Shear strength of soil

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WHAT IS SHEAR STRENGTH OF SOIL?

➢ Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain.

➢ The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts.

DEFINITIONS

➤ Cohesion:-
> ➤ The attraction between the molecules of the same material is called cohesion.
> ➤ Dry sand is cohesion less.
> ➤ Addition of water in the dry and induces, a little cohesion in it.
> ➤ Clayey soil has maximum cohesion
> ➤ The cohesion of soil depends on: 1. Fineness of clay particles
>   2. Amount of clay
>   3. Water content of soil

➤ Internal friction:-
> ➤ The frictional resistance between the individual soil particles at their contact
>   point is known as internal friction.

➤ Angle of Internal friction : Φ
> ➤ It represents the frictional resistance between the soil particles, which is directly
>   proportional to the normal stress.

MOHR CIRCLE OF STRESS

➢ At any point a strained material, there exist three mutually perpendicular planes on which only direct stresses are acting, i.e. no shearing stress acting.

➢ These are known as the principal planes. The normal stress that act on a planes are called the principal stresses.

➢ The largest of this is called the major principal stress ($\sigma 3$), the smallest, the minor principal stress ($\sigma 3$), and the third one is called intermediate principal stress ($\sigma 2$).

➢ The corresponding planes are respectively designated as the major principal plane, minor principal plane and intermediate principal plane.
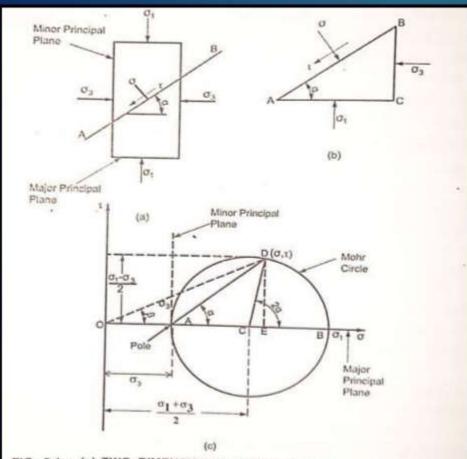
FIG. 2.1 : (a) TWO DIMENSIONAL STRESS SYSTEM ON AN ELEMENT
(b) ELEMENT AT EQUILIBRIUM
(c) MOHR DIAGRAM FOR STATE OF STRESS AT A POINT

$$\sigma = \frac{(\sigma_1 + \sigma_3)}{2} + \frac{(\sigma_1 - \sigma_3)}{2} \cos 2\,\alpha$$

$$\tau = \frac{(\sigma_1 - \sigma_3)}{2} \sin 2\,\alpha$$

$$\sigma_r = \sqrt{\sigma^2 + \tau^2}$$

MOHR-COULOMB'S STRENGTH THEORY

➤ Coulomb (1776), in his investigations observed that one component of the shearing Strength, called the intrinsic cohesion (apparent cohesion) is constant for a given soil and is independent of the applied stress.

➤ The other component, namely, the friction resistance, varies directly as the magnitude of the normal stress on the plane of rupture.

➤ The shear strength of a soil at a point on a particular plane was expressed by coulomb as a linear function of the normal stress on that plane, as
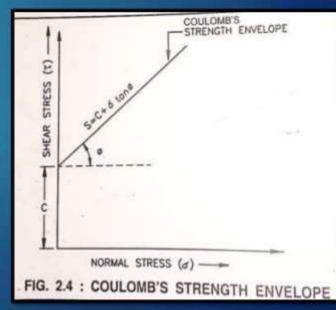
$$S = C + \sigma \tan \Phi$$

Where,

S = Shear strength of the soil

C = Apparent Cohesion

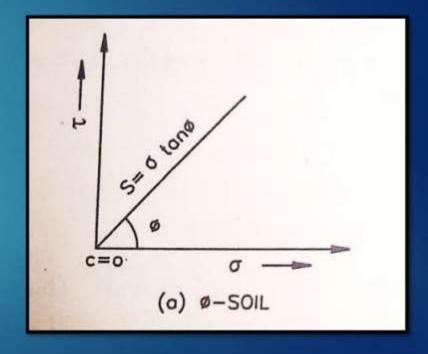σ = Normal stress on the failure plane

Φ = Angle of internal friction

➤ C and Φ are also referred to as the shear strength parameters of soil.

FIG. 2.4 : COULOMB'S STRENGTH ENVELOPE

TYPES OF SOIL BASED ON TOTAL STRENGTH

1. Cohesion less soil (Φ- Soil)
    - These are the soils which do not have cohesion. (C=0)
    - These soils derive the shear strength from the intergranular friction.
    - These soils are also called frictional soils.
    - Examples: Sands and gravels.
    - Equation for strength is,

        $S = \sigma . \tan \Phi$

(a) ø−SOIL

2. Purely cohesive soil: (C-Soil)

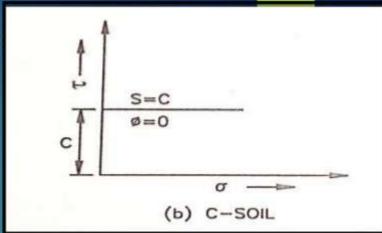➤ These are the soils which exhibit cohesion but, the angle of shearing resistance,

$\Phi = 0$

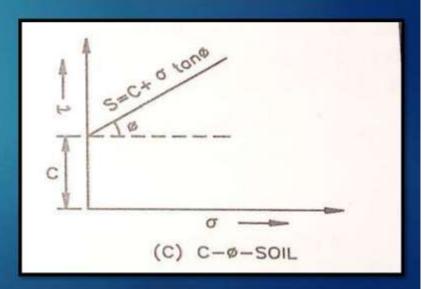➤ These soils are called C-Soils.
➤ Example: Saturated clays
➤ Equation for shear strength is

$S = C$

(b) C—SOIL

3. Cohesive frictional soil: (C-Φ soil)

➤ These are composite soil having c and Φ both.
➤ These are also called C-Φ soils.
➤ Example: Clayey sand, silty sand, sandy clay
➤ The equation for shear strength is,

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

(C) C—Φ—SOIL

SHEAR TEST BASED ON DRAINAGE CONDITION

❖ Unconsolidated un-drained test:
  ➢ In this type of test, no drainage is permitted during the consolidation stage. The drainage is permitted in the shear stage.
  ➢ As no time is allowed for consolidation for dissipation of excess pore water Pressure the test can be conducted quickly in a few minutes.
  ➢ The test is also known as quick test (Q-test)

❖ Consolidated un-drained test:
  ➢ In this type of test, the specimen is allowed to consolidated in the first stage. The drainage permitted until the consolidation is complete.
  ➢ In the second stage, when the specimen is sheared, no drainage is permitted.
  ➢ The test is also known as R test. Q used for quick test, S used for slow test and R falls between Q and S.

❖ **Consolidated Drainage test:**

   In this type of test, drainage is permitted in both the stages.

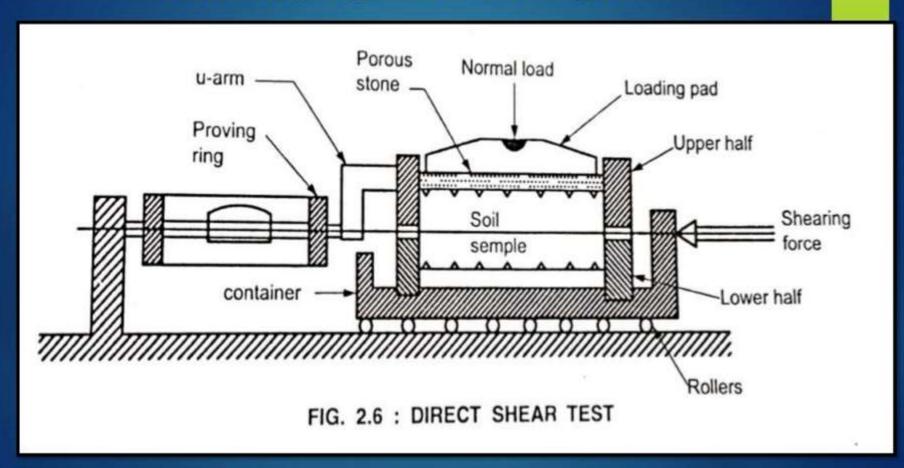   The sample is allowed to consolidated in the first stage.

   When the consolidation is complete, is sheared at a very slow rate to ensure that ensure that fully drained condition exist and the excess pore water is zero.

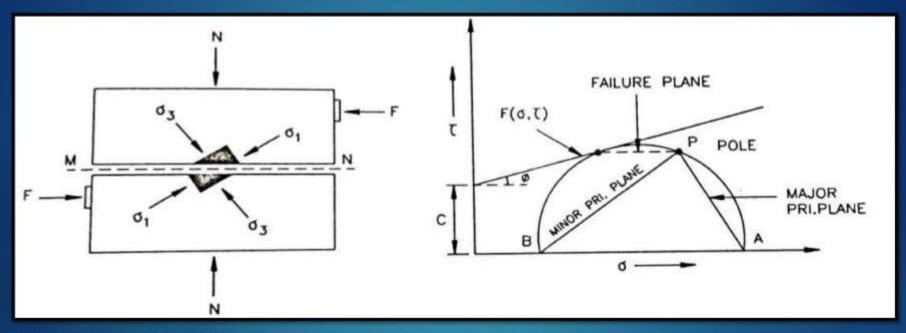   The test is also known as drained test or slow test (S test).

TEST FOR SHEAR STRENGTH:

❖Direct shear test
❖Triaxial compression test
❖Unconfined compression test
❖Vane shear test

❖ DIRECT SHEAR TEST

FIG. 2.6 : DIRECT SHEAR TEST

PRINCIPLE OF DIRECT SHEAR TEST

MN = plane of shear failure
N = vertical normal load
F = horizontal shear force
σ_1 = Major principal stress
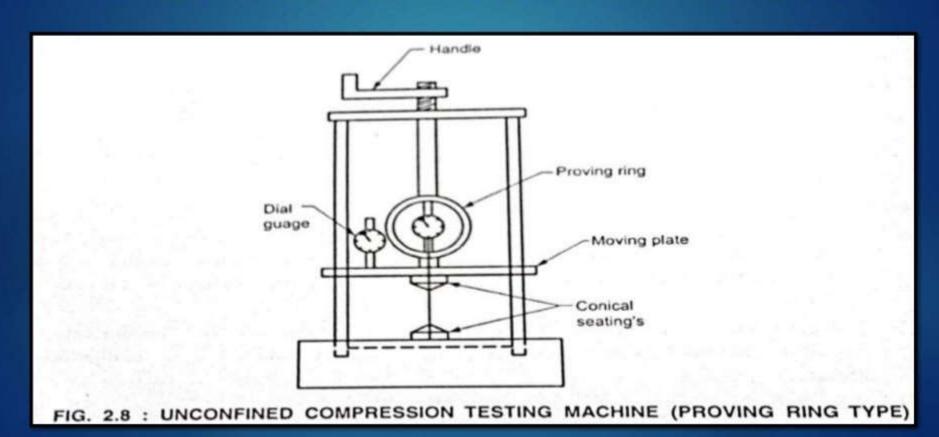σ_3 = Minor principal stress

MERITS OF SHEAR TEST

➢ The sample preparation is easy. The test is simple and convenient.
➢ As the thickness of the sample is small the drainage is quick and the pore pressure dissipates very rapidly. thus CD and CU tests takes relatively small period.
➢ It is ideally suited for conducting drained tests on cohesion less soils.
➢ The apparatus is relatively cheap.

DEMERITS OF SHEAR TEST

➢ The stress conditions are known only at failure.
➢ The orientation of the failure plane is predetermined. This may nit be weakest plane.
➢ Control on the drainage condition is very difficult. Consequently only drained tests can be conducted on highly permeable soils.
➢ The measurement of pore water pressure is not possible.
➢ The side walls of the shear box cause lateral restraint on the specimen and do not allow it to deform laterally.
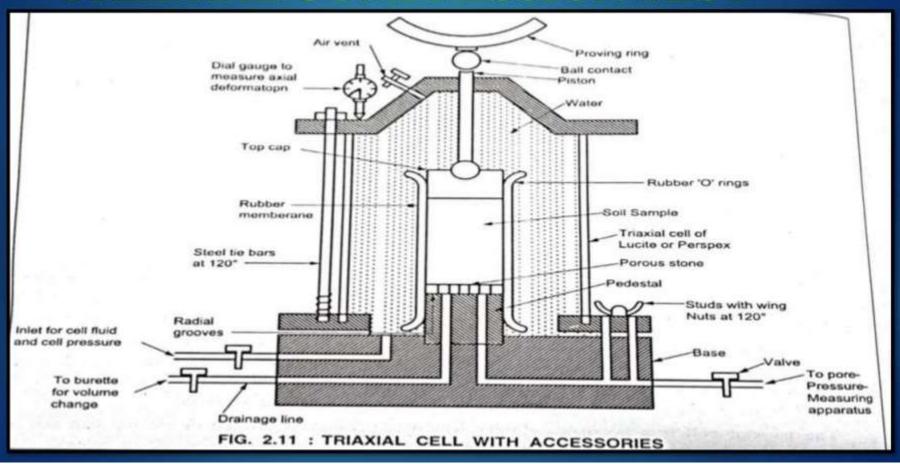
UNCONFINED COMPRESSION TEST

FIG. 2.8 : UNCONFINED COMPRESSION TESTING MACHINE (PROVING RING TYPE)

MERITS OF UNCONFINED COMPRESSION TEST

➢ The test is quick, simple and convenient.
➢ The test is ideally for measuring unconsolidated- undrained shear strength intact, saturated clays.
➢ The sensitivity of the soil may be easily determined by conducting the test on undisturbed sample and then on the re-moulded sample.

DEMERITS OF UNCONFINED COMPRESSION TEST

➢ The test cannot be conducted on coarse grained soils such as sands and gravels.
➢ The test also cannot be conducted on fissured clays.
➢ The soils for which $\emptyset = 0$ the test results may be misleading.

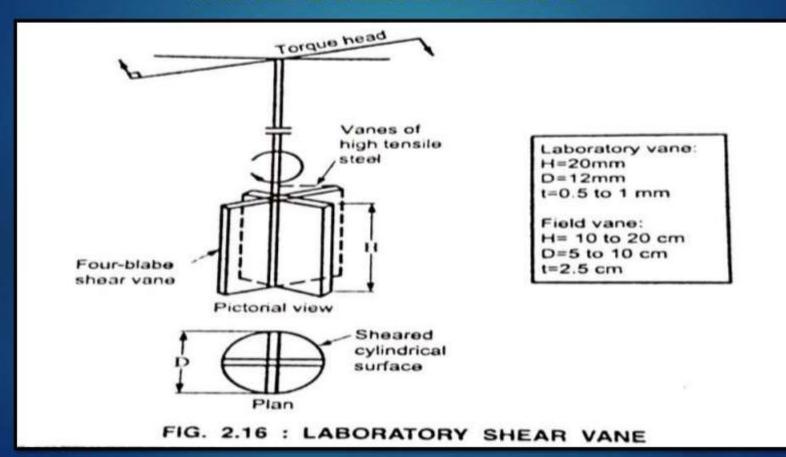# TRIAXIAL COMPRESSION TEST

FIG. 2.11 : TRIAXIAL CELL WITH ACCESSORIES

ADVANTAGES OF TRIAXIAL TEST

➢ The shear tests under all the three drainage conditions can be performed with complete control.
➢ Pore pressure and volumetric changes can be measured directly.
➢ The stress distribution on the failure plane is uniform.
➢ The specimen is free on the weakest plane.
➢ The test is suitable foe accurate research work.

DISADVANTAGES OF TRIAXIAL TEST

➢ In case of drained test the test takes longer period as compared with that in a direct shear test.
➢ The apparatus is bulky, costly and elaborate.
➢ It is possible to determine the c/s area of the soil sample accurately at large strains.
➢ The consolidation of the soil sample in the test is isotropic whereas in the field the consolidation is generally anistrophic.

VANE SHEAR TEST

FIG. 2.16 : LABORATORY SHEAR VANE

➢ The shear strength S of the clay is given by

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

if both the top and bottom of the vane partake in shearing the soil.

T = Torque

D = Diameter of the vane

H = height of the vane

if only the bottom end partakes in the shearing the above equation takes the form:

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

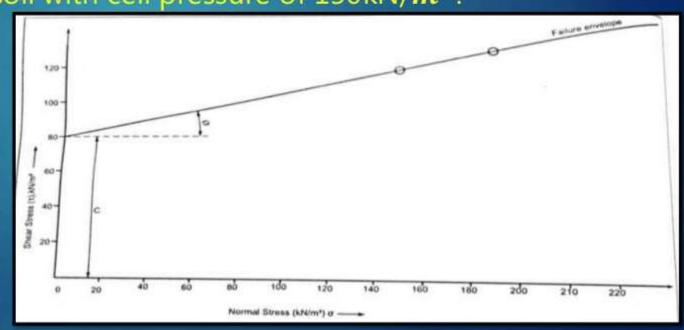□ The direct shear test was carried out on a soil sample and the following results were obtained.

Normal stress kN/m^2	150	200
shear stress kN/m^2	110	120

What would be the deviator stress if a triaxial test is carried out on the same soil with cell pressure of 150kN/m^2?

Form the graph
$$\emptyset = 12°$$
$$C = 80kN/m^2$$

For triaxial test

$$\sigma_3 = 150 \text{kN/m}^2$$

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

$$= 150 \tan^2 51° + 2 \times 80\tan51°$$

$$= 228.75 + 197.58$$

$$= 426.33 \text{ kN/m}^2$$

$$\sigma_d = \text{deviator stress}$$

$$\sigma_d = \sigma_1 - \sigma_3$$

$$= 426.33 - 150$$

$$= 276.33 \text{ kN/m}^2$$

❑ In an unconfined compression test a sample of clay 8 cm long and 4 cm in diameter fails under a load 120 N at 10% strain. Compute the shearing resistance taking into account the effect of change in c/s of the sample.

$d_0 = 4cm = 40mm$

$A_0 = \frac{\pi}{4} \times 40^2 = 1256.63\ mm^2$

$L_0 = 8cm = 80mm$

$\varepsilon = 10\% = 0.10$

$A_f = \frac{A_0}{1-\varepsilon} = \frac{1256.63}{1-0.10} = 1396.26mm^2$

P = 120 N

Unconfined compressive strength

$q_u = \sigma_1 = \frac{P}{A_f}$

$= \frac{120}{1396.26} = 0.086\frac{N}{mm^2} = 86kN/m^2$

Shear stress at failure

$C = \frac{q_u}{2} = \frac{86}{2} = 43kN/m^2$