Shear Strength of soil

INTRODUCTION

When soil is loaded, shearing stresses are induced in it. When the shearing stress reaches a maximum value, failure of the soil mass taking place.

All stability analysis in soil mechanics involves a basic knowledge of the shearing properties of the soil. The shear strength is the most important soil characteristics.

The method used to determine the shear characteristics in the laboratory must be understood in detail.

The Shearing behavior of depends on the following factors,

a) **Frictional** Resistance (ϕ)
b) **Cohesion** between the particles (C)

The shear strength in cohesion less soil is purely due to **friction.**

The shear strength in cohesive soil is purely due to **cohesion.**

Shear strength of cohesive and cohesion less soils:

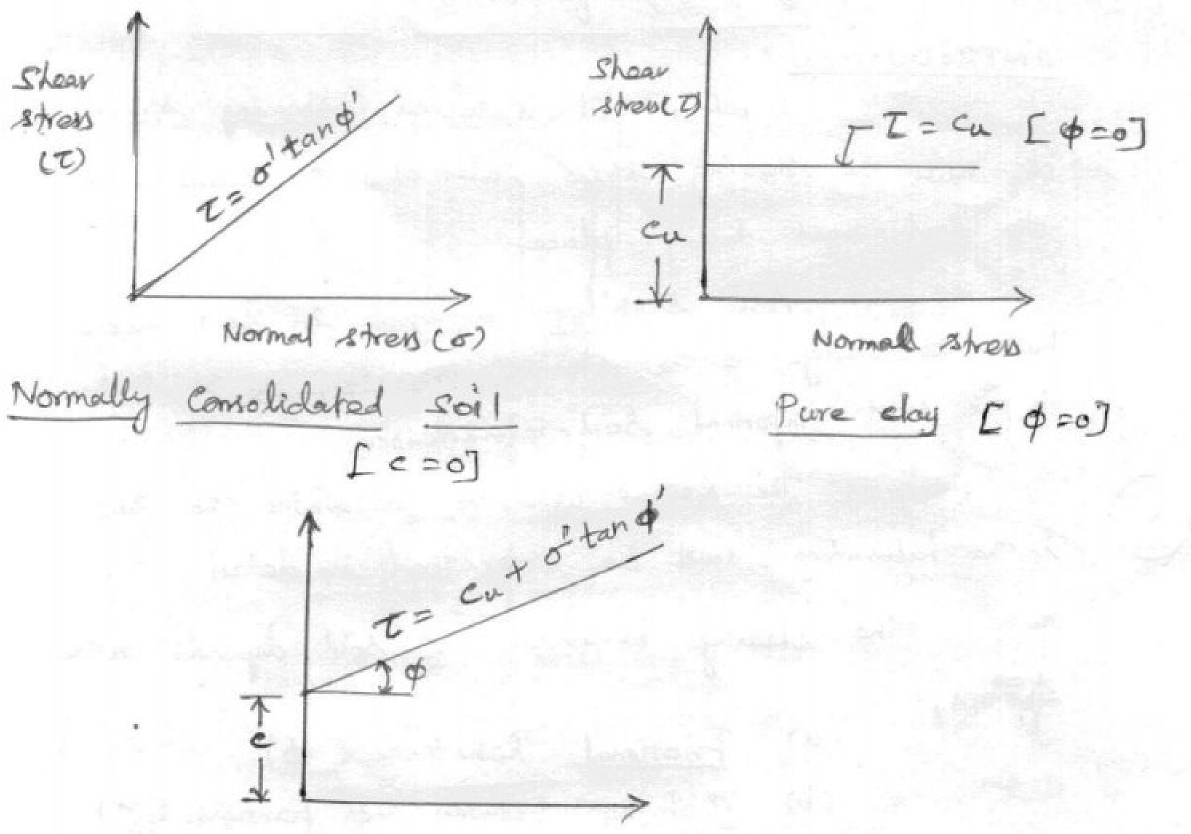
Shear Strength of COHESIVE soil:

The shear strength of a cohesive soil depends upon whether the soil is **normally consolidated** or **over consolidated**. The shear strain curve for an over consolidated clay is similar to that of a dense sand and that of a normally consolidated clay is identical. to that of a **loose sand**. However, the strain required to **reach peak stress** are generally **greater** in **clay** than in **sand.** The

$$S \text{ or } \tau = C' + \sigma \tan \phi'$$

effective stress parameters (c,ϕ) for an over consolidated clay are determined from the failure envelope.

For a **normally consolidated soil** (or) **clay**, the failure envelope passes through the origin and hence **c'= 0.** sometimes, for pure **clay** soil, $\phi = 0$ *and* $r = c_u$.



The following parameters that affects the shear strength of cohesive soils,

i) Structure of clay
ii) Clay Content
iii) Drainage Condition
iv) Rate of strain
v) Repeated loading
vi) Confining pressure
vii) Stress history
viii) Disturbance

Plastic undrained clay does not possess internal friction.

Shear strength of COHESIONLESS soil:

Shear strength in sand may be said to **consist** of **two parts,**

i) **Internal frictional resistance** between the soil, to **translocation** between the individual soil particles at their **contact points**.

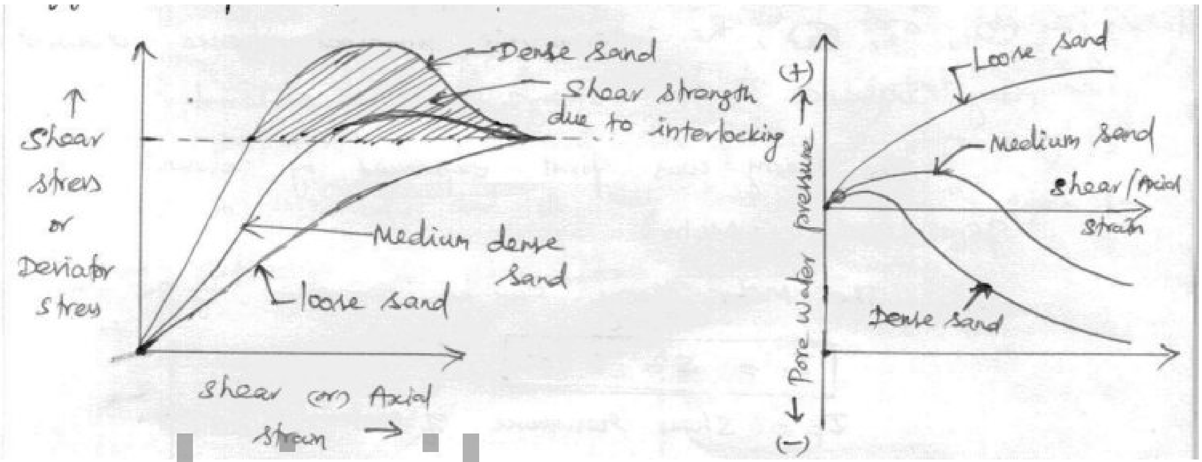
ii) Structural resistance to **displacement** of the soil because of the

interlocking of theparticles.

The shear strength in cohesion less soil results from inter granular friction alone, [c=0] while in all other soils it results both from **internal friction** as well as cohesion. [**c = ϕ soil**]

However, **Plastic** undrained **clay** does not possess internal **friction**. [φ=0]

The stress – strain behavior of sand is given by the following fig. as expressed below.



STRESS – STRAIN CHARACTERISTICS OF SANDS

It can be observed from the fig (a), the **shear stress increases** gradually for **loose sand**. while for an initially dense sand, it **reaches** a **peak value** and **decreases** at **greater value** of **strain**. The hatched portion represents the **additional strength** due to the phenomenon of **inter locking**.

The changes in pore water pressure as shown in the **fig (b) positive** pore pressure pore pressure develop in the case of an **loose specimen** and **negative** pore pressure developed. in the case of **dense sand** due to the permeability of soil.

The Following Parameters are affects the shear strength of cohesion less soils.

i) Shape of particles ii) Gradation iii) Density iv) Confining pressure

v) Deviator stress vi) Loading vii) Type of minerals viii) Moisture

MOHR – COULOMB FAILURE THEORY:

Of the many theories of failure that have been proposed the Mohr strength theory and Mohr theory have been well accepted by soil engineers. The following are the essential points of Mohr's strength theory.

i) Materials fails by shear
ii) The ultimate strength of the material is determined by the stresses in the failure plane.
iii) When the material subjected to three principal stresses ($\sigma1$, $\sigma2$, $\sigma3$),the intermediate principal stresses does not have any influence on the strength of the material.
The theory was first expressed by coulomb and later generalized by Mohr.

The Mohr theory can be expressed by the equation,

$\tau_f = S = F(\sigma)$

τ_f = Shear Resistance of material

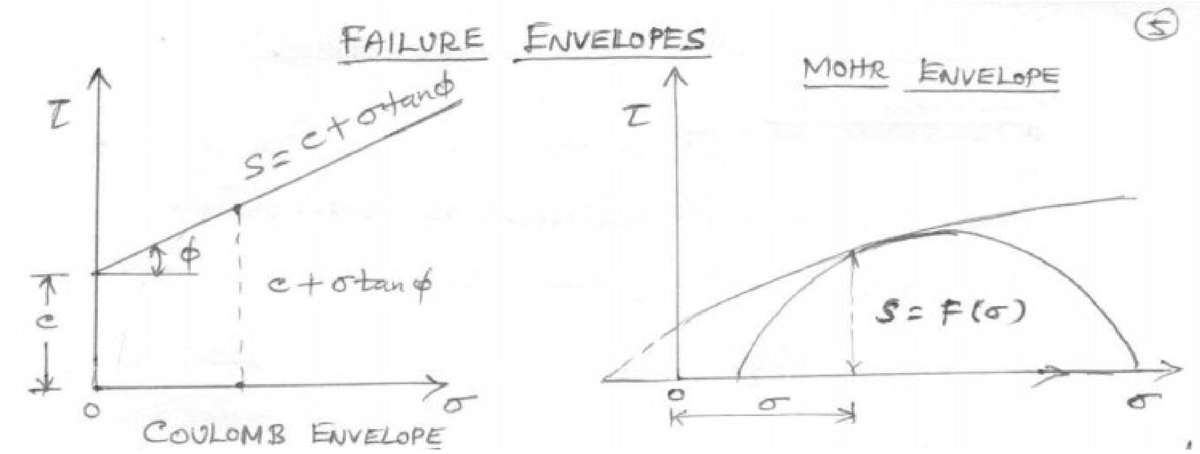
$F(\sigma)$ = Function of normal stress

If the normal and shear corresponding to failure are plotted then a curve is obtained. The plot (or) the curve is called the sheen envelope.

$$S \text{ or } \tau = C + \sigma \tan \varphi$$

Coulomb defined the function **F** (σ) as a **linear function** of σ **and c**.

C- Cohesion ϕ - Angle of internal friction (or) Angle of shearing resistancerespectively.

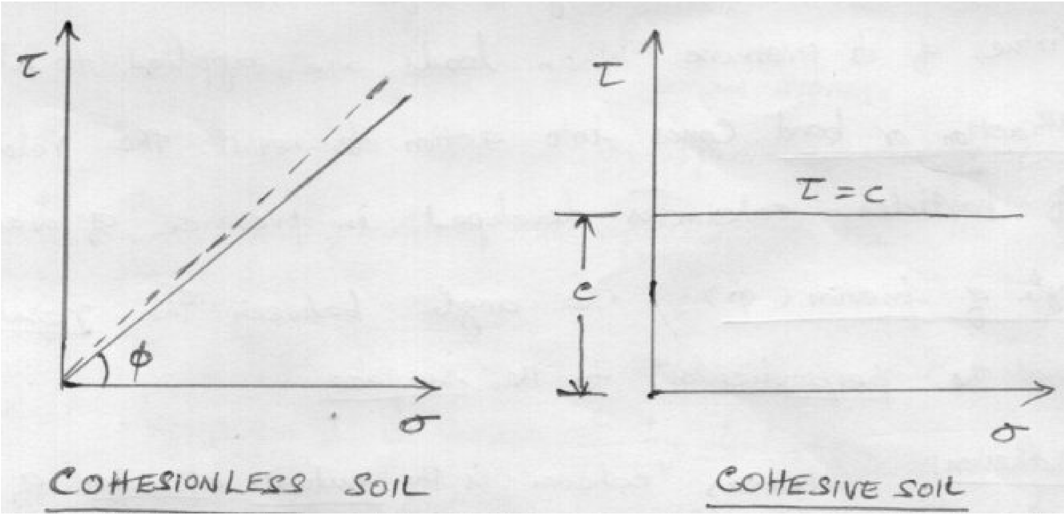


Coulomb considered, that the relationship between shear strength and **normal** stress, is represented by a **straight line**.

In **Mohr** theory, the **shear** strength and normal stress gives **non linear curve**. the curved failure envelope of Mohr is referred to as a straight line for most cases.

For an ideal pure friction material, straight line passes through the origin.

The Mohr envelope can be considered to be straight of 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 (or) it may intersect the stress axis.



SATURATED AND UNSATURATED SOILS :

Saturated soils :

It is soil, in which the voids are filled by water. Entire soil mass is subjected to the water pressure .Normally this soil is classified into three types

1.Partially saturated soil : The soil is partially subjected to water pressure.

2.Fully saturated soil : The water is filled in voids. (s_r=100%)

3.Submerged soils : The water is floating over the soil. Soil is in the submerged condition . The permeability propertyis low.

Unsaturated soils:

The soil contains no water. But all types of soil have some amount of initial moisture content (2% to 5%) The permeability property is high due to dry condition, it absorb more water.

STRENGTH PARAMETER:

The parameters c and ϕ termed as strength parameters

$c = cohesion$

$\varphi \;\; = angle\ of\ internal\ friction\ (or)\ angle\ of\ shearing\ \ resistance$

Cohesion (c) :

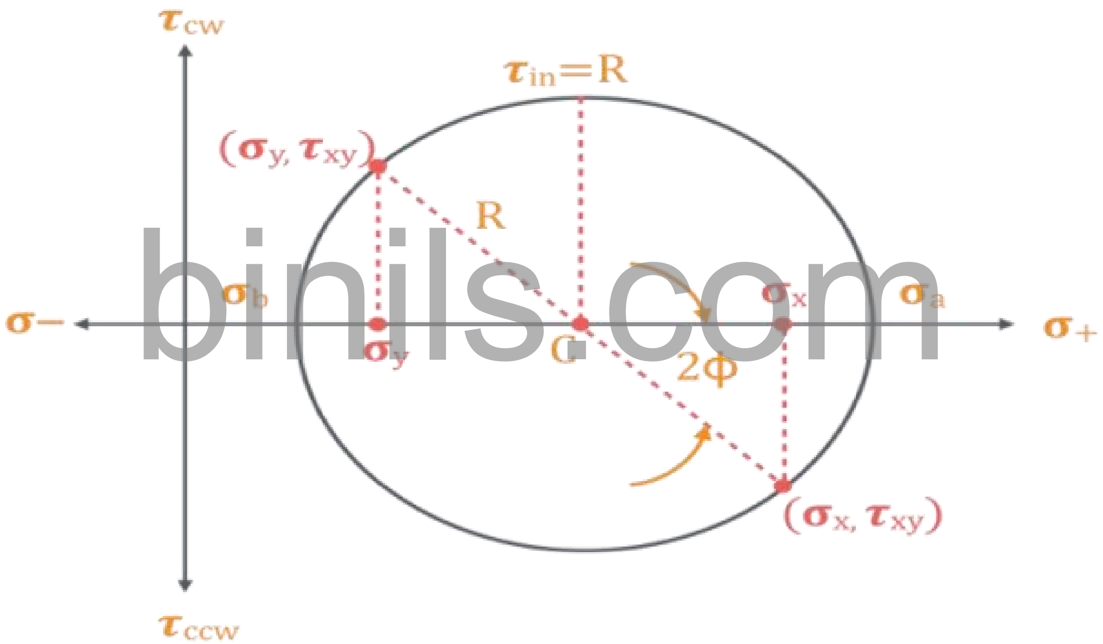
The shearing strength in which a soil passes by virtue of its pressure When loads are applied to a cohesive soil **attraction or bond** comes in to action to resist. The relative displacement of particles. Cohesion is developed in presence of water.

Angle of friction (ϕ) : The angle between the resultant force and the **perpendicular** to the **surface.**

Adhesion: where as cohesion is the mutual attraction of two different parts of a Clay mass to each other, clay often also exhibit the property of ‘ adhesion’ which is a Propensity to adhere to other materials at a common surface. This has no relation to the normal pressure. This is of particular interest in relation to the supporting capacity of friction piling in clays and to the lateral pressure on retaining walls.

Mohr’s Circle :

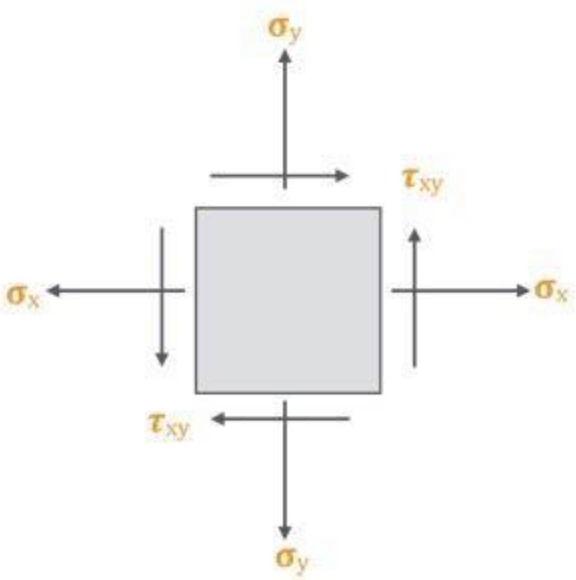
Mohr’s Circle is graphical tool that is commonly used by engineers to graphically analyze the principal and maximum shear stresses on any plane, as well as provide graphical coordinates of these shear stresses.



However, there can be infinite number of planes passing through a point, and the normal stress on each plane will vary.

The **PRINCIPAL PLANE** or maximum principal plane is the plane on which the normal stress value is at a MAXIMUM, with this value being referred to as the **MAXIMUM PRINCIPAL STRESS**.

A typical 2D stress element is shown below with all indicated components shown in their positive sense:



Using a graphical approach, we are able to determine the PRINCIPAL STRESSES on each plane using a MOHR'S CIRCLE.

Mohr's circle is a geometric representation of the 2-D transformation of stresses, in which the component stresses and are found as the coordinates of a point whose location depends upon the angle to determine the aspect of the cross section.

Mohr's circle is used to determine the principle angles (orientations) of the principal stresses without have to plug an angle into stress transformation equations

To draw a Mohr's Circle for a typical 2-D element, we can use the following **procedure** to determine the principal stresses.

1. Define The Shear Stress Coordinate System:

Define the coordinate system for the normal and shear axes – Tensile normal stress components are plotted on the horizontal axis and are considered positive. Compressive normal stress components are also plotted on the horizontal axis and are negative.

2. Define The Torsional Coordinate System:

For the construction of a Mohr's circle, shearing stresses are plotted ABOVE the normal stress axis when the pair of shearing stresses, acting on opposite and parallel faces of an element, form a

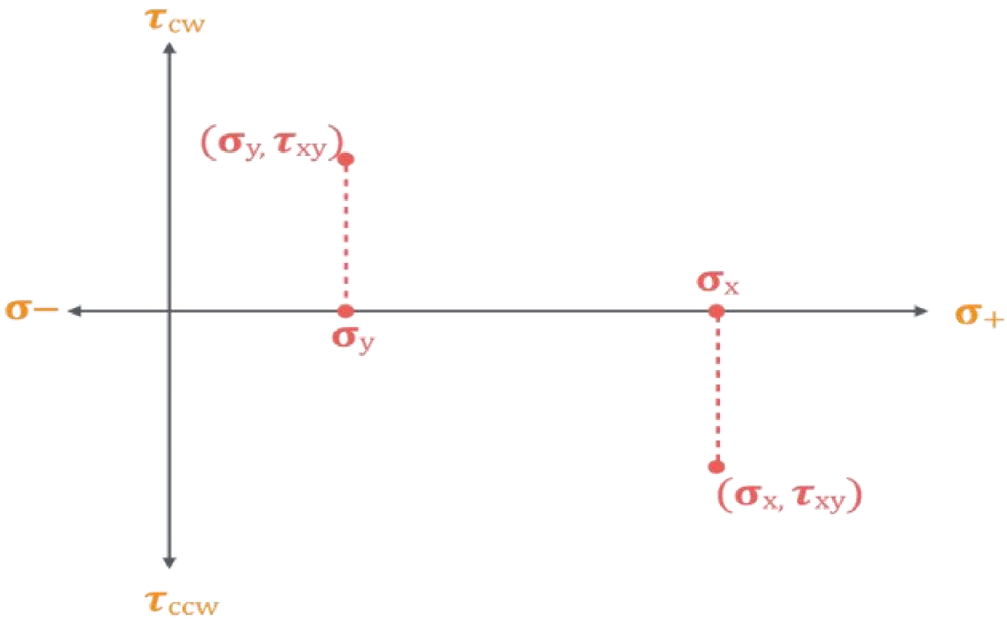
CLOCKWISE (cw) couple. Shearing stresses are plotted BELOW the normal axis when the shear stresses form a COUNTERCLOCKWISE (ccw) couple.

3. Plot The Shear Stress values:

Plot the shear stress values given in the problem statement, or plot generic points on the for σ_x-axis and σ_y as shown below.

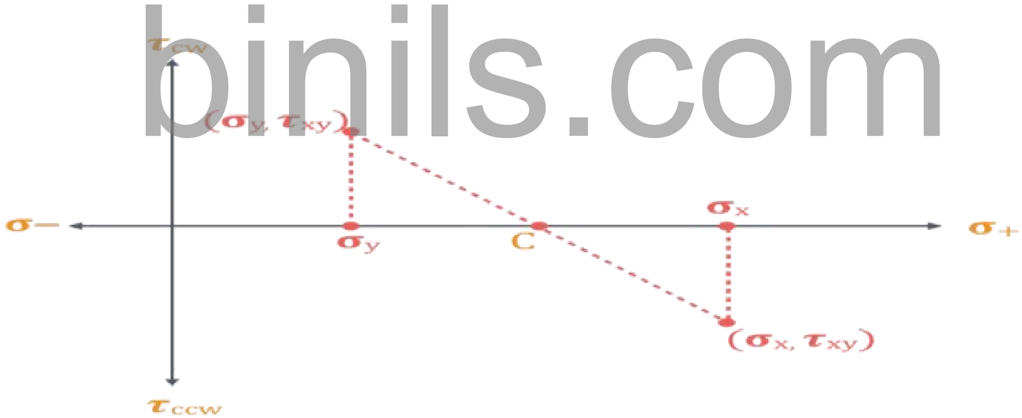
4. Plot the magnitude of the couple:

Plot the magnitude of the couple given in the problem statement with a clockwise (cw) couple being plotted above the σ_x-axis, and a counter clockwise (ccw) couple being plotted below the σ_x-axis.If not values are provided for the moment plot generic points above and below the σ-axis for τ_{xy} as shown below



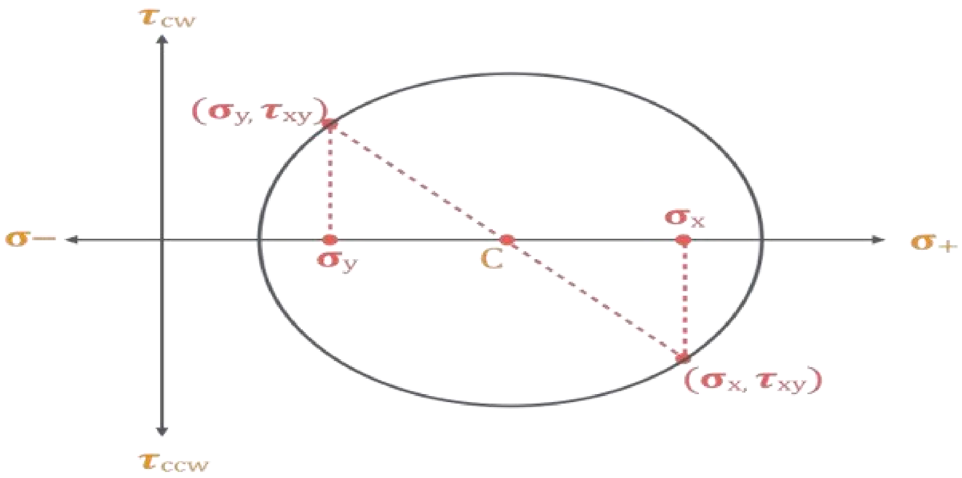
5. **Obtain the center of the mohr's circle:**

The center of the Mohr's circle is obtained graphically by plotting the two points representing the two known states of stress, and drawing a straight line between the two points. The intersection of this straight line and the -axis is the location of the center of the circle.



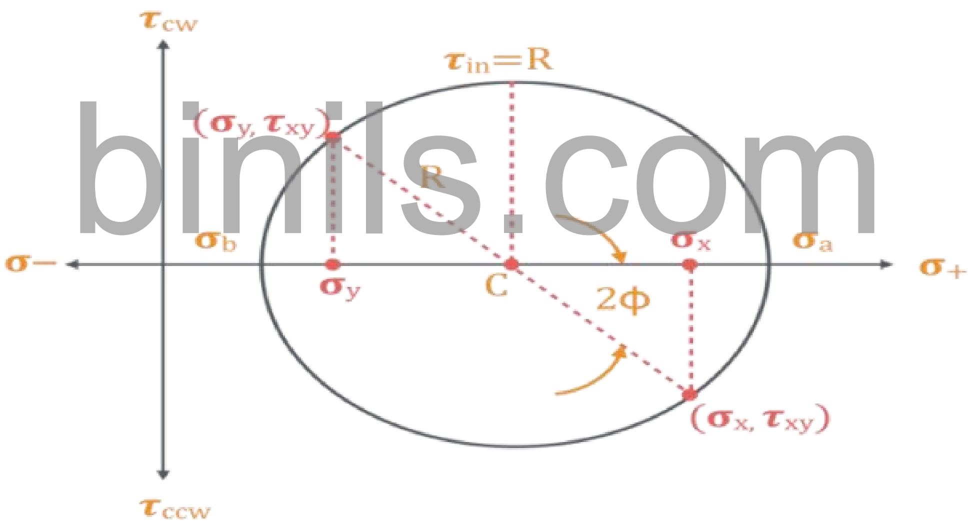
6. **Draw The Mohr's circle:**

Draw the Mohr's circle assuming the connection line as the diameter of the circle, using the intersection of the diagonal straight line and the σ-axis as the center of the circle



7. **Stress Analysis With The Mohr's circle**

Stress Analysis on Mohr's circle – To get normal and shear stress values at any plane theta, take angle 2φ in the Mohr's circle starting from diagonal of the circle and locate a peripheral point as as shown. Shear stress value will be on the y-axis and normal stress values will be on the x-axis



MEASUREMENT OF SHEAR STRENGTH:

The shear strength of the soil can be determined in the lab by following four methods . (Based on the method of application of loads)

1. Direct shear test
2. Traixial shear test (or) Traixial compression test
3. Unconfined compression test (UCC)
4. Vane shear test

Based on drainage condition the shear test are classified as

1. Undrained test (UU test)→ $Unconsolidated$
2. Consolidated undrained test (CU test) → $Consolidated$
3. Drained test (CD test) → $Consolidated$

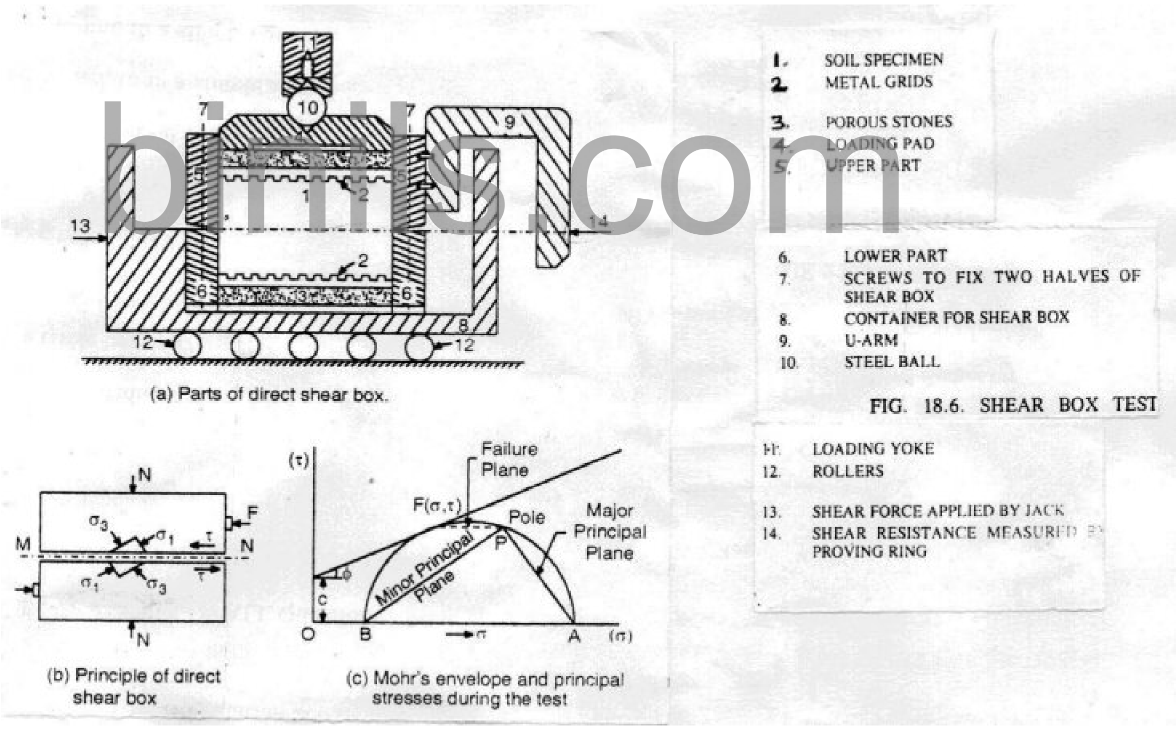
1. **DIRECT SHEAR TEST** :
   - This is a simple and commonly used test and is performance in a shear box apparatus **(60x60mm) square size** . It consists a two piece of square section . **Thickness** about **20 to 25 mm**
   - The **lower half** of the box is rigid hold in position which rest over **rulers** and driven by electric motor (or) by hand
   - The **upper half** of the box **connected with proving** ring
   - The soil sample is compacted in the shear box and in hold between metal bricks and porous stones
   - Normal load is applied on specimen through loading yoke (constant)
   - The shearing force is applied to a lower by means of geared jack
   - The **change in volume** shear displacement shear force , vertical deformation is measured by **dial gauge**
   - A number of identical specimen are tested under increasing the normal loads and maximum shear force is recorded (Until specimen fails)
   - If test continuous **beyond 20 %** Strain it is used to stop the test and defined failure point as corresponding to any desired level of strain upto **20%.**
   - A graph is plotted between normal stress in x- axis and shear stress in y- axis
   - Such a plot gives the failure envelope for the given tested soil mass.

ADVANTAGES (or) MERITS:

- The sample preparation is easy. the test is simple and convenient.
- The drainage is quick.
- It is ideally suited for cohesion less soils.
- This apparatus is relatively cheap.

DISADVANTAGES (or) DEMERITS:

- The Mohr circle cannot be drawn.
- The stress distribution is not uniform.
- The failure plane is predetermined. Therefore the specimen is not allowed to failalong it weakest plane.
- T he area under shear gradually decreases corrected area should be used in computingnormal and shear stresses.
- Measurement of pore pressure is not possible.



(a) Parts of direct shear box.

(b) Principle of direct shear box

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

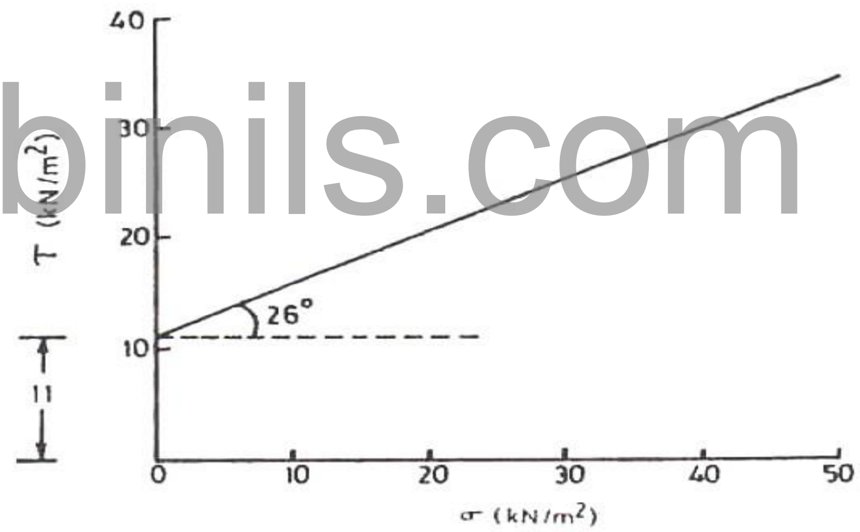
FIG. 18.6. SHEAR BOX TEST

Problems:

1) A series of direct shear test was conducted on soil each test was carried out till the samplefailed .the following results were obtained.

Sample number	Normal stress(KN/m^2)	shear stress(KN/m^2)
1	15	18
2	30	25
3	45	32

Determine the cohesion intercept and angle of shearing resistance



From the plot,

Cohesion intercept C=11 KN/m^2 ,

angle of shearing resistance $\varphi=26^0$

2) Samples of compacted, clean dry sand were tested in a shear box,6cm x6cm and the following results were obtained:

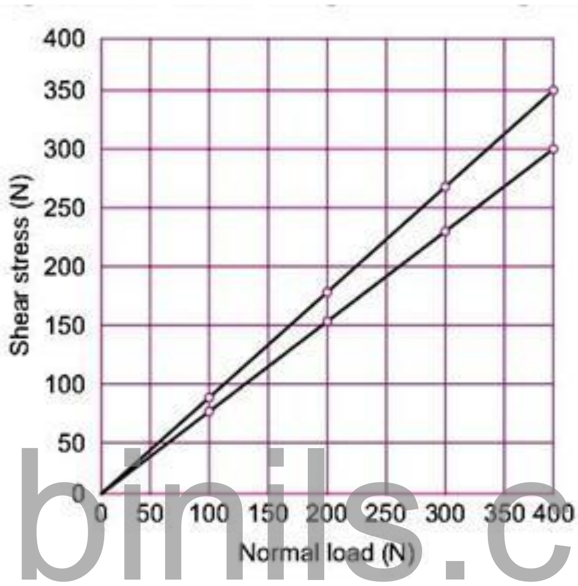
Normal load(N)		100	200	300	400
Peak shear load (N)	:	90	181	270	362
Ultimate shear load(N)	:	55	152	277	300

Determine the angle of shearing resistance of the sand in a)the dense, and

b) the loose state.

Solution.

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



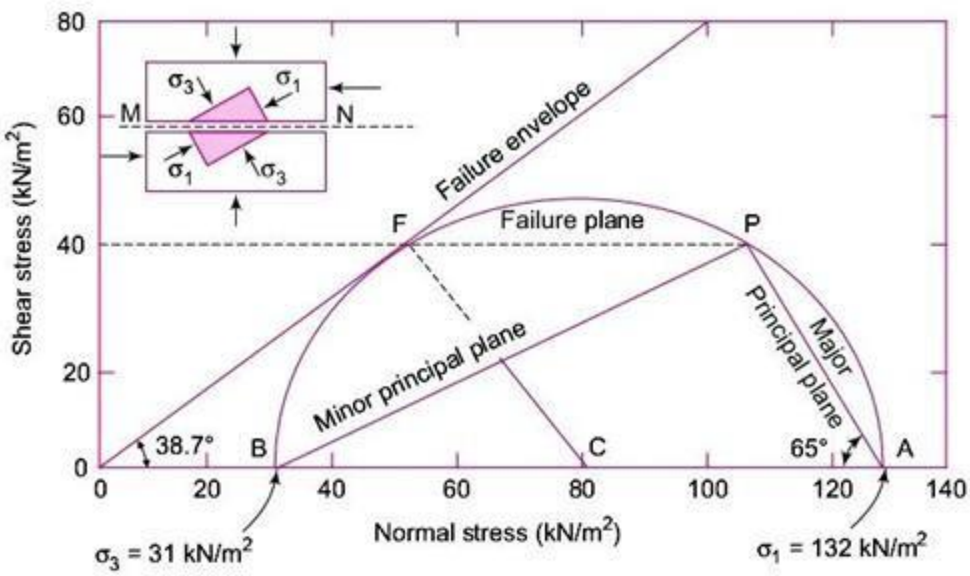
From the

a) Dense state:$\varphi=42^0$

b) Loose state :$\varphi=37^0$

3)A specimen of clean. dry, cohesion less and is tested in shear box and the soil failed at a shear stress of 40 kN/m^2.when the normal load on the specimen was 50kN/m2. Determine (a)the angle of shearing resistance, (b)the principal stress during the failure, (c)the directions of the principal planes with respect to the direction of the plane of shearing.

Solution: The failure envelope will pass through (i)origin, and (ii) a point F whose co-ordinates are : shear stress=40kN/m2(40kPa) and normal stress=50kN/m2(50kPa). The angle of shearing resistance is found to be 38.7°



The Mohr's stress circle is so drawn that it is tangential to the envelope at point F.To do this, a line FC is drawn perpendicular to the envelope. With C as the centre and CF as the radius, a circle is drawn, which intersects the normal load axis at points A and B. Point A corresponds to the major principal stress σ1 which comes out to be 132kN/m^2 and point B corresponds to the minor principal stress σ3 which Comes out to be 31 kN/ m^2 (31kPa).

To locate the position of the pole, a line FP is drawn parallel to the plane of failure in the shear box (i.e., horizontal), P is the pole.PA is the direction of the major principal plane which makes an angle of 65° in the clock wise direction with the plane of shear, while PB is the minor principal plane, making an angle of 25° in the anti-clock wise direction with the plane of shearing.

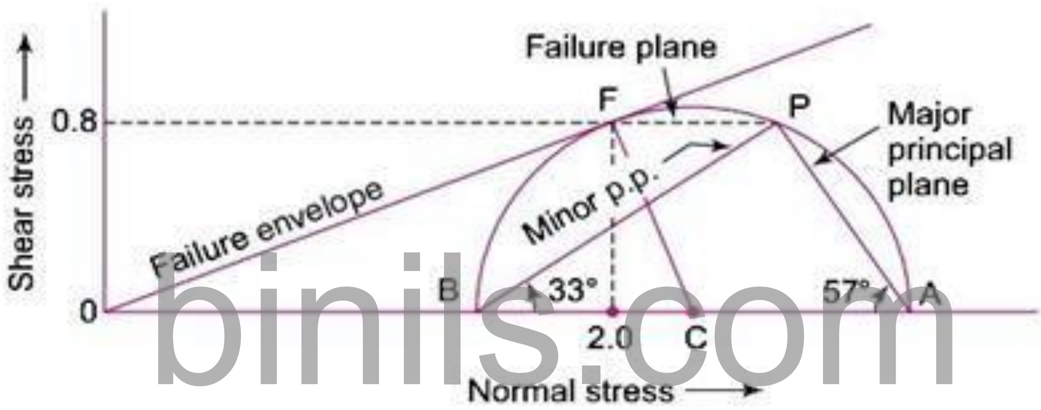
4)In a direct shear test o.n sand the normal stress was 2.0kg/cm^2 and shear stress at failure was 0.8 kN/cm^2. Determine the orientations of the principal planes at failure.

Solution. Figure shows the graphical solution. The failure envelope will pass through (i)the origin O and

(ii) a point F whose coordinates are:

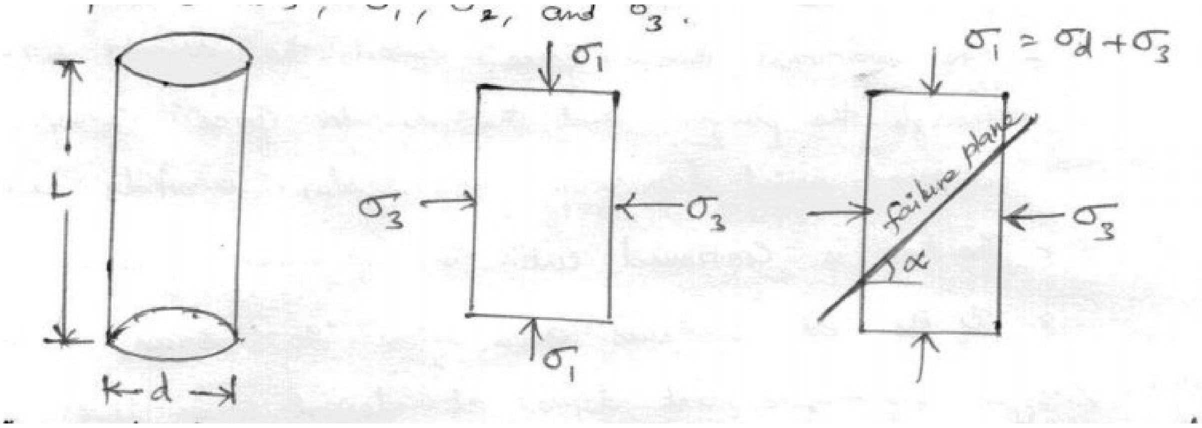
Shear stress=0.8kg/cm^2 and normal stress =2.0kg/cm^2 .Mohr circle is so drawn that **it** is tangential to the failure envelope at point F. Then PA is the direction of major principal plane which makes an angle

Of 57° in the clockwise direction with the plane of shear. Similarly, PB is thedirection of minor principal plane, which makes angle of 33° in the anticlockwise direction, with the plane of shear



TRAIAXAIL COMPRESSION TEST:

It was introduced by Casagrande and Terzaghi in 1936 and most extensively used type of shear test. As the name indicates in this test the specimen is compressed by applying all the three principal stresses, $\sigma 1$ $\sigma 2$ *and* $\sigma 3$.



The soil specimen used specimen used in the test is cylindrical in shape with length **2 to 2.5 times the diameter**. The triaxial compression test equipment essentially consists of triaxial cell, loading frame with accessories for applying gradually increasing axial load on specimen at constant rate, of strain, provision for measuring axial force and displacement, contact pressure system to apply and maintain constant cell pressure, pore pressure measuring apparatus and volume change gauge.

PROCEDURE:

- The triaxial cell [Fig] consists of a high pressure cylindrical cell, made of a transparent material like Perspex, fitted between base and top cap.
- The base is provided with an inlet for cell fluid, outlets for drainage of pore water from specimen and measurement of pore pressure.
- At the top an air release value to expel air from the cell and a steel plunger for applying axial force on specimen are provided.
- The soil specimen is kept inside the triaxial cell with porous plate (non porous plates for undrained test) at top and bottom.
- The loading cap is placed on top porous plate.
- The specimen is enclosed in a rubber membrane to prevent its contact with the cell fluid.
- After filling the cell with fluid (usually water) required cell pressure (σ_3) is applied by means of contact pressure system.
- The additional axial force called the deviator force is applied through the plunger and the deviator force corresponding to different axial deformations at regular intervals are noted.
- The test is continued until the specimen fails.
- If the test continues even after 20% strain, it may be stopped and failure point defined at desired strain level upto 20%.

- The deviator stress 'σ_d' at any stage of the test is given by

$$\sigma_d = F / A_c$$

σ_d = Deviator stress
F= Deviator force ie., additional axial force
A_c= cross sectional area of the specimen

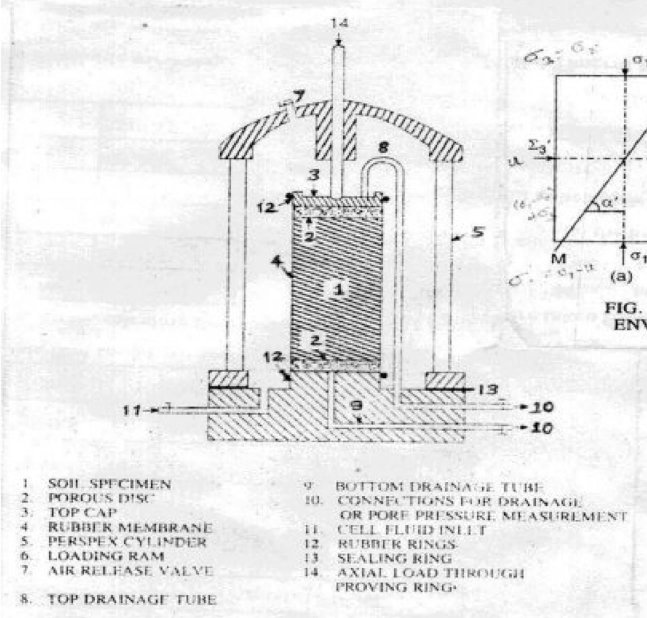


FIG. 18.7. THE TRIAXIAL CELL

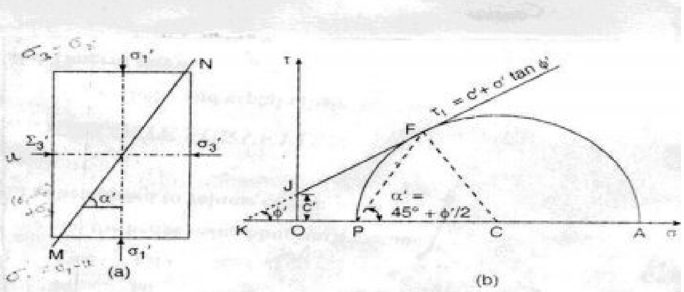
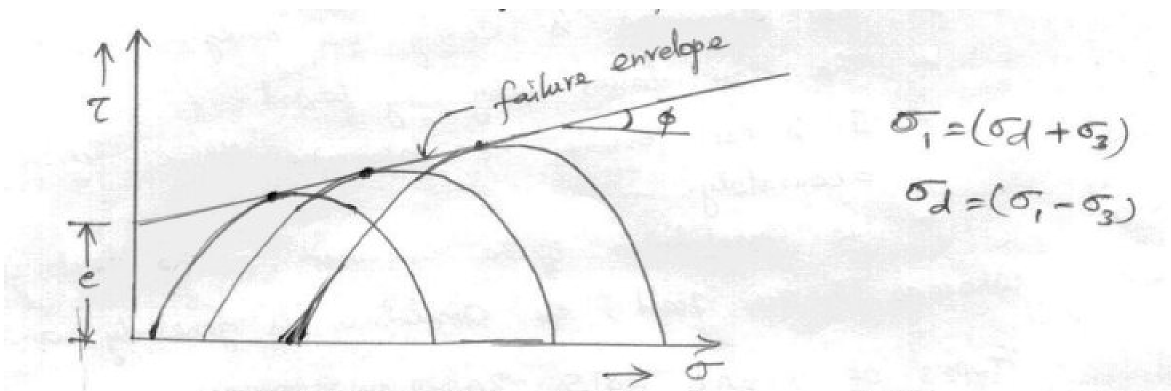


FIG. 18.10. STRESS CONDITIONS AND FAILURE ENVELOPE IN TRIAXIAL COMPRESSION TESTS

- After finding deviator stress σ_d at failure, we have major principal stress at failure $\sigma 1 = (\sigma d + \sigma 3)$.
- With this set of ($\sigma 1$,$\sigma 3$) values, Mohr circles at failure is drawn.
- The test is conducted on preferably a minimum of 3 specimens subjected to different values of $\sigma 3$.
- The Mohr circle at failure is drawn for each specimen and the common tangent touching all the circles will be failure envelope (fig)
- C and ϕ are readout from the plot.



MOHR CIRCLES AT FAILURE

If Ai = Initial cross sectional area of specimen

Li = Initial length of specimen

A_c = Corrected area of specimen when axial compression is ΔL

and change in volume is ΔV .

Initial volume, Vi = Ai Li and volume at any stage of compression,

$(V_i + \Delta V) = A_c (L - \Delta L)$

$$A_c = \frac{V_i + \Delta V}{L_i - \Delta L}$$

Incase of undrained test, on saturated soil sample, $\Delta V = 0.$ and

$$A_c = \frac{V_i + \Delta V}{L_i - \Delta L} = \frac{A_i}{1 - \frac{\Delta L}{Li}}$$

$$A_c = \frac{A_i}{1 - \in}$$

$$A_c = \frac{A_i}{1 - \in}$$

$\in \rightarrow Axial$ strain at that stage

MERITS:

- Complete control of the drainage condition is possible
- The Possibility to vary the cell pressure (or) confining pressure
- Precise measurement of pore water pressure is possible
- Stress distribution is uniform
- The test involves three stresses, it shows the behavior of field condition
- Determine the state of stress at any stage during the test and of failure.

DEMERITS:

- The apparatus is costly and bulky
- The test takes very long period
- It is not possible to determine the cross sectional area of the specimen accurately
- The Consolidation of the specimen in the test is isotropic, whereas ih the field, the consolidation is generally an isotopic.

TYPES OS SHEAR TESTS BASED ON DRANAGE AND THEIR APPLICABILITY

1. **Unconsolidated Undrained Test (UU)**

   In this type of test, no drainage is permitted during the consolidation stage. The drainage is also not permitted in the sheer stage. As so time is allowed for consolidation (or) dissipation of excess pore water pressure, the test can be conducted quickly in a few minutes the test is also Known as **quick test**. All parameters are expressed interms of total stress concepts. **Plain grids (or) non porous plates** are used.

2. Consolidated Undrained Test:

   In this test, the specimen is allowed to consolidated in the first stage. The drainage is permitted until the consolidation is completed. In the second stage, when the specimen is shared, no drainage is permitted. All parameters are expressed interms of total stress concepts. **Perforated grids (or) porous plates** are used.

3. **Consolidated Drained Test (CD):**

   In this test, the drainage of specimen is permitted in both stages. The Sample is allowed to consolidated fully and dissipation of pore water is possible. All parameters are expressed as effective stress. The magnitude of effective stress & total stress both are equal.

   ie., u = o ; $\sigma = \sigma' + u$ $\boxed{\therefore \sigma = \sigma'}$

   Porous plate (or) perforated grids are used for specimen.

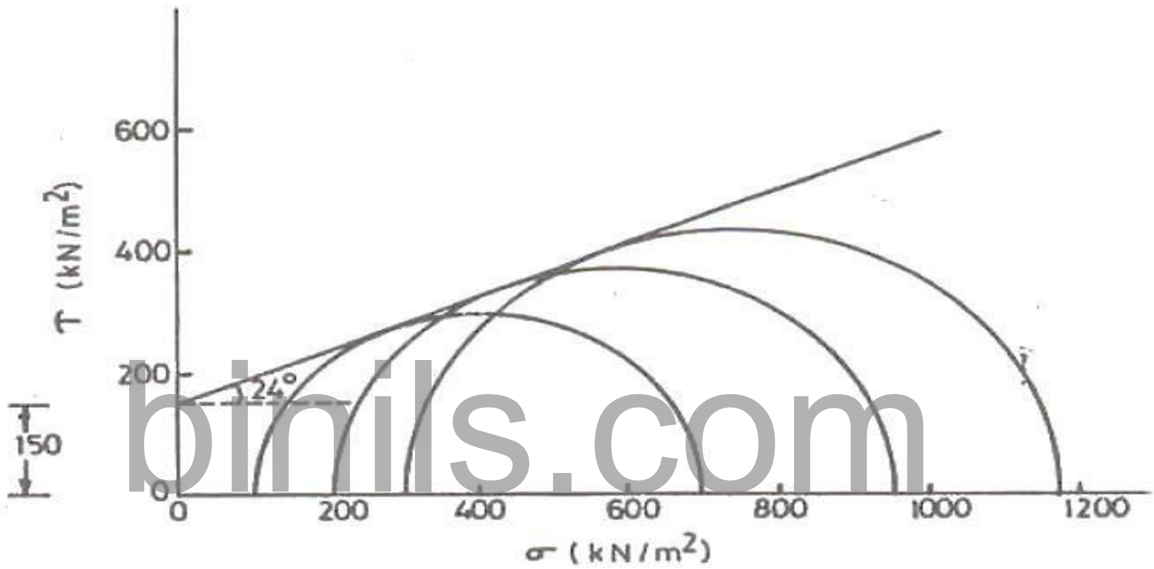
   The test may continue for several hours to several days. It is also known as **slow test**.

Problems:

1) The following results were obtained from a series of consolidated undrained test on a soil ,in which the pore water pressure was not determined .Determine the cohesion intercept and the angle of shearing resistance.

Sample number	Confining pressure(KN/m^2)	Deviator stress at failure (KN/m^2)
1	100	600
2	200	750
3	300	870

The major principal stresses in the three test are 700,950 and 1170 KN/m^2



From the plot C=150 KN/m^2 ,φ=24^0

2) The stresses on a failure plane in a drained test on a cohesionless soil are as under:

Normal stress(σ)=100 KN/m^2

Shear stress(τ)=40 KN/m^2

a) Determine the angle of searing resistance and the angle which the failure plane makes with the major principal plane.

b) Find the major and minor principal stresses.

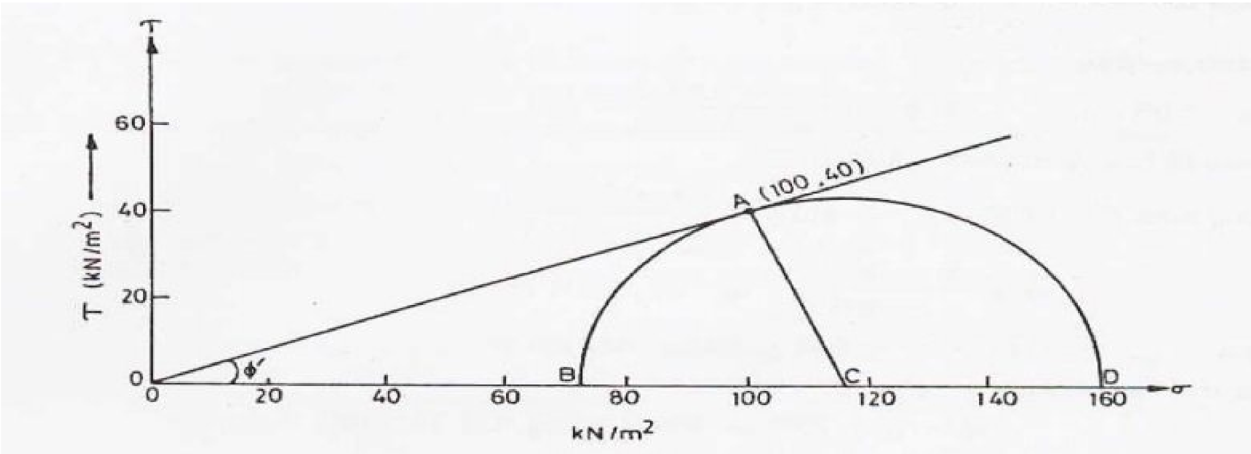
$$tan\varphi' = \frac{40}{100} = 0.4$$

$$\Phi=21.80^0$$

The angle which the failure plane makes with the major principal plane,

$$\theta = 45 + \frac{\varphi'}{2}$$

$$= 45 + \frac{21.8}{2} = 55.9^0$$



σ_3=73KN/m^2 ,σ_1=159 KN/m^2

Analytical method:

Length $OA = \sqrt{100^2 + 40^2}$ =107.7

AC=OA tan φ'=107.7Xtan 21.8^0 =43 KN/m^2

OC=OA Secφ'=107.7Xsec 21.8^0 =116 KN/m^2

OD=OC+AC=116+43=159 KN/m^2=σ_1

OB=OC-AC=116-43=73 KN/m^2=σ_3

3) A cylindrical sample of soil having cohesion of 0.8kg/cm^2 and angle of internal friction of 20°,is subjected to a cell pressure of 1.0kg/cm^2. Calculate the maximum deviator stress at which the sample will fail and the angle made by the failure plane with the axis of the sample.

Solution:

$\sigma_3 = 1.0\ Kg/cm^2$,C=0.8kg/cm^2

$$\sigma_1 = \sigma_3 \tan^2 \alpha_f + 2Ctan\, \alpha_f$$

$$\alpha_f = 45 + \frac{\varphi}{2}$$

$$\alpha_f = 45 + \frac{20}{2} = 55^0$$

$$\sigma_1 = 1\tan^2 55^0 + 2X0.8tan\ 55^0 = 4.32Kg/cm^2$$

$$\sigma_d = \sigma_1 - \sigma_3 = 4.32 - 1 = 3.32\ kg/cm^2$$

Angle made by the failure plane with the axis of the sample

$$= 90^0 - \alpha_f = 90^0 - 55^0 = 35^0$$

4) A standard specimen of cohesionless and was tested in triaxial compression and the sample failed at a deviator stress of 482kN/m^2 when the cell pressure was 100kN/m^2 under drained condition. Find the effective angle of shearing resistance of sand. What would be the deviators sand the major principal stress at failure for another identical specimen of sand if it is tested under cell pressure of 200 kN/m^2?

Given:

σ_d =482 KN/m^2

σ_3 =100 KN/m^2

C=0

$$\sigma_1 = \sigma_3 \tan^2 \alpha_f + 2Ctan\ \alpha_f$$

$$\tan^2 \alpha_f = \frac{\sigma_1}{\sigma_3} = \frac{582}{100}$$

$$\alpha_f = 5.82$$

$$\alpha_f = 45 + \frac{\varphi}{2}$$

$$\varphi = 2(67.485 - 45) = 44.97^0$$

For another specimen:

σ_3 =200 KN/m^2 ,C=0

$$\sigma_1 = \sigma_3 \tan^2 \alpha_f + 2Ctan\ \alpha_f$$

$$\sigma_1 = \sigma_3 \tan^2 \alpha_f$$

=200X5.82=1164KN/m^2

$$\sigma_d = \sigma_1 - \sigma_3 = 1164 - 200 = 964KN/m^2$$

5)Two identical specimen of 4cm in diameter and 8cm height of partially saturated compacted soil are tested in a triaxial cell under undrained condition.The first specimen failed at an deviator load(additional load) of 720KN.under a cell pressure of 100 KN/m^2 . The second specimen failed at an deviator load(additional load) of 915 KN.under a cell pressure of 200 KN/m^2 .The increase in volume of first specimen at failure is 1.2 ml and its shorten by 0.6 cm at failure. The increase in volume of second specimen at failure is 1.6 ml and its shorten by 0.8 cm at failure. Determine the apparent cohesion and angle of shearing resistance. By analytical method.

Given data:

Triaxial test

Diameter=4cm

height=8cm

first specimen:

deviator load(additional load) =720 KN

cell pressure = 100 KN/m^2

increase in volume ΔV=1.2 ml=1.2 cm^3

shorten by length= 0.6 cm

Second specimen:

deviator load(additional load) =915 KN

cell pressure = 200 KN/m^2

increase in volume ΔV=1.6 ml=1.6 cm^3

shorten by length= 0.8 cm

To find:

and angle of shearing resistance

Solution:

For first specimen:

$$A_2 = \frac{V_1 \pm \Delta V}{L_1 - \Delta L}$$

$$A_2 = \frac{V_1 + \Delta V}{L_1 - \Delta L}$$

$$V_1 = AxL_1$$

$$V_1 = \frac{\pi d^2}{4} XL_1$$

$$V_1 = \frac{\pi x 4^2}{4} X8 = 100.53 cm^3$$

$$A_2 = \frac{100.53 + 1.2}{8 - 0.6} = 13.74 cm^2$$

Calculation of σ_d:

$$\sigma_d = \frac{additional\ axial\ load}{A_2}$$

$$= \frac{720}{13.74}$$

$$= 52.37 \frac{N}{cm^2} = 523.7 KN/m^2$$

$$\sigma_1 = \sigma_3 + \sigma_d$$

$$=100+523.7=623.7 KN/m^2$$

Triaxial equation:

$$\sigma_1 = \sigma_3 N\varphi + 2Cu\sqrt{N\varphi}$$

$$624 = 100 N\varphi + 2Cu\sqrt{N\varphi} - - - - - (1)$$

For second specimen:

$$A_2 = \frac{V_1 \pm \Delta V}{L_1 - \Delta L}$$

$$A_2 = \frac{V_1 + \Delta V}{L_1 - \Delta L}$$

$$V_1 = AxL_1$$

$$V_1 = \frac{\pi d^2}{4} XL_1$$

$$V_1 = \frac{\pi x 4^2}{4} X8 = 100.53cm^3$$

$$A_2 = \frac{100.53 + 1.6}{8 - 0.8} = 14.184cm^2$$

Calculation of σ_d:

$$\sigma_d = \frac{additional\ axial\ load}{A_2}$$

$$= \frac{915}{14.184}$$

$$= 64.506 \frac{N}{cm^2} = 645.06KN/m^2$$

$$\sigma_1 = \sigma_3 + \sigma_d$$

$$=200+645=845KN/m^2$$

Triaxial equation:

$$\sigma_1 = \sigma_3 N\varphi + 2Cu\sqrt{N\varphi}$$

$$845 = 200N\varphi + 2Cu\sqrt{N\varphi} - - - - - - (2)$$

$$Solve\ (1)\&(2)$$

$$(1) - - - \quad 624 = 100N\varphi + 2Cu\sqrt{N\varphi}$$

$$(2) - - - \quad 845 = 200N\varphi + 2Cu\sqrt{N\varphi}$$

(1)-(2) =-221=-100 $N\varphi$

$$N\varphi = \frac{221}{100} = 2.21$$

solve $N\varphi$ in equation(1)

$$(1) - - - \quad 624 = 100x2.21 + 2Cu\sqrt{2.21}$$

$$624 = 221 + 2.97Cu$$

$$403 = 2.97Cu$$

$$Cu = 135.69\frac{KN}{m^2} = 136\ KN/m^2$$

Calculation of angle of shearing resistance:

$$N\varphi = \tan^2 [45 + \frac{\varphi}{2}]$$

$$2.21 = \tan^2 [45 + \frac{\varphi}{2}]$$

Square root on both sides

$$\sqrt{2.21} = tan\,[45 + \frac{\varphi}{2}]$$

$$\tan^{-1} 1.486 = 45 + \frac{\varphi}{2}$$

$$11.072 = \frac{\varphi}{2} = 22.1447$$

$$\varphi = 22^0 8' 93$$

4.4. UNCONFINED COMPRESSION TEST (UCC)

- The object of the experiment is to determine the unconfined compressive strength of the clayey soil.
- The purpose of the test is to obtain the value of compressive and shearing strength of the soils.
- The split mould is oiled lightly from inside, the mould is pushed into the soil. The split mould is opened carefully and sample is taken out after taken from the soil man.

  Measure the initial length and diameter of specimen place the specimen on the bottom plate of the loading device, adjust the upper plate to make contact with the specimen.
- Set the loading dial gauge and the strain dial gauge to zero.
- The cracks are formed on the soil specimen due to compression and take dial gauge readings and draw the failure envelope.
- This test is simple test and used to determine the sensitivity of the clay soils.

$$\text{Sensitivity} = \frac{Q_u \text{ (undisturbed)}}{Q_u \text{ (remoulded (or) disturbed)}}$$

- It is a special case of triaxial compression test in which $\sigma 2 = \sigma 3 = 0$ due to the absence of such confining pressure, the uniaxial test is called as UnConfined Compression test.
- This test is applicable for saturated clay soil ($\phi = 0$)

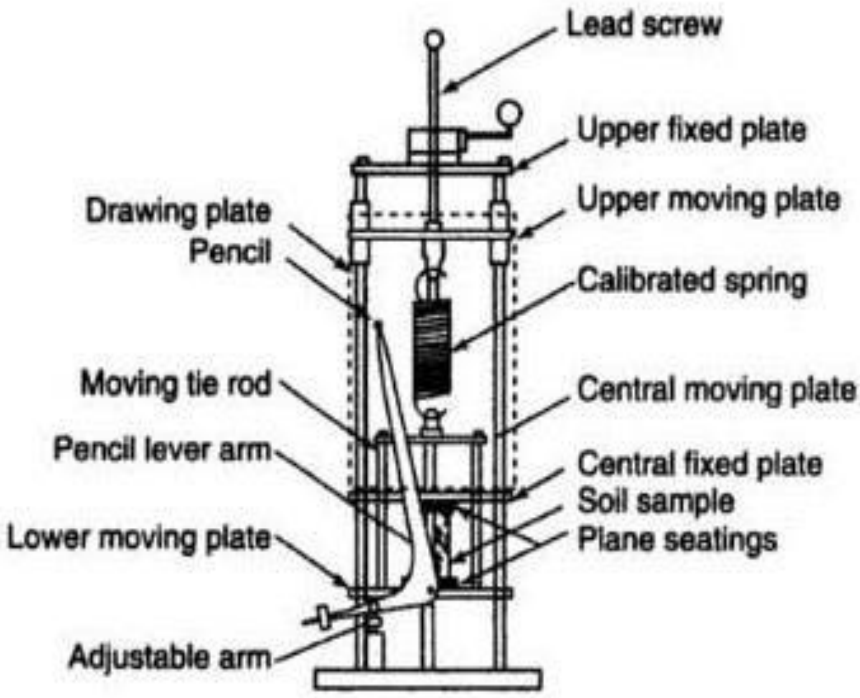


fig 4.4.1 UCC

We Know that,

$\sigma 1 = \sigma 3 \tan^2 \alpha + 2c \tan \alpha$

$\sigma 3 = 0$

$\sigma 1 = 2c \tan \alpha$;

$$\alpha = 45 + \frac{\varphi}{2}$$

$$\sigma_1 = 2C tan\, [45 + \frac{\varphi}{2}]$$

$$\sigma 1 = 2c \tan 45° \; [\varphi = 0]$$

$$\sigma 1 = 2c$$

$$C = \frac{\sigma_1}{2}$$

but, $\tau = c + \sigma \tan \phi$

$$\tau = C = \frac{\sigma_1}{2}$$

$$\tau = C = \frac{\sigma_1}{2} = \frac{q_u}{2}$$

(Ref.fig.4.4.1) q_u = Unconfined Compressive strength

$$\varepsilon = \frac{\Delta L}{L} = 0.1$$

$$A_f = \frac{A}{1 - \frac{\Delta L}{L}}$$

$$q_u = \frac{P_f}{A}$$

f

MERITS:

1. The test is simple and quick
2. It is used for determining the unconfined compressive strength of clayey soil.
3. The sensitivity of soil is also determined from the test results.

DEMERITS:

- The test cannot be conducted on hard clay
- The test cannot be used for friction soils.

Problem:

1)In an unconfined compression test ,a sample of clay 100 mm long and 50mm in diameter fails under a load of 150 N at 10% strain. calculate the shearing resistance taking into account theeffectof changein cross section of the sample.

Solution:

$$\varepsilon = \frac{\Delta L}{L} = 0.1$$

$$A_f = \frac{A}{1 - \frac{\Delta L}{L}}$$

$$A = \frac{\pi x d^2}{4} = \frac{\pi(50^2)}{4}$$

$$A_f = \frac{\frac{\pi(50^2)}{4}}{1-0.1} = 2181.7 mm^2$$

$$q_u = \frac{P_f}{A_f} = \frac{150}{2181.7}$$

$$= 0.06875 \text{ N/mm}^2$$

Shear resistance$= \frac{q_u}{2} = \frac{68.75}{2} = 34.38\ KN/m^2$

2) A shear vane of 7.5 cm diameter and 11 cm length was used to measure the shear strength of soft clay. If torque of 600 Kg-cm was requires to shear the soil, Calculate the shear strength .The vane was then rotated rapidly to cause remoulding of the soil. The torque required in the remoulded state was200kg/m. Determine the sensitivity of the soil

Solution:

$$\tau_f = \frac{T}{\pi d^2 \left[\frac{H}{2} + \frac{d}{6}\right]}$$

$$\tau_f = \frac{600}{\pi(7.5)^2 \left[\frac{11}{2} + \frac{7.5}{6}\right]}$$

$$C = \tau_f = 0.503 \text{ Kg/cm}^2$$

For remoulded state: The shear strength will be in direct proportion to the torque

$$Sensitivity = \frac{C \text{ in undisturbed condition}}{C \text{ in disturbed condition}} = \frac{T \text{ in undisturbed condition}}{T \text{ in disturbed condition}}$$

$$= \frac{600}{200} = 3$$

3) A cylindrical specimen of saturated clay,4cm in diameter and 9cm in overall length is tested in an unconfined compression tester. The specimen has coned end and its length between the apices of cone is 8cm.Find the unconfined compressive

strength of clay, if the specimen fails under an axial load of 46.5N.The change in the length of specimen at failure is 1cm.

Solution:

Original length of specimen=9cm overall & 8cm apices of cone

Length of cylinder of the same volume and diameter(avg length) L_1=8.66cm.

$$A_1 = \frac{\pi x d^2}{4} = \frac{\pi(4^2)}{4} = 12.57\ cm^2$$

Change in length ,ΔL=1cm

$$A_2 = \frac{A_1}{1 - \frac{\Delta L}{L}}$$

$$A_2 = \frac{12.57}{1 - \frac{1}{8.66}} = 14.2\ cm^2$$

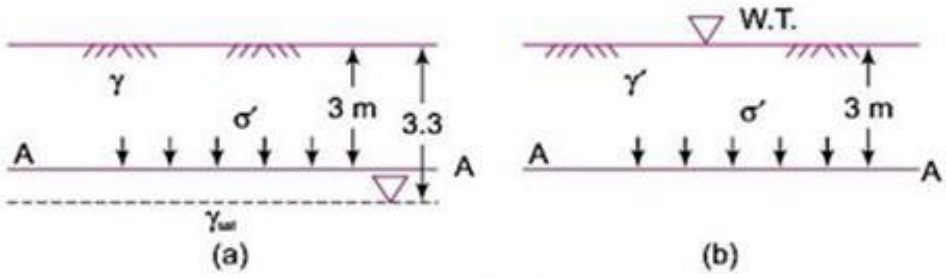
$$unconfined\ compression\ test\ q_u = \frac{failure\ load}{A_2}$$

$$= \frac{465}{14.2} = 32.8KN/cm^2$$

=328KN/m^2

Shear strength C_u= $\frac{q_u}{2} = \frac{328}{2} = 164\ KN/m^2$

4) Calculate the potential shear strength on a horizontal plane at a depth of 3m below the surface in a formation of cohesionless soil when the water table is at a depth of 3.3 m.The degree of saturation may be taken as 0.5 on the average ,void ratio=0.5,grain specific gravity=2.7, angle of internal friction=30^0.what will be the modified values of shear strength if water table reaches the ground surface?



Solution:

a)water table at 3.3m depth

$$w = \frac{eS}{G} = \frac{0.5x0.5}{2.7} = 0.0926$$

$$\gamma = \frac{G\gamma_w}{1+e}(1+w)$$

$$= \frac{G\gamma_w}{1+e}(1+w)$$

$$= \frac{2.7x9.81}{1+0.5}(1+0.0926)$$

$$= 19.293\ KN/m^3$$

σ' at AA,at 3m depth=γH

=19.293x3

=57.879 KN/m^2

τ_f=C+σ'tanφ

=0+57.879 tan 30^0

=33.42 KN/m^2

b)water table at GL

$$w_{sat} = \frac{eS}{G} = \frac{0.5x1}{2.7} = 0.1852$$

$$\gamma_{sat} = \frac{G\gamma_w}{1+e}(1+w_{sat})$$

$$= \frac{G\gamma_w}{1+e}(1+w_{sat})$$

$$= \frac{2.7x9.81}{1+0.5}(1+0.1852)$$

$$= 20.928\ KN/m^3$$

γ'=20.928-9.81=11.118 KN/m^2

σ' at AA =γ'H

=11.118x3=33.354 KN/m^2

τ_f=C+σ'tanφ

=0+33.354 tan 30^0

=19.26 KN/m^2

4.5VANE SHEAR TEST:

- Vane shear test is a quick test, used either in the lab (or) in the field, to determine theundrained shear strength of cohesive soils.
- The vane shear tester consists of four thin steel plates called vanes, weldedorthogonally to a steel rod.
- A torque measuring arrangement is attached to the rod which is rotated by a wheelarrangement.
- After pushing the vanes gently into the soil, the torque rod is rotated at a uniformspeed.
- The torque 'T' is then calculated by multiplying the dial reading with the springconstant.
- The vane is 20mm high and 12mm in diameter with thickness of 0.5 to 1mm.
- The field shear vane is 10 to 20cm in height and from 5 to 10cm in diameter, withthickness of about 2.5mm.

$$T = \pi d^2 \tau_f [H / 2 + d / 6]$$

Let, τ_f be the shear strength of soil,

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

If only bottom end partakes in the shearing, then

$$T = \pi d2 \tau_f [H / 2 + d / 12]$$

$$\tau_f = \frac{T}{\pi D^2 (\frac{H}{2} + \frac{D^3}{12})}$$

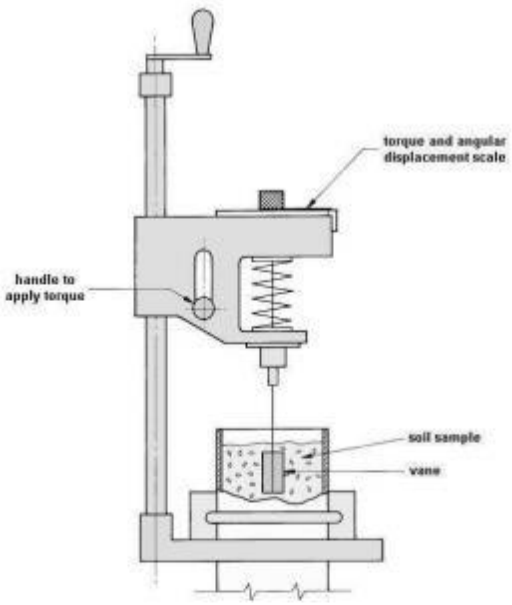


Fig 4.5.1 vane shear

1) A shear vane of 7.5 cm diameter and 11 cm length was used to measure the shear strength of a soft clay. If a torque of 600 N-m was required to shear the soil, Calculate the shear strength. The vane was rotated rapidly to cause remoulding of the soil. The torque required in the remoulded state was 200N-m Determine the sensitivity of the soil.

Solution:

In natural state:

$$c \text{ or } \tau_f = \frac{T}{\pi D^2(\frac{H}{2} + \frac{D^3}{6})}$$

$$= \frac{4500}{\pi x 8^2 (\frac{10}{2} + \frac{(7.5)^3}{6}) x 10^{-6}}$$

=503 KN/m^2

In the remoulded state,

$$c \text{ or } \tau_f = \frac{200 x 10^{-3}}{\pi x 7.5^2 (\frac{11}{2} + \frac{(7.5)^3}{6}) x 10^{-6}}$$

=168 KN/m^2

$$Sensitivity = \frac{c(\text{ natural state})}{c(\text{ remoulded state})}$$

$$Sensitivity = \frac{503}{168} = 3$$

2)A vane 10cm long and 8cm in diameter was pressed into soft clay at the bottom of a bore hole. Torque was applied and gradually increased to 45N-m.When failure takes place .Subsequently, the vane rotated rapidly so as to completely remould the soil. The remoulded soil was sheared at a torque of 18 N-m. Calculate the cohesion of the clay in the natural and remoulded state and also the value of sensitivity

Solution:

In natural state:

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

$$= \frac{4500}{\pi x 8^2 \ (\frac{10}{2} + \frac{(8)^3}{6})}$$

$=35.4$ KN/m^2 ($\varphi=0$)

In the remoulded state,

$$c \ or \ \tau_f = \frac{1800}{\pi x 8^2 \ (\frac{10}{2} + \frac{(8)^3}{6})}$$

$=14.1$ KN/m^2

$$Sensitivity = \frac{c(\text{ natural state})}{c(\text{ remoulded state})}$$

$$Sensitivity = \frac{35.4}{14.1} = 2.5$$

LIQUEFACTION:

Liquefaction is a phenomenon which can saturated in loose deposit of saturated fine a cohesion less soils. If a saturated fine sand deposit is subjected to a sudden disturbance as caused by vibrations of heavy machinery, blasting (or) earth quake, rapid decrease in volume takes place and the pore pressure may increase to such an extent that pore pressure may increase to such an extent that effective stresses become zero loading to complete loss of shear strength. The soil at this stage behaves like a liquid and the phenomenon is referred to as liquefaction.