UNIT 6

SHEAR STRENGTH OF SOILS

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. Define shear strength. List out the different types of laboratory strength tests.

Answer :

Shear strength of soils can be defined as the resistance offered to the shear stresses and shear deformation by the soil.

The different types of laboratory strength test are as follows,

(a) Direct shear test

(b) Ring shear test

(c) Torsion test

(d) Triaxial compression test

(e) Unconfined compression test

(f) Vane shear test (Laboratory).

Q2. List out the different types of undrained shear test and under what conditions should the undrained shear strength parameters are used.

Answer :

Model Paper-IV, Q1(f)

Undrained Shear Test

There are two types of undrained tests,

(i) Unconsolidated undrained test

(ii) Consolidated undrained test.

Conditions for Undrained Shear Strength Parameters

The shear strength parameters such as cohesion (c) and angle of repose (ϕ) for consolidated undrained-test is used if there is a problem of long-term stability of foundations, earth dams and excavations, whereas the shear strength parameters for unconsolidated undrained-test is used, if there is a problem of short-term stability.

The profile of undrained shear strength can be measured from the coefficient of earth pressure at rest, effective strength parameters vertical effective stress. The undrained shear strength rely upon the relative magnitude of the intermediate principle stress.

Q3. What are the advantages and disadvantages of direct shear test.

Answer :

Model Paper-I, Q1(f)

Advantages of Direct Shear Test

1. Direct shear test is simple and can be performed easily.
2. This method is more suitable for sand.
3. It can be performed within a short period of time.
4. Specimen preparation and test procedure is simple.
5. This test is inexpensive.

Disadvantages of Direct Shear Test

1. The pore water pressure cannot be measured.
2. Preparation of undisturbed samples is difficult due to square cross-section.
3. Drainage flow cannot be controlled due to which undrained tests are impossible.
4. Principal stresses cannot be determined in direct shear test.
5. Directions of the principal planes cannot be estimated at each and every stage of the test.

Q4. Differentiate between unconsolidated undrained test and drained test.

Model Paper-III, Q1(f)

Answer :

Differences Between Unconsolidated Undrained Test and Drained Test

Unconsolidated Undrained Test	Drained Test
1. The unconsolidated undrained tests does not require the authorization of drainage at any of the stages.	1. The drained test require the authorization of drainage at every stage. i.e., Before and during the commencement of the test.
2. The time span required for the unconsolidated undrained test is approximately about 5 to 10 minutes.	2. The time span required for the completion of the undrained test is about 4 to 6 weeks.
3. The unconsolidated undrained test is also known as the 'consolidated quick test'.	3. The drained test is also known as the 'slow test' or the 'consolidated slow test'.
4. The unconsolidated undrained test is designated as "UU", "Q" or "Q_U" test.	4. The drained test is designated as "CD", "S" or "S_c" test.
5. There is no dissipation of pore water pressure and consequent consolidation of soil, due to which the volume remains unchanged.	5. There is no development of pore pressure at any of the stages, but a change in the volume is observed.

Q5. Write short notes on importance of shear strength.

Answer :

1. Shear strength is one of the most important engineering property's of soil.
2. The significance of shear strength is such that it is involved in the stability analysis part of geotechnical engineering.
3. To transfer the laboratory test results on the field of application, the engineer should possess high skills.
4. Shearing strength is obtained from resistance due to interlocking soil grains and frictional resistance in between the grains of the soil.
5. Cohesion or adhesion between the soil grains also produces shear strength in soil.
6. The shear strength is different for various engineering conditions under various fields. Hence, it cannot be tabulated in codes of practise.

Q6. What are the advantages and disadvantages of triaxial compressive test over direct shear test?

Answer :

Model Paper-II, Q1(f)

The advantages and disadvantages of the triaxial compressive test over direct shear test are as follows,

Advantages

1. The uniform distribution of stress on failure plane is obtained
2. Variations in pore water pressure and volume can be measured directly
3. The control over drainage conditions is possible
4. The state of stress at every middle sections is known, therefore the Mohr's circle can be drawn at any stage of shear
5. It provides more accurate results when compared to direct shear test
6. The flexibility of triaxial compression test is high when compared to shear stress.

Disadvantages

1. Equipments used in this test are very complex, expensive and bulky
2. It is very slow test when compared to direct shear test
3. Loading cap and pedestal disc of the specimen produce frictional resistance, due to which the strain conditions are not uniform.

Q7. Explain the basic mechanism of shear strength of soils. Nov.-15, Set-1, Q1(f)

OR

How soils attain their shear strength? Nov.-15, Set-3, Q7(a) | Nov.-15, Set-2, Q1(f)

Answer :

Shearing Strength of Soils

Shearing strength in a soil is achieved from the following sources,

1. From the interlocking effect of particles.
2. Due to various frictional resistances exhibiting between two or more soil particles such as sliding friction, rolling friction or both.
3. By the property of cohesion or adhesion between the soil particles.

The granular soil extracts its shear strength from interlocking of particles and friction forces whereas clays derive their shearing strength from the cohesion or adhesion process. Soils which are partly cohesive and partly granular are very abundant in nature and they derive their shearing strength from the frictional forces between soil grains. A soil exhibit different shear strengths according to different field and engineering conditions. Therefore, shear strength of soil is not recommended by any standard code of practice.

Q8. What is the name of the test used to determine quickly the un drained shear strength of soft clay? Write the formula to determine the sensitivity of a clay.

Answer : Oct./Nov.-16, Set-2, Q1(f)

- The test used to determine quickly the undrained shear strength of soft clay is unconsolidated undrained test (UU Test).
  - ❖ In this, during the application of cell pressure in first stage and deviator stress in second stage, the drainage is restricted. Moreover, if the sample used is of fully saturated, then there occurs zero consolidation.
  - ❖ Thus, due to above two conditions this test is termed as unconsolidated undrained test (U-U Test).

  For answer refer Unit-II, Q2.

Q9. What is usual length to diameter ratio of a lab triaxial test sample? What is the formula of additional axial stress and what is another name for additional axial stress.

Answer : Oct./Nov.-16, Set-4, Q1(f)

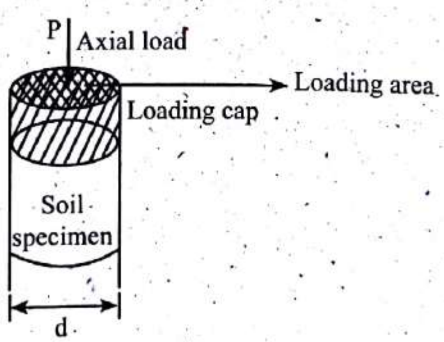
- For answer refer Unit-II, Q16.

The formula for additional axial stress is given by,

$$\sigma_a = \frac{\text{Axial load}}{\text{Loaded area}} = \frac{F}{A}$$

$$= \left(\frac{P'}{\left(\frac{\pi d^2}{4}\right)}\right)$$

$$\boxed{\therefore \sigma_a = \frac{4P}{\pi d^2}}$$



Q10. Define Critical Void Ratio and explain in which state sand can have cohesion.

Answer : Oct./Nov.-16, Set-3, Q1(f)

For answer refer Unit-VI, Q43.

When sand is in dry state it does not possess cohesion. It attains the cohesion parameter when a small quantity of water is mixed but does not possess inherent strength.

Q11. Explain different drainage conditions for shear testing of soils.

Answer : (Nov.-15, Set-4, Q1(f) | Nov.-15, Set-3, Q1(f))

For answer refer Unit-VI, Q19.

Q12. Define shear strength of a soil. What are the names of shear tests based on drainage conditions?

Answer : Oct./Nov.-16, Set-1, Q1(f)

For answer refer Unit-VI, Q1 and Q19, Topic: Triaxial Shear Test.

Q13. Discuss about triaxial shear test.

Answer : Oct./Nov.-17, Set-1, Q1(f)

For answer refer Unit-VI, Q16.

PART-B

ESSAY QUESTIONS WITH SOLUTIONS

6.1 BASIC MECHANISM OF SHEAR STRENGTH – MOHR COULOMB FAILURE THEORIES – VARIOUS DRAINAGE CONDITIONS

Q14. Explain briefly about the Mohr's Coulomb failure theory.

(Oct./Nov.-17, Set-2, Q7(a) | Nov.-15, Set-1, Q7(a))

OR

Explain Mohr - Coulombs shear failure theory.

Answer :

Model Paper-I, Q7(a)

Various theories of failure have been proposed but the theory proposed by Mohr has been helpful in soils. The important points of Mohr's strength theory are as follows,

(a) The failure of material is due to shear. The critical shear stress producing failure rely on the characteristics of the material and normal stress on the failure plane

(b) The stresses on the potential failure plane determines the ultimate strength of the material

(c) When the material depends on three dimensional principal stress, the intermediate principal stress does not have any effect on the strength of material.

The theory was first proposed by Coulomb in 1776 and later it was generalized by Mohr. The algebraic expression for this theory is as follows,

$$\tau_f = S = F(\sigma) \quad \text{... (1)}$$

Where,

$\tau_f - S$ – Shear stress on failure plane, shear resistance of material at failure

$F(\sigma)$ – Normal stress function.

A curve obtained by plotting the normal stress and shear stress is known as strength envelope. The following strength equation is given by coulomb,

$$S = C + \sigma \tan \phi$$

Where,

C – Cohesion intercept

ϕ – Angle of internal friction

The Mohr's envelope, as shown in figure, is the graphical representation of equation (1).

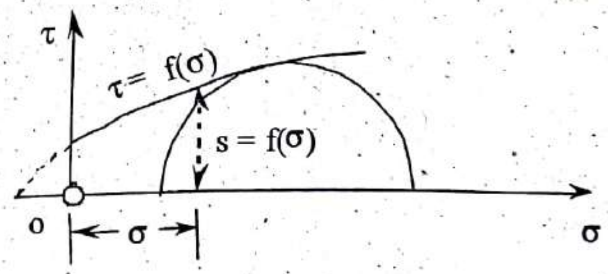


Figure (1): Mohr's Envelope

The relation between shear strength and normal stress as considered by coulomb, is a straight line whereas in Mohr theory, the shear strength rely on the normal stress but shows that the relation between them is not linear. Coulomb and Mohr strength lines depends on the strength theory and this theory shows that the definite relationship exists among the principal stresses, the angle of internal friction and the inclination of the failure plane. The Mohr's curved failure envelope is considered as a straight line for the stability of soil mass. This line moves through the origin for an ideal pure friction material, as shown in figure. In case of dense sands, a slightly curved strength line is exhibited, which is indicated by dotted line.

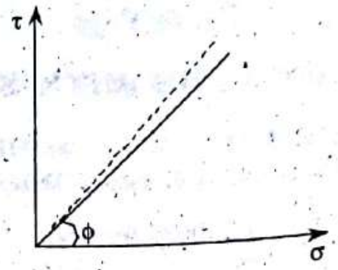


Figure (2)

For purely cohesive material, the straight line is parallel to the σ-axis and the strength is different with the normal stress acting on the failure plane.

Figure (3)

A straight line which is attached to a Mohr envelope rely on the range of 'α'. Therefore, if the angle of internal friction is constant, then the Mohr envelope is considered as a straight line. Based on the characteristics of the material,

(a) The failure envelope may be straight or curved.

(b) The failure envelope may move through the origin of stress or may intersect the shess-stress axis..

Q15. Discuss about vane shear test.

Oct./Nov.-17, Set-2, Q1(f)

OR

What are the different types of laboratory strength test? Explain any one.

Answer :

Types of Laboratory Tests

The different types of laboratory strength test are as follows,

(a) Direct shear test

(b) Ring shear test

(c) Torsion test

(d) Triaxial compression test

(e) Unconfined compression test

(f) Vane shear test.

Vane Shear Test

Vane shear test is conducted to determine the undained shear strength of soft clays. The shear vane comprises of four thin stainless steel blades fixed at the bottom of the vertical steel rod.

IS: 2720 – XXX – 1980 recommends,

(i) Height of the vane, $H = 2D$

(ii) Length of the rod, $L = 60$ mm

(iii) Diameter of the rod, $d = 2.5$ mm

Procedure

(i) A specimen of size 38 mm diameter and 75 mm height is taken in a container which is attached to the base.

(ii) The vane is then inserted in the specimen to a depth of 10 to 20 mm and the readings of strain indicator and torque indicator are noted down.

(iii) Torque at a rate of 6°/m to the top of the steel rod is applied.

(iv) A pointer attached to the spring indicates the applied torque.

(v) A torque acting on the specimen is continued till the soil specimen fails in shear.

(vi) The shear strength of the soil is calculated by using an equation,

$$S = \frac{T}{\pi D^2\left(\frac{H}{2}+\frac{D}{6}\right)}$$; if top vane and bottom vane are involved in shearing action.

$$S = \frac{T}{\pi D^2\left(\frac{H}{2}+\frac{D}{12}\right)}$$; if only one of the vane is involved in shearing action.

Where,

T – Torque

D – Diameter of the vane

H – Height of the vane.

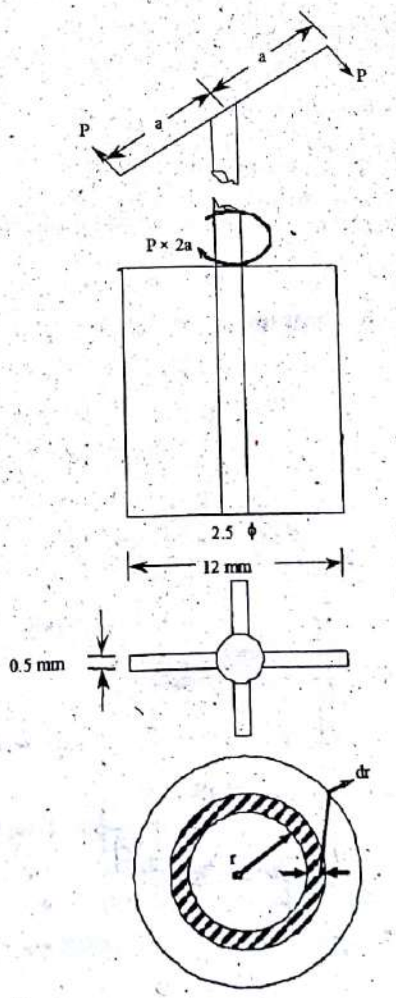


Figure: Vane Shear Test

Q16. Write a note on the laboratory triaxial shear test. Oct./Nov.-16, Set-2, Q7(a)

Answer :

Triaxial Shear Test

The main aim of triaxial shear test is to measure the shear strength of soil. In this test, there is a feasibility of controlling drainage conditions and thus more accurate pore water pressure values are obtained.

Procedure

- A cylindrical specimen of sizes 76 × 38 mm and 100 × 50 mm are used i.e., the ratio of length to diameter of specimen should be equal to 2.
- To conduct this test, a triaxial cell is used which consists of saturated porous disc at the pedestal. It also consists of rubber membranes and o-rings, so as to avoid the pressure developed by cell-fluid which otherwise disturb the specimen.
- Firstly, the specimen is placed over the porous disc and is covered with rubber membrance.The top and bottom of specimen is sealed by o-rings.
- Now, in order to apply the cell pressure (σ_c), which acts radially over the lateral surface and axially over top and bottom surface of specimen, the triaxial cell is filled with water.
- An additional axial pressure called deviator stress is also applied until the specimen fails.
- Using dail guage (or) a displacement transducer, axial strain is calcualted.
- During the triaxial test, there exists 2 cases,
  1. Open pore water line and closed drainage line
  2. Closed pore water line and open drainage line

In both the cases, the pore pressure is measured in undrained condition while the volume changes are measured in drained conditions.

Thus, the laboratory procedure of triaxial shear test.

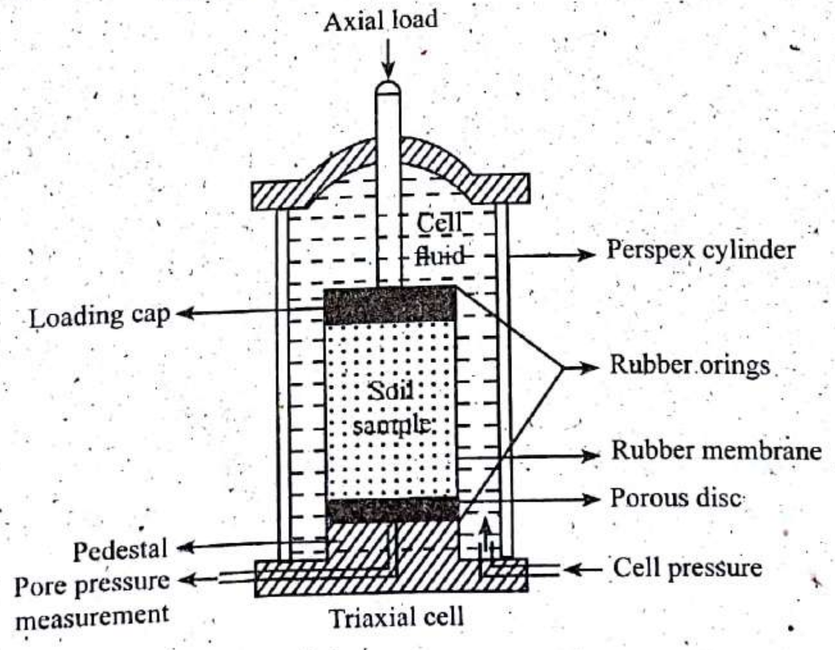


Figure: Triaxial Cell

Q17. Discuss about unconfined compression test.

Answer : Oct./Nov.-17, Set-4, Q1(f)

Unconfined Compression Test

In unconfined compression test, the confining pressure is zero. The test can be carried out on clayey soils or intact, saturated clay specimens. The two types of machines, which are used to conduct unconfined compression test are,

(a) Spring type machine

(b) Proving ring type machine.

Proving Ring Type Machine

Figure indicates the unconfined compression testing machine in which the proving ring is used for determining the compressive force. The machine comprises of two plates with conical seatings.

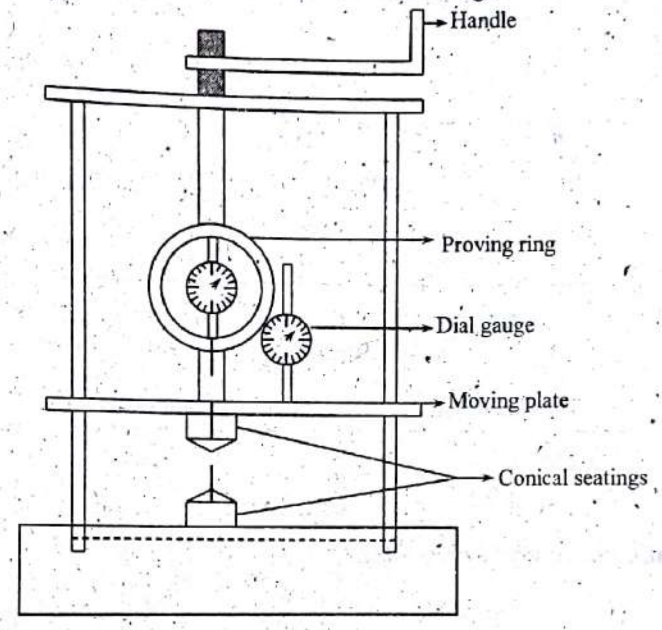


Figure: Proving Ring Type Machine

Procedure

1. Place the specimen at the top of the lower plate and set the readings of dial gauge and proving ring to zero.
2. Apply the compressive load on the specimen by rotating the handle of the machine.
3. When the handle is rotated, the top plate is forced to downward direction, which produces compression.
4. An axial strain of ½% to 2% per minute is produced by gradually rotating the handle.
5. The load applied on the specimen is continued till it fails or till the occurence of 20% of axial strain.
6. The compressive force and the axial strain is measured from the readings of proving ring and dial gauge respectively.

Results

In this test,

Minor principal stress, $\sigma_3 = 0$

Major principal stress, $\sigma_1 = \frac{P}{A}$

Where,

P – Axial load

A – Area of cross-section of the specimen.

The failure of specimen at an axial stress is known as unconfined compressive strength. The stress-strain ($\sigma-\varepsilon$) curve can be drawn between the axial stress and axial strain at varying stages prior to the failure of specimen.

While computing the axial stress, cross-section area of the specimen at that axial strain should be utilized. The corrected area can be achieved from equation,

$$A = \frac{A_0}{(1-\varepsilon)}$$

Mohr Circle

Plot the Mohr circle for the conditions of stress at failure. When the minor principal stress is zero,

(i) Mohr circle moves through the origin

(ii) Failure envelope is horizontal

(iii) Cohesion intercept is equal to the radius of the circle.

$$S = C_u = \frac{\sigma_1}{2} = \frac{q_u}{2}$$

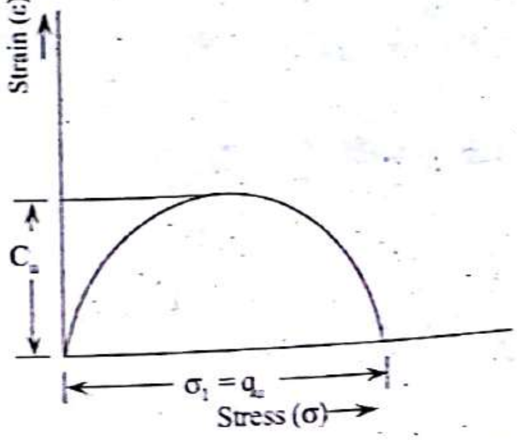


Figure: Mohr Circle for Unconfined Compression Test

Q18. Discuss about direct shear test. Oct./Nov.-17, Set-3, Q1(f)

OR

Write a note on the laboratory box shear test. Oct./Nov.-16, Set-1, Q7(a)

OR

Explain shear box test with neat figure. Nov.-15, Set-4, Q7(a)

Answer :

Direct Shear Test

Direct shear test is used for calculating the strength parameters of silt and clay under different drainage conditions (i.e., unconsolidated-undrained, consolidated drained conditions). This test is performed on cohesionless soils and imparts good results for the strength parameters.

Procedure

Soil specimen of size 60 × 60 × 25 mm is taken, which may be made directly in the shear box and compacted. The base plate is fixed to the bottom half of the box. A porous stone is kept in the shear box. In case of undrained tests, a plain grid is placed on the porous stone whereas in drained tests, a perforated grids are utilized. Then the mass of the base plate, porous stone and grid are taken. The soil specimen, if prepared separately is transmitted to the box and then its mass is taken.

The upper grid, porous stone and the pressure pad are kept on the soil specimen, which is placed in the box. The box is then kept inside the container on the loading frame, which is mounted. Due to which, the top half of the box contacts with the proving ring. The steel ball is placed on the pressure pad and the loading yoke is kept on the steel ball. Two dial gauges are provided in the direct shear test apparatus.

(a) One dial gauge is fixed to the container to provide shear displacement.

(b) Other is fixed on the loading yoke to note down the vertical movement.

The locking pins are taken off and the top half box is pulled slightly by means of spacing screws. Based on the maximum particle size, the space between the two halves of the box is so adjusted that the upper half of the box does not mount on soil grains.

Now, apply the normal load on the specimen to provide a normal stress of 25 kN/m^2 and then shear load is applied on it at a constant rate of strain.

Table indicates the rate of strain for different tests,

Undrained tests	Drained tests
Rate of strain	Rate of strain
1 mm to 2 mm/minute	0.2 m/minute for sandy soils
	0.005 – 0.02 mm/minute for clayey soils

The specimen of the soil shears between the two halves of the box along the horizontal plane. The readings of the proving ring and dial gauges are noted after every ½ minute. The test is continued till the failure of the specimen occurs. After reaching the maximum value, the readings of proving ring dial gauge begins to decrease. This shows the shear failure of the soil specimen. In case of soils which do not provide peak point, the failure of the specimen occurs when a shearing strain of 20% is achieved.

After the completion of test, the specimen is taken out from the shear box and the water content of the specimen is determined.

The test is repeated under the normal stress of 50,100,, 200 and 400 kN/m^2

During shear,

$$\text{Shear stress} = \frac{\text{Shear force indicated by proving ring}}{\text{Area of the specimen}}$$

A curve can be plotted between shear stress and shear strain, where,

$$\text{Shear strain} = \frac{\text{shear displacement } (\Delta H)}{\text{Length of the specimen } (L)}$$

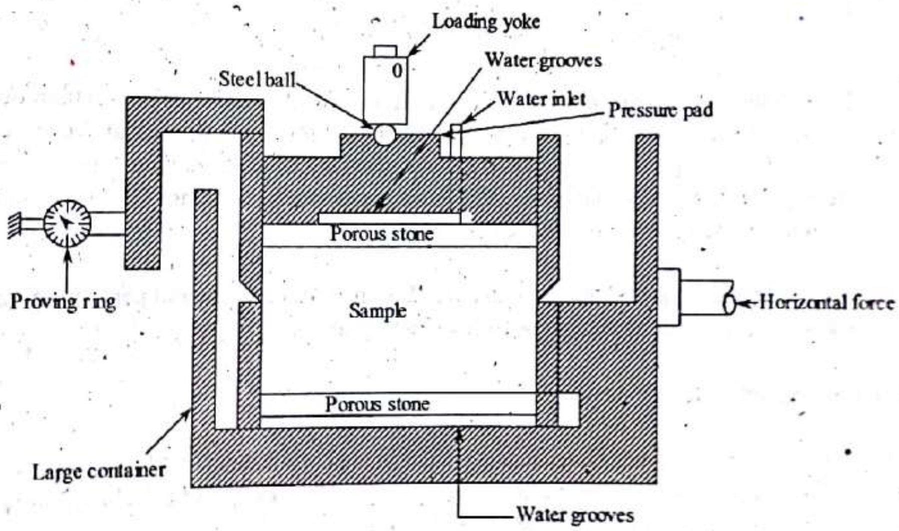


Figure: Direct Shear Test

Q19. Explain three drainage conditions for conducting shear testing of soils. Nov.-15, Set-1, Q7(b)

OR

What are the three standard triaxial shear tests with respect to drainage conditions? Explain with reasons the situations for which each test is preferred.

Answer : Model Paper-III, Q7(a)

Triaxial Shear Test

The three standard triaxial shear test with respect to drainage conditions are,

(i) Consolidated - undrained test (CU-test)

(ii) Unconsolidated - undrained test (UU-test)

(iii) Consolidated drained test (CD test)

(i) Consolidated-Undrained Test (CU Test)

In triaxial test apparatus, a deaired porous stone is kept on the top of the pedestal. The porous stone is covered with a filter paper disc on the top. The cohesive soil specimen is then kept over the filter paper disc. The diameter and height of the specimen is 37.5 mm and 75 mm respectively. Porous stone is also kept over the specimen. To touch both the porous stones, deaired vertical filter strips are positioned at regular spacing around the entire boundary. The sample is then covered with the rubber membrane and the entire unit is sealed with the help of O-rings.

The triaxial cell is first kept over the base and then secured with the help of nuts. Now, the water is poured in the cell through pressure supply and the oil is injected through the oil valve in the top portion of the cell, which have some empty space. After injecting oil, the surplus oil overflows, due to which both oil value and air-vent value are closed. The pressure is then exerted to the water poured in the triaxial cell by associating to the mercury-pot system. When pressure acts, the specimen starts consolidating. The specimen is associated to the burette by means of pressure connections for calculations of volume changes. If there is no change in volume, then the consolidation process is complete.

After the completion of consolidation, the specimen is ready for sheared. The valve of drainage is closed and the pore water pressure measurement device is fixed to the specimen by means of pressure connections. The reading of proving ring dial gauge is then set to zero. Then the ram is pushed into the triaxial cell with the help of manual control but care should be taken that it does not touch the loading cap. The loading machine is then started at the selected speed. The proving ring records the force due to friction and the upward thrust, which acts on the ram. The machine is haulted with the help of manual control and the ram is allowed to be in contact with the loading cap and then the dial gauge is again set to zero. The deviator stress is applied on the sample with the help of loading material. The reedings of proving ring are taken corresponding to axial strains of

$\frac{1}{3}\%$, $\frac{2}{3}\%$, 1%, 2%, 3%, 4%, 5%..... (or) 20%.

After completing the test, the loading machine is switched off and all extra axial stress is taken out. The pressure acting on the triaxial cell is lowered to zero and then it is evacuated. The nuts used for fixing the cell are removed and the cell is taken out from the base. After removing the cell, the O-rings and rubber membranes are removed. The specimen is then improved after pulling out the loading cap and the top porous stone. The filter paper strips are removed. The post-shear mass and length are calculated. The water content of the specimen is also calculated.

The consolidated undrained test is carried out on undisturbed sample of clay, silt and peat, on remoulded samples of clay and silt and also on redeposits samples of cohesionless soils (sand and gravel).

(ii) Unconsolidated-Undrained Test (UU-test)

The procedure for the unconsolidated-undrained test is similar to the consolidated-undrainted test except that the specimen is not permitted to consolidate in the first stage. During the test, the valve of drainage is kept closed, although the specimen can be associated to the pore-water pressure measurement device if needed.

The specimen is sheared by applying the cell pressure, the second stage for this test is similar to that for a consolidated-undrained test.

This test is carried out on undisturbed sample of clay, silt and peat for determining the strength of natural ground. It is also used on remoulded sample of clay for measuring its strength.

(iii) Consolidated Drained Test (CD-Test)

The procedure for consolidated drained test is same as the consolidated-undrained test, except that the shearing of the specimen is very slow in the second stage. During the test, the drainage valve is not closed. Although, the specimen can be associated to the burrette. During the shearing of specimen, the volume changes are calculated by using burette. Due to very low permeability of cohesive soils, the consolidated drained test takes 4-5 days to complete.

Drained tests are carried out on both undisturbed and remoulded samples of cohesive soils for determining the shear strength parameters directly which are related to the long term stability conditions.

Q20. Discuss failure envelopes of UU, CU and CD for saturated clays, normally consolidated and over consolidated clays.

Answer :

Failure Envelopes of Unconsolidated Undrained Test (UU)

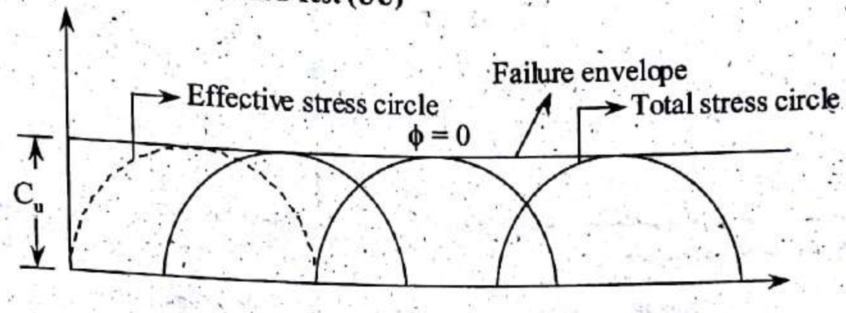


Figure (1)

(a) The failure envelopes is obtained from U.U test.

(b) The angle of shearing resistance ϕ is zero (0) in consolidated undrained test.

(c) The failure envelope will be horizontal, if ($\phi = 0$) i.e., shearing resistance angle is zero.

(d) The shear strength parameters will be equal to $s = c_u$, where c_u is cohesion intercept. For a normally consolidated clay.

(e) The value of cohesion intercept is more in over consolidated clay, but the failure envelope is horizontal.

(f) The failure envelope obtained from U.U test cannot be expressed in terms of effective stress.

Failure Envelope of Consolidated Undrained Test (C.U)

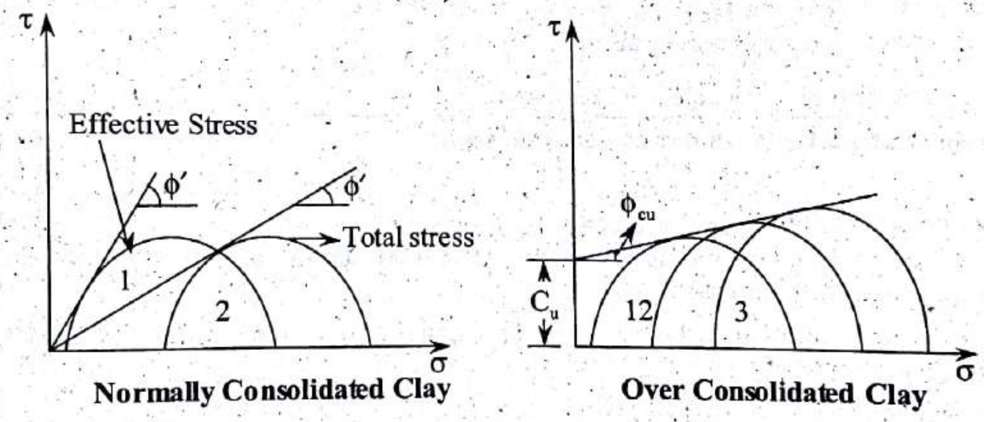


Figure (a) **Figure (b)**

Figure (2)

Failure envelope obtained from consolidated undrained ($c.u$) test is expressed in terms of effective stresses and also total stress.

The shape of the failure envelopes drawn in terms of both total and effective stresses are same. The values of the strength parameters are slightly different in both failure envelopes. The angle of shearing resistance for effective stress (ϕ') is greater than that of total stress. Shearing angle of resistance (ϕ_{cu})

The shear strength for normally consolidated clay is given by,

$$S = \sigma \tan \phi_{cu}$$

The shear strength for over consolidated clay is given by,

$$S = C_{cu} + \sigma \tan \phi_{cu}$$

ϕ_{cu} is also known as apparent angle of shearing resistance for the total stress envelope

Failure Envelope for Consolidated Drained Tests (CD)

Figure (a)

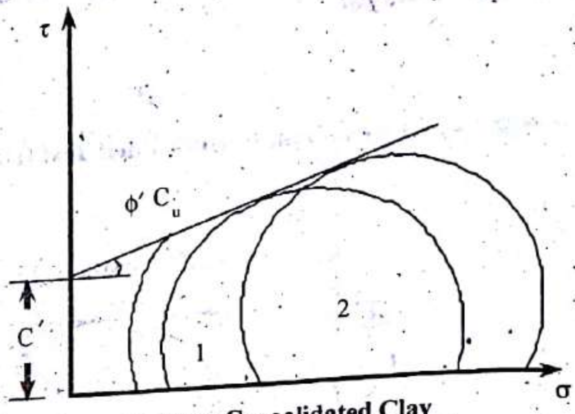


Figure (b)

Figure (3)

(a) The failure envelopes are obtained from consolidated drained (C.D) test for a normally consolidated and over consolidated clay.

(b) The angle of shearing resistance (ϕ') passes through the origin and it does have not any cohesion interrupt.

(c) Three samples are tested and then Mohr's circles are drawn in terms of effective stress only

(d) A tangent is drawn passing through all the circles corresponding to failure conditions

(e) The shear strength for normally consolidated clay is given by,

$S = \overline{\sigma} \tan \phi'$

(f) The shear strength for over consolidated clay is given by

$S = c' + \overline{\sigma} \tan\phi'$; [where c' is cohesion intercept]

Q21. Explain briefly about the skempton's pore pressure. Oct.Nov.-17, Set-4, Q7(a)

Answer :

Skempton's Pore Pressure Parameters

A pore pressure parameter is the dimensionless number that indicates the fraction of total stress increment which exhibits an excess pore pressure for no drainage conditions.

Consider a soil mass subjected to increase in the three principal stresses i.e., $\Delta\sigma_1$, $\Delta\sigma_2$, $\Delta\sigma_3$. This leads to the decrease in volume, (ΔV) with a gradual increase in pore pressure of Δu.

The increment in the effective stresses are given as,

$$\left.\begin{aligned} \Delta\sigma_1' &= \Delta\sigma_1 - u \\ \Delta\sigma_2' &= \Delta\sigma_2 - u \\ \Delta\sigma_3' &= \Delta\sigma_3 - u \end{aligned}\right\} \quad \text{...(1)}$$

Suppose ε_1, ε_2 and ε_3 indicates the strains in all the three directions, then,

$$\left.\begin{aligned} E.\varepsilon_1 &= \Delta\sigma_1' - \mu(\Delta\sigma_2' + \Delta\sigma_3') \\ E.\varepsilon_2 &= \Delta\sigma_2' - \mu(\Delta\sigma_3' + \Delta\sigma_1') \\ E.\varepsilon_3 &= \Delta\sigma_3' - \mu(\Delta\sigma_1' + \Delta\sigma_2') \end{aligned}\right\} \quad \text{...(2)}$$

$$\therefore \quad E(\varepsilon_1 + \varepsilon_2 + \varepsilon_3) = E.\varepsilon_V \qquad (\because \varepsilon_V = \varepsilon_1 + \varepsilon_2 + \varepsilon_3)$$

$$E.\varepsilon_V = E.\frac{\Delta V}{V} = \Delta\sigma_1' + \Delta\sigma_2' + \Delta\sigma_3' - \mu(\Delta\sigma_2' + \Delta\sigma_3' + \Delta\sigma_3' + \Delta\sigma_1' + \Delta\sigma_1' + \Delta\sigma_2')$$

$$= \Delta\sigma_1' + \Delta\sigma_2' + \Delta\sigma_3' - \mu[2(\Delta\sigma_1' + \Delta\sigma_2' + \Delta\sigma_3')]$$

$$\therefore \quad E.\frac{\Delta V}{V} = \Delta\sigma_1' + \Delta\sigma_2' + \Delta\sigma_3' (1-2\mu)$$

$$= (1-2\mu)(\Delta\sigma_1' + \Delta\sigma_2' + \Delta\sigma_3')$$

$$\therefore \quad \frac{\Delta V}{V} = \frac{(1-2\mu)}{E}(\Delta\sigma_1' + \Delta\sigma_2' + \Delta\sigma_3')$$

By multiplying and dividing R.H.S by 3 we get,

$$\frac{\Delta V}{V} = \frac{3(1-2\mu)}{E} \cdot \frac{1}{3}(\Delta\sigma_1' + \Delta\sigma_2' + \Delta\sigma_3')$$

Where,

$$\frac{3(1-2\mu)}{E} = C_C - \text{Compressibility of soil mass.}$$

By substituting the values of effective stresses in terms of total stresses, we get,

$$\frac{\Delta V}{V} = C_C \frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3 - 3\Delta u)$$

$$= C_C\left[\frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3) - \Delta u\right] \quad \text{... (3)}$$

If n is the porosity, then,

Volume of voids (volume of pore fluid) $= nV$

If the pore fluid (air + water) is indicated by the linear relationship between volume change and stress, then its coefficient of volume compressibility is represented by C_V.

The volume change of pore fluid ΔV_w due to the increment in the pore pressure Δu under no drainage condition is given as,

$$\Delta V_w = nVC_V\Delta u$$

$$\therefore \quad \frac{\Delta V_w}{V} = nC_V\Delta u \quad \text{... (4)}$$

As the decrease in volume of soil mass is completely due to the decrease in the volume of voids,

Equation (3) is equal to equation (4).

$$\therefore \quad nC_V\Delta u = C_C\left[\frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3) - \Delta u\right]$$

$$nC_V\Delta u = C_C\left[\frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3)\right] - (C_C\Delta u)$$

$$nC_V\Delta u + C_C\Delta u = C_C\left[\frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3)\right]$$

$$\Delta u(nC_V + C_C) = C_C\left[\frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3)\right]$$

$$\Delta u = \frac{C_C\left[\frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3)\right]}{nC_V + C_C}$$

$$\therefore \quad \Delta u = \frac{1}{\frac{nC_V}{C_C}+1}\left[\frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3)\right] \quad \text{... (5)}$$

In a conventional triaxial test,

$$\Delta\sigma_2 = \Delta\sigma_3$$

$$\therefore \quad \Delta u = \frac{1}{\frac{nC_V}{C_C}+1}\left[\frac{1}{3}(\Delta\sigma_1 + 2\Delta\sigma_3)\right]$$

$$\Delta u = \frac{1}{\frac{nC_V}{C_C}+1}\left[\frac{1}{3}(\Delta\sigma_1 + 2\Delta\sigma_3 + \Delta\sigma_3 - \Delta\sigma_3)\right]$$

$$= \frac{1}{\frac{nC_V}{C_C}+1}\left[\frac{1}{3}(\Delta\sigma_1 - \Delta\sigma_3) + \frac{3\Delta\sigma_3}{3}\right]$$

$$\Delta u = \frac{1}{\frac{nC_V}{C_C}+1}\left[\Delta\sigma_3 + \frac{1}{3}(\Delta\sigma_1 - \Delta\sigma_3)\right] \quad \text{... (6)}$$

Equation (6) is obtained by considering that soil mass is elastic and isotropic.

The general expression for pore water pressure developed and changes in applied stresses is as follows,

$$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)] \quad \text{... (7)}$$

Where,

A and B are called as Skempton's pore pressure parameters.

In a undrained triaxial test, variation in stress occur in two different stages.

1. Increase in cell pressure $\Delta\sigma_3$, which leads to overall change in the stress.
2. Increase in axial load, which leads to the variation in the deviator stress i.e., $\Delta\sigma_d = (\Delta\sigma_1 - \Delta\sigma_3)$.

Q22. The following results were obtained from a triaxial test on two soil specimens.

Sample No.	Confining Pressure (kPa)	Deviator Stress at failure (kPa)	Pore water Pressure (kPa)
1	200	244	55
2	300	314	107

Determine the shear strength parameters of the soil terms of (i) total stresses (ii) effective stresses.

Oct./Nov.-16, Set-1, Q7(b)

Answer :

Sample Number	Cell Pressure (kPa)	Failure Deviator Stress (kPa)	Failure Pore Pressure (kPa)
Sample I	200	244	55
Sample II	300	314	107

Calculating Total Stress and Effective Stress.

Sample-I

Cell pressure, $\sigma_3 = 200$

Major principal stress, $\sigma_1 = \sigma_3 +$ Deviator Stress

$= 200 + 244 = 444$ kPa

Pore pressure, $u = 55$ kPa

Effective stress, $\overline{\sigma_3} = \sigma_3 - u$

$= 200 - 55$

$= 145$ kPa

Major effective stress, $\overline{\sigma_1} = \sigma_1 - u$

$= 444 - 55$

$= 389$ kPa

Sample-II

Cell pressure, $\sigma_3 = 300$ kPa

Major principal stress, $\sigma_1 = \sigma_3 +$ Deviator Stress

$= 300 + 314$

$= 614$ kPa

Pore water pressure, $u = 107$ kPa

Effective stress, $\overline{\sigma_3} = \sigma_3 - u$

$= 300 - 107$

$= 193$ kPa

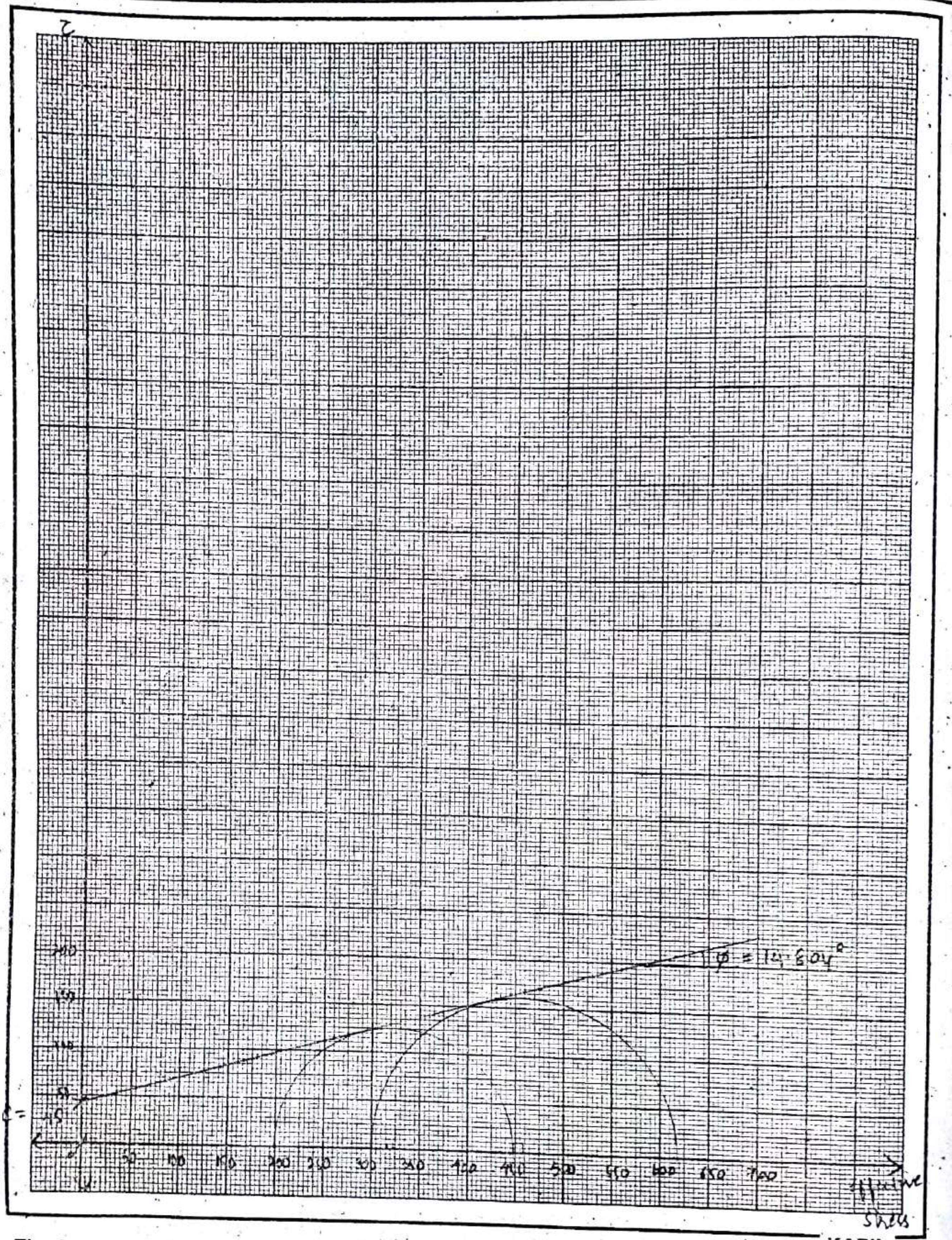
Major effective stress, $\overline{\sigma_1} = \sigma_1 - u$

$= 614 - 107$

$= 507$ kPa

Table of all calculations of total stress and effective stress,

Sample No	σ_3	σ_1	u	$\overline{\sigma_3}$	$\overline{\sigma_1}$
1	200	444	55	145	389
2	300	614	107	193	507



Q23. **The following results were obtained at failure in series of triaxial compression tests, on specimens of clay. Determine the values of shear strength parameters C and ϕ either by drawing Mohr circles or analytically,**

Confining pressure (σ_3), KPa	150	300	450
Deviator stress (σ_d), KPa	192	341	504

Answer :

S.No	Confining pressure (σ_3) (KPa)	Deviator stress (σ_d) (KPa)
1.	150	192
2.	300	341
3.	450	504

Major principal stresses are,

$(150 + 192) = 342$ KPa

$(300 + 341) = 641$ KPa

$(450 + 504) = 954$ KPa

Analytical Method

Average of major principal stresses is, $\sigma_1 = 645.67$ KPa

Average of confining pressure, $\sigma_3 = 300$ KPa

We know that,

$$\sin\phi = \frac{(\sigma_1 - \sigma_3)/2}{(\sigma_1 + \sigma_3)/2}$$

$$\sin\phi = \left[\frac{\frac{645.67 - 300}{2}}{\frac{645.67 + 300}{2}}\right]$$

$$\sin\phi = 0.366$$

$$\phi = 21°$$

$$\sigma_1 = \sigma_3 N_\phi + 2C\sqrt{N_\phi} \qquad (\because N_\phi = \tan^2(45° + \phi/2))$$

$$645.67 = 300 \times 2.117 + 2 \times C \times 1.455$$

$$C = \frac{10.57}{2.91} = 3.63$$

$$\therefore \quad C = 3.63$$

Q24. The following data relate to a triaxial compression test performed on a soil sample,

Test No.	Cell pressure (σ_3), KPa	Maximum deviator stress (σ_d), KPa
1.	80	175
2.	150	240
3.	210	300

Determine the shear parameters such as cohesion and angle of internal friction from the above data using the relation of σ_1 and σ_3.

Answer : Model Paper-II, Q7(b)

Test No. 1

Given that,

Total and effective axial stress at failure, $\sigma_3' = \sigma_3 = 80$ KN/m^2

Maximum Deviator Stress, $\sigma_d = 175$ kN/m^2

$$\therefore \sigma_1 = \sigma_1' = \sigma_3 + \sigma_d.$$

$$= 80 + 175$$

$$\sigma_1' = 255 \text{ KN/m}^2$$

Using the relationship of σ_1 and σ_3, we get,

$$\sigma_1' = \sigma_3' \tan^2\left[45+\frac{\phi'}{2}\right] + 2C' \tan\left[45+\frac{\phi'}{2}\right]$$

$$255 = 80 \tan^2\left[45+\frac{\phi'}{2}\right] + 2C' \tan\left[45+\frac{\phi'}{2}\right] \quad ...(1)$$

Test No.2

Given that,

Total and effective confining stress, $\sigma_3 = \sigma_3' = 150$ kN/m^2

Maximum deviator stress, $\sigma_d = 240$ kN/m^2

$$\sigma_1 = \sigma'_1 = \sigma_3 + \sigma_d$$

$$= 150 + 240$$

$$\sigma'_1 = 390 \text{ kN/m}^2$$

Using the relation of σ_1 and σ_3, we get,

$$\sigma_1' = \sigma_3' \tan\left[45+\frac{\phi'}{2}\right] + 2C' \tan\left[45+\frac{\phi'}{2}\right]$$

$$390 = 150 \tan^2\left[45+\frac{\phi'}{2}\right] + 2C' \tan\left[45+\frac{\phi'}{2}\right] \quad ...(2)$$

By solving equation (1) and (2), i.e., equation (1) – equation (2), we get,

$$-135 = -70 \tan^2\left[45+\frac{\phi'}{2}\right] \quad ...(3)$$

$$1.928 = \tan^2\left[45+\frac{\phi'}{2}\right]$$

$$\tan\left[45+\frac{\phi'}{2}\right] = 1.388$$

$$\tan^{-1}(1.388) = 45 + \frac{\phi'}{2}$$

$$54.228 = 45 + \frac{\phi'}{2}$$

$$\phi' = 18.45$$

Substituting the value of 'ϕ" in equation (1), we get;

$$255 = 80 \tan^2\left[45+\frac{18.45^\circ}{2}\right] + 2C' \tan\left[45+\frac{18.45^\circ}{2}\right]$$

$$255 = 154.08 + 2C^1 \times 1.3878$$

$$100.92 = 2.775\ C'$$

$$C' = \frac{100.92}{2.775}$$

$$\therefore\ C' = 36.36 \text{ kN/m}^2$$

Q25. The following results were obtained from a direct shear test on a sandy clay sample.

Normal laod (N)	Shear load proving ring reading (divisions)
360	13
720	19
1080	26
1440	26

If the shear box is 60 mm square and the proving ring constant is 20 N per division, estimate the shear strength parameters of the soil. Would failure occur on a plane within this soil at a point where the normal stress is 320 kN/m² and the corresponding shear stress is 138 kN/m²?

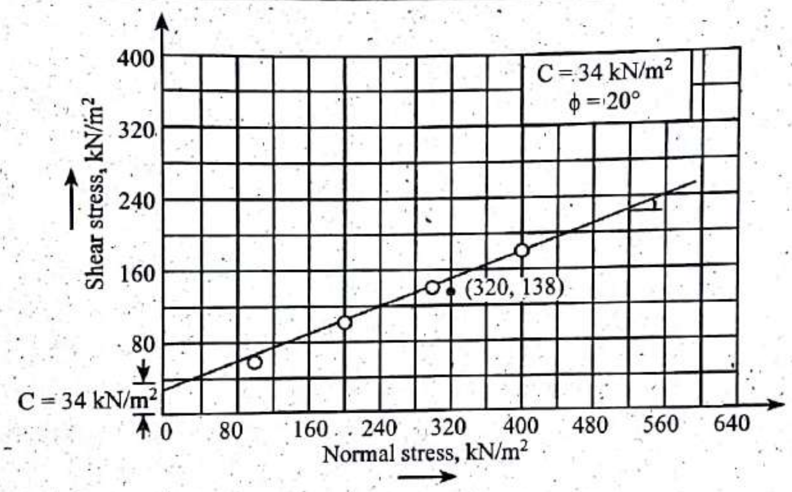
Oct./Nov.-16, Set-2, Q7(b)

Answer :

Given that,

Size of shear box = 60 mm × 60 mm

Normal Load (N)	Proving Ring Daily Reading	Normal Stress (kN/m²)	Shear Stress (kN/m²)
360	13	$360/[(0.06)^2 \times 1000] = 100$	$(13 \times 20)/[(0.06)2 \times 1000] = 72.2$
720	19	200	105.6
1,080	26	300	144.4
4,440	32	400	177.7



The shear stresses are plotted a long y-axis and the normal stresses are plotted on x-axis as shown in graph. The straight line is formed by joining the plotted points. The shear strength parameters obtained are,

$c = 34$ kN/m², $\phi = 20°$

The stress state $\tau = 138$ kN/m², $\sigma_n = 320$ kN/m² point under the failure envelope and thus do not cause any failure.

Q26 The following are the results of four drained direct shear test on a normally consolidated clay. Diameter of the specimen = 50 mm, thickness of the sample is 25 mm.

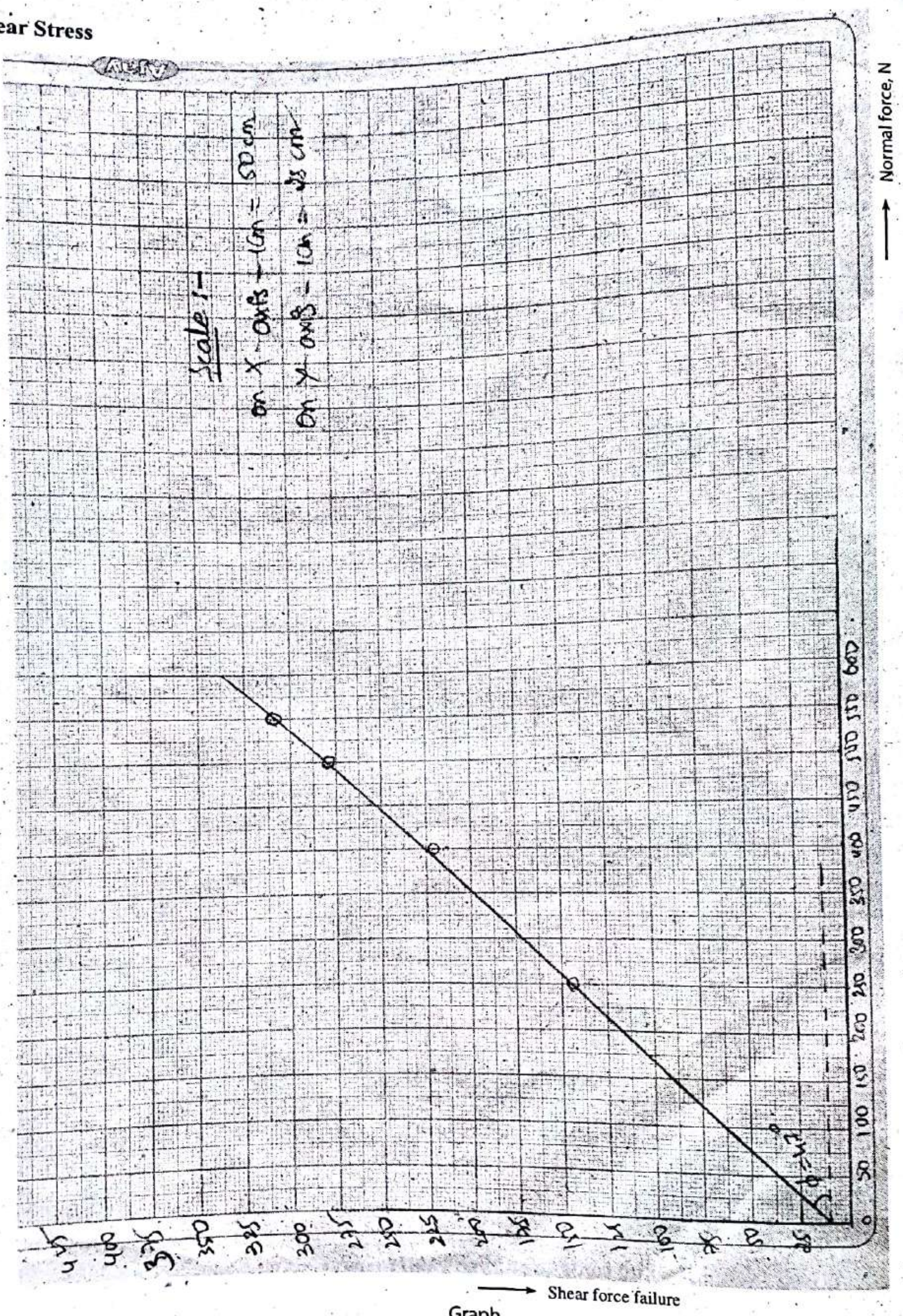
Test Number	1	2	3	4
Normal force (N)	250	400	500	550
Shear force at failure (N)	139	222	279	308

Draw a graph for the shear stress at failure against the normal stress and determine the drained shear strength parameters from the graph.

April/May-13, Set-2, Q8(b)

Answer :

Graph of Shear Stress



Graph

Drained Shear Stress Parameters

The drained shear-strength parameters from the graph such as 'ϕ' and 'c' are given as 47° and 10 kN/m^2

$\therefore \quad \phi = 47°$

and $c = 10$ kN/m^2.

Q27. The following data was obtained in a direct shear test. Normal pressure = 20 kN/m², tangential pressure = 16 kN/m². Angle of internal friction = 20°, cohesion = 8 kN/m². Represent the data by Mohr's circle and compute the principal stresses and the direction of the principal planes.

Answer : (April/May-13, Set-3, Q8 | Model Paper-IV, Q7(b))

Given that,

Normal pressure, $\sigma_n = 20$ kN/m²

Tangential pressure = 16 kN/m²

Angle of internal friction, $\phi = 20°$

Cohesion, $c = 8$ kN/m²

Analytical Calculation

$$\sigma_a = \sigma_b N_\phi + 2c\sqrt{N_\phi}$$

$$N_\phi = \tan^2(45 + \phi/2)$$

$$= \tan^2(45 + 20/2)$$

$$= \tan^2(55°)$$

$$N_\phi = 2.04$$

$$\sigma_a = 2.04\ \sigma_b + 2 \times 8 \times \tan 55°$$

$$\sigma_a = 2.04\ \sigma_b + 22.850 \quad \text{... (1)}$$

Normal pressure, $\sigma_n = \sigma_a \cos^2 55° + \sigma_b \sin^2 55°$

$$20 = 0.33\ \sigma_a + 0.67\ \sigma_b \quad \text{... (2)}$$

Solving equations (1) and (2), we get,

$\sigma_a - 2.04\ \sigma_b = 22.850$

$\sigma_a + 2.03\ \sigma_b = 60.60$ Divide equation (2) with 0.33

$4.07\ \sigma_b = 37.75$

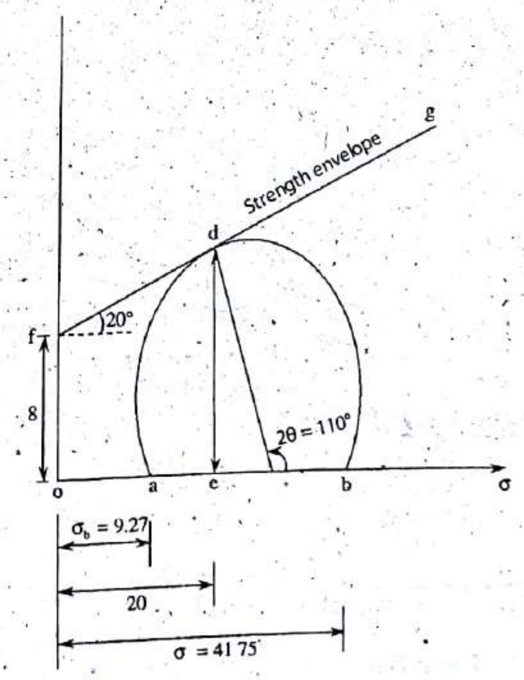
$$\therefore \sigma_b = 9.27 \text{ kN/m}^2$$

Substituting σ_b value in equation (2), we get,

$$20 = 0.33\ \sigma_b + 6.210$$

$$0.33\ \sigma_a = 13.789$$

$$\therefore \sigma_b = 41.75 \text{ kN/m}^2$$



Construction Steps

(i) The cohesion and angle of internal friction are given. So, the strength envelope '*fg*' is located.

(ii) With respect to origin the coordinates of point '*d*' are (20, 16) is located on the strength envelope '*fg*'.

(iii) With respect to '*fd*' draw a perpendicular line that meets *x*-axis at '*c*' which denotes '*dc*'.

(iv) With '*cd*' as radius and taking '*c*' as centre draw the Mohr's circle.

(v) According to the analytical calculations obtained plot the values.

(vi) Here '*oa*' and '*ob*' represents principal stresses i.e., $\sigma_b = 9.2$ kN/m² and $\sigma_a = 42.75$ kN/m².

(vii) With the help of protractor measure the angle '*bcd*' and it is found to be 110°.

(viii) Here 55° (Clockwise) is inclined to major principal plane and 35° (counter clockwise) to minor principal plane of the shear.

Q28. In a direct shear test on a specimen of clean dry sand, a normal stress of 180 kPa was applied and failure occurred at a shear stress of 100 kPa. Determine analytically the angle of shearing resistance, the principal stresses during failure, and directions of the principal planes with respect to the direction of the plane of shearing.

Answer : Oct./Nov.-16, Set-4, Q7(b)

Given that,

Normal stress, $\sigma = 180$ kN/m²

Shear stress, $\tau = 100$ kN/m²

(i) According to Coulomb's law, we have $T_f = c + \sigma \tan\phi$

Therefore, $100 = 0 + 180 \tan\phi$, or $\tan\phi = 100/180 = 0.556$

Hence,

$$\phi = \tan^{-1}(0.556) = 29.07°$$

(ii) Principal Stresses

The major principal stress $\sigma_1 = \sigma + \dfrac{T_f}{\tan(45-\phi/2)} = 180 + \dfrac{100}{\tan(45-29.07)} = 350.004 \text{ kN/m}^2$

The minor principal stress $\sigma_3 = 180 - \dfrac{100}{\tan(45+29.07/2)} = 180 - \dfrac{100}{1.7} = 127.17 \text{ kN/m}^2$

(iii) The minor principal Q-plane makes an angle [45 – (ϕ/2)] in the anticlockwise direction with the plane of shearing, i.e., 45 – 29.07/2 = 30.465. The major principal plane makes an angle [45 + (ϕ/2)] in the clockwise direction with the plane of shearing, i.e., 45 + (29.07/2) = 59.53°. The direction of the major and minor principal planes with reference to the plane of shearing are shown in figure below.

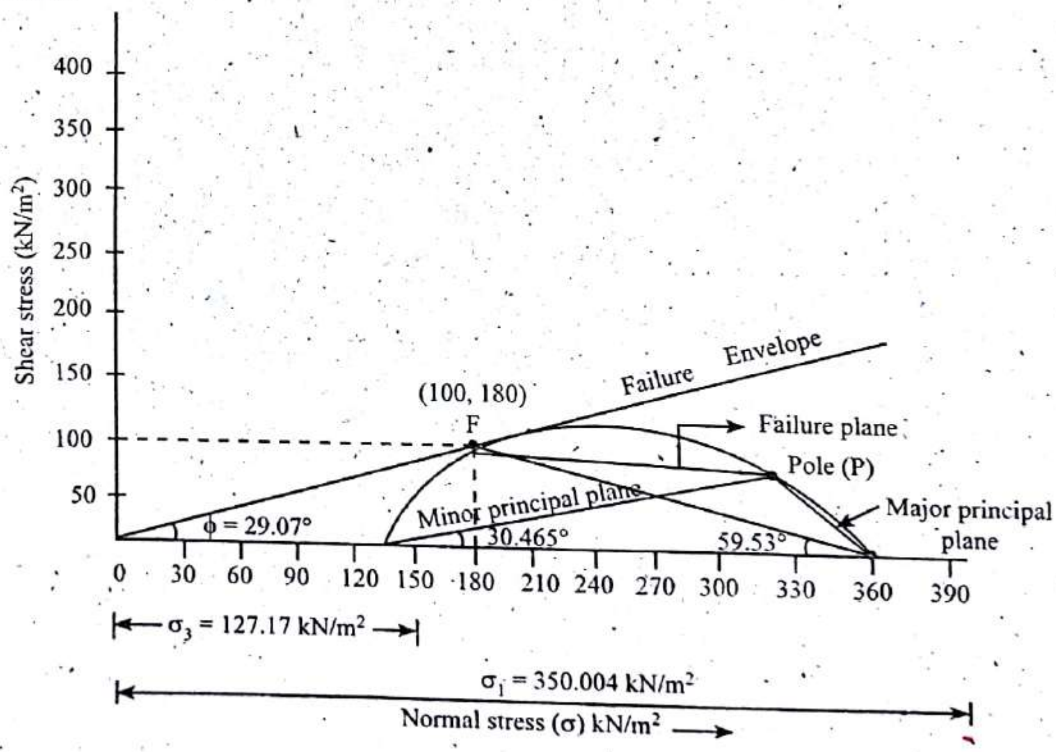


Figure: Mohr's Circle for Direct Shear Test

Q29. The flowing test results are obtained from the direct shear test. Compute the shear strength parameters. Dimensions of the sample is 6 cm × 6 cm × 2 cm.

Normal stress (kg/cm^2)	0.3	0.4	0.5	0.6	0.7
Shear load (kg)	7.85	10.46	13.08	15.70	18.30

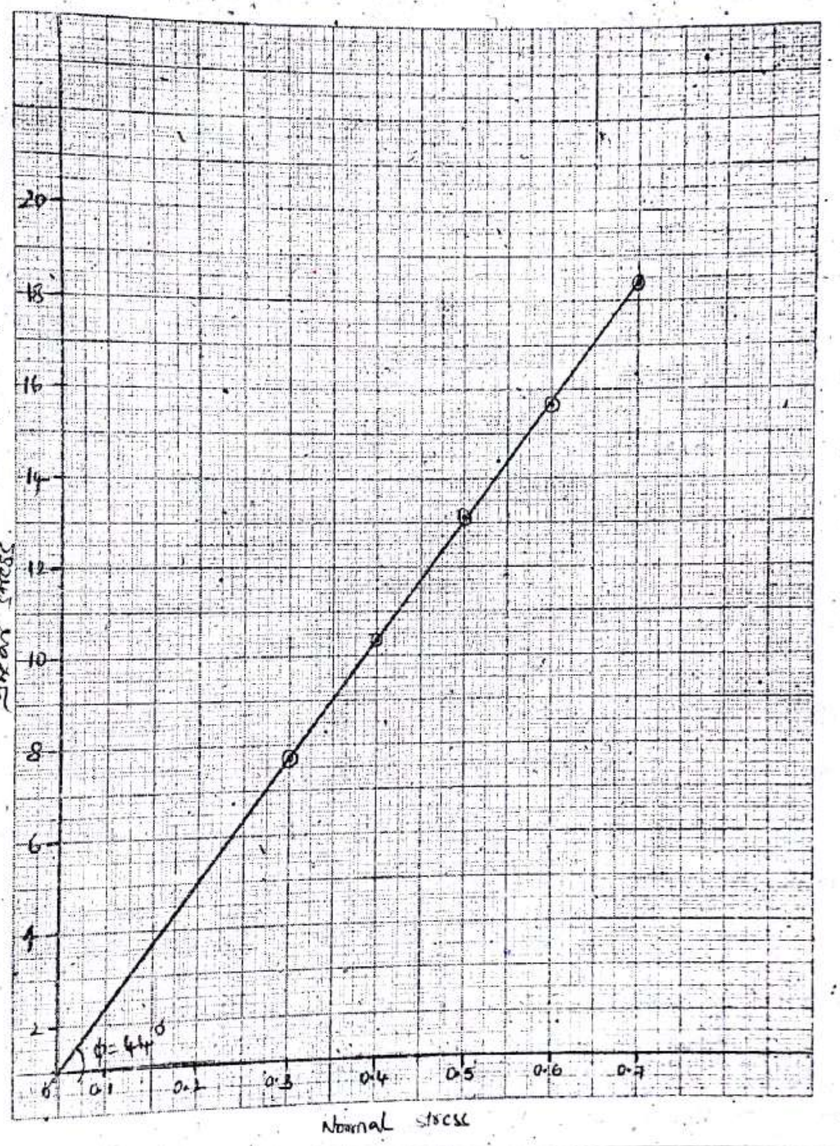
Answer : May/June-14, Set-4, Q8(b)

The normal and shear stresses on the failure plane is plotted on a graph.

Results obtained from the graph are as follows,

Cohesion intercept, $C = 0^\circ$.

Angle of shear resistance, $\phi = 44^\circ$



Q30. A cylindrical specimen of a saturated soil fails under an axial stress of 150 kpa in an unconfined compression test. The failure plane makes angle of 55° with the horizontal. Calculate the cohesion and angle of internal friction of the soil.

Answer :

Given that,

Axial stress, $\sigma_1 = 150$ KPa $= 150$ kN/m^2

Angle of failure plane, $\theta = 55^\circ$

The failure plane angle with respect to the plane on which the major principle axial stress acts is,

$$\theta = 45° + \phi/2$$

$$55° = 45° + \phi/2$$

$$10 = \phi/2$$

$$\phi = 20°$$

Therefore Angle of internal friction is, $\phi = 20°$

We know that,

$$\sigma_1 = \sigma_3 N_\phi + 2C\sqrt{N_\phi} \; (\sigma_3 = 0) \quad \ldots(1)$$

$$150 \text{ kN/m}^2 = 0 + 2C\sqrt{N_\phi}$$

But, $N_\phi = \tan^2(45° + \phi/2)$

$$N_\phi = \tan^2(45° + 10°) \qquad [\because \phi = 20°]$$

$$\sqrt{N_\phi} = \tan 55°$$

$$N_\phi = \tan^2 55°$$

Subsituting $\sqrt{N_\phi}$ in equation (1),

We get,

$$150 = 2\,C\,(\tan 55°)$$

$$75 = C\,(\tan 55°)$$

$$C = \frac{75}{1.428} = 52.52 \text{ kN/m}^2$$

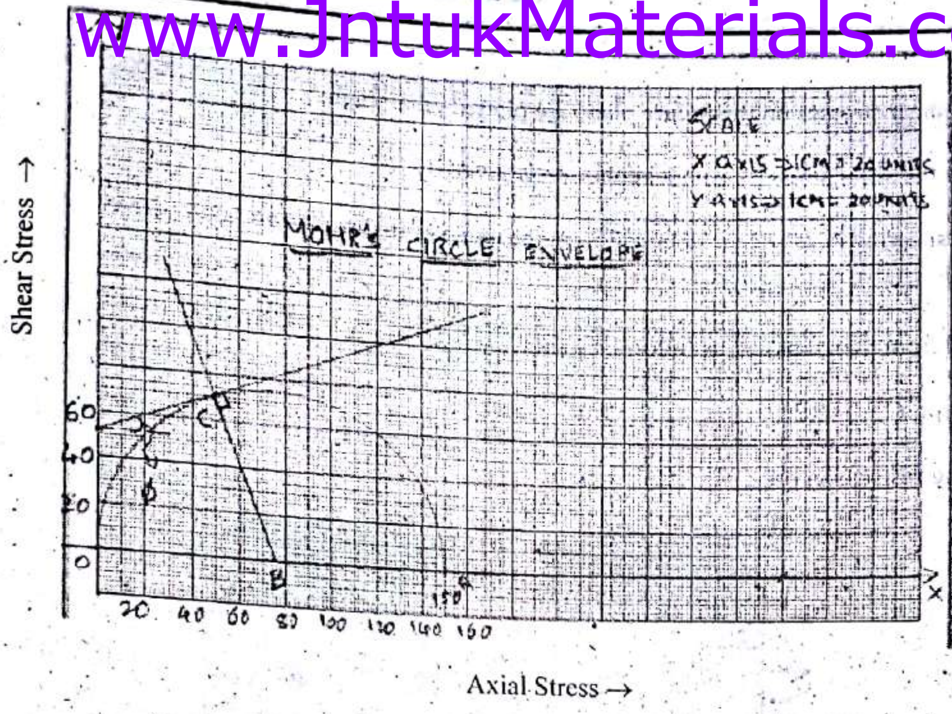
Therefore, the cohesion, $C = 52.52$ kN/m^2

Graphical Solution

This problem can also be done in graphical method.

Steps

1. Axial stress and shear stress is plotted on a graph in 'x' and 'y' axis respectively
2. Take suitable scale on the graph, as 'OA'
3. With OA as diameter draw Mohr's circle
4. Take 'B' as the centre of OA and draw an arc, whi[illegible] intersect x-axis at 'O' and 'A'
5. Take angle ABC as $2 \times 55° = 110°$ and cut the circle at point C
6. Draw a tangent passing through the point 'C' and intersect y-axis at some point, which gives the value of cohesion as 52.52 kN/m^2
7. The angle of friction is then determined with the horizontal, as 20°
8. Values obtained from graphical method and analytical method match equally.

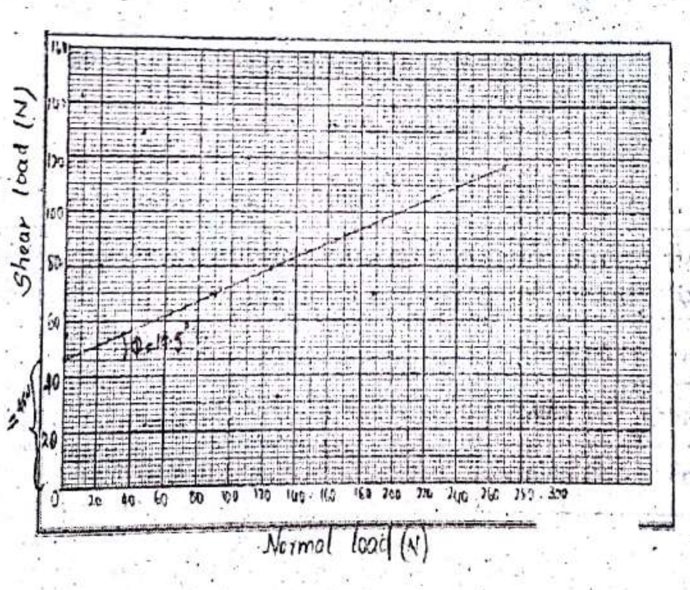


Graph

Q31. A series of box shear (area of box = 36 cm^2) tests were conducted on a soil sample. For the results presented in below table, estimate the cohesion and angle of internal friction of soil

Normal load (N)	90	180	270
Shear load (N)	70	90	117

Answer :



Graph

From graph,

Cohesion of soil, $C = 46$N

Angle of internal friction, $\phi = 14.5°$.

Q32. The following results were obtained in a shear box test. Determine the angle of shearing resistance and cohesion intercept,

Normal stress (kPa)	100	200	300
Shear stress (kPa)	130	185	240

Answer :

The normal and shear stresses on the failure plane are plotted on a graph.

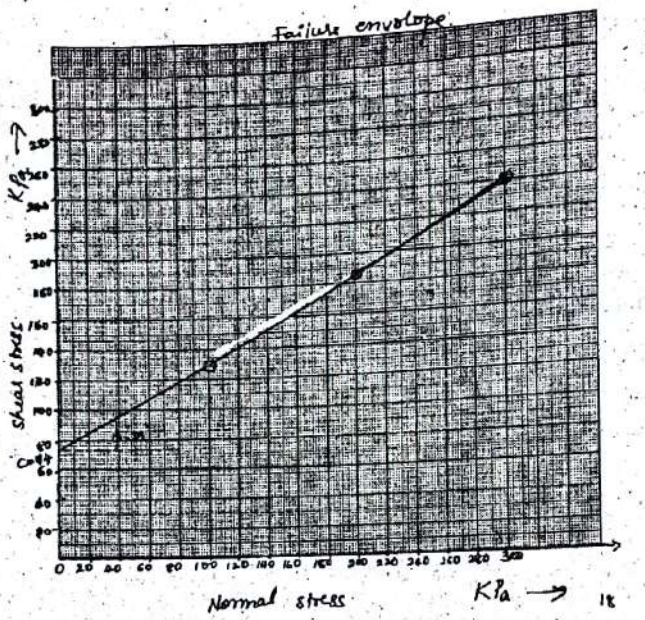
The intercept for the shear stress axis under cohesion is given by 'C'.

'ϕ', the angle of shearing resistance is obtained from the angle of inclination on failure envelope plotted with the normal stress axis.

Results obtained from the graph are as follows,

Cohesion intercept, $C = 74$ kPa

Angle of shearing resistance, $\phi = 29°$



Graph

Q33. Given the following data from a consolidated undrained test with pore water pressure measurement, determine the total and effective determine the total and effective stress parameters.

σ3	99 kN/m²	201 kN/m²
$(\sigma_1 - \sigma_3)$	155 kN/m²	197 kN/m²
u_f	58 kN/m²	138 kN/m².

Answer : Nov.-15, Set-3, Q7(c)

Given values are,

σ_3	99 kN/m²	201KN/m²
$(\sigma_1 - \sigma_3)$	155 kN/m²	197KN/m²
u_f	58 KN/m²	138 KN/m²

(a) Calculation Of Total Stresses

$\sigma_3 = 99$ kN/m² (From given) ....(1)

$(\sigma_1 - \sigma_3)_f = 155$ kN/m² (From given) .... (2)

Sub equation(1) in (2) we get

$\sigma_1 = 155 + \sigma_3$

$\sigma_1 = 155 + 99$

$\sigma_1 = 254$ kN/m²

$\sigma_3' = 201$ kN/m², then

$\sigma_1' = 201 + 197 = 398$ KN/m²

(b) Calculation Of Effective Stresses

$U_f = 58$ kN/m²	$U_f = 138$ kN/m²
$\overline{\sigma_3} = 99 - 58$	$\overline{\sigma_3} = 201 - 138$
$\overline{\sigma_3} = 41$ kN/m²	$\overline{\sigma_3} = 63$ kN/m²
$\overline{\sigma_1} = 254 - 58$	$\overline{\sigma_1} = 398 - 138$
$\overline{\sigma_1} = 196$ kN/m²	$\overline{\sigma_1} = 260$ kN/m²

Graphical Procedure For Determining Total and Effective Stress Parameters

Step:1 Take scale 1 unit = 20 kN/m² on both x and y axes.

Step:2 Let x–axis represents the normal stress in kN/m² and y–axis represents the shear stress in kN/m²

Step:3 Take the average of σ_1 and σ_3 and consider it as a origin point.

Step:4 With the help of compass, draw a semicircle on normal stress ie x–axis with average of σ_1 and σ_3 as origin (represented by dark line in graph).

Step:5 Similar procedure is repeated for σ_3^1 and σ_1^1

Step:6 Now draw the line in such a way that the line should touch both the semicircles (represented by dark straight line)

Step:7 The value of 'C' is equal to the line touching on the y–axis which are obtained from graph.[Refer Q36]

Step:8 The value of 'ϕ' is equal to the straight line making angle with the horizontal axis which are obtained from graph.

Step: 9 The parameters of total stresses are determined.

Step: 10 The parameters of the effective stresses i.e C' and ϕ' can also be determined using the above similar procedure.

Step:11 Hence the parameters of total stresses and effective stresses are calculated and showed in graph.

Q34. Given the following data from a consolidated undrained test with pore water pressure measurement, determine the total and effective stress parameters:

σ_3	100 KN/m²	200 KN/m²
$(\sigma_1 - \sigma_3)$	150 KN/m²	192 KN/m²
u_f	60 KNm²	140 KN/m².

Answer : Nov.-15, Set-1, Q7(c)

Given that,

σ_3	100 kN/m²	200KN.m²
$(\sigma_1 - \sigma_3)_f$	50 kN/m²	192KN/m²
u_f	60 KN/m²	140 KN/m²

(a) Calculation Of Total Stresses

$\sigma_3 = 100$ kN/m² (From given) ....(1)

$(\sigma_1 - \sigma_3)_f = 150$ kN/m² (From given) .... (2)

Sub equation(1) in (2) we get

$\sigma_1 = 150 + \sigma_3$

$\sigma_1 = 150 + 100$

$\sigma_1 = 250\ KN/m^2$

Similarly

$\sigma_3^1 = 200\ KN/m^2$, then

$\therefore \sigma_1^1 = 200 + 192 = 392 KN/m^2$

(b) Calculation Of Effective Stresses

$U_f = 60KN/m^2$	$U_f = 140KN/m^2$
$\overline{\sigma_3} = 100 - 60$	$\overline{\sigma_3} = 200 - 140$
$= 40KN/m^2$	$= 60KN/m^2$
$\overline{\sigma_1} = 250 - 60$	$\overline{\sigma_1}\ 392 - 140$
$= 190\ KN/m^2$	$= 252KN/m^2$

Graphical Procedure For Determining Total and Effective Stress Parameters

Step:1 Take scale 1 unit = 20KN/m² on both x and y axes.

Step:2 Let x–axis represents the normal stress in KN/m²and y–axis represents the shear stress inKN/m².

Step:3 Take the average of σ_1 and σ_3 and consider it as a origin point.

Step:4 With the help of compass, draw a semicircle on normal stress i.e x–axis with average of σ_1 and σ_3 as origin (represented by drak line in graph).

Step:5 Similar procedure is repeated for σ_3^1 and σ_1^1.

Step:6 Now draw the line in such a way that the line should touch both the semicircles (represented by drak straight line)

Step:7 The value of 'C' is equal to the line touching on the y–axis which are obtained from graph [Refer: Q36 graph]

Step:8 The value of ϕ, is equal to the straight line making angle with the horizontal axis which are obtained from graph.

Step: 9 The parameters of total stresses are determined.

Step: 10 The parameters of the effective stresses i.e C' and ϕ' can also be determined using the above similar procedure.

Step:11 Hence the parameters of total stresses and effective stresses are calculated and showed in graph

Q35. Given the following data from a consolidated undrained test with pore water pressure measurement, determine the total and effective stress parameters:

σ3	100kN/m²	200kN/m²
(σ1– σ3)	157kN/m²	199kN/m²
u_f	57 kN/m²	136 kN/m²

Nov.-15, Set-2, Q7(c)

Answer :

Given values are,

σ_3	100 kN/m^2	200KN.m^2
$(\sigma_1-\sigma_3)_f$	157 kN/m^2	199KN/m^2
u_f	57 KN/m^2	136 KN/m^2

(a) Calculation Of Total Stresses

σ_3 = 100 kN/m^2 (From given) ....(1)

$(\sigma_1-\sigma_3)_f$ = 157 KN/m^2 (From given) .... (2)

Sub equation(1) in (2) we get

$\sigma_1 = 157 + \sigma_3$

$\sigma_1 = 157 + 100$

$\sigma_1 = 257$ KN/m^2

Similarly

$\sigma_3' = 200$ KN/m^2, then

$\sigma_1' = 200 + 199 = 399$KN/m^2

(b) Calculation OF Effective Stresses

$U_f = 57$**KN/m^2**	$U_f = 136$**KN/m^2**
$\overline{\sigma_3} = 100 - 57$	$\overline{\sigma_3} = 200 - 136$
$\overline{\sigma_3} = 43$KN/m^2	$\overline{\sigma_3} = 64$KN/m^2
$\overline{\sigma_1} = 257 - 57$	$\overline{\sigma_1} = 399 - 136$
$\overline{\sigma_1} = 200$ KN/m^2	$\overline{\sigma_1} = 263$KN/m^2

Graphical Procedure For Determining Total and Effective Stress Parameters

Step:1 Take scale 1 unit = 20KN/m^2 on both x and y axes

Step:2 Let x–axis represents the normal stress in KN/m^2 and y–axis represents the shear stress in KN/m^2.

Step:3 Take the average of σ_1 and σ_3 and consider it as a origin point.

Step:4 With the help of compass, draw a semicircle on normal stress i.e x–axis with average of σ_1 and σ_3 as origin (represented by drak line in graph)

Step:5 Similar procedure is repeated for σ_3^1 and σ_1^1.

Step:6 Now draw the line in such a way that the line should touch both the semicircles (represented by drak straight line)

Step:7 The value of 'C' is equal to the line touching on the y–axis which are obtained from graph.[Refer Q36]

Step:8 The value of 'ϕ is equal to the straight line making angle with the horizontal axis which are obtained from graph

Step: 9 The parameters of total stresses are determined.

Step: 10 The parameters of the effective stresses i.e C' and ϕ' can also be determined using the above similar procedure.

Step:11 Hence the parameters of total stresses and effective stresses are calculated and showed in graph.

Q36. **Given the following data from a consolidated undrained test with pore water pressure measurement, determine the total and effective stress parameters:**

σ_3	100 kN/m^2	200 kN/m^2
$(\sigma_1 - \sigma_3)$	156 kN/m^2	198 kN/m^2
u_f	58 kN/m^2	138 kN/m^2

Answer : Nov.-15, Set-4, Q7(b)

Given values are,

σ_3	100 kN/m^2	200 kN/m^2
$(\sigma_1 - \sigma_3)$	156 kN/m^2	198 kN/m^2
u_f	58 kN/m^2	138 kN/m^2

(a) Calculation of Total Stresses

$$\sigma_3 = 100 \text{ kN/m}^2 \text{ (From given)} \quad \text{... (1)}$$

$$(\sigma_1 - \sigma_3)_f = 156 \text{ kN/m}^2 \text{ (From given)} \quad \text{... (2)}$$

Substitute equation (1) in (2), we get,

$$\sigma_1 = 156 + \sigma_3$$

$$\sigma_1 = 156 + 100$$

$$\sigma_1 = 256 \text{ kN/m}^2$$

Similary,

$$\sigma_3' = 200 \text{ kN/m}^2, \text{ then}$$

$$\sigma_1' = 200 + 198 = 398 \text{ kN/m}^2$$

(b) Calculation of Effective Stresses

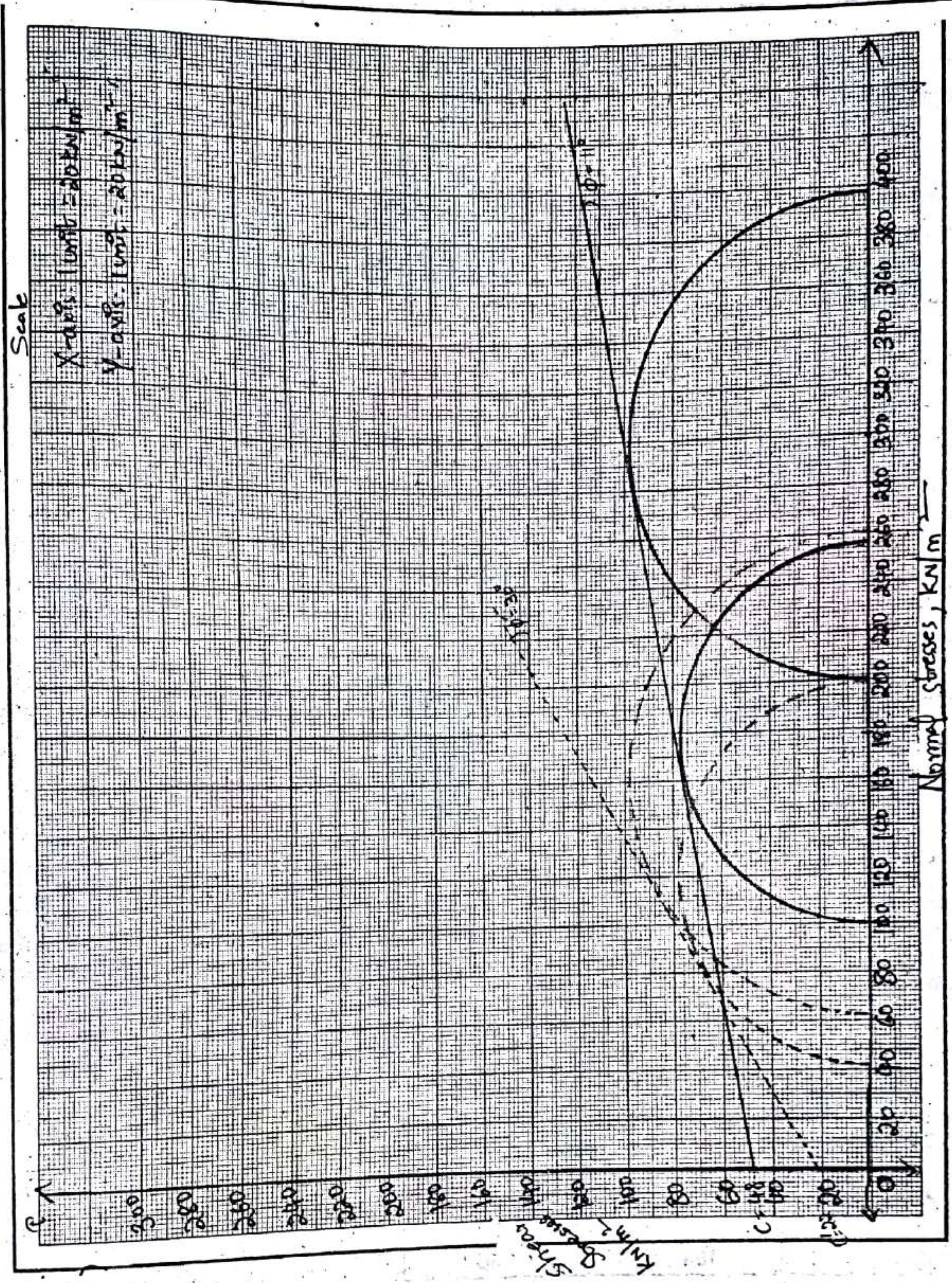
$$u_f = 58 \text{ kN/m}^2 \quad ; u_f = 138 \text{ kN/m}^2$$

$$\overline{\sigma_3} = 100 - 58 \qquad \overline{\sigma_3} = 200 - 138$$

$$\overline{\sigma_3} = 42 \text{ kN/m}^2 \qquad \overline{\sigma_3} = 62 \text{ kN/m}^2$$

$$\overline{\sigma_1} = 256 - 58 \qquad \overline{\sigma_1} = 398 - 138$$

$$\overline{\sigma_1} = 198 \text{ kNm}^2 \qquad \overline{\sigma_1} = 260 \text{ kN/m}^2$$



Graphical Procedure for Determining Total and Effective Stress Parameters

Step 1

Take scale 1 unit = 20 kN/m² on both x and y axes.

Step 2

Let x-axis represents the normal stress in kN/m² and y-axis represents the shear stress in kN/m².

Step 3

Take the average of σ_1 and σ_2 and consider it as a origin point.

Step 4

With the help of compass, draw a semicircle on normal stress i.e., x-axis with average of σ_1 and σ_3 as origin (represented by drak line in graph).

Step 5

Similar procedure is repeated for σ_3' and σ_1'.

Step 6

Now draw the line in such a way that the line should touch both the semicircles (represent by drak straight line).

Step 7

The value of 'C' is equal to the line touching on the y-axis i.e., $C = 48$.

Step 8

The value of 'ϕ' is equal to the straight line making angle with the horizontal axis i.e., $\phi = 11°$.

Step 9

The parameters of total stresses are determined.

Step 10

The parameters of the effective stresses i.e., C' and ϕ' on also be determined using the above similar procedure. The parameter of effective stresses are,

$C' = 22$ and $\phi' = 30$

Step 11

Hence, the parameters of total stresses and effective stresses are calculated and showed in graph.

Q37. Undrained triaxial with pore pressure measurement have been performed on three samples of a particular soil, after consolidation to different cell pressures. What information (strength parameters) can be obtained from the results given below?

Cell Pressure (kPa)	Failure Deviator Stress (kPa)	Failure Pore Pressure (kPa)
24	31	12
48	76	18
72	104	30

May/June-14, Set-1, Q8(b)

Answer :

	Cell Pressure (kPa)	Failure Deviator Stress (kPa)	Failure Pore Pressure (kPa)
Sample I	24	31	12
Sample II	48	76	18
Sample III	72	104	30

Calculating Total Stress and Effective Stress

Sample-I

Cell pressure, $\sigma_3 = 24$

Major principle stress, $\sigma_1 = \sigma_3 + \text{Deviator Stress}$

$= 24 + 31 = 55$

Pore pressure, $u = 12$ kPa

Effective stress, $\overline{\sigma}_3 = \sigma_3 - u$

$= 24 - 12$

$= 12$

Major effective stress, $\overline{\sigma}_1 = \sigma_1 - u$

$= 55 - 12$

$= 43$

Sample-II

Cell pressure, $\sigma_3 = 48$

Major principle stress, $\sigma_1 = \sigma_3 + \text{Deviator Stress}$

$= 48 + 7$

$= 124$

Pore water pressure, $u = 18$

Effective stress, $\overline{\sigma}_3 = \sigma_3 - u$

$= 48 - 18$

$= 30$

Major effective stress, $\overline{\sigma}_1 = \sigma_1 - u$

$= 128 - 18$

$= 110$

Sample-III

Cell pressure, $\sigma_3 = 72$

Major principle stress, $\sigma_1 = \sigma_3 + \text{Deviator Stress}$

$= 72 + 104$

$= 176$

Pore water pressure, $u = 30$

Effective stress, $\overline{\sigma}_3 = (\sigma_3 - u)$

$= 72 - 30$

$= 42$

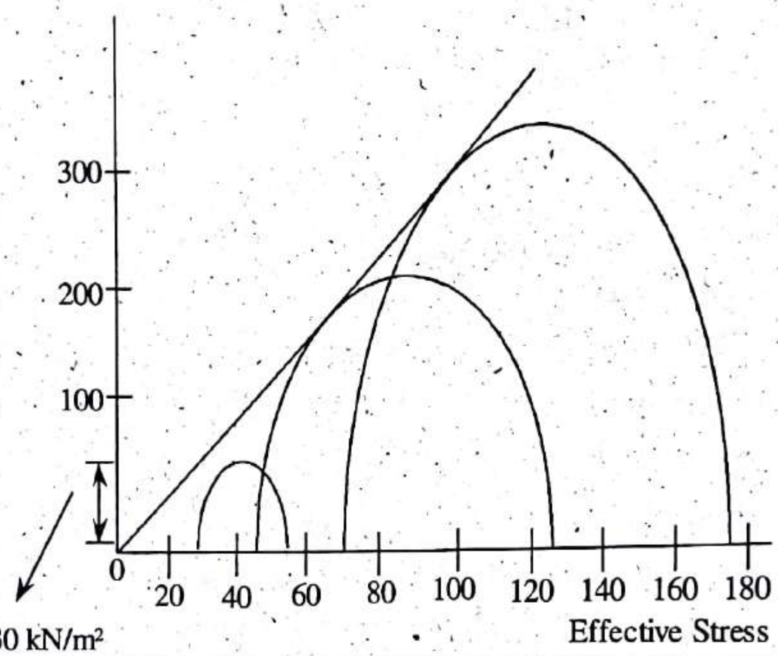
Ma,or effective stress, $\overline{\sigma}_3 = (\sigma_1 + u)$

$= 176 + 30$

$= 206$

Table of all calculations of total stress and effective stress,

Sample No	σ_3	σ_1	u	$\bar{\sigma}_3$	$\bar{\sigma}_1$
1	24	55	12	12	43
2	48	124	18	30	110
3	72	176	30	42	206



Q38. Given the following data from a consolidated undrained test with pore water pressure measurement, determine the total and effective stress parameters:

$\sigma 3$	99 kN/m^2	201 kN/m^2
$(\sigma 1-\sigma 3)$	155 kN/m^2	197 kN/m^2
u_f	58 kN/m^2	138 kN/m^2.

Answer :

Nov.-15, Set-3, Q7(c)

Given values are

σ_3	99 kN/m^2	201KN/m^2
$(\sigma_1-\sigma_3)$	155 kN/m^2	197KN/m^2
u_f	58 KN/m^2	138 KN/m^2

(a) Calculation Of Total Stresses

$\sigma_3 = 99$ kN/m^2 (From given) ....(1)

$(\sigma_1-\sigma_3)_f = 155$ kN/m^2 (From given) .... (2)

Sub equation(1) in (2) we get

$\sigma_1 = 155 + \sigma_3$

$\sigma_1 = 155 + 99$.

$\sigma_1 = 254$ kN/m^2

$\sigma_3' = 201$ kN/m^2, then

$\sigma_1' = 201 + 197 = 398$ KN/m^2

(b) Calculation Of Effective Stresses

$U_f = 57$ kN/m^2	$U_f = 136$ kN/m^2
$\overline{\sigma_3} = 99 - 58$	$\overline{\sigma_3} = 201 - 138$
$\overline{\sigma_3} = 41$ kN/m^2	$\overline{\sigma_3} = 63$ kN/m^2
$\overline{\sigma_1} = 254 - 58$	$\overline{\sigma_1} = 398 - 138$
$\overline{\sigma_1} = 196$ kN/m^2	$\overline{\sigma_1} = 260$ kN/m^2

Graphical Procedure For Determining Total and Effective Stress Parameters

Step:1 Take scale 1 unit = 20 kN/m^2 on both x and y axes.

Step:2 Let x–axis represents the normal stress in kN/m^2 and y–axis represents the shear stress in kN/m^2 and y–axis represents the stare stress in kN/m^2

Step:3 Take the average of σ_1 and σ_3 and consider it as a origin point.

Step:4 With the help of compass, draw a semi circle on normal stress ie x–axis with average of σ_1 and σ_3 as origin (represented by dark line in graph).

Step:5 Similar procedure is repeated for σ_3^1 and σ_1^1.

Step:6 Now draw the line in such a way that the line should touch both the semicircles (represented by dark straight line)

Step:7 The value of 'C' is equal to the line touching on the y–axis which are obtained from graph.[Refer set-4,7(b)]

Step:8 The value of 'ϕ' is equal to the straight line making angle with the horizontal axis which are obtain from graph.

Step: 9 The parameters of total stresses are determined.

Step: 10 The parameters of the effective stresses i.e C' and ϕ' can also be determined using the above similar procedure.

Step:11 Hence the parameters of total stresses and effective stresses are calculated and showed in graph.

Q38. Explain the limitations of shear box test.

Answer : Nov.-15, Set-2, Q7(a) M[4]

For answer refer Unit-VI, Q3, Topic: Disadvantages of direct shear test.

Q39. Name different lab shear tests on soils.

Answer : Nov.-15, Set-2, Q7(b) M[4]

For answer refer Unit-VI, Q1.

6.2 STRESS – STRAIN BEHAVIOUR OF SANDS – CRITICAL VOID RATIO – STRESS – STRAIN BEHAVIOUR OF CLAYS – SHEAR STRENGTH DETERMINATION

Q41. Explain the shear characteristics of sand?

Oct./Nov.-16, Set-3, Q7(a)

OR

Explain briefly the shearing strength of the sands.

Model Paper-II, Q7(a)

Answer :

The shearing strength of soil is defined as the resistance offered to the shear stresses and shear deformation by the soil.

1. For cohesion less soils, shear strength rely upon the angle of internal friction 'ϕ', which itself depends upon many other factors including normal pressure on the failure plane.
2. The outcome of the shear tests will be affected by the type of stresses considered (total stresses or effective stresses)
3. It is also affected by the type of tests such as direct shear or triaxial compression tests.
4. Under the influence of different normal stresses, number of soil samples are tested and for each stress-strain curve is drawn, which shows the behaviour of sample under each normal stress.
5. But only the effective stresses are capable of activating the shear strength.

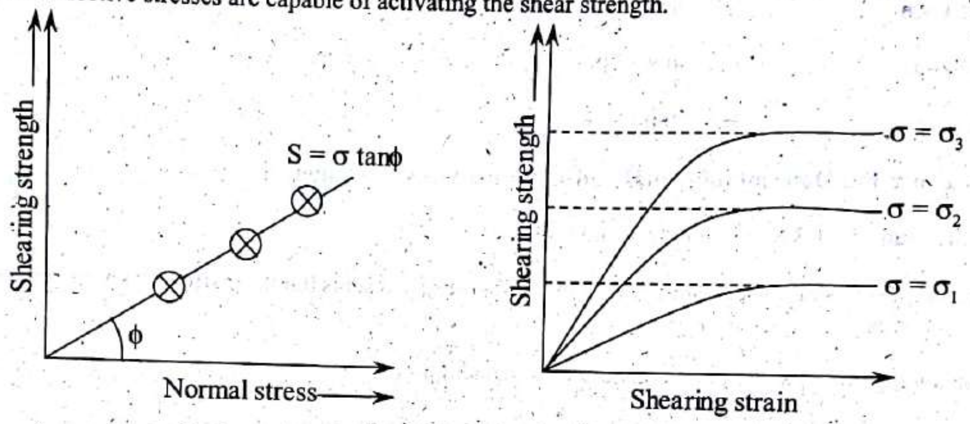


Figure (1)

The normal stress versus shearing strength diagram provides the coloumb strength envelop, which is a straight line passing through the origin and making an angle ϕ with the normal stress axis.

In case of dry cohesion less soils, the maximum shear strength values are assumed to pass through origin which is obtained by failure envelope of ultimate shear strength.

In case of saturated soils, it is similar as cohesionless soils only if the plot is in terms of effective stresses.

In case of dense sands the value of ϕ will be larger than that of ultimate shear strength values.

Case (i) : Failure Envelope For Moist Sand

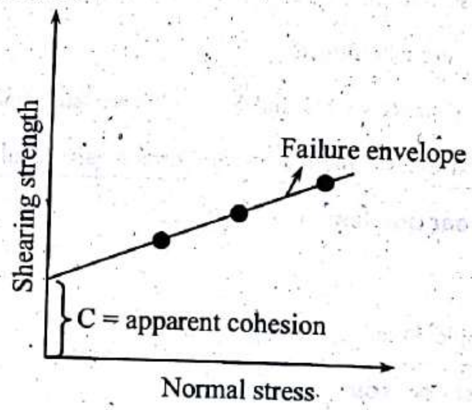


Figure (2)

In case of moist sand, the failure envelope is a straight line but does not passes through the origin. It makes an intercept on shear strength axis, which is termed as apparent cohesion. The value of angle of internal friction is obtained by drawing Mohr's circles.

Case (ii) : Failure Envelope For Saturated Sand (Drained Test)

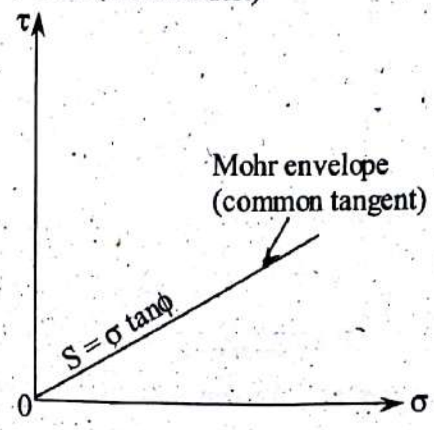


Figure (3)

In the case of saturated soil, under drained triaxial compression tests the results are similar but, the line or the failure envelope passes through the origin making an angle of friction ϕ. No apparent cohesion is observed in this test.

Case (iii) : Failure Envelope For Saturated Sand (Undrained Test)

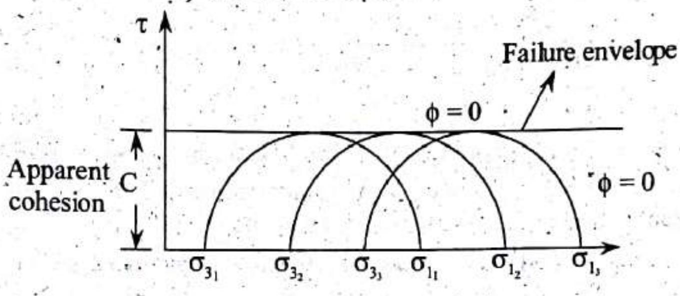


Figure (4)

The failure envelope for saturated soil under undrained triaxial tests is horizontal making an intercept (C) on shearing strength axis.

The angle of internal friction in zero is this case .Mohr's circles are plotted in terms of effective stresses $(\bar{\sigma})$.

Q42. Explain dilatancy test.

Answer :

Dilatancy Test

Initially, take a soil sample of 5 c.c and mix it with water till the soil gets saturated. Place a pat of soil on the palm of hand and shake it horizontally by striking the soil with other hand. Now, the soil sample is squeezed between the fingers.

This process is continued till the water appears or disappears to form a positive reaction.

There are mainly three reactions which are observed in dilatancy test.

1. If water appears or disappears rapidly then the reaction is called as quick reaction.
2. If water appears or disappears slowly then the reaction is called as slow reaction.
3. If the water condition does not appear to change then no reaction will exists.

Example :

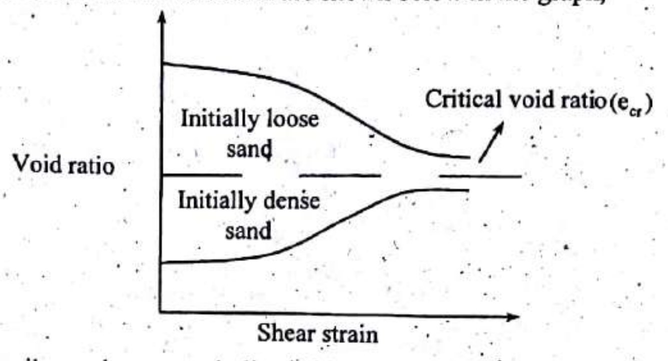
- Silts and fine sands exhibits quick reaciton
- Clays exhibits slow reaction.

Q43. Explain critical void ratio.

Answer :

Critical void ratio is defined as the void ratio at which there is no change in sand with an increase in strain. The properties of change in volume rely upon different factors such as shape, grain size, principal stresses, previous stress history and more importantly density index.

The representation of shear strain versus void ratio are shown below in the graph,



1. Initially dense and loose soil sample posses similar void ratio at the larger strain values and beyond this strain does not produce any volume changes.
2. Sands, which have critical value greater than the initial void ratio will tend to increase in volume during shearing and sands with critical value less than the initial void ratio will tend to decrease during shearing.
3. Other than a few particle properties, critical void ratio depends upon effective normal pressure or cell pressure.
4. Critical void ratio value is evaluated by plotting a graph between void ratio and volume change.
5. The volume at which volume change becomes zero is the critical value.

Q44. What is liquefaction? Explain.

Answer :

Liquefaction is the significant, complex and interesting problem in earthquake geotechnics.

1. Liquefaction is frequently seen in loose, saturated or uncompacted soils. The sand is essential since it has capability to compress when load is applied whereas, dense sands tend to dilate.
2. If the soil is saturated by water then soil should be beneath the growth water table, such that the water fills the gap between the soil particles.
3. The soil deposit acts as a liquid and the shear strength is not always zero during the earthquake.
4. If the pore water pressure is more, which can easily carry the applied load then it produces a condition as of quick sand condition.
5. Liquefaction is grouped as flow liquefaction and cyclic mobility.
6. Flow liquefaction occurs when shear stresses in the soil is more than strength of liquefied soil.
7. Cyclic mobility occurs when shear stresses are slightly less than liquefied shear strength of soil.

Q45. Explain briefly the shearing characteristics of clays.

Answer :

Following are the shearing characteristics of clays,

(a) Adhesion

Adhesion indicated by clay have the tendency to bond with other materials at common surface. It depends on the supporting capacity of friction piling in clays and lateral pressures on retaining walls. It is independent to normal pressure.

(b) Cohesion

The mutual attraction of two varying parts of clay mass to each other is known as cohesion (or) no-load shear strength. Cohesion is a property of true clay. Sometimes, it is responsible for unconfined specimen strength. In clays, cohesion differs considerably with consistency and thus, varies with both the type and condition of clay. It is a type of surface attraction among particles.

(c) Tensile Strength

Clays have the ability to develop a certain amount of tensile strength, due to which the magnitude of normal stresses on failure planes gets influenced.

(d) Viscous Friction

The effects of viscous friction are quite prominent when compared to solid friction effects. The total frictional resistance changes directly with the contact area but does not depend on normal force. It alters with the rate of shearing or the relative velocity of adjoining layers of fluid.

Q46. Explain the stress-strain behaviour of clays.

Answer :

(Oct./Nov.-16, Set-4, Q7(a) | Model Paper-IV, Q7(a)

Stress-strain Behaviour of Clays

The stress-strain behaviour of clays is a complex phenomena as the void ratio of over consolidated clays at a particular effective stress is less than that of normally consolidated clay at the same effective stress. The normally consolidated clays are less denser than over consolidated clays.

The various cases of clays and their behaviour compared to sand is tabulated below,

S.No	Type of Clay	Behaviour
1.	Over consolidated clays with a high over consolidation ratio	Dense sand
2.	Over consolidated clays with low over consolidation ratio.	Medium dense sand

The stress-strain behaviour of normally consolidated clay is identical to the stress-strain behaviour of loose sands.

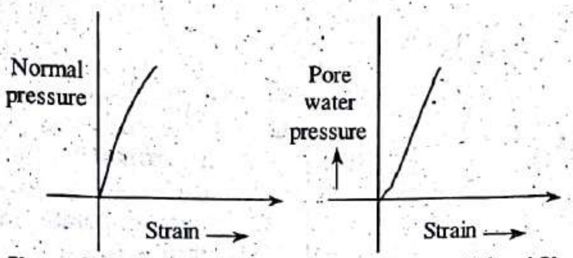


Figure: Stress-strain Behaviour of Normally Consolidated Clays

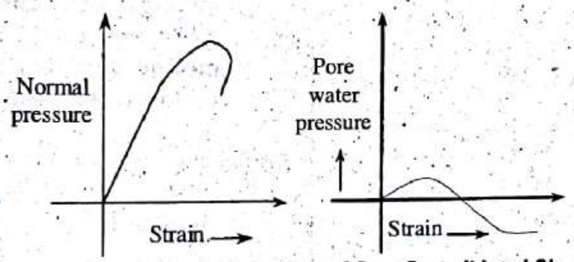


Figure: Stress-Strain Behaviour of Over-Consolidated Clays

Q47. 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.

(Oct./Nov.-16, Set-3, Q7(v) | Model Paper-III, Q7(b))

Answer :

Given that,

Diameter of the sample $(d) = 4$ cm

Length of the sample $(l) = 8$ m

Load of failure = 120 N

Strain $(\varepsilon) = 10\%$

$$= \frac{10}{100}$$

$$= 0.10$$

Initial area of cross section,

$$\Rightarrow A_0 = \frac{\pi}{4} \times d^2$$

$$= \frac{\pi}{4} \times 4^2$$

$$= 4\pi$$

$$A_0 = 4\pi \text{ cm}^2$$

Area of cross section at failure,

$$A_1 = \frac{A_0}{(1-\varepsilon)}$$

$$= \frac{4\pi}{(1-0.10)}$$

$$= \frac{4\pi}{0.9}$$

$$= \frac{40\pi}{9} \text{ cm}^2$$

$$= 13.96 \text{ cm}^2$$

Axial stress at failure,

$$\varepsilon_0 = \frac{120 \times 9}{40\pi}$$

$$= 8.59$$

$$\therefore \varepsilon_0 \simeq 8.60 \text{ N/cm}^2$$

$$\text{Shear stress at failure} = \frac{1}{2} \times 8.6$$

$$= 4.3 \text{ N/cm}^2$$

Mohr's Circle

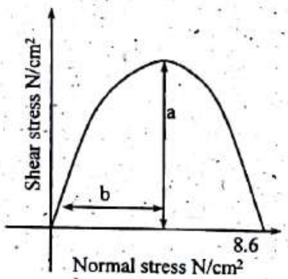


Figure: Mohr's Circle for Unconfined Compression Test

Where,

$$a = b = 4.3 \text{ N/cm}^2$$

Q48. A cylindrical specimen of saturated soil fails under a axial stress 150 kN/m² in an unconfined compression test. The failure plane makes an angle of 52° with the horizontal. Calculate the cohesion and angle of internal friction of the soil.

Answer : April/May-13, Set-4, Q8

Given that,

Axial stress, σ_1 = 150 KPa = 150 kN/mm².

Angle of failure plane, θ = 52°.

The failure plane angle with respect to the plane on which the major principal axial stress acts is,

$$\theta = 45° + \frac{\phi}{2}$$

$$52° = 45° + \frac{\phi}{2}$$

$$\phi = 14°$$

Angle of internal friction, ϕ = 14°

As,

$$\sigma_1 = \sigma_3 N_\phi + 2C\sqrt{N_\phi} \quad (\because \sigma_3 = 0)$$

$$150 = 0 + 2C\sqrt{N_\phi}$$

$$N_\phi = \tan^2\left(45° + \frac{\phi}{2}\right)$$

$$\sqrt{N_\phi} = \tan 52°$$

$$\therefore \quad 150 = 2C \tan 52°$$

$$C = \frac{150}{2 \times 1.279}$$

$\therefore$ Cohesion, C = 58.59 kN/m².

Q49. Calculate the potential shear strength on a horizontal plane at a depth of 3 m below the surface in a formation of cohesionless soil when the water table is at a depth of 3.5 m. The degree of saturation may be taken as 0.5 on the average. Void ratio = 0.50, grain specific gravity = 2.70, angle of internal friction = 30°. What will be the modified value of shear strength if the water table reaches the ground surface?

Answer : Model Paper-I, Q7(b)

Given that,

Specific gravity, G = 2.70

Degree of saturation, S = 0.5

Void ratio, e = 0.5

Normal depth, h = 3 m

Angle of internal friction, ϕ = 30°

Effective unit weight γ' is given by the equation,

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

$$= \frac{2.70-1}{1+0.5} \times 10$$

$$= \frac{1.70}{1.5} \times 10$$

$$= 1.133 \times 10$$

$$\therefore \gamma' = 11.33 \text{ kN/m}^3.$$

The value of γ at 50% saturation is,

$$\gamma = \frac{(G+S.e)}{(1+e)}\gamma_\omega \gamma_\omega$$

$$= \frac{2.70+0.05\times 0.5}{1+05}\times 10$$

$$= \frac{2.95}{1.5}\times 10$$

$$= 1.966 \times 10$$

$$\gamma = 19.667 \text{ kN/m}^3$$

Case (i)

When the water table is 3.5 m below the surface.

Stress at a depth of 3 m,

$$\sigma = \gamma \times h$$

$$= 19.67 \times 3$$

$$= 59 \text{ kN/m}^2$$

Shear strength 's' of sand,

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

$$= 59 \times \tan 30°$$

$$= 59 \times 0.577$$

$$= 34 \text{ kN/m}^2$$

Case (ii)

When water table reaches the ground surface, effective stress at 3 m depth,

$$\overline{\sigma} = \gamma' . h$$

$$= 11.33 \times 3$$

$$= 34 \text{ kN/m}^2$$

Shear strength 's' of sand,

$$s = \overline{\sigma} \tan\phi$$

$$= 34 \times \tan 30°$$

$$= 34 \times 0.577$$

$$= 19.62 \text{ kN/m}^2$$

Q50. Pore pressure measurements were made during undrained tri-axial tests on samples of compacted fill material from an earth dam saturating them in the laboratory. The results were as follows,

Property measured (kN/m³)	I Test	II Test
Lateral Earth Pressure	150	200
Total Vertical Pressure	450	550
Pore Water Pressure	35	45

Determine the apparent cohesion and the angle of shearing resistance as referred to,

(i) Total stress and

(ii) Effective stress.

Answer : **May/June-14, Set-3, Q8(b)**

	Lateral Earth Pressure (kN/m³)	Total Vertical Pressure (kN/m³)	Pore Water Pressure (kN/m³)
Test I	150	450	35
Test II	200	550	45

Calculating Total Stress and Effective Stress

Test-I

Lateral earth pressure, $\sigma_3 = 150$

Major principle stress, $\sigma_1 = \sigma_3$ + Total vertical pressure

$= 150 + 450 = 600$

Pore pressure, $u = 35$ kN/m³

Effective stress, $\bar{\sigma}_3 = \sigma_3 - u$

$= 150 - 35$

$= 115$

Major effective stress, $\bar{\sigma}_1 = (\sigma_1 - u)$

$= 600 - 35$

$= 565$

Test-II

Lateral earth pressure, $\sigma_3 = 200$

Major principle stress, $\sigma_1 = \sigma_3$ + Total vertical pressure

$= 200 + 550$

$= 750$

Pore water pressure, $u = 45$

Effective stress, $\bar{\sigma}_3 = \sigma_3 - u$

$= 200 - 45$

$= 155$

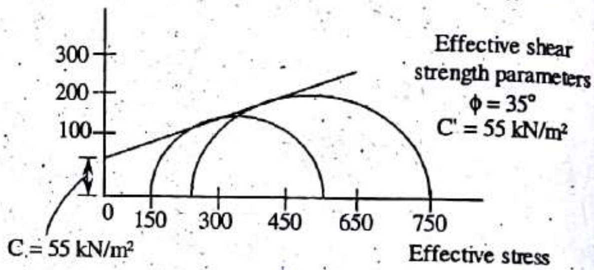
Major effective stress, $\bar{\sigma}_1 = (\sigma_1 - u)$

$= 750 - 45$

$= 705$

Table of all calculations of total stress and effective stress,

Test No	σ_3	σ_1	u	$\bar{\sigma}_3$	$\bar{\sigma}_1$
1	150	600	35	115	565
2	200	750	45	155	705



Figure