Chapter 8

Shear Strength

CHAPTER HIGHLIGHTS

- *Introduction*
- *Definition*
- *Important points on mohr's circle*
- *Strength theories for soils*
- *Coulomb envelopes for pure sand and for pure clay*
- *Types of shear tests based on drainage conditions*
- *Laboratory tests*
- *Pore pressure parameters*
- *Liquefaction of sands*

Introduction

In this chapter, the concept on shearing strength of soil is discussed. It is an important engineering property of soil which controls the stability of soil mass. It governs the bearing capacity of soils, the stability of slopes in soils and the earth pressure against retaining structures. In this chapter, the basic concepts and accepted theories of the shear strength are discussed.

Definition

The shearing strength of the soils is defined as its maximum resistance to shear stresses just before the failure. Shearing strength of the soil is mainly due to:

1. Resistance due to interlocking of particles.
2. Frictional resistance between the individual soil grains.
3. Adhesion between soil particles or cohesion.
    - Granular soils of sands derive their shear strength from the first two while cohesive soils or clays may derive their shear strength from second and third whereas the high plastic clays derive its strength from third source alone.

NOTES

1. Shear stresses develops only when the soil is subjected to compressive loads.
2. Shear stresses are not relevant in soils subjected to tension as they may fail in tension only and is responsible for opening of cracks and fissures.

Important Points on Mohr's Circle

1. Any plane without shear stress, the corresponding plane is known as principal plane and the normal stress on plane is known as principal stress.
2. The maximum shear stress (τ_{max}) is equal to radius of Mohr's circle $\left[\text{numerically equal to } \frac{\sigma_1 - \sigma_3}{2}\right]$ and it occurs on a plane inclined at 45° to the principal plane.
3. The normal stress on plane of maximum shear stress is equal to $\left[\frac{\sigma_1 + \sigma_3}{2}\right]$ and is equal to distance of center of Mohr's circle form origin.

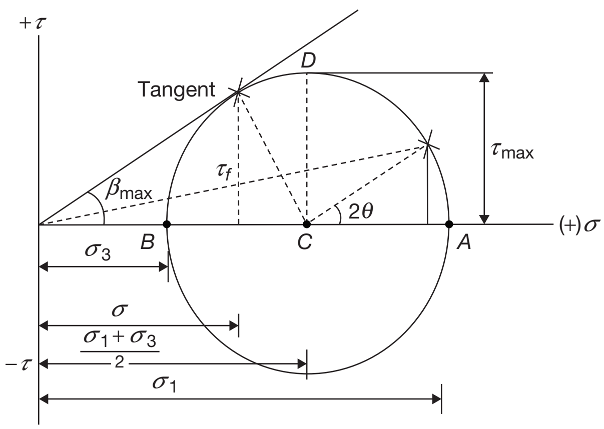
4. The resultant stress on any plane (σ_r) is equal to $\sqrt{\sigma_\theta^2 + \tau_\theta^2}$ making an angle β with the normal stress.
   Where, β = angle of obliquity

$$\boxed{\beta : \tan^{-1}\left(\frac{\tau_\theta}{\sigma_\theta}\right)}$$

5. The maximum angle of obliquity β_{max} is obtained by drawing a tangent to the circle from the origin 'O'. It has an angle of $\left(45° + \frac{\phi}{2}\right)$ with reference to major principal plane. It is the most dangerous plane.

$$\boxed{\beta_{max} = \sin^{-1}\left[\frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}\right]}$$

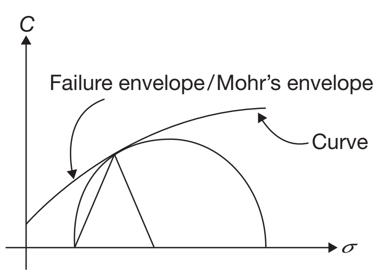
6. The shear stress (τ_f) on the plane of the maximum obliquity is less than the maximum shear stress (τ_{max}). Thus, the shear stress at failure is less than the maximum shear stress and the plane which carries the maximum shear stress is not the critical plane.
7. Shear stresses on planes at the right angles to each other are numerically equal, but are of opposite sign.



Strength Theories for Soils

1. **Mohr's theory:** According to Mohr, the failure is caused by a critical combination of normal and shear stresses. The shear stress at failure is a function of normal stress (σ) acting on that plane.

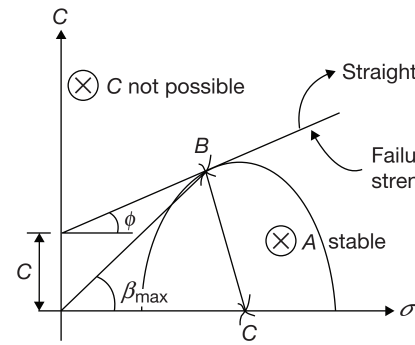
$$\boxed{S = f(\sigma)}$$



2. **Mohr-coulomb theory:** Mohr's envelope is replaced by a straight line by Coulomb and expressed as a function of the normal stress on that plane as:

$$\boxed{S = C + (\sigma)\tan\phi}$$

   Where C and ϕ are the empirical parameters known as apparent cohesion and angle of shearing resistance or angle of internal friction, respectively.
   - C and ϕ are total stress parameters.



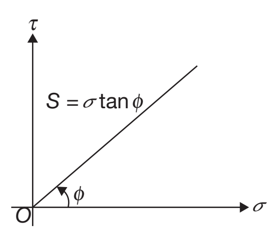
3. Revised Mohr–Coulomb equation:
   - Terzaghi established that the normal stresses which control the shearing strength of a soil are the effective stresses and not the total stresses.
   - Infact, effective stresses control the shearing strength of soil.

$$\boxed{S = C' + \sigma' \tan\phi'}$$

   Where C', ϕ' are effective cohesion and effective angle of internal friction.

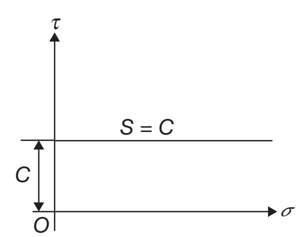
Coulomb Envelopes for Pure Sand and for Pure Clay

1. For pure sand: [$C = 0$ or ϕ soil]



(a) Pure sand

2. Pure clay ($\phi = 0°$ or C – soil)



(a) Pure clay

Types of Shear Tests Based on Drainage Conditions

In shear tests, there are two stages:

1. Consolidation stage in which the normal stress (or confining pressure) is applied to the specimen and it is allowed to consolidate.
2. Shear stage in which shear stress (or deviator stress) is applied to the specimen to shear it.

Depending upon the drainage conditions, there are three types of tests as explained below.

1. **Unconsolidated undrained test: (UU test, Quick test, Q-test):** In these tests, drainage is not permitted during the consolidation stage and, also during the shearing stage. The test can be conducted quickly in few minutes as there is no dissipation of excess pore water pressure. It is known as quick test or Q-test as it can be conducted in few minutes, i.e., 5 to 10 minutes. Undrained tests are performed only on soils having low permeability and, also for ascertaining short-term stability of clays.
2. **Consolidated-undrained test (CU test or R-test):** In this test, drainage is fully permitted during the application of the normal stress and, no drainage is permitted during the application of shear stress.
3. **Consolidated-drained test (CD test, slow test, S-test):** In this test, drainage is permitted during the both consolidation stage and, also in shearing stage to ensure the full primary consolidation occurs and no excess pore pressure is set up at any stage of loading. It is a slow test.

   In case of cohesive soil, usually, it takes 4–6 weeks to complete the test.
   - The test is ideally suited for less permeable soils, such as clays and also for ascertaining long-term stability of clays.

Shearing strength tests: The following tests are available.

Laboratory Tests

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

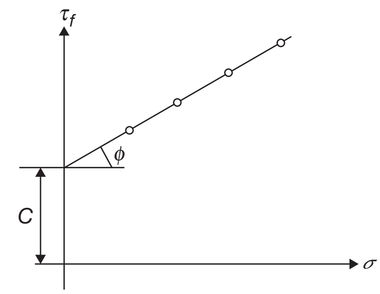
Field Test

- Vane shear test

Direct Shear Test

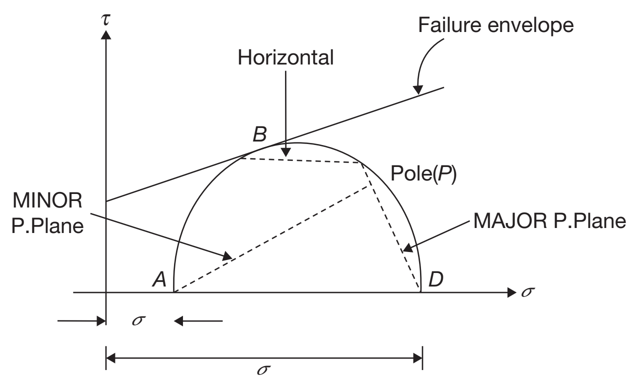
- A soil specimen of size $60 \times 60 \times 25$ mm is used.
- The direct shear test is conducted on cohesionless soil as CD test.
- It is occasionally used for silt and clay under unconsolidated, undrained and consolidated drained conditions.

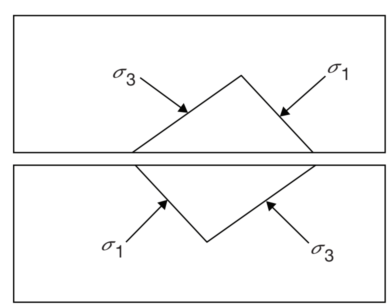
Failure envelope: For obtaining a failure envelope, a number of identical specimens are tested under different normal stresses and the shear stress required to cause failure is determined.



(a) Pure clay

- The Mohr circle can be drawn at the failure condition assuming that the failure plane is horizontal.





Merits and Demerits

Merits

1. The sample preparation is easy and the test is simple.
2. It is ideally suited for cohesion less soil as C-D test.

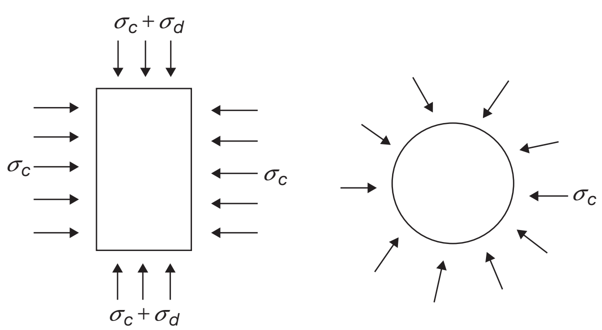
Demerits

1. The stress conditions at failure are only known and, hence the Mohr circle cannot be drawn prior to failure as they are indeterminate.
2. The stress distribution on failure plane is not uniform. The strength of soil is not mobilized on entire failure plane.

3. The area under shear gradually decreases as the test progresses, but instead of corrected area, original area is used.
4. The orientation of failure plane is fixed (Horizontal). This may not be the weakest plane.
5. The measurement of pore water is not possible.
6. Little control on drainage of soil. Consequently, only drained tests can be conducted on highly- permeable soils.
7. Lateral restrains by the side walls of the shear box and do not allow it to deform laterally.

Triaxial Compression Test

- This test can be used for determination of shear characteristics of all types of soils under different drainage conditions.
- This test was introduced by Terzaghi and Casagrande in 1936.
- Usually, cylindrical specimen with a height equal to twice its diameter is used. The soil specimen is subjected to three compressive stresses in mutually perpendicular direction.



(A) Elevation **(B) Plan**

- The loading is applied in two stages. In the first stage, a confining pressure is applied all round the soil specimen. In the second stage of test, called 'the shearing stage', an additional axial stress called 'deviator stress' is applied on the top of specimen.

Area corrections:

$$A = \frac{V_0 \pm \Delta V}{h_0 - \Delta h}$$

For undrained test,

$$\Delta V = 0$$

Corrected area,

$$A = \frac{A_0}{1 - \varepsilon_a}$$

Where

$$\varepsilon_a = \frac{\Delta h}{h_0}$$

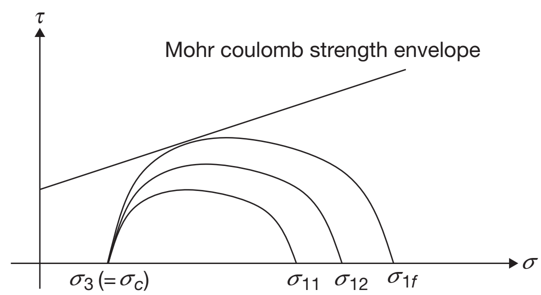
h_0 = Initial height
A_0 = Initial area of cross-section
V_0 = Initial volume of soil sample

The above equation is called 'the area correction' and $\frac{1}{(1-\varepsilon_a)}$ is the correction factor.

A more accurate expression for the corrected area is given by:

$$A = \frac{A_0}{(1-\varepsilon_a)}\left(1 \pm \frac{\Delta V}{V_0}\right) = \frac{V_0 \pm \Delta V}{(h_0 - \Delta h)}$$

Mohr's Circle for Triaxial Test

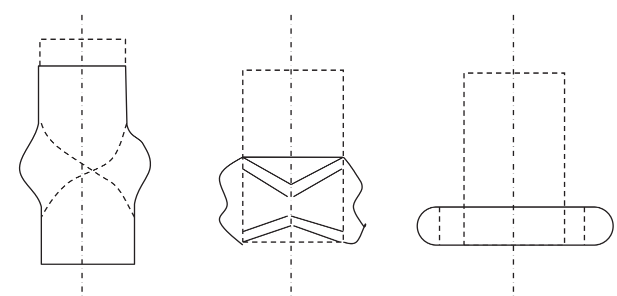


Mohr circle during triaxial test

In the above figure, σ_3 is minor principal stress which is constant and σ_{11}, σ_{12}, ..., σ_{1f} are the major principal stresses at different stages of loading and at failure.

Types of Failure of a Triaxial Compression Test Specimen

Depending upon the nature of soil and its condition, there are three types of failures as follows.



(a) Brittle failure (b) Semi-plastic failure (c) Plastic failure

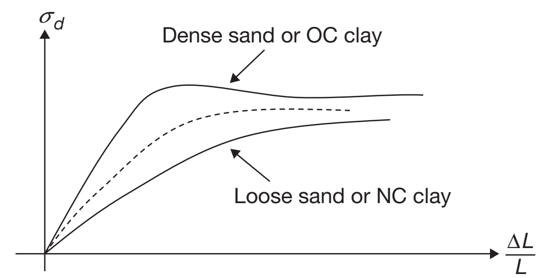
Failure patterns in triaxial compression test

- The first type is a brittle failure with well-defined shear plane. The second type is a plastic failure showing shear cones and some lateral bulging. The third type is plastic failure with well-expressed lateral bulging.

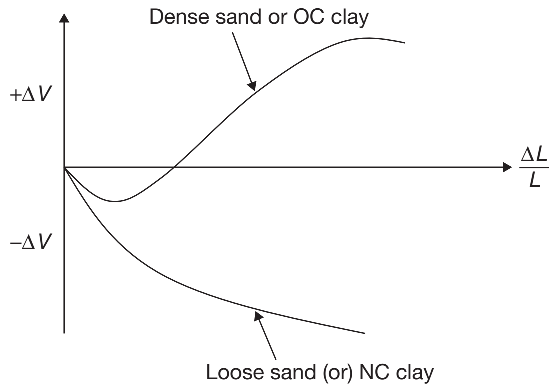
Merits of Triaxial Compression Test

1. Failure occurs along the weakest plane and stress distribution on failure plane is also uniform.
2. Complete control on drainage of soil and measurement of pore pressure at any stage is possible.

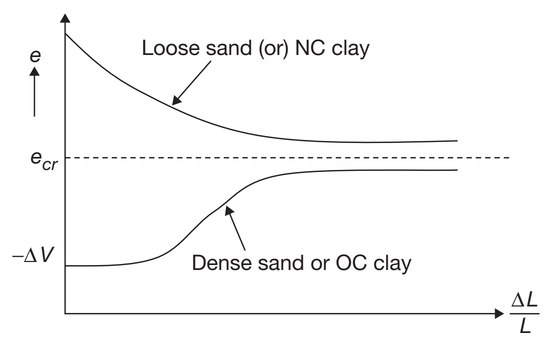
Presentation of Results



(a) Stress-strain curve

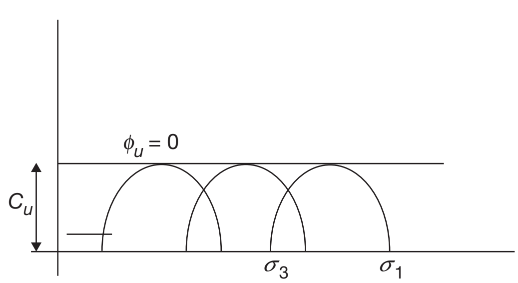


(b) Volume change vs strain

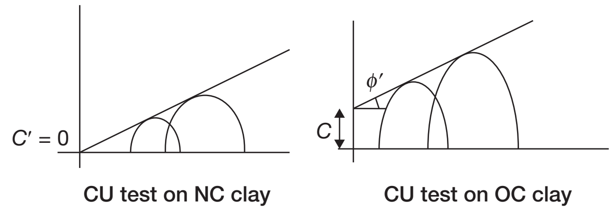


(c) Void ratio vs strain

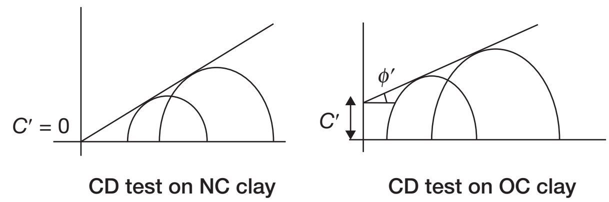
Shear Tests on Clays



UU – on NC clay and OC clay



CU tests on clay



CD tests on clay

Unconfined Compression Test

- This is a special case of triaxial compression test in which the confining pressure is zero.
- Generally, this test is conducted on undisturbed or remoulded cohesive soils. It cannot be conducted on coarse-grained soils, such as gravel, sand, etc. as they cannot withstand without lateral support.
- In unconfined compression test,

  Minor principal stress, $\sigma_3 = 0$

  Major principal stress, σ_1 = Deviator stress = $\frac{P}{A}$

  Where P = Axial load

  A = Corrected area = $\frac{A_0}{1-\varepsilon}$

  ε = Strain = $\frac{\Delta L}{L}$

  Now, we have $\sigma_1 = 2C_u \tan\left(45° + \frac{\phi}{2}\right)$

  Here, $\sigma_1 = q_u$

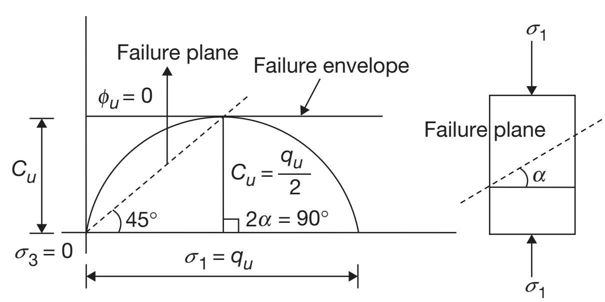
  Where, q_u = Unconfined compression strength.

  For pure clays, $\phi_u = 0$

$$q_u = 2C_u$$

$$\boxed{C_u = \frac{q_u}{2}}$$

Mohr's Circle for Unconfined Test



For pure clay

Merits

1. The test is ideally suited for measuring the unconsolidated undrained shear strength of intact, saturated clays.
2. Sensitivity of soil can be easily determined.

Demerits

1. The test cannot be conducted on fissured clays.
2. The test may be misleading for soils for which angle of shearing resistance is not zero.

Sensitivity (S_t)

It is defined as a ratio of undisturbed strength to remoulded strength at same water content.

- It can be determined by unconfined compression test.

$$S_t = \frac{(q_u)_u}{(q_u)_r}$$

Where

$(q_u)_u$ = Unconfined compressive strength of undisturbed clay.

$(q_u)_r$ = Unconfined compressive strength of remoulded clay.

- If sensitivity is 1, the soil is insensitive. For quick soils, sensitivity is > 16.

Vane Shear Test

- It is suited for the determination of the undrained shear strength of non-fissured, fully-saturated clay.
- The test can be conveniently used to determine the sensitivity of the soil.
- The test can be conducted in laboratory or field.
- The test cannot be conducted on the fissured clay or the clay containing sand or silt laminations.
- The shear strength (s) of the clay is given:
  If both top and bottom of the Vane takes part in shearing the soil.

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

If only one end of the Vane takes part in shearing the soil.

$$S = \frac{T}{\pi D^2\left(\frac{H}{2}+\frac{D}{12}\right)}$$

Where

T = Torque

D = Diameters of the vane

H = Height of the vane = $2D$ [As per IS recommendations]

Pore Pressure Parameters

- The characteristics, which represents the change in pore pressure due to the change in applied stress are called 'pore pressure coefficients' or 'pore pressure parameters A and B'.
- It was propounded by Skempton.

1. B-parameter:

- The ratio of pore water pressure developed to the applied confining pressure is known as 'B-parameter'.

$$B = \frac{\Delta U_c}{\Delta \sigma_3}$$

ΔU_c = Increase in pore water pressure due to increase of confining pressure, $\Delta\sigma_3$.

- For a saturated soil, B is nearly equal to unity.
- For a dry soil, $B = 0$.

2. A-parameter:

- The ratio of pore water developed to the applied deviator stress is called 'A-parameter'.

$$\bar{A} = \frac{\Delta U_d}{(\Delta\sigma_1 - \Delta\sigma_3)}$$

Where, ΔU_d = Pore pressure developed due to increase of deviator stress.

- The A-factor or parameter is not a constant. It varies with the soil, its stress history and the applied deviator stress.
- Therefore, its value can be specified at failure or maximum deviator stress.
- Total increase in pore water pressure,

$$\begin{aligned}\Delta U &= \Delta U_c + \Delta U_d \\ &= B\Delta\sigma_c + AB(\Delta\sigma_1 - \Delta\sigma_c) \\ &= B\Delta\sigma_c + AB(\Delta\sigma_d)\end{aligned}$$

$$\Delta U = B(\Delta\sigma_c + \Delta\sigma_d)$$

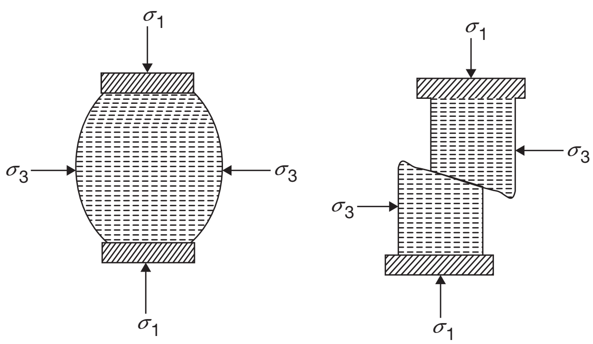
- A factor may be as high as 2 to 3 for saturated fine sands in loose condition, and as low as −0.5 for heavy pre-consolidated clay.

Liquefaction of Sands

- The phenomenon when saturated sand loses its shear strength due to oscillatory motion is known as liquefaction of sand.
- Soils most susceptible to liquefaction are the saturated fine and medium sands.

Important Points

1. The shear strength of cohesionless soils is mainly due to the friction between particles. In case of dense sands, it is due to interlocking between particles also.
2. The stress-strain curves for a dense sand has high initial tangent modulus compared to loose sands and, also attains a high peak value at a lower strain, whereas loose sands attains a high-stress value after larger strains.
3. In case of loose sands, the specimen bulges and ultimately fails by sliding on numerous planes, whereas in case of dense sands, the specimen shows a clear failure plane and the failure is known as brittle failure.



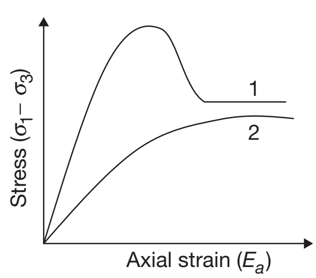
(a) Loose sand (a) Dense sand

Types of failure in sand

4. The shear characteristic of a cohesive soil depends on drainage conditions of soil, i.e., whether a soil is normally consolidated or over-consolidated.
5. The stress-strain curve of over-consolidated clay is similar to that of dense sand and the stress strain curve of normally consolidated clay is similar to that of loose sands.
6. For a normally consolidated clay, the failure envelope passes through the origin and $C' = 0$. For unconsolidated undrained clay, the failure envelope is horizontal ($\phi_u = 0$) and for an over-consolidated clay, the effective stress parameters (C', ϕ') envelope ($S = C' + \sigma' \tan \phi'$).
7. Consolidated drained tests are generally conducted in case of coarse-grained soil, whereas in case of fine-grained soil, undrained tests are more suitable for immediately after application of load and drained tests are conducted for final stability problems.
8. Consolidated undrained tests are conducted on soils which get consolidated under a certain loading and, then additional load is applied. For example, in case of earth dams, wherein the soil gets consolidated under self-weight before the reservoir is filled and the water pressure causes additional stress.

Exercises

1. Vane tester is normally used for determining in-situ shear strength of
   (A) soft clays (B) sand
   (C) stiff clays (D) gravel
2. The ratio of unconfined compressive strength of an undisturbed sample of soil to that of a remoulded sample, at the same water content, is known as
   (A) activity (B) damping
   (C) plasticity (D) sensitivity
3. The stress-strain behaviour of soils as shown in the figure corresponding to:



   (A) Curve 1: Loose sand and normally consolidated clay
   Curve 2: Loose sand and over consolidated clay
   (B) Curve 1: Dense sand and normally consolidated clay
   Curve 2: Dense sand and over consolidated clay
   (C) Curve 1: Dense sand and over consolidated clay
   Curve 2: Loose sand and normally consolidated clay
   (D) Curve 1: Loose sand and over consolidated clay
   Curve 2: Dense sand normally consolidated clay
4. The following two statements are made with respect to different sand samples having the same relative density. Identify if they are true or false.
   I. Poorly graded sands will have lower friction angle than the well graded sand.
   II. The particle size has no influence on the friction angle of sand.
   (A) II is true but I is false
   (B) Both are false statements
   (C) Both are true statements
   (D) I is true but II is false
5. The undrained cohesion of a remoulded clay soils is 10 kN/m^2. If the sensitivity of the clay is 20, the corresponding remoulded compressive strength is
   (A) 5 kN/m^2 (B) 10 kN/m^2
   (C) 20 kN/m^2 (D) 200 kN/m^2

6. In an undrained traixial test on a saturated clay, the Poisson's ratio is

(A) $\dfrac{\sigma_3}{(\sigma_1+\sigma_3)}$ (B) $\dfrac{\sigma_3}{(\sigma_1-\sigma_3)}$

(C) $\dfrac{(\sigma_1-\sigma_3)}{\sigma_3}$ (D) $\dfrac{(\sigma_1+\sigma_3)}{\sigma_3}$

7. When an unconfined compression test is conducted on a cylinder of soil, it fails under axial stress of 1.2 kg/cm^2. The failure plane makes an angle of 50° with the horizontal. Determine the cohesion and angle of internal friction of the soil.

8. On a saturated triaxial cylindrical test specimen of soil if the major and minor principle stresses applied are 200 and 60 kN/m^2 respectively. Check whether the test specimen will fail if it is assumed that soil will have C' = 5 kN/m^2. ϕ' = 25° with pore pressure developed equal to 20 kN/m^2.

9. In a consolidated drained triaxial test a specimen of clay fails at a cell pressure of 60 kN/m^2. The effective shear strength parameters are C' = 15 kN/m^2 and ϕ' = 20°. Find the compressive strength of the soil.

10. In an unconfined compression test on a saturated clay, the undrained shear strength was found to be 6t/m^2. If a sample of the same soil is tested in an undrained condition in triaxial compression at a cell pressure of 20 t/m^2, then the major principal stress at failure will be

(A) 48 t/m^2 (B) 32 t/m^2
(C) 24 t/m^2 (D) 12 t/m^2

11. A laboratory vane shear test apparatus is used to determine the shear strength of a clay sample and only one end of the vane takes part in shearing the soil. If T = applied torque, H = height of vane and D = diameter of the vane, then shear strength of the clay is given by

(A) $\dfrac{T}{\pi D^2\left(H+\dfrac{D}{6}\right)}$ (B) $\dfrac{T}{\pi D^2\left(\dfrac{H}{2}+\dfrac{D}{12}\right)}$

(C) $\dfrac{T}{\pi D^2\left(H+\dfrac{D}{10}\right)}$ (D) $\dfrac{T}{\pi D^2\left(H+\dfrac{D}{12}\right)}$

12. A soil fails under an axial vertical stress of 100 kN/m^2 in unconfined compression test. The failure plane makes an angle of 50° with the horizontal. The shear parameters 'c' and 'f' respectively will be

(A) 41.9 kN/m^2, 0° (B) 50.0 kN/m^2, 0°
(C) 41.9 kN/m^2, 10° (D) 50.0 kN/m^2, 10°

13. A dry sand specimen is put through a triaxial test. The cell pressure is 50 kPa and the deviator stress at failure is 100 kPa, the angle of internal friction for the sand specimen is

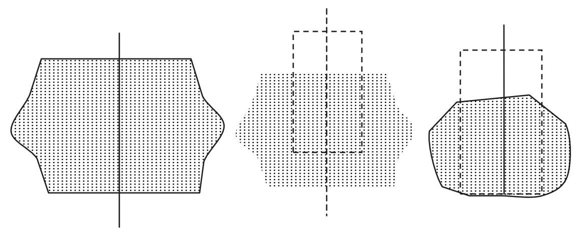
(A) 15° (B) 30°
(C) 37° (D) 45°

14. In an unconfined compression test on stiff clay, if the failure plane made an angle of 52° to the horizontal, what would be the angle of shearing resistance?

(A) 16° (B) 14°
(C) 12° (D) 13°

15. What is the shear strength in terms of effective stress on a plane within a saturated soil mass at a point where the total normal stress is 295 kPa and the pore water pressure 120 kPa? The effective stress shear strength parameters are C' = 11 kPa and f' = 30°.

16. Triaxial compression test of three soil specimens exhibited the patterns of failure as shown in the figure. Failure models of the samples respectively are



(A) (i) brittle, (ii) semi-plastic, (iii) plastic
(B) (i) semi-plastic, (ii) brittle, (iii) plastic
(C) (i) plastic, (ii) brittle, (iii) semi-plastic
(D) (i) brittle, (ii) plastic, (iii) semi-plastic

17. In a drained traixial compression test, a saturated specimen of a cohesionless sand fails under a deviator stress of 3 kgf/cm^2 when the cell pressure is 1 kgf/cm^2. The effective angle of shearing resistance of sand is about

(A) 37° (B) 45°
(C) 53° (D) 20°

18. A CU triaxial compression test was performed on a saturated sand at a cell pressure of 100 kPa. The ultimate deviator stress was 350 kPa and the pore pressure at the peak stress was 40 kPa (suction). Estimate the total and effective stress shear strength parameters.

19. If the effective stress-strength parameters of soil are C' = 10 kPa and ϕ' = 30°, the shear strength on a plane within the saturated soil mass at a point where the total normal stress is 300 kPa and pore water pressure is 150 kPa will be

(A) 90.5 kPa (B) 96.6 kPa
(C) 101.5 kPa (D) 105.5 kPa

20. In a triaxial test carried out on a cohesionless soil sample with a cell pressure of 20 kPa, the observed value of applied deviator stress at the point of failure was 40 kPa. The angle of internal friction of the soil is

(A) 10° (B) 15°
(C) 25° (D) 30°

21. For a triaxial shear test conducted on a sand specimen at a confining pressure of 100 kN/m^2 under drained conditions, resulted in a deviator stress at failure of 100 kN/m^2. The angle of shearing resistant of the soil would be

(A) 18.43° (B) 19.47°
(C) 26.56° (D) 30°

22. A sample of saturated cohesionless soil tested in a drained traixial compression test showed an angle of internal friction of 30°. The deviatoric stress at failure for the sample at a confining pressure of 200 kPa is equal to
(A) 200 kPa (B) 400 kPa
(C) 600 kPa (D) 800 kPa

23. The critical shear plane will have an angle of __________ with reference to major principle plane.
(A) $45° + \frac{\phi}{2}$ (B) $35° + \frac{\phi}{2}$
(C) $90° + \phi$ (D) $135° + \frac{\phi}{2}$

Direction for questions 24 and 25:

When an unconfined compression test is conducted on a cylinder of soil, it fails under axial stress of 4.3 kg/cm^2. The failure plane makes an angle of 60° with horizontal.

24. The cohesion of soil is
(A) 0.58 kg/cm^2
(B) 0.63 kg/cm^2
(C) 0.68 kg/cm^2
(D) 1.24 kg/cm^2

25. The angle of internal friction of soil is
(A) 6.5° (B) 20°
(C) 30° (D) 10°

26. The term mobilized shear strength is referred to as
(A) shear strength.
(B) maximum shear stress.
(C) applied shear stress.
(D) None of these

27. When an unconfined compression test is conducted on a cylinder of soil, it fails under axial stress of 1.5 kg/cm^2. If an angle of internal friction of the soil is 30°, what will be the cohesion of the soil?
(A) 0.43 kg/cm^2 (B) 0.67 kg/cm^2
(C) 0.75 kg/cm^2 (D) 0.35 kg/cm^2

28. What is the shear strength in terms of effective stress on a plane with in the saturated soil mass at a point where total normal stress is 245 kPa and pore water pressure is 80 kPa? The effective shear stress parameters are C' = 12 kPa, and ϕ' = 30°.
(A) 105.3 kPa
(B) 106.3 kPa
(C) 107.3 kPa
(D) 108.3 kPa

29. A sample of saturated cohesionless soil tested in a drained triaxial compression test showed an angle of internal friction of 35°. The deviator stress at failure for the sample at a confining pressure of 150 kPa is equal to
(A) 800 kPa (B) 400 kPa
(C) 600 kPa (D) 300 kPa

30. In a triaxial test at failure, major principal stress was 200 kPa, minor principal stress was 110 kPa, and pore pressure was 25 kPa. The sine of the angle of shearing resistance of the sandy soil was
(A) 0.35 (B) 0.25
(C) 0.40 (D) 0

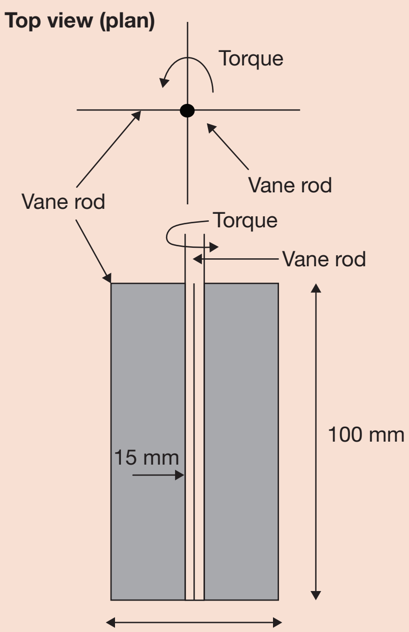
31. Triaxial shear test conducted on a sand specimen at a confining pressure of 100 kN/m^2 under drained conditions, resulted in a deviator stress at failure of 100 kN/m^2. The angle of shearing resistance of the soil would be _______.
(A) 18.43°
(B) 19.47°
(C) 26.56°
(D) 30°

Previous Years' Questions

1. A clay soil sample is tested in traixial apparatus in consolidated–drained condition at a cell pressure of 100 kN/m^2. What will be the pore water pressure at a deviator stress of 40 kN/m^2? **[GATE, 2007]**
(A) 0 kN/m^2 (B) 20 kN/m^2
(C) 40 kN/m^2 (D) 60 kN/m^2

2. A direct shear test was conducted on a cohesionless soil (c = 0) specimen under a normal stress of 200 kN/m^2. The specimen failure at a shear stress of 100 kN/m^2. The angle of internal friction of the soil (degrees) is **[GATE, 2008]**
(A) 26.6 (B) 29.5
(C) 30.0 (D) 32.6

3. A field vane shear testing instrument (shown in the figure) was inserted completely into a deposit of soft, saturated silty clay with the vane rod vertical such that the top of the blades were 500 mm below the ground surface. Upon application of a rapidly increasing torque about the vane rod, the soil was found to fail when the torque reached 4.6 Nm. Assuming mobilization of undrained shear strength on all failure surfaces to be uniform and the resistance mobilized on the surface of the vane rod to be negligible, what would be the peak undrained shear strength (rounded off to the nearest integer value of kPa) of the soil? **[GATE, 2011]**



(A) 5
(B) 10
(C) 15
(D) 20

4. For a sample of dry, cohesionless soil with friction angle ϕ, the failure plane will be inclined to the major principal plane by an angle equal to **[GATE, 2011]**

(A) ϕ

(B) 45°

(C) $45° - \frac{\phi}{2}$

(D) $45° + \frac{\phi}{2}$

5. The effective stress friction angle of a saturated cohesionless soil is 38°. The ratio of shear stress to normal effective stress on the failure plane is **[GATE, 2012]**

(A) 0.781
(B) 0.616
(C) 0.488
(D) 0.438

6. For a saturated cohesive soil, a traixial test yields the angle of internal friction (ϕ) as zero. The conducted test is **[GATE, 2014]**

(A) consolidated drained (CD) test.
(B) consolidated undrained (CU) test.
(C) unconfined compression (UC) test.
(D) unconsolidated undrained (UU) test.

7. Which of the following statements is NOT correct? **[GATE, 2015]**

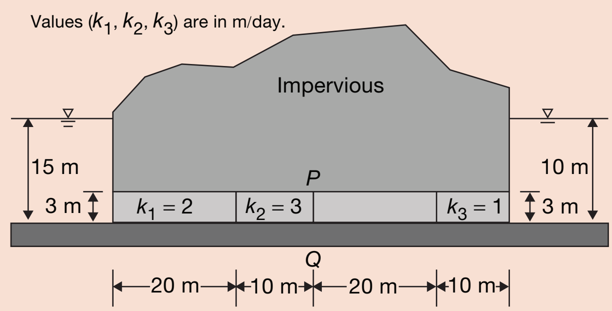
(A) Loose and exhibits contractive behavior upon shearing.
(B) Dense and when sheared under undrained condition, may lead to generation of negative pore pressure.
(C) Black cotton soil exhibits expansive behavior.
(D) Liquefaction is the phenomenon where cohesionless soil near the downstream side of dams or sheet-piles loses its shear strength due to high upward hydraulic gradient.

8. Stress path equation for tri-axial test upon application of deviatoric stress is, $q = 10\sqrt{3} + 0.5p$. The respective values of cohesion, c (in kPa) and angles of internal friction, ϕ are **[GATE, 2015]**

(A) 20 and 20° (B) 20 and 30°
(C) 30 and 30° (D) 30 and 20°

9. A drained tri-axial compression test on a saturated clay yielded the effective shear strength parameters as c' = 15 kPa and ϕ' = 22°. Consolidated undrained tri-axial test on an identical sample of this clay at a cell pressure of 200 kPa developed a pore water pressure of 150 kPa at failure. The deviator stress (expressed in kPa) at failure is ________. **[GATE, 2016]**

10. Seepage is occurring through a porous media shown in the figure. The hydraulic conductivity values (k_1, k_2, k_3) are in m/day. **[GATE, 2016]**



The seepage discharge (m^3/day per m) through the porous media at section PQ is

(A) $\frac{7}{12}$ (B) $\frac{1}{2}$

(C) $\frac{9}{16}$ (D) $\frac{3}{4}$

Answer Keys

Exercises

1. A **2.** D **3.** C **4.** D **5.** C **6.** A **7.** $\phi_u = 10°$, $C_u = 0.50$ kg/cm^2
8. Fails **9.** 105.22 kN/m^2 **10.** B **11.** B **12.** C **13.** B **14.** B **15.** 113.03 kN/m^2
16. C **17.** A **18.** $C_u = 0$ $\phi_u = 39.52°$; $C' = 0$, $\phi' = 33.75°$ **19.** B **20.** B **21.** B **22.** B
23. A **24.** D **25.** C **26.** C **27.** A **28.** C **29.** B **30.** A **31.** B

Previous Years' Questions

1. A **2.** A **3.** B **4.** D **5.** A **6.** D **7.** D **8.** B **9.** 104.37
10. B