SHEAR STRENGTH OF SOIL

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Outlines

- Introduction
- Mohr-Coulomb Failure Criterion
- Direct Shear Test
- Triaxial Shear Test
- Unconfined Compression Test
- Vane Shear Test
- Skempton’s Pore Pressure Coefficient
- Important Links
- References

Introduction

- The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside it.
- One must understand the nature of shearing resistance in order to analyze soil stability problems such as bearing capacity, slope stability, and lateral pressure on earth retaining structures.
- The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts.

Mohr-Coulomb Failure Criterion

- Charles Augustin de Coulomb (1736-1806) is well known from his studies on friction, electrostatic attraction and repulsion.

- Christian Otto Mohr (1835-1918) hypothesized (1900) a criterion of failure for real materials in which he stated that materials fail when the shear stress on the failure plane at failure reaches some unique function of the normal stress on that plane:

$$\tau_{ff} = f\,(\sigma_{ff})$$

where τ is the shear stress and σ is the normal stress.

- The first subscript f refers to the plane on which the stress acts (in this case the failure plane) and the second f means “at failure.” τ_{ff} is the shear the material.

- The Mohr-Coulomb failure criterion is commonly used to describe the strength of soils
- Its main hypothesis is based on the premise that a combination of normal and shear stresses creates a more critical limiting state than would be found if only the major principal stress or maximum shear stress were to be considered individually
- Shear strength consists of two components : Cohesion(c) and Angle of internal friction (ϕ)
- According to Mohr-Coulomb failure criterion

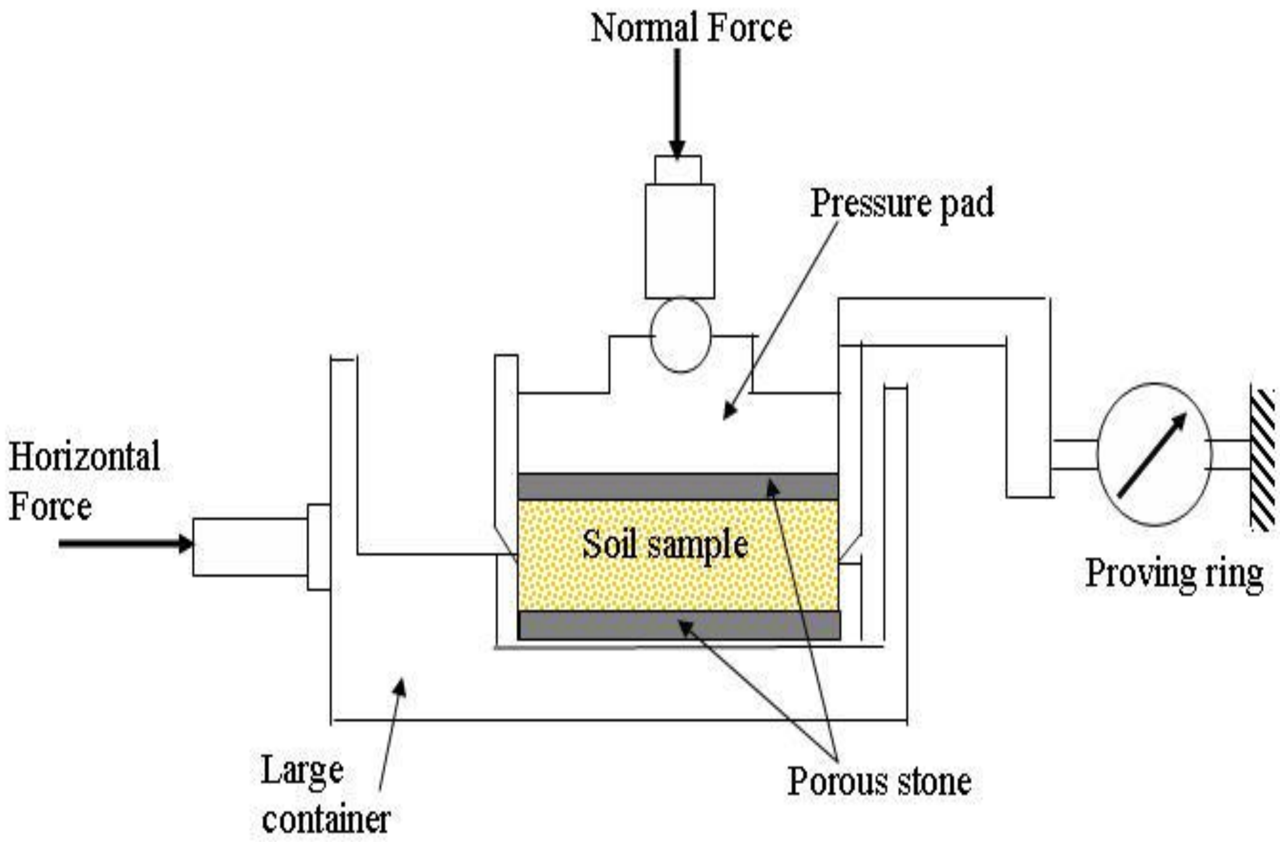
$$\tau = \mathrm{c} + \sigma \tan\phi$$

- Higher the values of c and φ , Higher the shear strength of soil.

Direct Shear Test

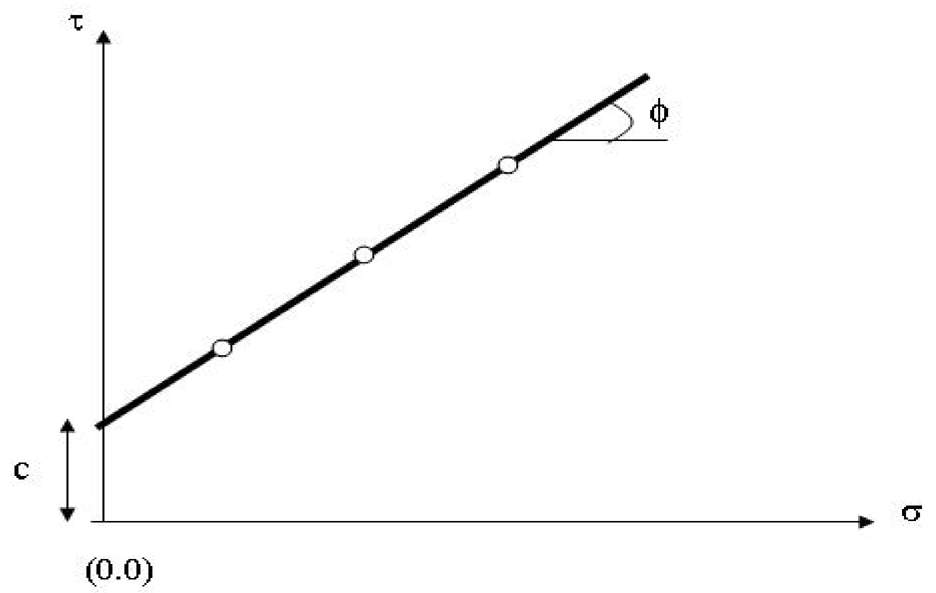
- Also called as Shear box test.
- Box can be of square or circular shape in plan.
- Used to determine soil strength and not the deformations.
- Different sizes of shear box can be used depending on grain size of the coarse grain soil.
- Sample is loaded first with normal stress with the help of dead loads.
- Then a lateral force is applied to split the sample in two parts

Direct Shear Test: Component Parts



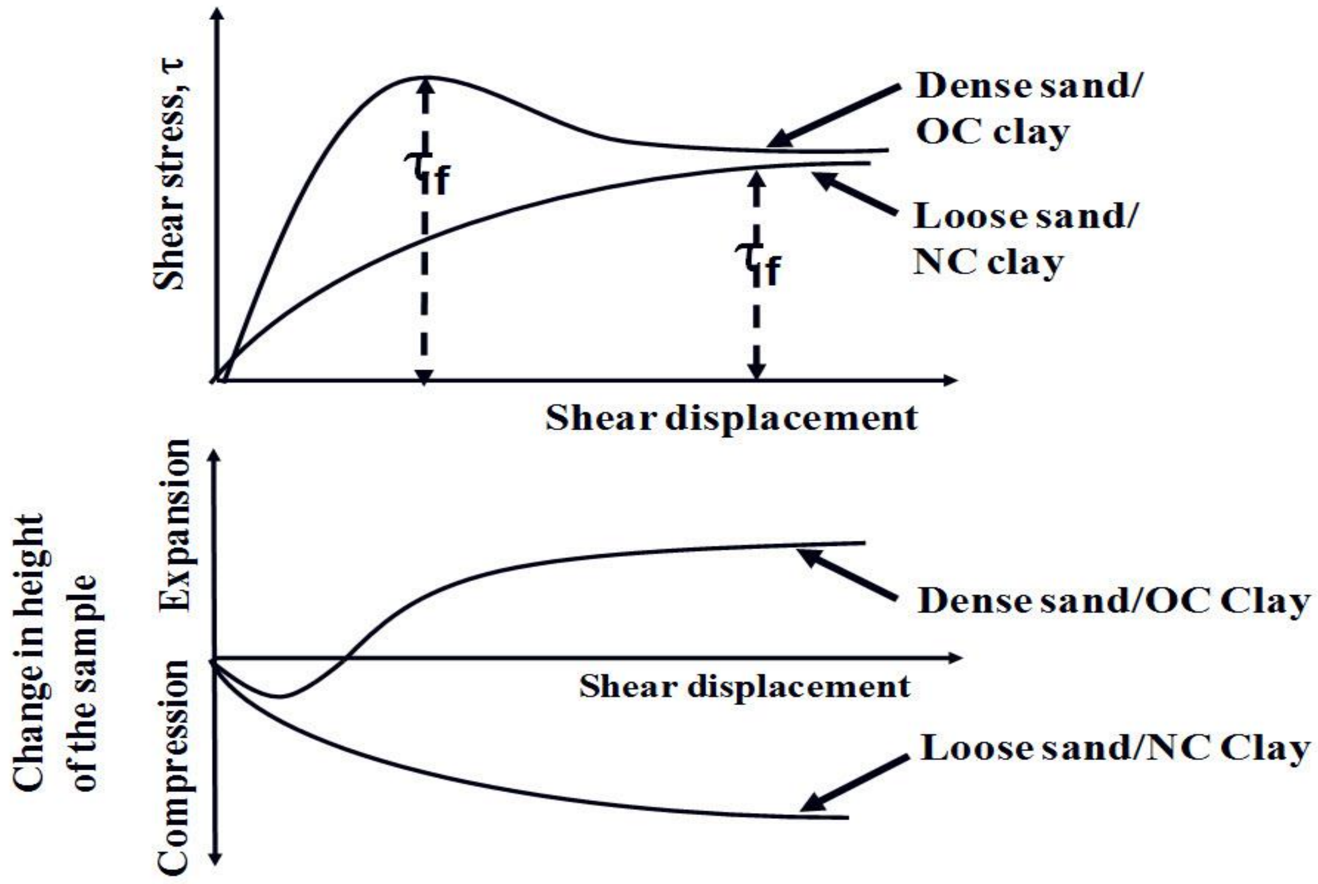
Direct shear test: Evaluation of results

- Peak shear stresses are noted down at each normal stress applied
- There will be ‘n’ numbers of normal and peak shear stresses for ‘n’ numbers of samples tested.
- A plot of Peak shear stress vs Normal stress do gives the shear strength parameters ‘φ’ and ‘c’ for a particular soil.



Shear stress-normal stress plot

Direct shear test: Sample results for sand



Shear stress-shear displacement and change in height of sample-shear displacement plot of soils obtained from direct shear tests.

Direct shear test: Disadvantages

- The drainage conditions cannot be controlled.
- As pore water pressure can not be measured, only total stresses can be determined.
- Shear stress on the failure plane are not uniform as failure occurs progressively from the edges to the center of the specimen.
- Area under the shear and vertical loads does not remain constant throughout the test.
- Soil is forced to shear at predetermined plane which should not be necessarily the weakest plane.
- Rotation of principal planes

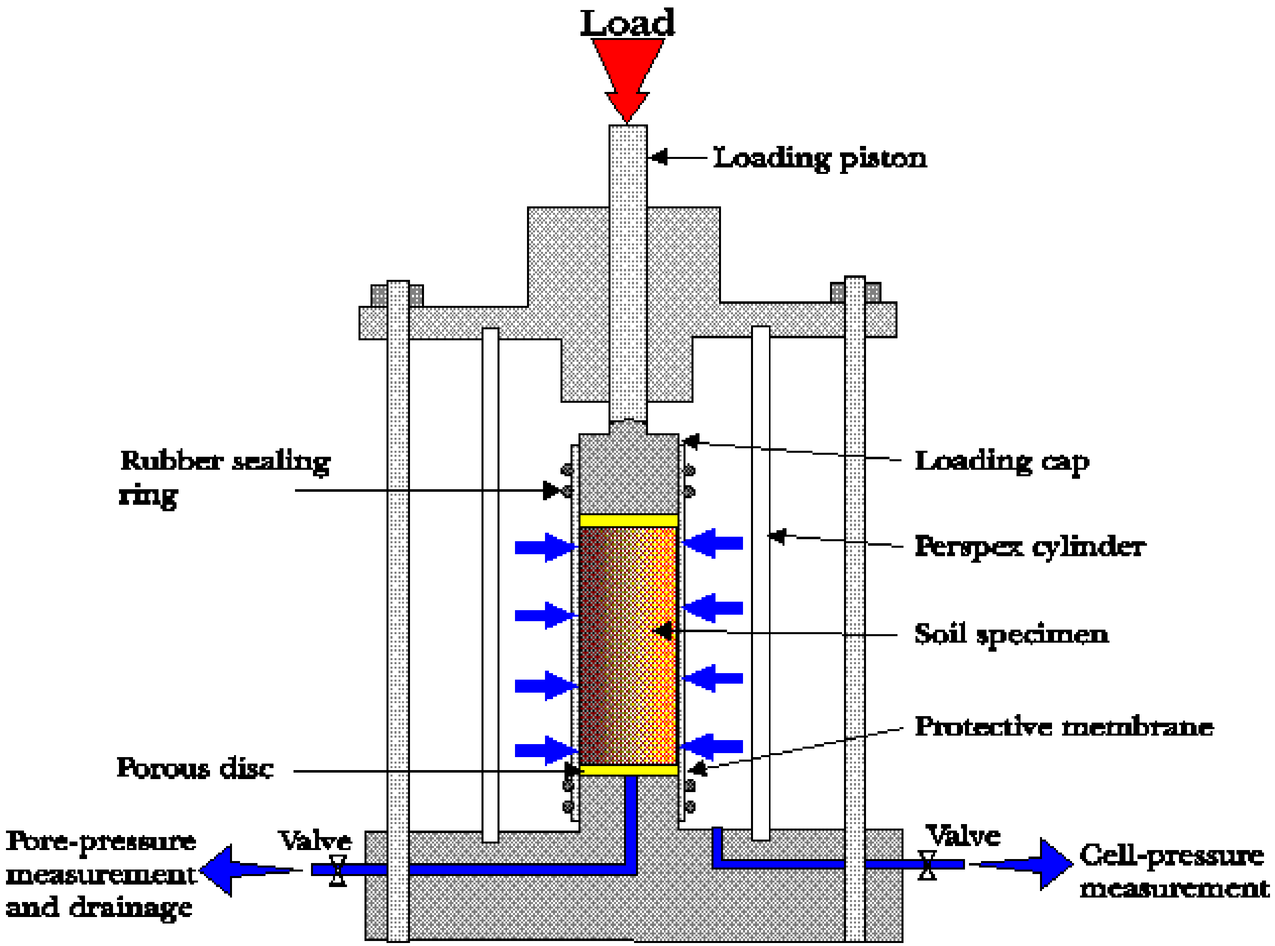
- The only advantage of direct shear test is its simplicity and, in the case of sands, the ease of specimen preparation.

Triaxial Test

- Most widely used shear strength test and is suitable for all types of soil.
- A cylindrical specimen, generally "L/D = 2" is used for the test, and stresses are applied under conditions of axial symmetry.
- Typical specimen diameters are 38mm, 100mm and 300 mm
- Depending on the combination of loading and drainage condition, three main types of triaxial tests can be carried out:

- Consolidated Drained (CD) Test
- Consolidated Undrained (CU) Test
- Unconsolidated Undrained (UU) Test

Triaxial Components



Triaxial apparatus

- The test specimen is subjected to all around lateral pressure called cell pressure (σ_3)
- Then addition load is applied on the sample till its fail and that load is called deviator load (σ_d)
- Corrected area (A_c) = $\frac{V-\Delta V}{L-\Delta L}$
- For an undrained test, the volumetric change (ΔV) is zero and then the equation above becomes:

$$Ac = A_0 / (1 - \epsilon_L)$$

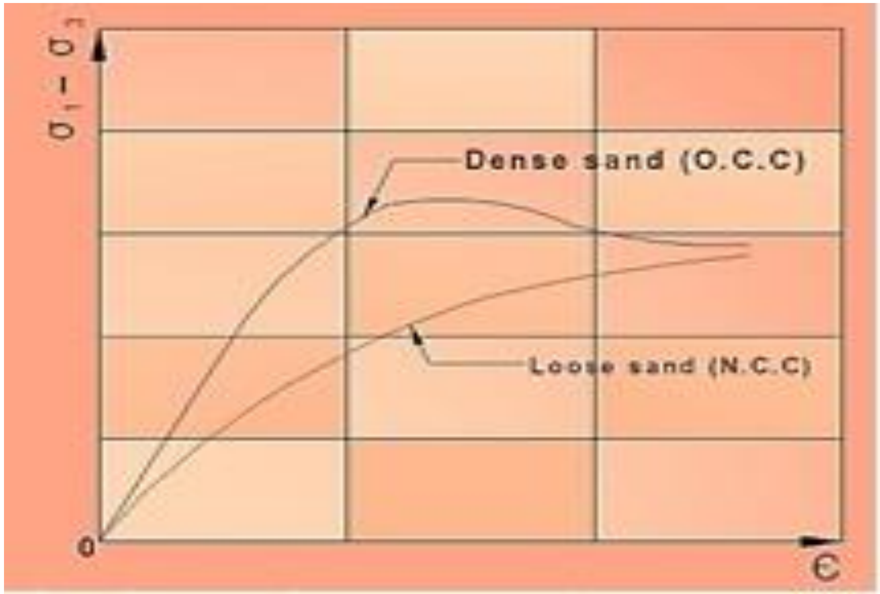
- Total stress (σ_1) = Cell pressure (σ_3) + deviator stress (σ_d)
- Deviator stress (σ_d) = Deviator load/A_c

- Relationship between total stress, cell pressure , deviator stress, cohesion and angle of internal friction in terms of effective as

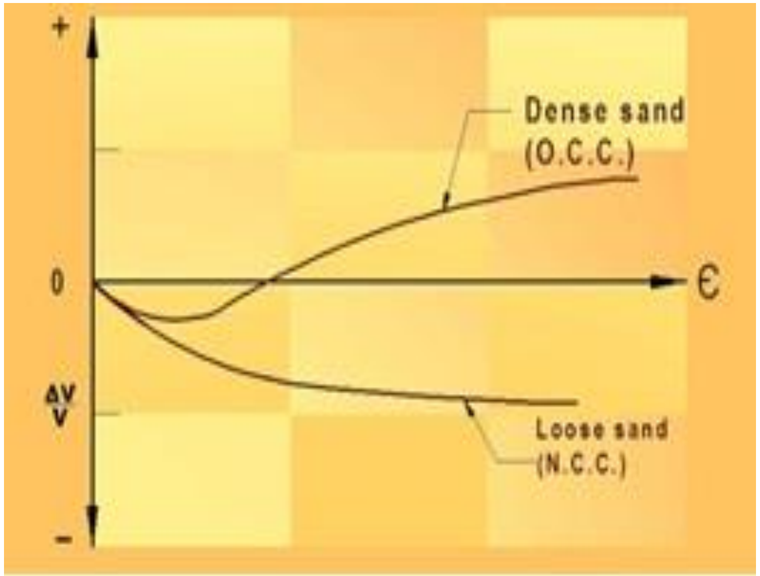
$$\sigma_1' = \sigma_3' \tan^2\left(45^\circ + \frac{\phi'}{2}\right) + 2c' \tan\left(45^\circ + \frac{\phi'}{2}\right)$$

Presentation of Results of Triaxial Tests

Consolidated Drained Test Results

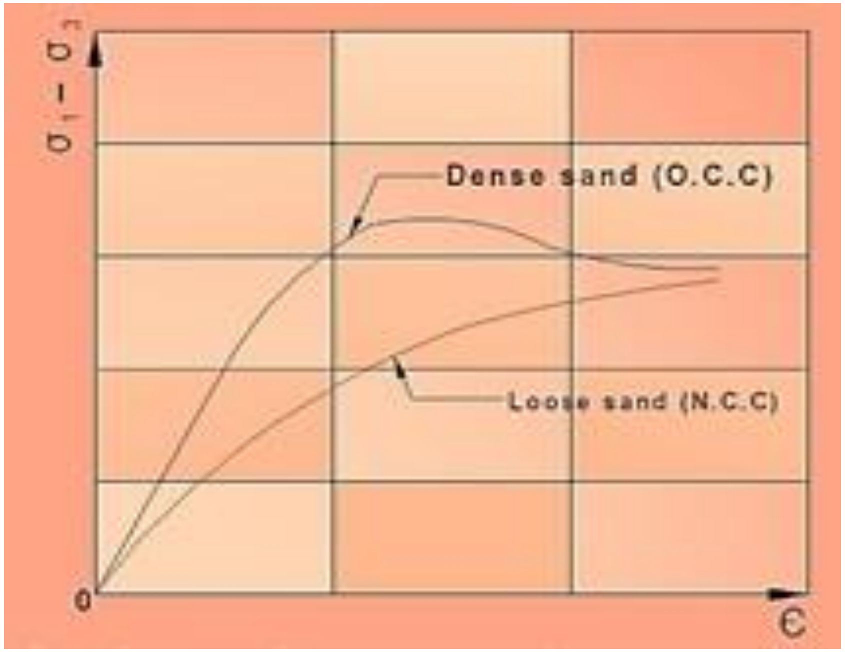


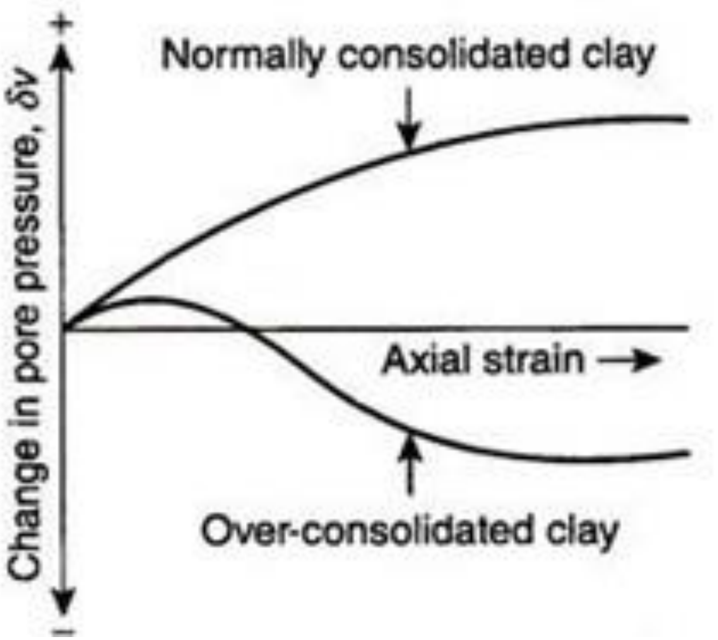
Stress – Strain Curve



Volumetric Strain

Consolidated Undrained Test



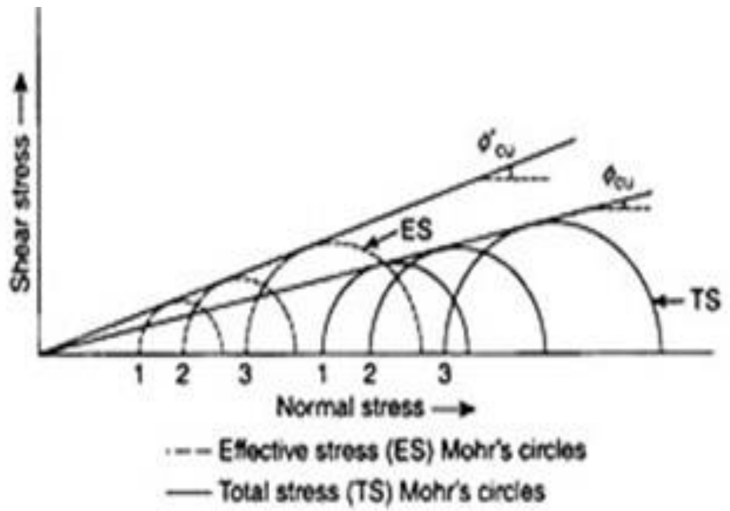


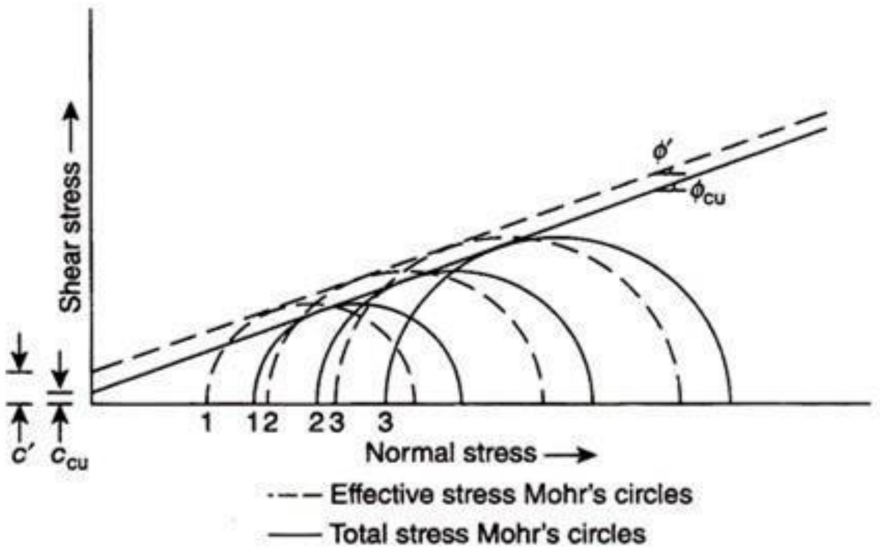
Stress – Strain Curve

Pore Pressure

Mohr Envelopes

- Effective Stresses

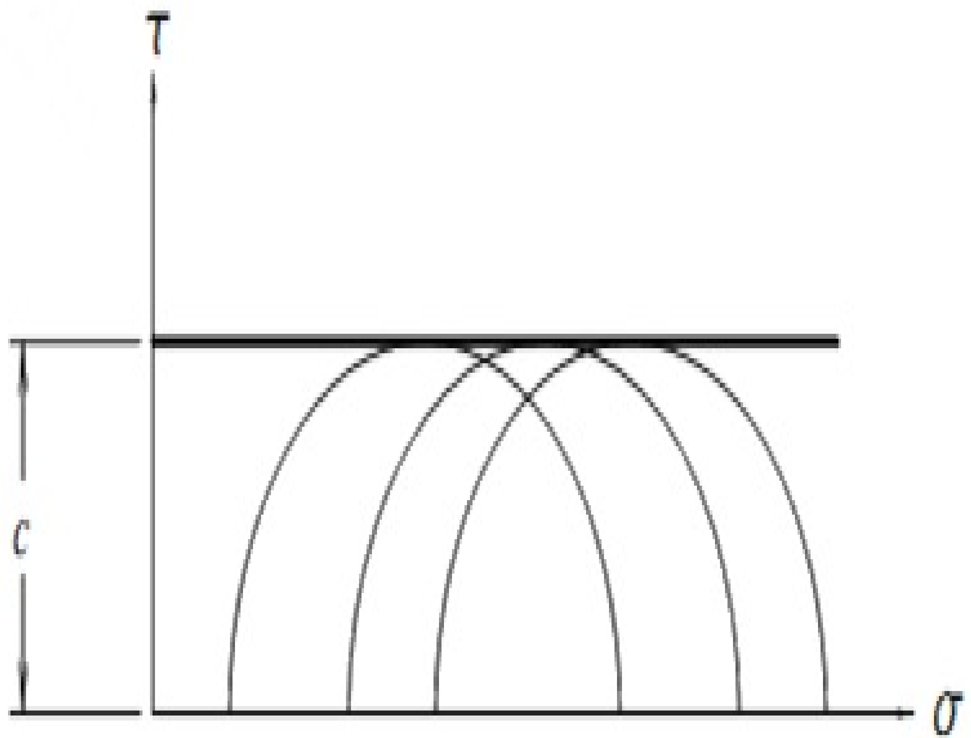




Failure Envelopes for normally consolidated Clay

Failure Envelopes for over consolidated Clay

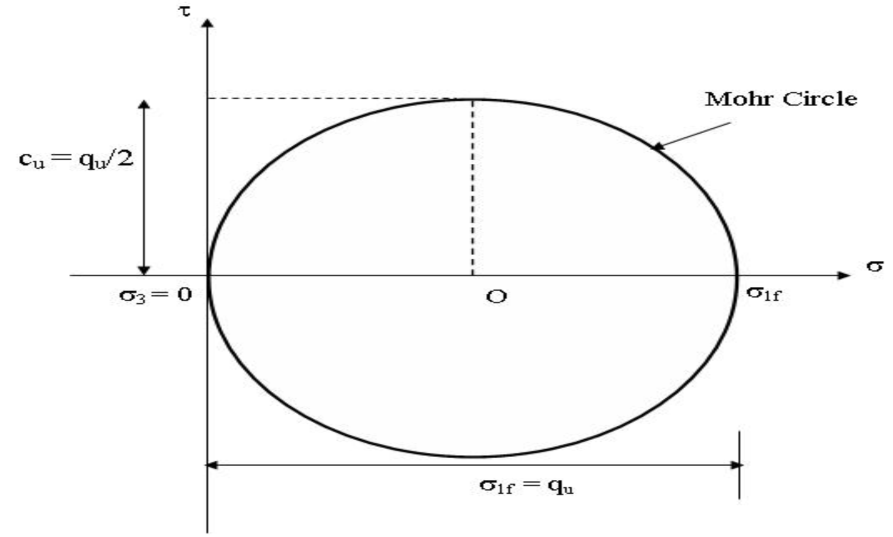
Total stresses



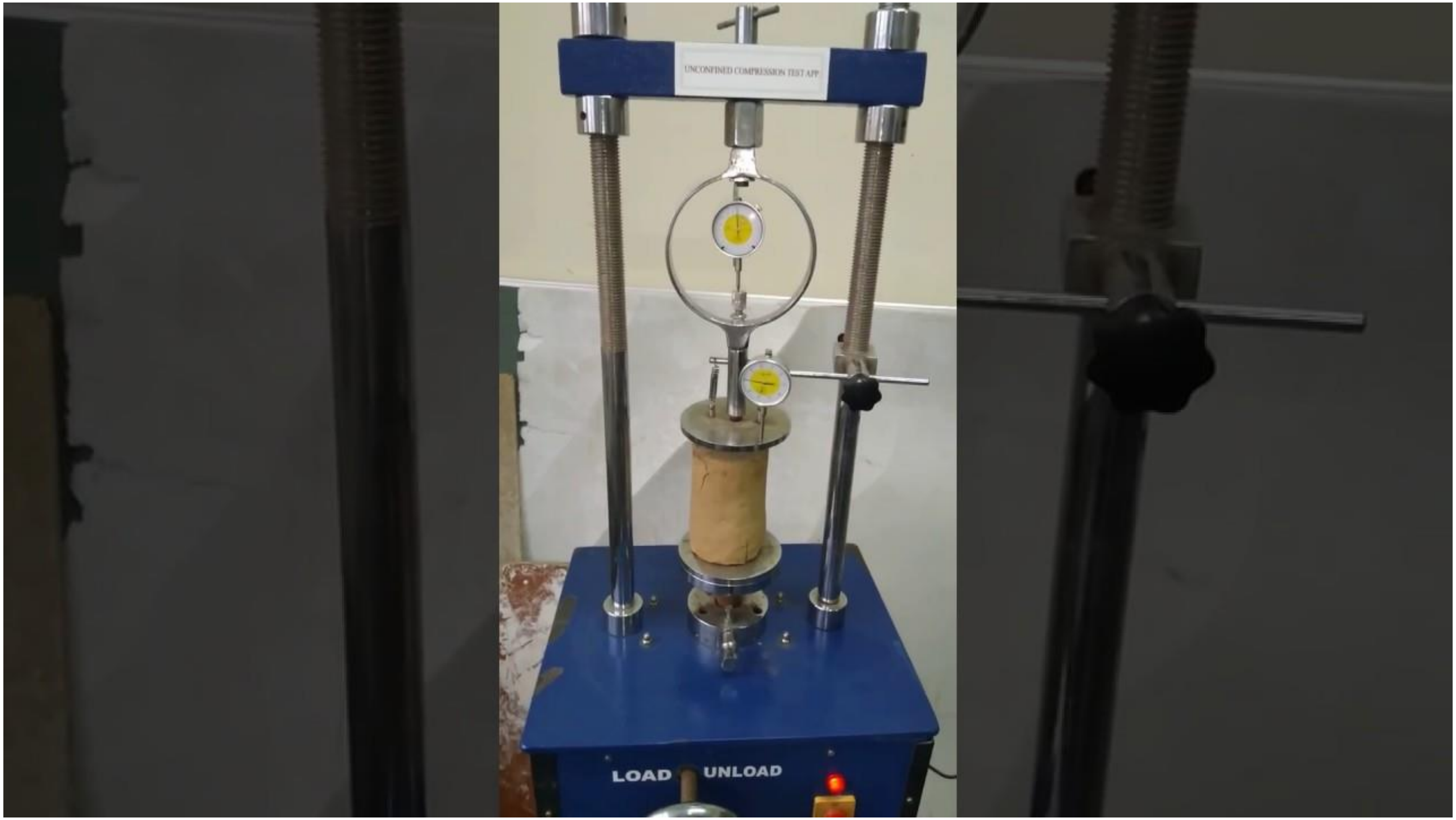
Failure Envelopes

Unconfined Compression Test

- The test is suitable for saturated clay ($\varnothing_u$ =0).
- The test is conducted under zero cell pressure.
- Special case of triaxial test with $\sigma_3 = 0$
- A cylindrical specimen is subjected to axial stress until failure.
- For purely clayey soil ϕu=0, the subscript u is used as the test is undrained test.
- The major principle stress (σ_1) is equal to the unconfined compressive strength of the soil (q_u).



Mohr-Coulomb plot for an unconfined compression test on saturated clay



Unconfined Compression Test

- The undrained cohesion can be determined as

$$c_u = \frac{q_u}{2}$$

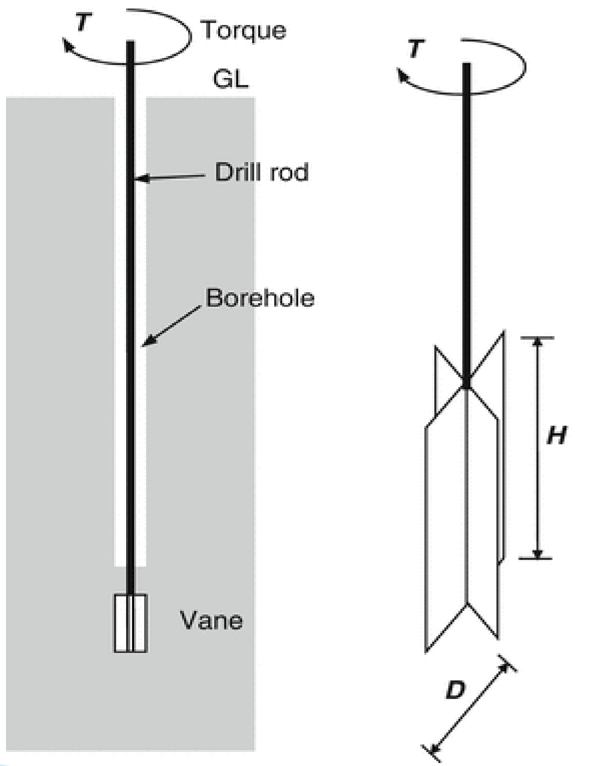
- For determining the unconfined compressive strength of the soil (q_u) (the applied load at failure divided by the cross-sectional area of the sample), the cross-section of the soil sample at failure load (A_f) is determined as

$$A_f = \frac{A_0}{1-\varepsilon}$$

where A_0 is the initial cross sectional area of the sample and ε is the axial strain in the sample

Vane Shear Test

- The laboratory vane shear apparatus consists shear vane which consists four steel blades defined as vanes which are welded at right angles to a steel rod whose diameter does not exceed 0.25 cm.
- Generally the diameter of the vane is 1.2 cm and height is equal to twice of its diameter i.e., 2.4 cm.



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- Prepare two or three specimens of the soil sample
- Mount the specimen container with the specimen on the base of the vane shear apparatus. If the specimen container is closed at one end, it should be provided with a hole of about 1 mm diameter at the bottom
- Lower the shear vanes into the specimen to their full length without disturbing the soil specimen. The top of the vanes should be at-least 10 mm below the top of the specimen. Note the readings of the angle of twist
- Rotate the vanes at a uniform rate say 0.1^o/s by suitable operating the torque application handle until the specimen fails
- Note the reading of the angle of twist
- Find the value of blade height in cm
- Find the value of blade width in cm

- Shear strength of soil (S) is calculated as

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

Where,

T is applied Torque

D is diameter of vane

H is height of vane

Advantage of Vane Shear Test:

- Vane shear test is easy and quick.
- This test can be performed either in laboratory or in the field directly on the ground.
- In-situ vane shear test ideal for the determination of undrained shear strength of non-fissured, fully saturated clay.
- Shear strength of soft clays at greater depths can also be found by vane shear test.
- Sensitivity of soil can also be determined using vane shear test results of undisturbed and remolded soil samples.

Drawbacks of Vane Shear Test

- Vane shear test is not suitable for clays which contain sand or silt laminations in it.
- It cannot be conducted on the fissured clay.
- If the failure envelope is not horizontal, vane shear test does not give accurate results.

Skempton's Pore Pressure Parameter

- The difference between the total and effective stresses is simply the pore water pressure u. Consequently, the total and effective stress Mohr circles have the same diameter and are only separated along the s - axis by the magnitude of the pore water pressure.
- In undrained tests, the general expression relating total pore water pressure developed and changes in applied stresses for both the stages is

$$\begin{aligned}\Delta u &= \Delta u_1 + \Delta u_2 \\ &= B.\Delta\sigma_3 + B.A.(\Delta\sigma_1 - \Delta\sigma_3) \\ &= B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]\end{aligned}$$

Where, Δu_1 = pore water pressure developed in the first stage during application of confining stress $\Delta\sigma_3$

Δu_2 = pore water pressure developed in the second stage during application of deviator stress $(\Delta\sigma_1 - \Delta\sigma_3)$

B and **A** are Skempton's pore water pressure parameters.

- Parameter B is a function of the degree of saturation of the soil (= 1 for saturated soils, and = 0 for dry soils).
- Parameter A is also not constant, and it varies with the over-consolidaton ratio of the soil and also with the magnitude of deviator stress. The value of A at failure is necessary in plotting the effective stress Mohr circles.
- Consider the behaviour of saturated soil samples in undrained triaxial tests. In the first stage, increasing the cell pressure without allowing drainage has the effect of increasing the pore water pressure by the same amount.
- There is no change in the effective stress. During the second shearing stage, the change in pore water pressure can be either positive or negative.
- For UU tests on saturated soils, pore water pressure is not dissipated in both the stages (i.e., $\Delta u = \Delta u_1 + \Delta u_2$).

  For CU tests on saturated soils, pore water pressure is not dissipated in the second stage only (i.e., $\Delta u = \Delta u_2$).

Important Links

- https://nptel.ac.in/content/storage2/courses/105103097/web/chap9final/s7.htm
- https://nptel.ac.in/noc/courses/noc16/SEM1/noc16-ce01/
- http://www.iricen.gov.in/LAB/res/html/Test-08.html
- https://en.wikipedia.org/wiki/Triaxial_shear_test
- https://theconstructor.org/geotechnical/shear-strength-soil-vane-shear-test/3435/

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