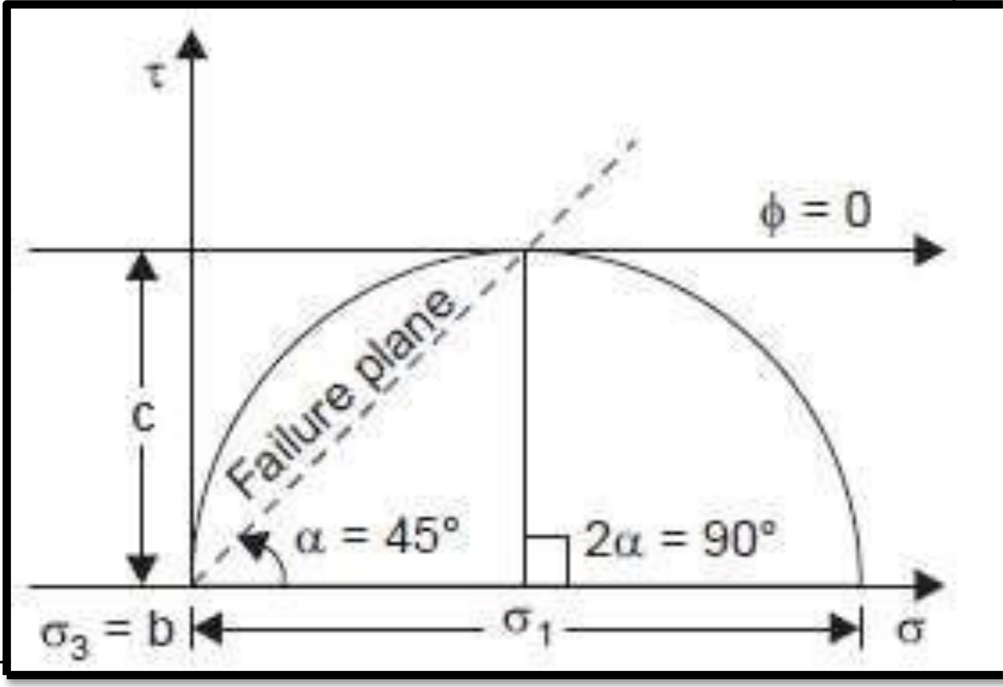
(a) Side view

(b) Front view

- The test specimen is loaded through a calibrated spring.
- A loading frame with proving ring and a dial gauge for measuring the axial compression of the specimen may also be used. The maximum compressive stress is that at the peak of the stress-strain curve. If the peak is not well-defined, an arbitrary strain value such as 20% is taken to represent failure.
- For any vertical or axial strain, the corrected area can be computed, assuming no change in volume. The axial stress is got by dividing the load by the corrected area.
- The stress-strain diagram is plotted.

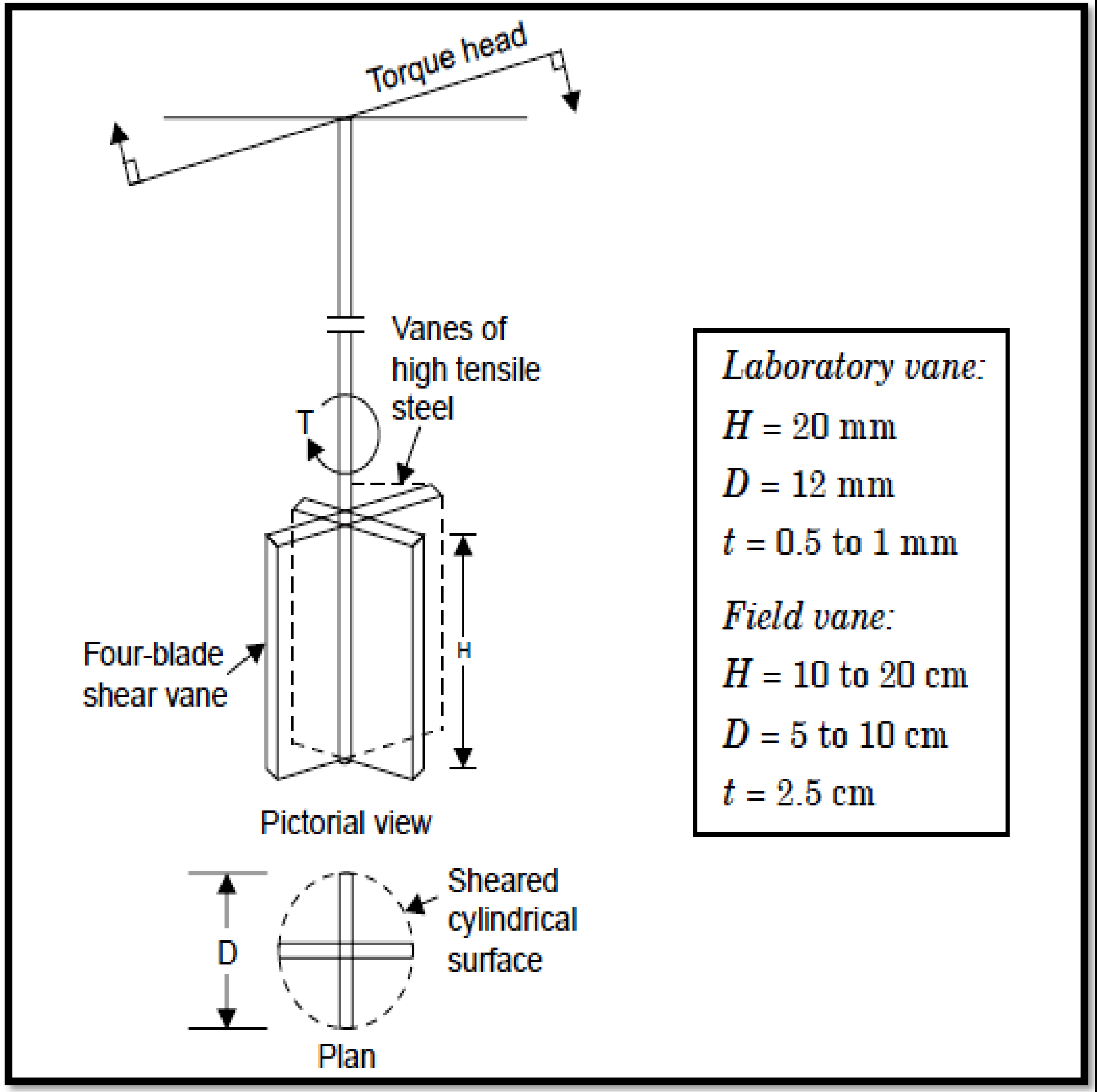
$$\boldsymbol{\sigma_1 = q_u = 2c}$$

- where q_u is the unconfined compression strength.
- Thus, the **shearing strength or cohesion value** a saturated clay from unconfined compression test is taken to be **half the unconfined compression strength**.



4. Vane Shear Test

- If suitable undisturbed for remoulded samples cannot be got for conducting triaxial or unconfined compression tests, the shear strength is determined by a device called the Shear Vane.
- The vane shear test may also conducted in the laboratory. The laboratory shear vane will be usually smaller in size as compared to the field vane.
- The shear vane usually consists of four steel plates welded orthogonally to a steel rod, as shown in Fig.

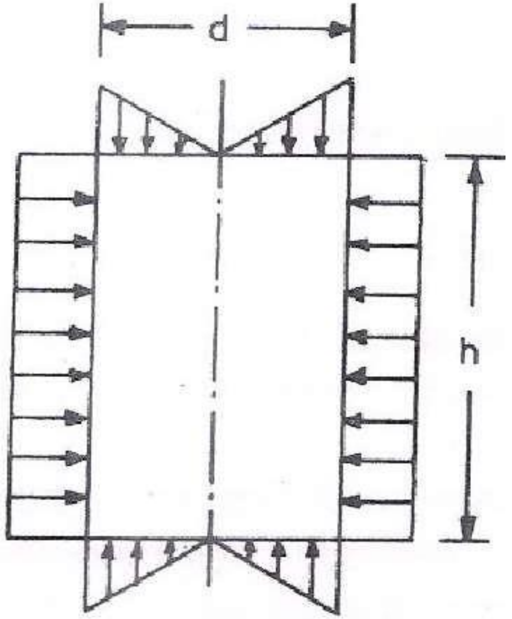


- The applied torque is measured by a calibrated torsion spring, the angle of twist being read on a special gauge. A uniform rotation of about 1° per minute is used.
- The vane is forced into the soil specimen or into the undisturbed soil at the bottom of a bore-hole in a gentle manner and torque is applied.
- The torque is computed by multiplying the angle of twist by the spring constant.
- The shear strength **s** of the clay is given by:
- If both the top and bottom of the vane partake in shearing the soil.
- Here, T = torque
- D = diameter of the vane
- H = height of the vane

$$s = \frac{T}{\pi D^2 (H/2 + D/6)}$$

- If only one end of the vane partakes in shearing the soil, then

$$s = \frac{T}{\pi D^2 (H/2 + D/12)}$$



(b) Assumed shear stress distribution

- The vane shear test is particularly suited for soft clays and sensitive clays for which suitable cylindrical specimens cannot be easily prepared.

Example Problems

In an unconfined compression test, a sample of sandy clay 8 cm long and 4 cm in diameter fails under a load of 120 N at 10% strain. Compute the shearing resistance taking into account the effect of change in cross-section of the sample.

Size of specimen = 4 cm dia. × 8 cm long.

Initial area of cross-section $= (\pi/4) \times 4^2 = 4\pi \text{ cm}^2$.

Area of cross-section at failure $= \dfrac{A_0}{(1-\varepsilon)}$

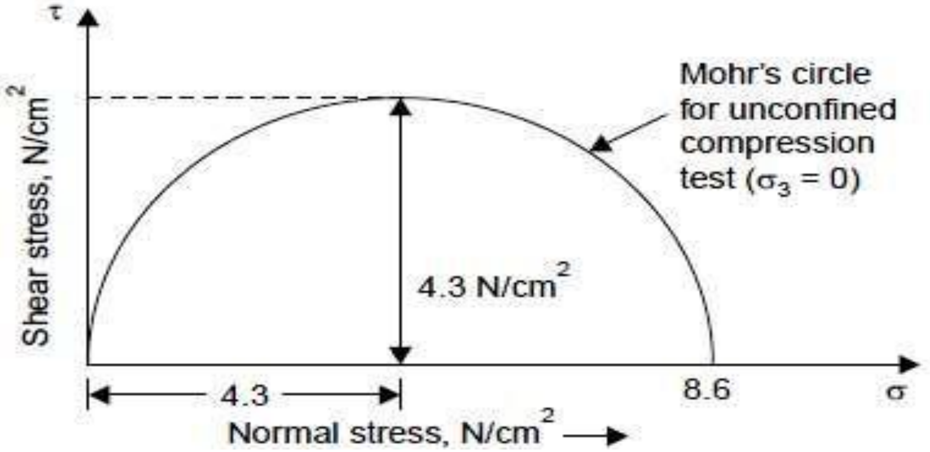
$= \dfrac{4\pi}{(1-0.10)} = 4\pi/0.9 = 40\,\pi/9 \text{ cm}^2$

Load at failure = 120 N.

Axial stress at failure $= \dfrac{120 \times 9}{40\pi} \text{ N/cm}^2$

$= 2.7/\pi \text{ N/cm}^2$

$= 8.6 \text{ N/cm}^2$



Shear stress at failure $= \dfrac{1}{2} \times 8.6 = 4.3 \text{ N/cm}^2$

A vane, 10.8 cm long, 7.2 cm in diameter, was pressed into a soft clay at the bottom of a bore hole. Torque was applied and the value at failure was 45 Nm. Find the shear strength of the clay on a horizontal plane.

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

for both end of the vane shear device partaking in shear.

$$45/1000 = c\pi\left(\frac{(7.2)^2 \times 10.8}{2} + \frac{7.2^3}{6}\right) \times \frac{1}{100 \times 100 \times 100}$$

$$c = \frac{45 \times 100 \times 100 \times 100}{1000\left(\frac{(7.2)^2 \times 10.8}{2} + \frac{7.2^3}{6}\right)} \text{ kN/m}^2 \approx 42 \text{ kN/m}^2$$

The shear strength of the clay (cohesion) is **42 kN/m²**, nearly.

Clean and dry sand samples were tested in a large shear box, 25 cm × 25 cm and the following results were obtained :

Normal load (kN)	**5**	**10**	**15**
Peak shear load (kN)	**5**	**10**	**15**
Ultimate shear load (kN)	**2.9**	**5.8**	**8.7**

Determine the angle of shearing resistance of the sand in the dense and loose states.

The value of ϕ obtained from the peak stress represents the angle of shearing resistance of the sand in its initial compacted state; that from the ultimate stress corresponds to the sand when loosened by the shearing action.

The area of the shear box = $25 \times 25 = 625 \text{ cm}^2$.

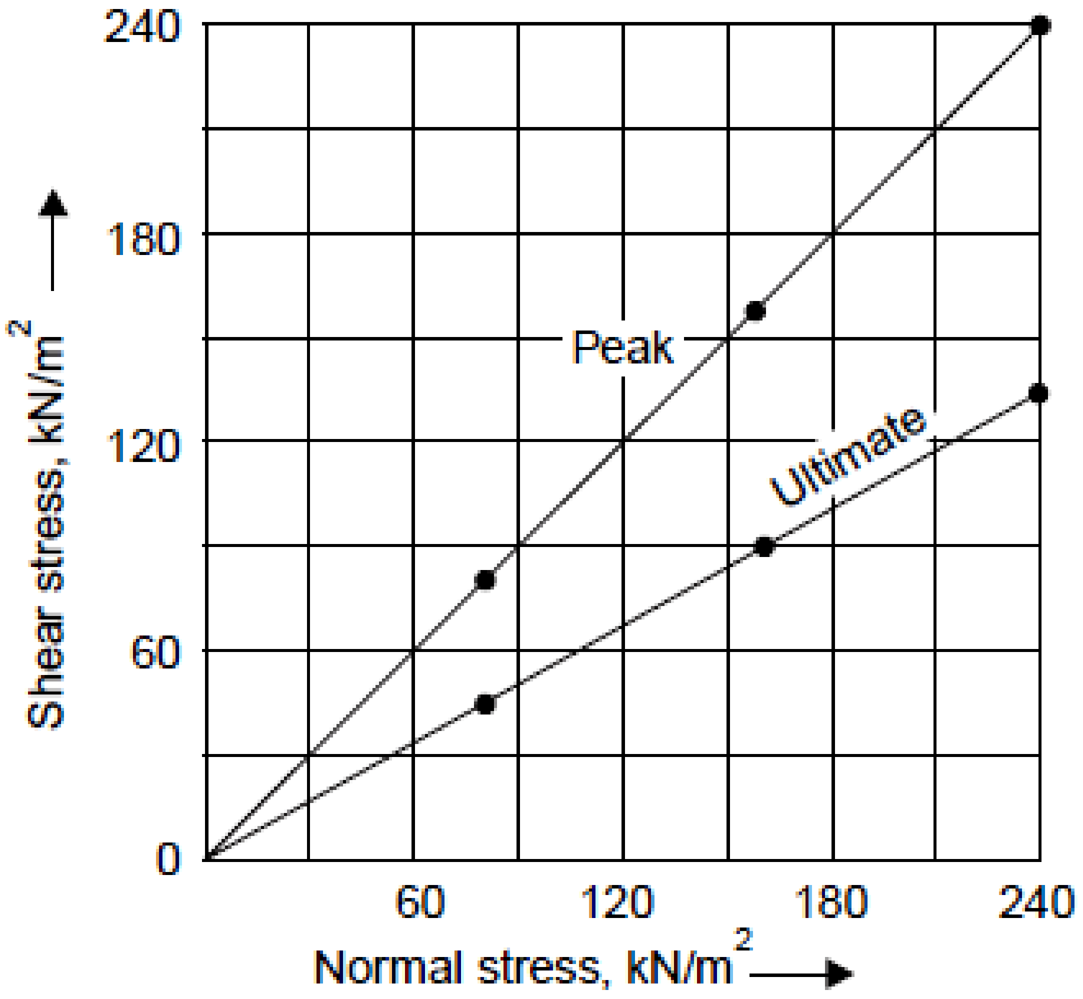
$$= 0.0625 \text{ m}^2.$$

Normal stress in the first test = $5/0.0625 \text{ kN/m}^2 = 80 \text{ kN/m}^2$

Similarly the other normal stresses and shear stresses are obtained by dividing by the area of the box and are as follows in kN/m^2 :

Normal stress, σ	80	160	240
Peak shear stress, τ_{max}	80	160	240
Ultimate shear stress, τ_f	46.4	92.8	139.2

Since more than one set of values are available, graphical method is better:



ϕ_{peak} (dense state) : 45°
$\phi_{ultimate}$ (loose state) : 30°
by measurement with a protractor

The following results were obtained in a shear box text. Determine the angle of shearing resistance and cohesion intercept:

Normal stress (kN/m^2)	100	200	300
Shear stress (kN/m^2)	130	185	240

The normal and shear stresses on the failure plane are plotted as shown:

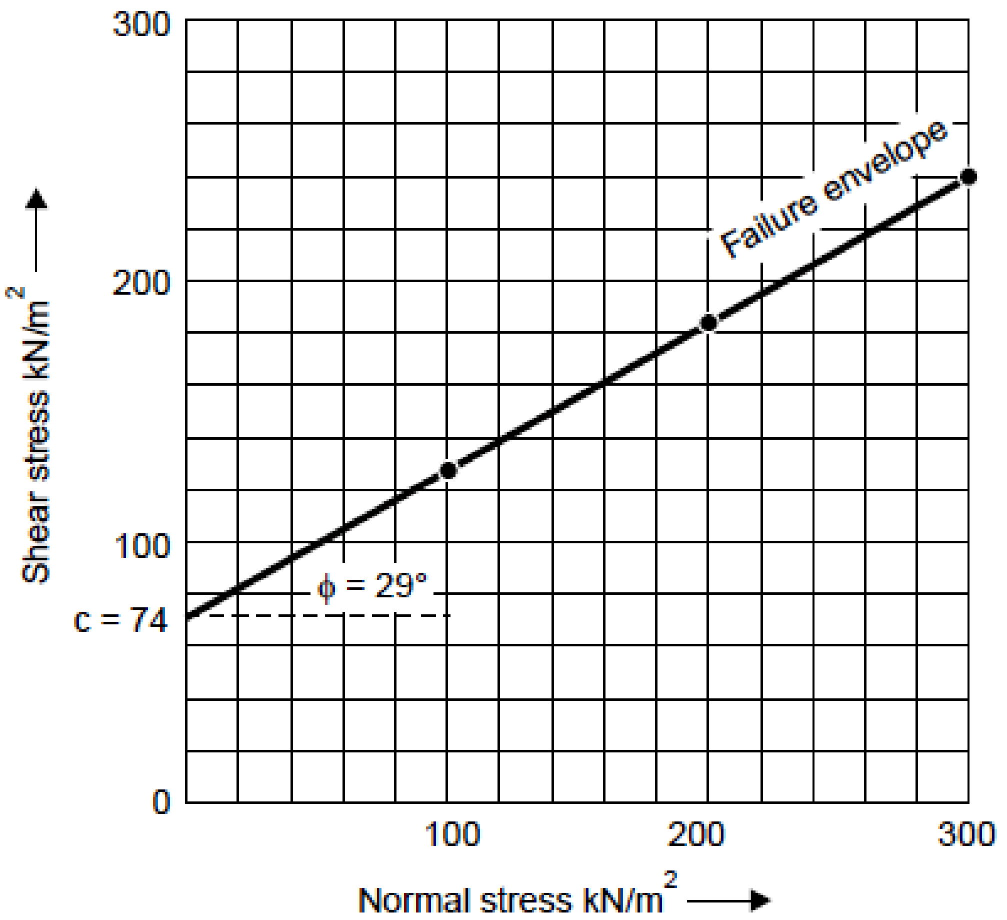


Fig. 8.48 Failure envelope (Ex. 8.5)

The intercept on the shear stress axis is cohesion, c, and the angle of inclination of the failure envelope with the normal stress axis of the angle of shearing resistance, ϕ.

From Fig. 8.48,

$$c = 74 \text{ kN/m}^2$$

$$\phi = \mathbf{29°}.$$

The following data relate to a triaxial compression tests performed on a soil sample:

Test No.	*Chamber pressure*	*Max. deviator stress*	*Pore pressure at maximum deviator stress*
1	80 kN/m^2	175 kN/m^2	45 kN/m^2
2	150 kN/m^2	240 kN/m^2	50 kN/m^2
3	210 kN/m^2	300 kN/m^2	60 kN/m^2

Determine the total and effective stress parameters of the soil.

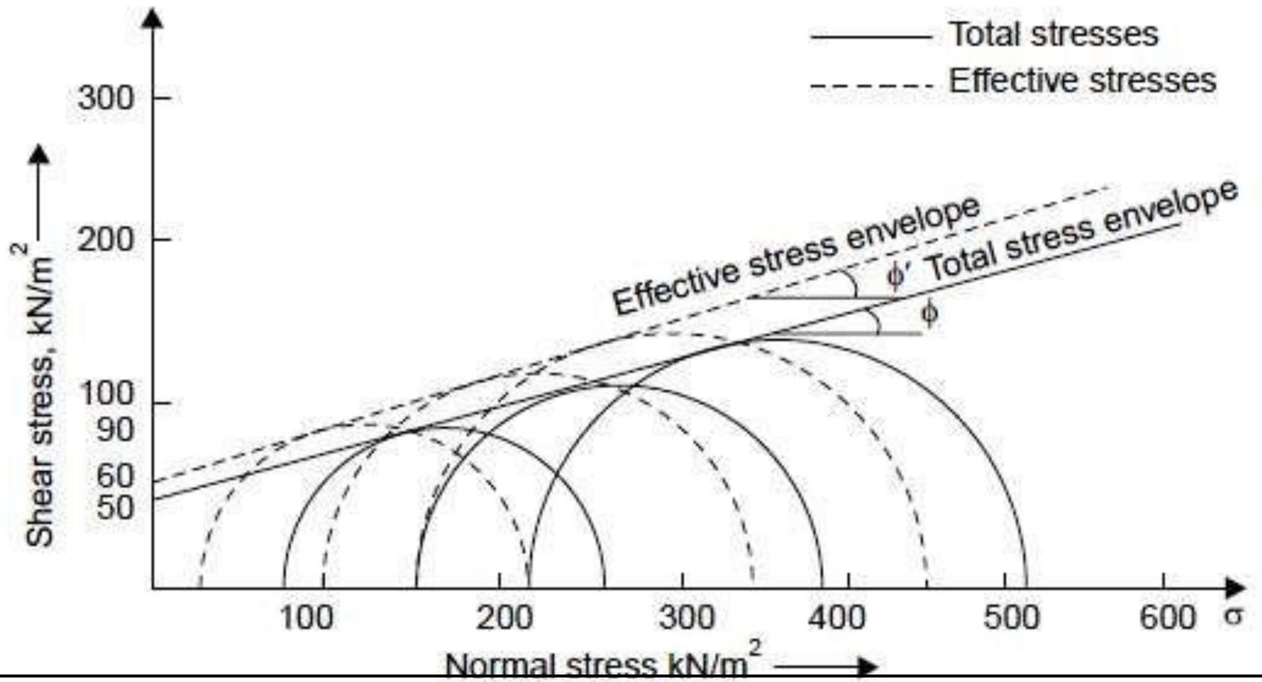
(a) Total stresses:			*(b) Effective stresses = (Total stress – pore pressure)*		
S.No.			*S.No.*		
1	255	80	1	210	35
2	390	150	2	340	100
3	510	210	3	450	150

Total stress parameters:

$$c = \mathbf{50\ kN/m^2};\ \phi = \mathbf{18°}$$

Effective stress parameters:

$$c' = \mathbf{60\ kN/m^2};\ \phi' = \mathbf{20°}\ \text{(Fig. 8.59)}.$$



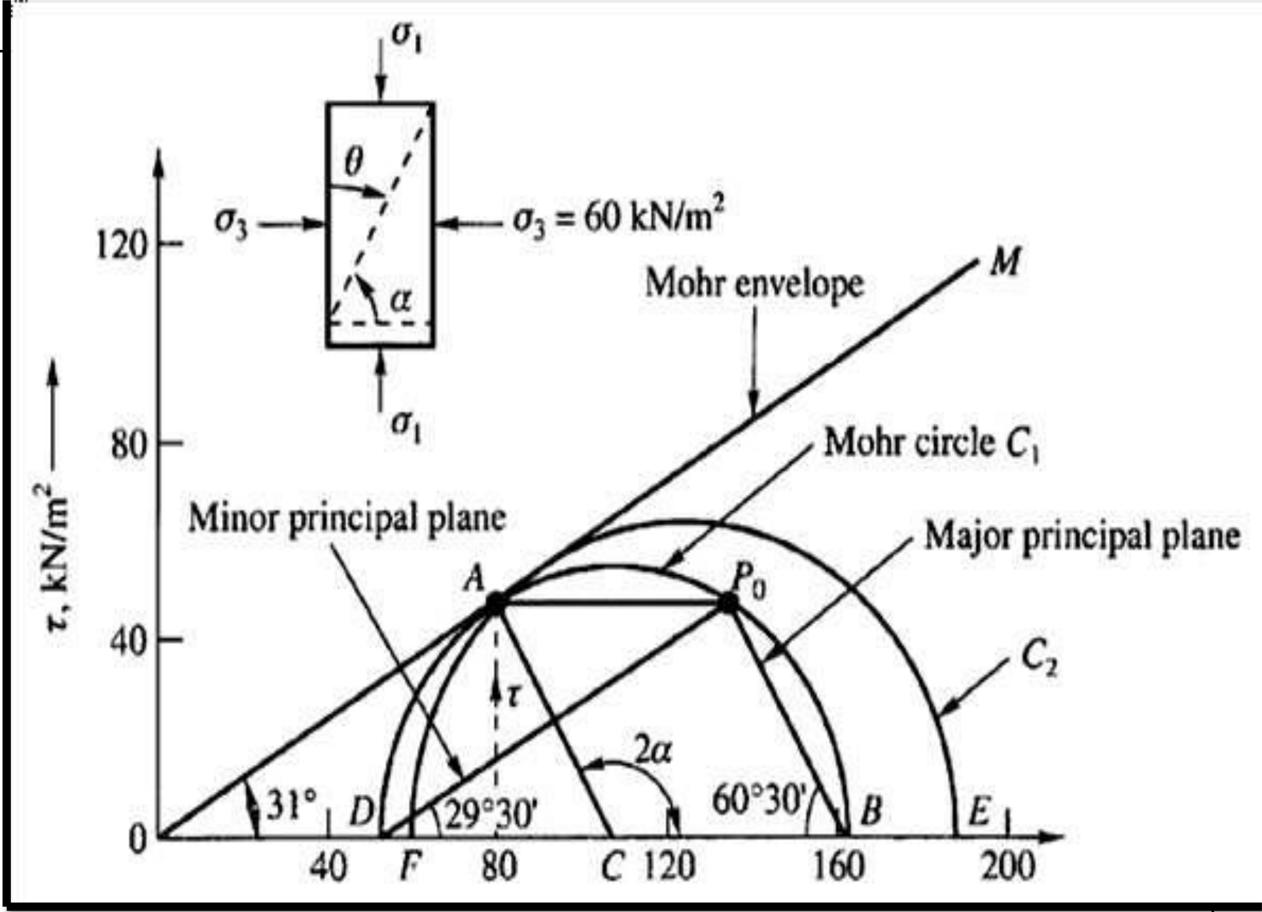
A direct shear test, when conducted on a remolded sample of sand, gave the following observations at the time of failure: Normal load = 288 N; shear load = 173 *N. The cross sectional area of the* sample = 36 cm2.
Determine: (i) the angle of internal friction, (ii) the magnitude and direction of the principal stresses in the zone of failure.

(i) Shear stress $\tau = \dfrac{173}{36} = 4.8 \ \text{N/cm}^2 = 48 \ \text{kN/m}^2$

Normal stress $\sigma = \dfrac{288}{36} = 8.0 \ \text{N/cm}^2 = 80 \ \text{kN/m}^2$

We know one point on the Mohr envelope. Plot point *A* (Fig. Ex. 8.3) with coordinates $\tau =$ 48 kN/m^2, and $\sigma = 80$ kN/m^2. Since cohesion $c = 0$ for sand, the Mohr envelope *OM* passes through the origin. The slope of *OM* gives the angle of internal friction $\phi = 31°$.

(ii) In Fig. Ex. 8.3, draw line *AC* normal to the envelope *OM* cutting the abscissa at point *C*. With *C* as center, and *AC* as radius, draw Mohr circle C_1 which cuts the abscissa at points *B* and *D*, which gives



major principal stress = $OB = \sigma_1 = 163.5$ kN/m²

minor principal stress = $OD = \sigma_3 = 53.5$ kN/m²

Now, $\angle ACB = 2\alpha$ = twice the angle between the failure plane and the major principal plane. Measurement gives

$$2\alpha = 121° \text{ or } \alpha = 60.5°$$

Since in a direct shear test the failure plane is horizontal, the angle made by the major principal plane with the horizontal will be 60.5°. The minor principal plane should be drawn at a right angle to the major principal plane.