IIT KHARAGPUR

NPTEL ONLINE
CERTIFICATION COURSES

NPTEL

SOIL MECHANICS/GEOTECHNICAL ENGINEEING I

SHEAR STRENGTH

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

Determination of Shear Strength Parameters

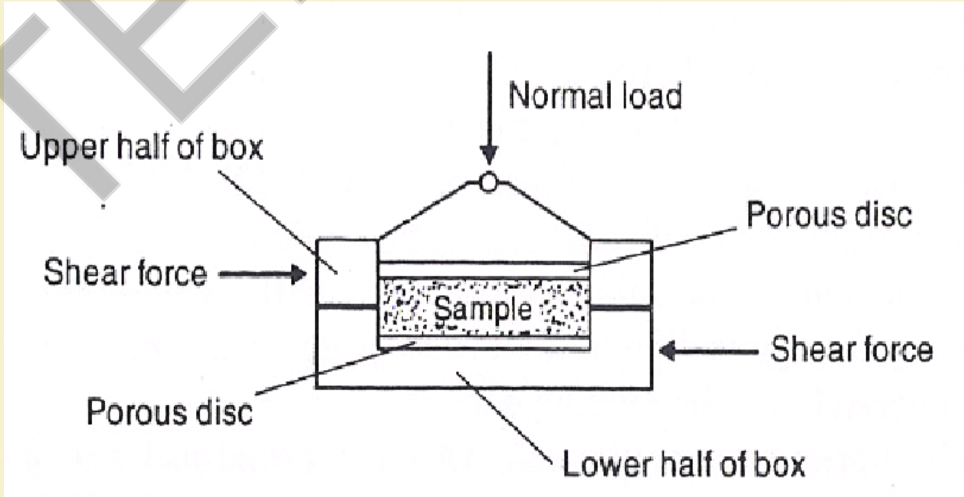
1. Direct Shear Test
2. Tri-axial Shear Test
3. Unconfined compression Test
4. Vane Shear Test

DILIP KUMAR BAIYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

The usual plan size of the sample 60 mm by 60 mm. For testing granular materials such s gravel larger size of box , generally 300 mm by 300 mm.

A vertical load is applied to the top of the sample by means of weight. As the shear plane is predetermined in the horizontal direction and the vertical load is nor mal to the plane of failure. Shearing force is gradually exerted on the box from an electrically driven screw jack



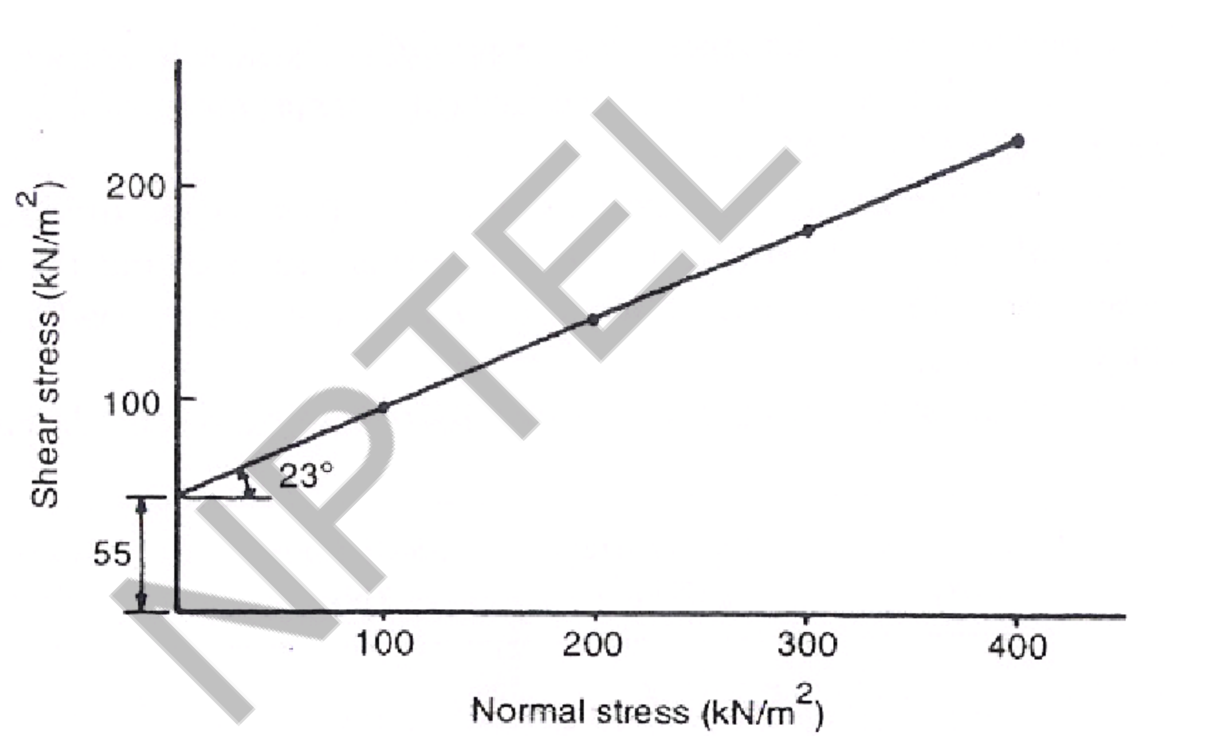
SHEAR STRENGTH

Undrained shear box tests were carried out on a series of soil samples with the following results

Test No	Total Normal Stress (kN/m2)	Total Shear stress at Failure (kN/m2)
1	100	98
2	200	139
3	300	180
4	400	222

Determine the cohesion and angle of internal friction of the soil, with respect to total stress

SHEAR STRENGTH

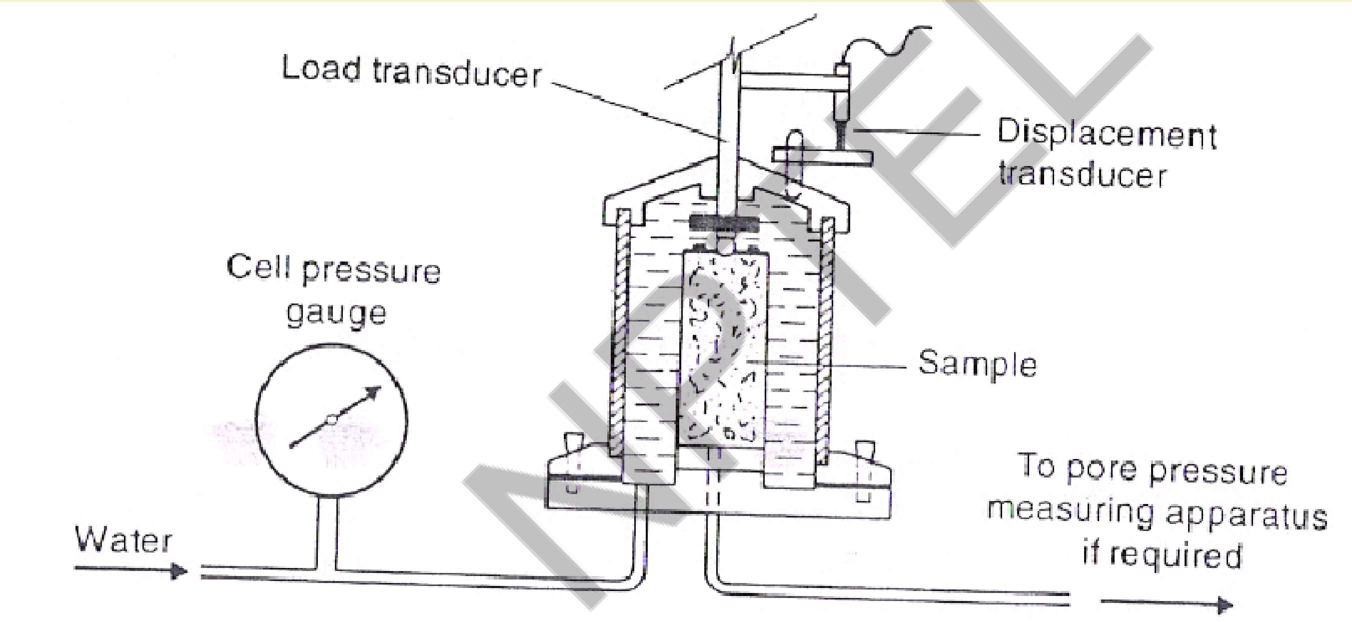


Tri-axial Test

The soil sample tested is cylindrical with a height twice of its diameter. Standard dimensions: 38 mm diameter and 76 mm long, 100 mm diameter and 200 mm long

DILIP KUMAR BAIYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

Tri-axial Test Apparatus



Determination of additional axial stress

From the load transducer it is possible at any time during the test to determine the additional axial load that is being applied to the sample

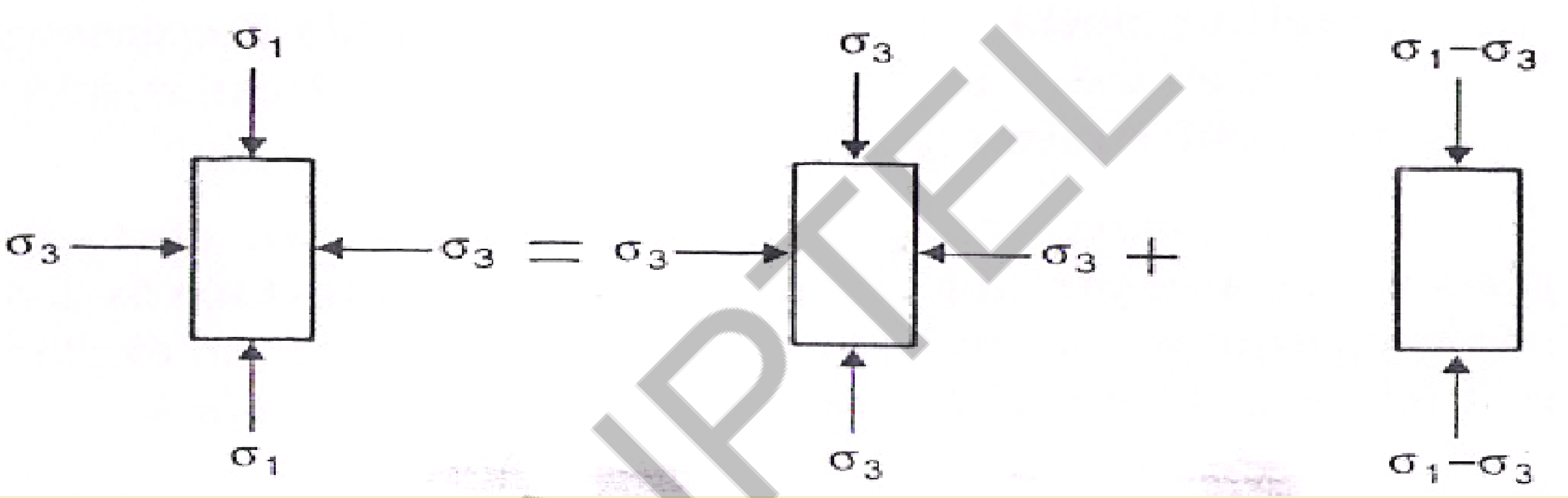
Cross sectional area
= Volume of sample/ (original length – vertical deformation)
= $A/(1-\epsilon)$

ϵ is the longitudinal strain

DILIP KUMAR BAIYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

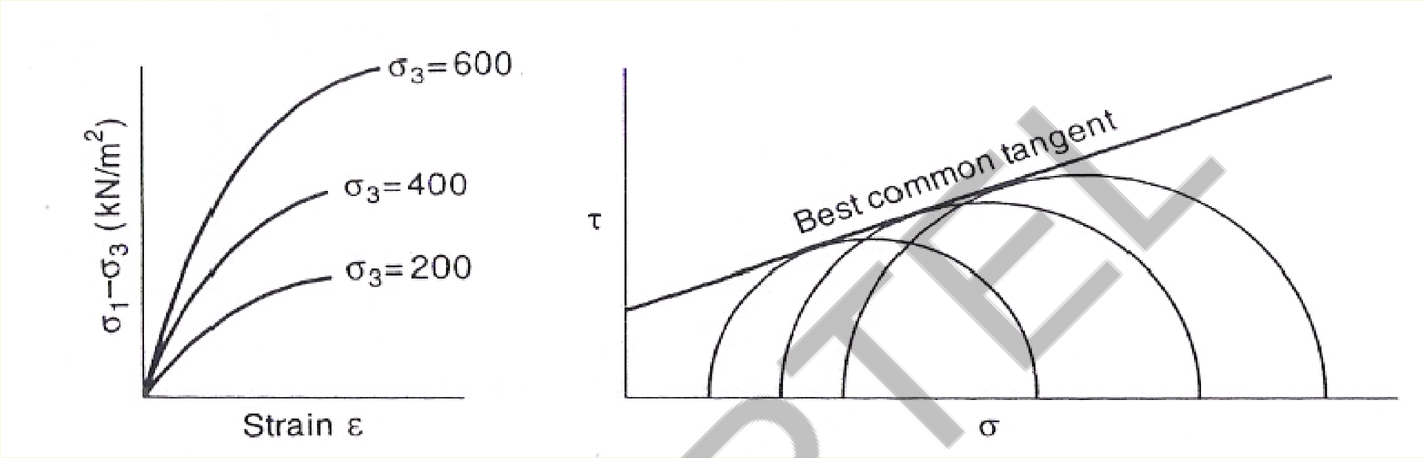
The principal stresses: The intermediate principal stress $\sigma 2$ and the minor principal stress $\sigma 3$ are equal and are the radial stresses caused by the cell pressure, pc. The major principal stress consists of two parts; the cell water pressure acting on the ends of the sample and additional axial stress from the load transducer

SHEAR STRENGTH



DILIP KUMAR BAIYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH



DILIP KUMAR BAIYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

Total stress parameters

The undrained shear test: The simplest method to determine the values for the total strength parameters of soil is to subject suitable samples of the soil to this test. In the test the soil sample is prevented from draining during shear and is therefore sheared immediately after the application of normal load (in direct shear test) and immediately after the application of confining pressure (in triaxial test). A sample can be tested in 15 minutes or less so that there is no time for any pore pressures developed to dissipate or to distribute themselves evenly throughout the sample.

DILIP KUMAR BAIYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

Unconfined compression apparatus is only capable of carrying out an undrained test on a saturated clay samples with no radial pressure applied.

Thank You!!

IIT KHARAGPUR

NPTEL ONLINE
CERTIFICATION COURSES

NPTEL

SOIL MECHANICS/GEOTECHNICAL ENGINEERING I

SHEAR STRENGTH

DILIP KUMAR BAIDYA

DEPARTMENT OF CIVIL ENGINEERING

IIT KHARAGPUR

Types of Tri-axial Test

1. Unconsolidated Undrained Test
2. Consolidated Undrained Test
3. Consolidated Drained Test

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

The undrained shear test: The simplest method to determine the values for the total strength parameters of soil is to subject suitable samples of the soil to this test. In the test the soil sample is prevented from draining during shear and is therefore sheared immediately after the application of normal load (in direct shear test) and immediately after the application of confining pressure and deviator stress (in triaxial test). A sample can be tested in 15 minutes or less so that there is no time for any pore pressures developed to dissipate or to distribute themselves evenly throughout the sample.

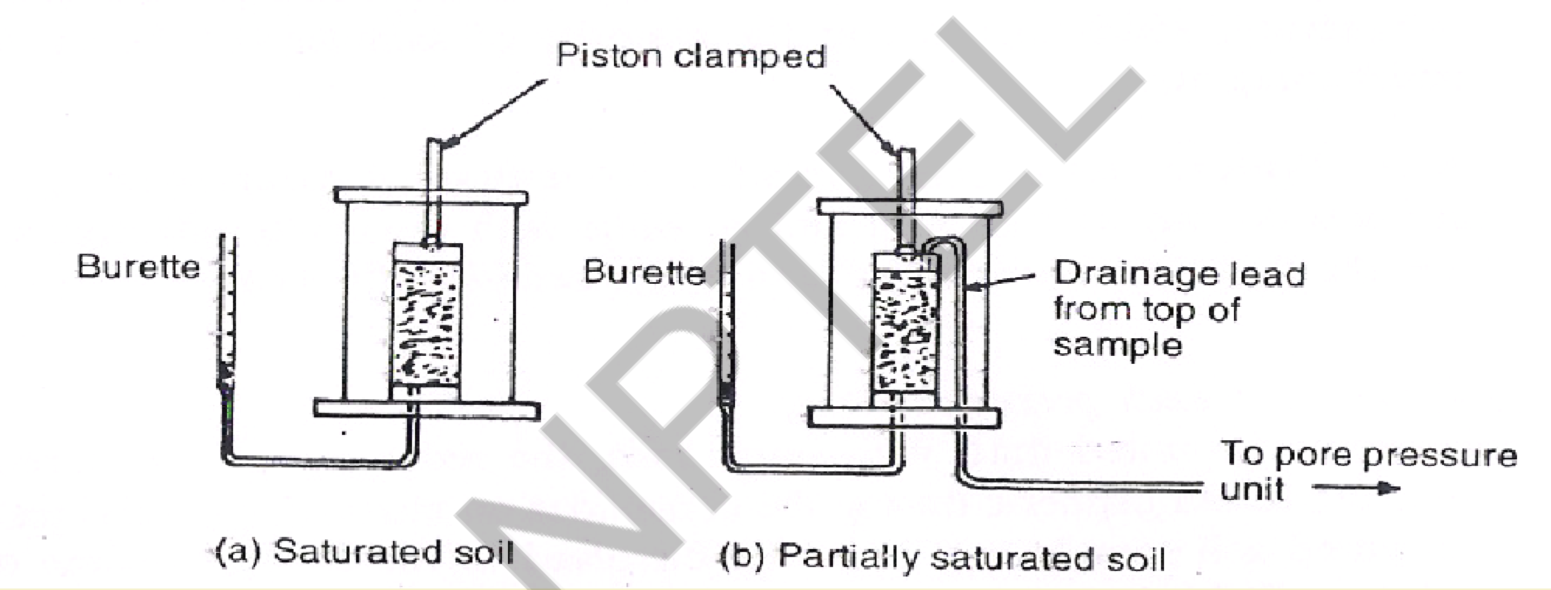
Drained Test

A porous disc is placed on the pedestal before the test sample is placed in position so that water can drain out from soil. The triaxial cell is then assembled, filled with water and pressurised. The cell pressure creates a pore water pressure within the soil sample and the apparatus is left until the sample get consolidated. This process usually takes about a day.

The main drawback of the drained test is the length of time it takes

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH



DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

When the consolidation has been completed the sample is sheared by applying a deviator stress at such a low rate of strain that any pore water pressures induced in the sample have time to dissipate through the porous disc. In this test the pore water pressure is therefore always zero and the effective stresses are consequently equal to the applied stresses.

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

Consolidated Undrained Test

This is the most common form of triaxial test used in soil mechanics laboratories to determine c′ and ϕ′. It has the advantage that shear part of the test can be carried out in only two to three hours. The sample is consolidated exactly as for the drained test.

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

The following results were obtained from a series of undrained tri-axial tests carried out on undisturbed samples of a compacted soil:

Cell pressure (kPa)	Additional axial load (N)
200	342
400	388
600	465

Each sample, originally 76 mm long and 38 mm in diameter, experienced a vertical deformation of 5.1 mm. Draw the strength envelope and determine the coulomb equation for the shear strength of the soil in terms of total stresses

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

Volume of sample = $\frac{\pi}{4} \times 38^2 \times 76 = 86193\ mm^3$

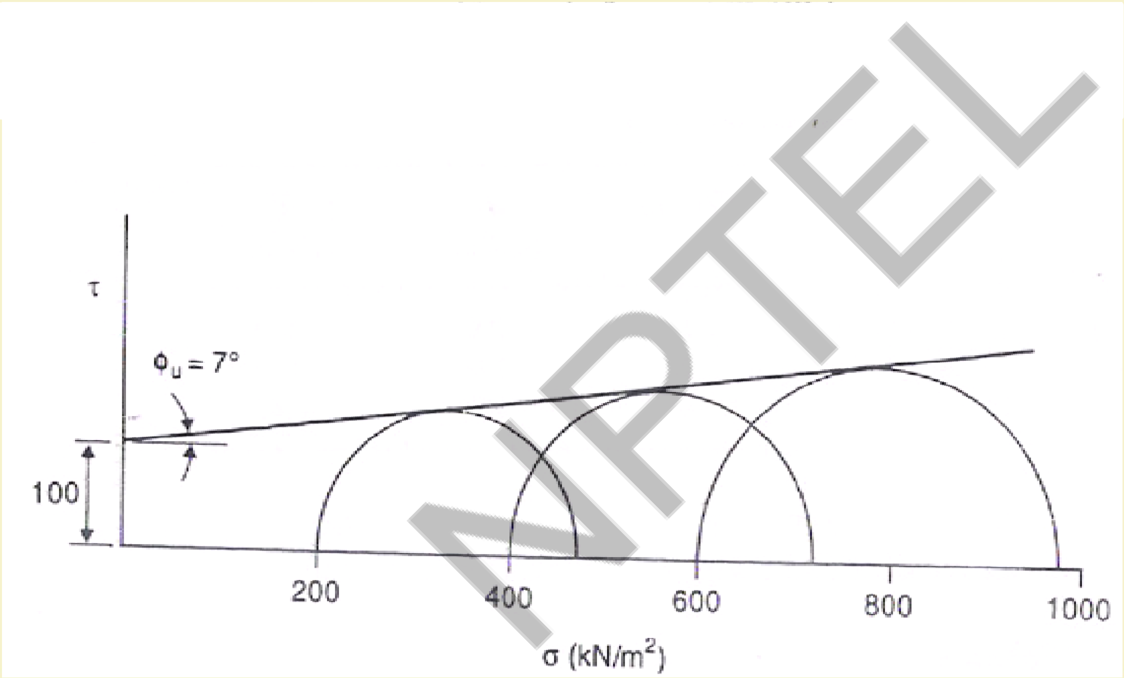
Cross sectional area at failure = $\frac{86193}{76 - 5.1} = 1216\ mm^2$

Cell pressure, σ_3 (kPa)	Deviator stress (σ_1-σ_3) kPa	Major principal stress, σ_1 kPa
200	$\frac{342 \times 10^6}{1216} = 281$	481
400	319	719
600	382	982

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

$$\tau = c_u + \sigma tan\emptyset_u = 100 + \sigma tan7^0 = 100 + 0.123\sigma \; kN/m^2$$



DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

Thank You!!

IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

NPTEL

SOIL MECHANICS/GEOTECHNICAL ENGINEERING I

SHEAR STRENGTH

DILIP KUMAR BAIDYA

DEPARTMENT OF CIVIL ENGINEERING

IIT KHARAGPUR

SHEAR STRENGTH: Application 2

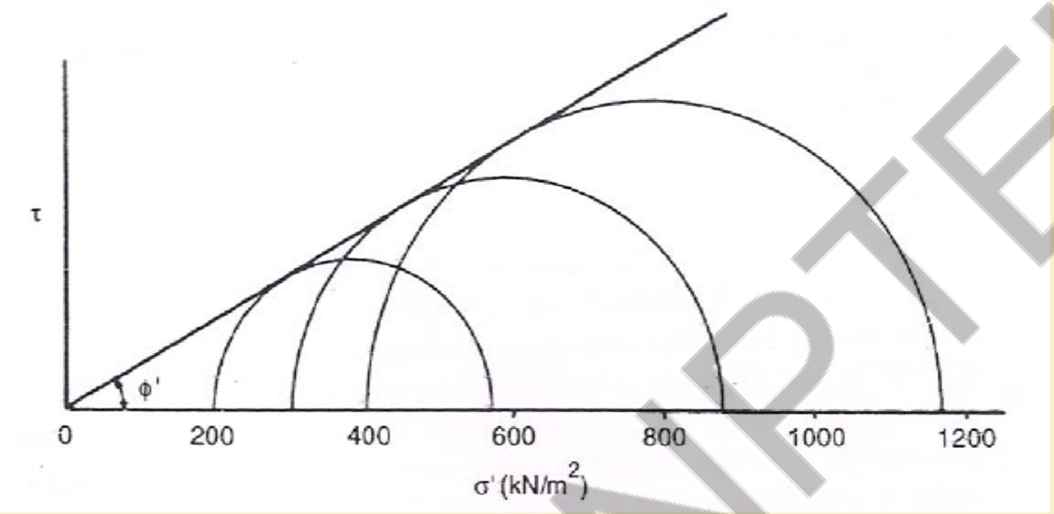
A series of drained tri-axial tests were performed on a soil. Each test was continued until failure and the effective principal stresses for the tests were

Test No.	σ_3' (kPa)	σ_1' (kPa)
1	200	570
2	300	875
3	400	1162

Plot the relevant Mohr stress circles and hence determine the strength envelope of the soil with respect to effective stress

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH: Application 2



By measurement $\varnothing' = 29$ deg no cohesion

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH: Application 3

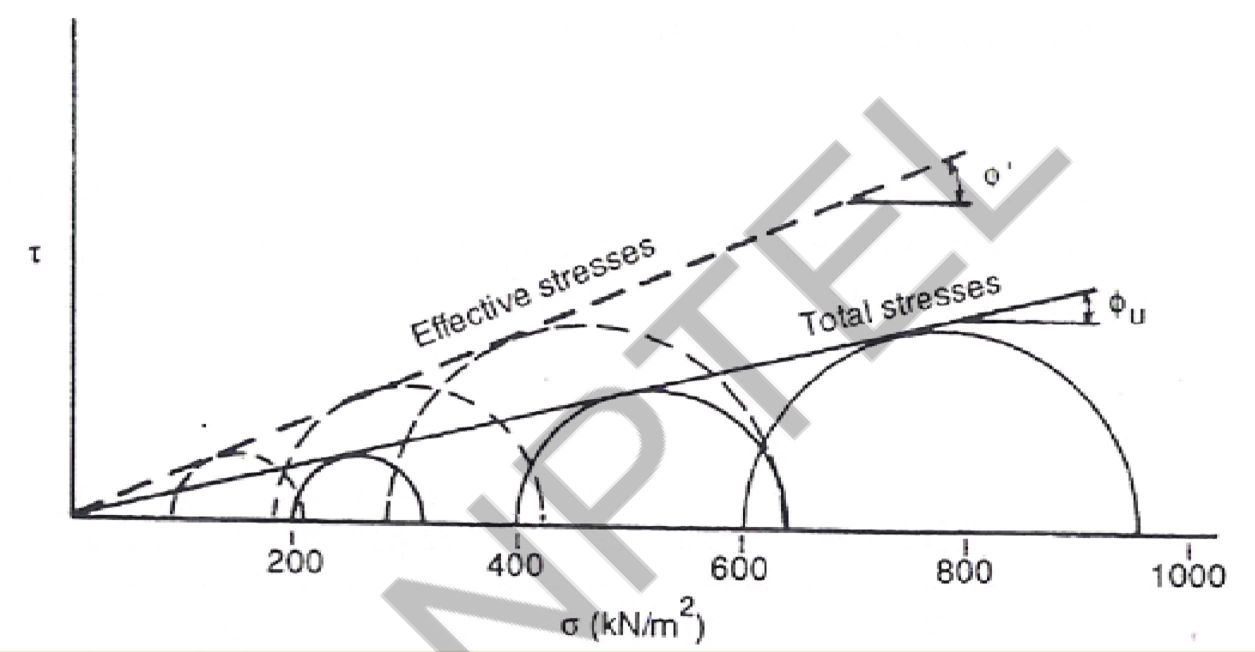
A series of undisturbed samples from a normally consolidated clay was subjected to consolidated undrained test. Te results were:

Cell pressure (kPa)	Deviator stress at failure (kPa)	Pore water pressure at failure (kPa)
200	118	110
400	240	2220
600	352	320

Plot the strength envelope of the soil (a) with respect to total stresses and (b) with respect to effective stresses

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH: Application 3



DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH: Application 4

The following results were obtained from consolidated undrained tests on specimens of a saturated clay. Determine the shear strength parameters (effective and total)

σ_3 (kPa)	Deviator stress (kPa) at peak	u (kPa)
100	137	28
200	210	86
300	283	147

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

Thank You!!

IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

NPTEL

SOIL MECHANICS/GEOTECHNICAL ENGINEERING I

SHEAR STRENGTH

DILIP KUMAR BAIDYA

DEPARTMENT OF CIVIL ENGINEERING

IIT KHARAGPUR

SHEAR STRENGTH

Behaviour of Soils Under Shear

Before going to this topic familiarity with the following terms are needed:

- Overburden and effective over burden pressure
- Normally consolidated clays
- Over consolidated clays
- Pre-consolidation pressure

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

Behavior of sand and other granular materials: Unless drainage is prevented deliberately a shear test on a sand will be a drained one as the high value of permeability makes consolidation and drainage virtually instantaneous.

Dry sand: there will be no pore water pressure and inter-granular pressure will be equal to the applied stress

Saturated Sand: the pore water pressure will be zero due to the quick drainage and the inter-granular pressure will be equal to the applied pressure

SHEAR STRENGTH

Dense sand: dilate during shear and the shear strength of the sand increases because of the development of negative pore pressure if the movement of pore water is restricted from movement

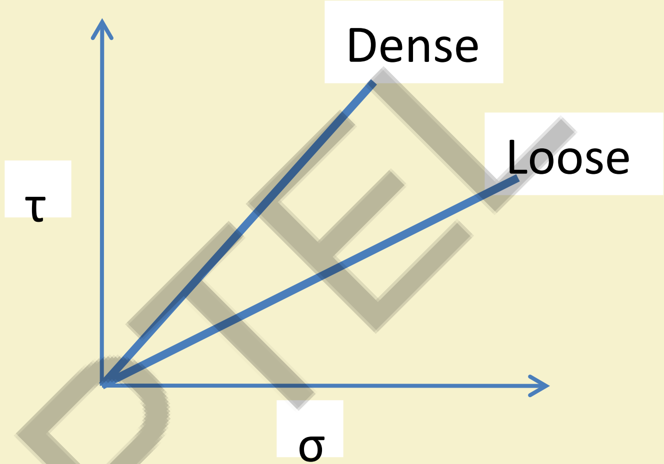
Loose sand: tends to decrease in volume during shear and the shear strength of the soil decreases because of the development of positive pore pressure if the movement of pore water is restricted from movement

Critical Density: The density at which there is no increase or decrease in shear strength when the sand is maintained at constant volume

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

Strength envelope of granular soils: greater shear resistance of dense sand than he loose sand



DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

Saturated Cohesive soil: these soils are defined as saturated clays and silts in either natural and remoulded state

Unsaturated cohesive soil: until the late 1980s it was felt that both the value of shear strength and the volume change characteristics of an unsaturated soil could be considered in as function of single effective stress in a similar manner to that for a saturated soil

This theory has been discarded now. We will consider only behavior of saturated clay only

SHEAR STRENGTH

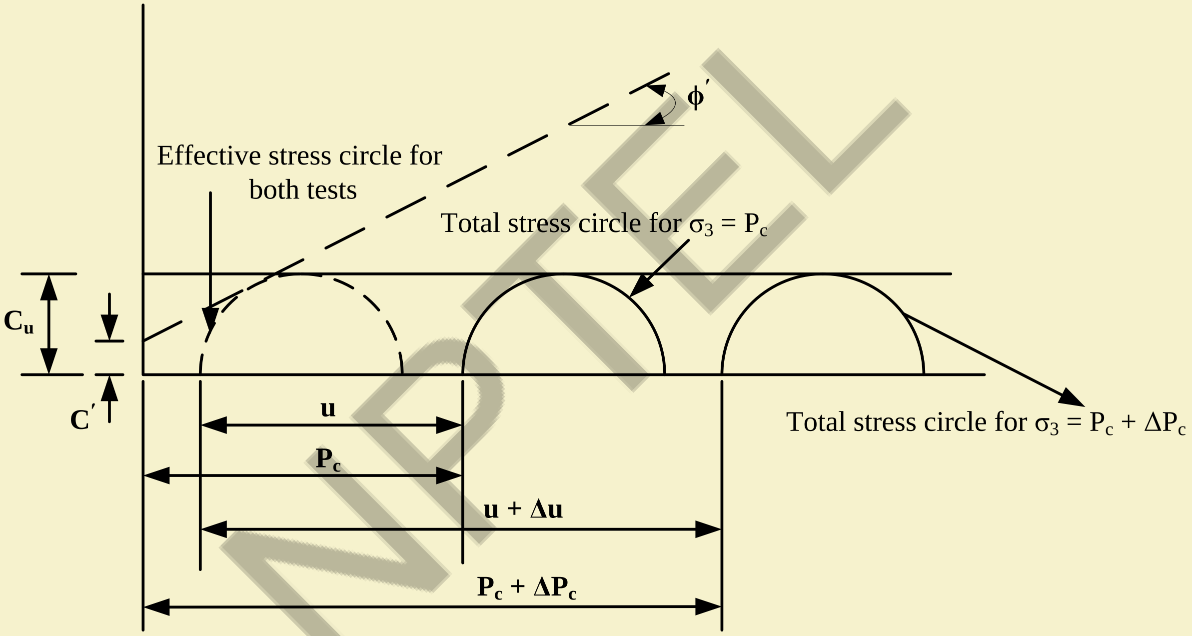
Undrained shear: The shear strength of soil if expressed in terms of total stress, corresponds to Coulomb's law, i.e.,

$$\tau_f = c_u + \sigma tan\emptyset_u$$

For saturated cohesive soils tested in undrained shear it is generally found that τf has a constant value being independent of the value of the cell pressure σ3. Hence we can say that ϕu = 0 when a saturated cohesive soil is subjected to undrained shear. Hence;

$$\tau = c_u = \frac{1}{2}(\sigma_1 - \sigma_3)$$

SHEAR STRENGTH



DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

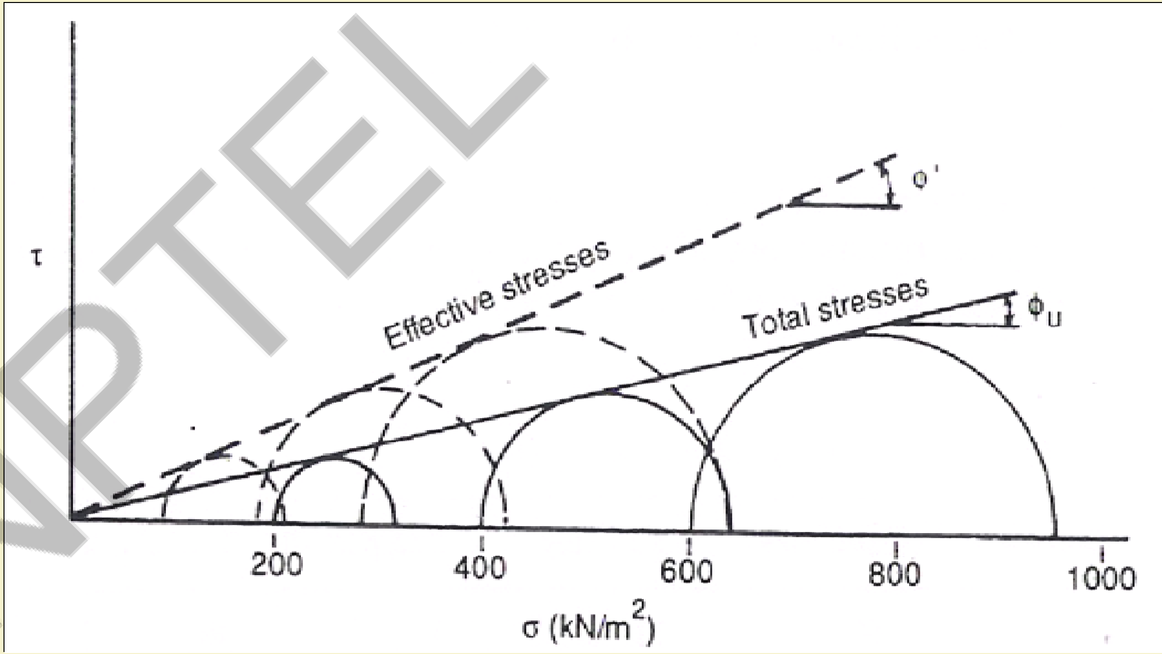
If we wish to think of the results of an undrained test in terms of effective stress we should consider the nature of test. If for a particular undrained shear test carried out at a cell pressure of pc, the pore pressure generated at failure is u then the effective stress at failure are: $\sigma_1{}' = \sigma_1 - u$ and $\sigma_3{}' = \sigma_3 - u = p_c - u$

If the test is repeated using a cell pressure of $p_c + \Delta p_c$ the value of the undrained strength of the soil will be exactly as that obtained from the first test because the increase in the cell pressure Δp_c will induce an increase in pore water pressure, Δu, of the same magnitude Δu = Δp_c . The effective stress circle at failure is therefore be the same as for the first case. It is therefore seem that there can be only one effective stress circle at failure, independent of cell pressure value, in an undrained shear test on saturated soil

SHEAR STRENGTH

Consolidated drained and undrained test

c’ for a normally consolidated clay is negligible and can be taken as zero in virtually every situation. A normally consolidated clay therefore has an effective stress strength envelope similar to that shown in the figure and under drained condition it will behave as if it were a frictional material



DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

A consolidated drained triaxial test was conducted on a normally consolidated clay. The results are as follows:

σ_3 = 276 kN/m^2, $(\Delta\sigma_d)_f$ =276 kN/m^2

Determine (i) the angle of internal friction, Φ (ii) the angle, θ that the failure plane makes with the major principal plane, and (iii) Normal and shear stress on the failure plane.

Thank You!!

IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

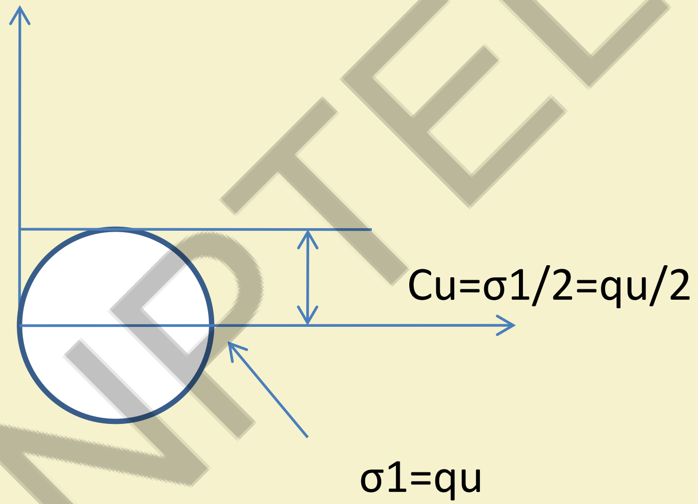
NPTEL

SOIL MECHANICS/GEOTECHNICAL ENGINEERNG I

SHEAR STRENGTH

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

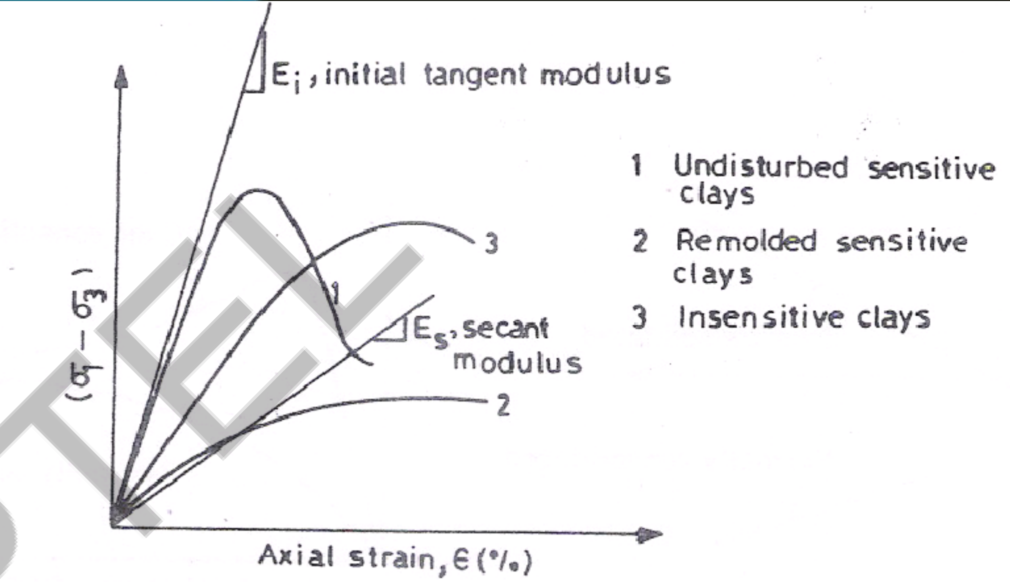
Unconfined compression test:

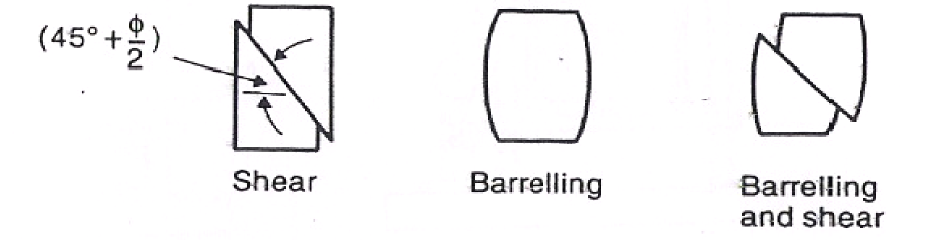


DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

Stress-strain relationships can be obtained from the results of tri-axial tests or direct shear test In the direct shear tests, the results are plotted in the form of shear displacement (x-axis) versus shear stress (y-axis). In the tri-axial test the deviator stress is plotted as ordinate against the axial strain in percent. The unconfined compression test data are shown by plotting axial stress against axial strain

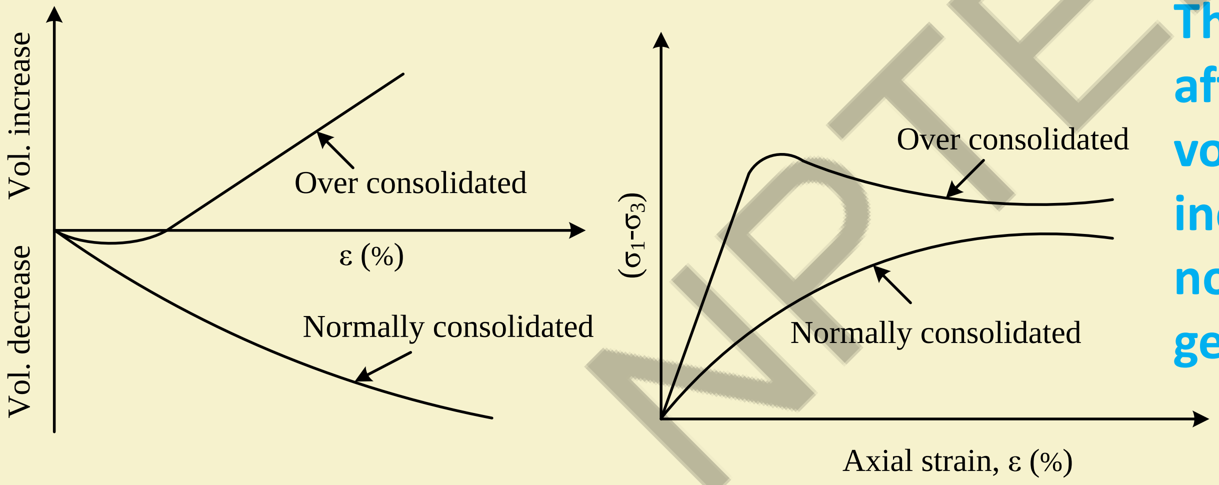




DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

The overconsolidated clay shows a greater strength than a normally consolidated clay and has a pronounced peak which occurs quite early. The stress falls off as the strain increases – a phenomenon called wok softening.

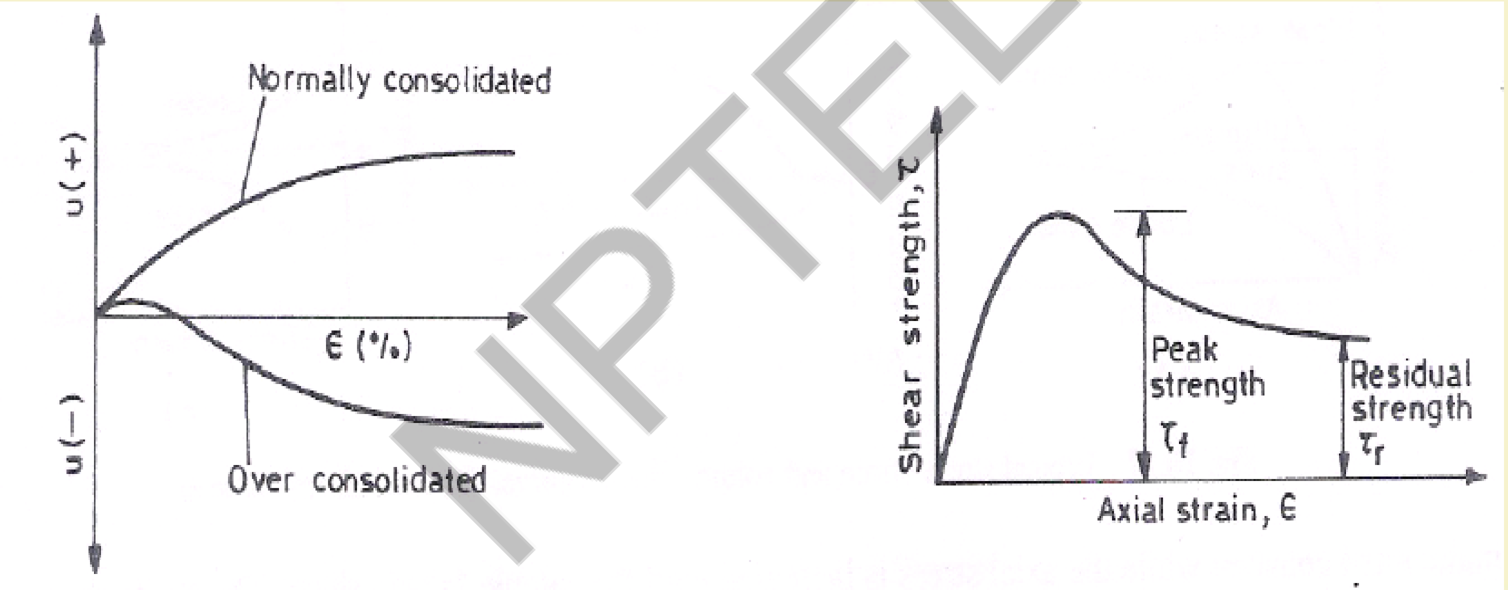


The overconsolidated clay, after a small initial decrease in volume, shows a volume increase upon shear while the normally consolidated clays gets compressed when sheared

DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

The reduction in the value of shear strength from a peak value to a residual value when large strains are applied to an overconsolidated clay

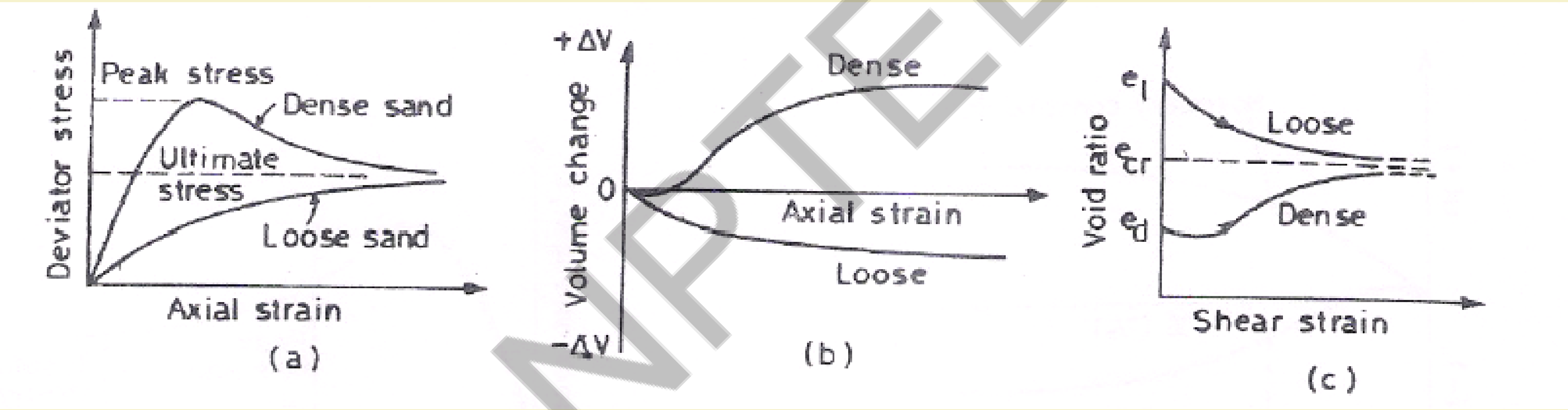


SHEAR STRENGTH

Effect of strain rate: The undrained strength of a clay is known to be affected by the rate of strain or rate of shear. The undrained strength increases with the increase in the rate of shear. Casagrande and wilson report a reduction in undrained strength of clay soils by 40-80% when the test duration was increased from 1 minute to 30 days. However small variation from the normal rate of strain in a laboratory tri-axial test do not appear to make significant difference in the undrained strength. When difference in the rate of shear in the laboratory and in the field is large, the undrained shear strength can be affected to an appreciable mount. The effect of rate of shear on CD test strength is negligible

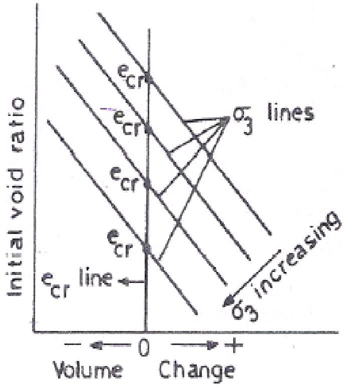
SHEAR STRENGTH

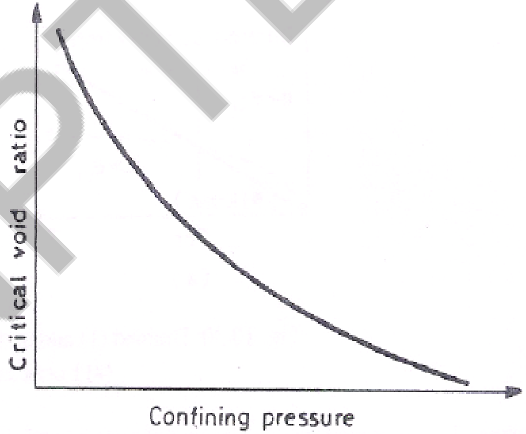
Stress – strain and volume change behaviour of sand:



SHEAR STRENGTH

To determine the e cr different specimens of soil, each at a different initial void ratio, are sheared to failure, after subjecting to them to the same cell pressure in all cases. The corresponding volume changes positive or negative are measured. These are plotted against the initial void ratio. The void ratio corresponding to zero volume change is then the critical void ratio for that prticular confining pressure.

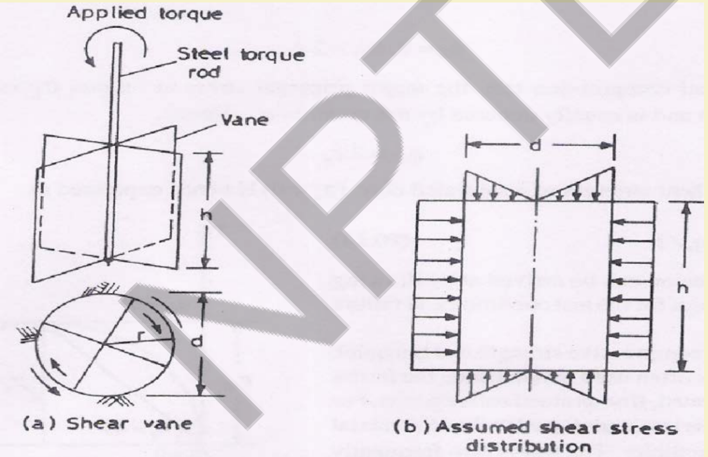




DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

Vane Shear Test: A difficulty often encountered in determining the shearing resistance of soft saturated clay deposits is in obtaining undisturbed samples. The shear strength of such sensitive clays may be significantly altered during the process of sampling and handling. Vane shear test offers a method of overcoming this problem.



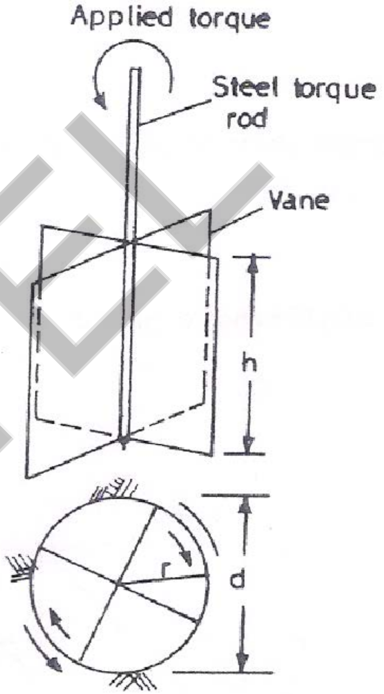
(a) Shear vane

(b) Assumed shear stress distribution

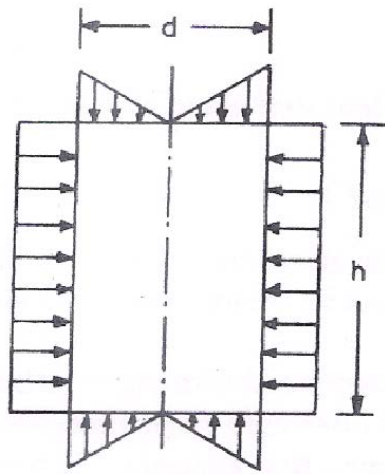
DILIP KUMAR BAIDYA
DEPARTMENT OF CIVIL ENGINEERING
IIT KHARAGPUR

SHEAR STRENGTH

Shear vane consists of four steel blades called vanes welded at right angles to a steel rod. The vane is pushed gently into the soil upto the required depth or at the bottom of a borehole and torque is applied gradually to the upper end of the torque rod until the soil fails in shear, due to the rotation of vane. The torque is measured by noting the angle of twist. Shear failure occurs over the surface and the ends of a cylinder having a diameter d equal to the diameter of the vane.



(a) Shear vane



(b) Assumed shear stress distribution

SHEAR STRENGTH

Total resistance of the soil at failure= $\pi d h c_u + 2\int_0^d (2\pi r dr) c_u$

The moment of the total shearing resistance about the center is the torque, at failure and is given by

$$T = (\pi d h c_u)^d/_2 + 2\int_0^{\frac{d}{2}} (2\pi r dr) c_u \times {}^d/_2$$

Simplifying the above one can get, $T = \pi c_u \left(\frac{d^2 h}{2} + \frac{d^3}{6} \right)$

Where cu is the undrained shear strength of the soil, d is the diameter of the vane, h is the height of the vane and

SHEAR STRENGTH

If the test is carried out such that the top end does not shear the soil (as in the case of a test in a borehole)

Total resistance of the soil at failure= $\pi d h c_u + \int_0^d (2\pi r dr) c_u$

The moment of the total shearing resistance about the center is the torque, at failure and is given by

$$T = (\pi d h c_u)\, {}^{d}/_{2} + \int_0^{\frac{d}{2}} (2\pi r dr) c_u \times {}^{d}/_{2}$$

On simplifying one can get $T = \pi c_u \left(\frac{d^2 h}{2} + \frac{d^3}{12} \right)$

SHEAR STRENGTH

A vane of 112.5 mm long and 75 mm in diameter was pressed into soft clay at the bottom of a borehole. Torque was applied to failure of the soil. The undrained shear strength of the clay soil was found from another test as 40 kN/m2. Determine the value of torque at which the failure of the soil occurred considering (i) resistance both from top and bottom, and (ii) from bottom only.

Thank You!!