Unit-IX: SHEAR STRENGTH OF SOIL

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Unit-VIII: Shear Strength of Soil

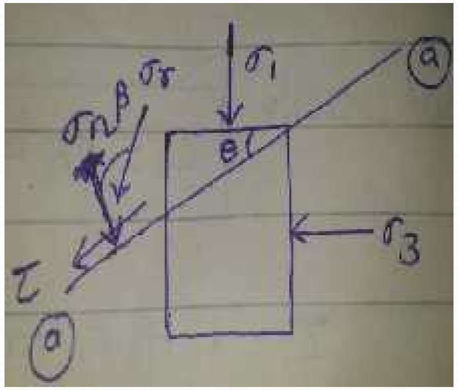
- Introduction, Mohr stress circle, Mohr-Coulomb failure-criterion, relationship between principal stresses at failure, shear tests, direct shear test, unconfined compression test, tri-axial compression tests, drainage conditions and strength parameters, Vane shear test, shear strength characteristics of sands, normally consolidated clays, over-consolidated clays and partially saturated soils, sensitivity and thixotropy.

SHEAR STRENGTH OF SOIL

- Shear strength of a soil is the resistance offered by the soil grains against the shear deformation.
- The soil may derive its shear strength from following parameters
  - Interlocking between particles
  - Frictional resistance
  - Cohesion/adhesion/Intermolecular attraction
- The coarse soils derive their strength from interlocking and friction whereas fine soils derive their strength from friction and cohesion/adhesion
- Shear failure may result into sliding or slipping along a slip plane or it may result in excessive settlement at rapid rate

SHEAR STRENGTH

- On experiment basis, it is found that shear failure occurs on a plane in which resultant stress is most (max.) inclined. It means if $\beta=\beta_{max}$ then τ will be shear strength S and that plane will be called failure plane



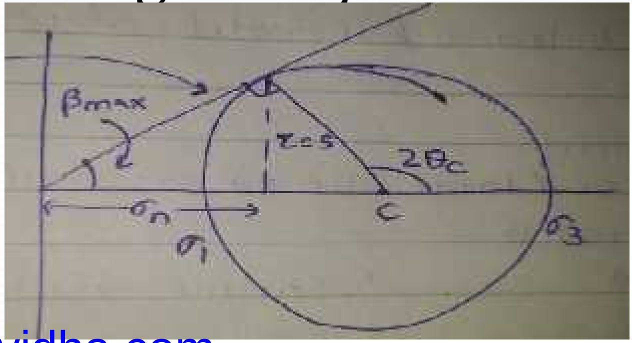
- Angle of critical plane θ = θc

$$- = 45^{\circ} + \frac{max}{2}$$

- θc is angle of critical plane with major principal plane
- If σ_1 is major principal stress and σ_3 is minor principal stress then normal stress on a critical plane is given by

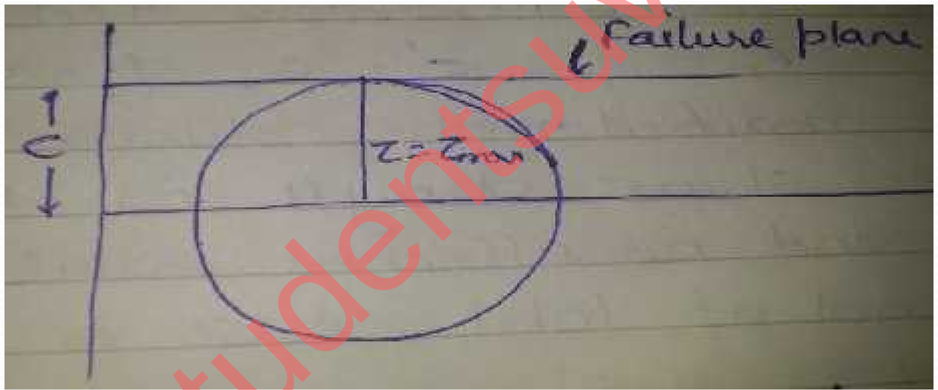
$$\pm_n = \pm_1(1 - \sin \quad max)$$

$$\pm_n = \pm_3(1 + \sin \quad max)$$



SHEAR STRENGTH

- In case of sands, failure does not occur on the plane of τ_{max} because on the plane of τ_{max}, $\beta<\beta_{max}$
- In frictional soils shear strength is less than τ_{max}
- For clays the mohr's failure envelop is found horizontal. Hence shear strength is equal to τ_{max}



- Relation between σ_1 and σ_3

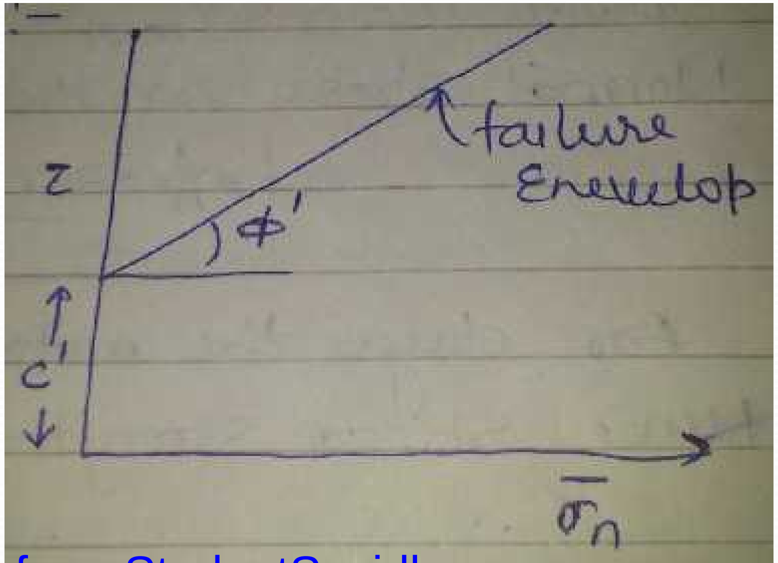
$$\sigma_1 = \sigma_3 \tan^2(45 + \frac{\phi}{2}) + 2C\tan(45 + \frac{\phi}{2})$$

MOHR's COLUMB THEORY

- Shear strength theory for Undrained Condition (Without water table condition)

$$S = C + \sigma_n (\tan \phi)$$

- Where σ_n is normal stress (Total stress) on failure plane and c, ϕ are total soil parameter
- This theory was found inaccurate under submerged condition and presence of water



MODIFIED MOHR's COLUMB THEORY

$$S = C' + \bar{\sigma}_n (\tan \phi')$$

- Where $\bar{\sigma}_n$ is effective normal stress on the shear failure plane and c' and ϕ' are effective soil parameter
  - If soil is water logged (flush with water) and on the application of load pore water is not allowed to flow out then effective stresses will not develop therefore under such condition shear strength will be called undrained shear strength and to find undrained shear strength total parameter should be used which are also called undrained parameter
  - If on loading pore pressure is allowed to flow out then soil is drained, under such condition shear strength will be called drained shear strength and to find drained shear strength, drain parameter/effective parameter should be used

LIMITATIONS OF MOHR's COLUMB THEORY

- Limitations
  - The effect of minor principal stress or major principal stress is considered but effect of intermediate principal stress is ignored
  - Failure mohr envelop is approximated to the straight line, In over consolidated soils failure envelop is found curve
- Types of shear test on the basis of drainage conditions
  - The choice of test depends upon type of soil and the purpose for which test is required and it also depends upon the drainage conditions of the soil in the field
    - UU Test (Unconsolidated Undrained Test)
    - Consolidated Undrained Test (CU Test)
    - Consolidated Drained Test (CD Test)

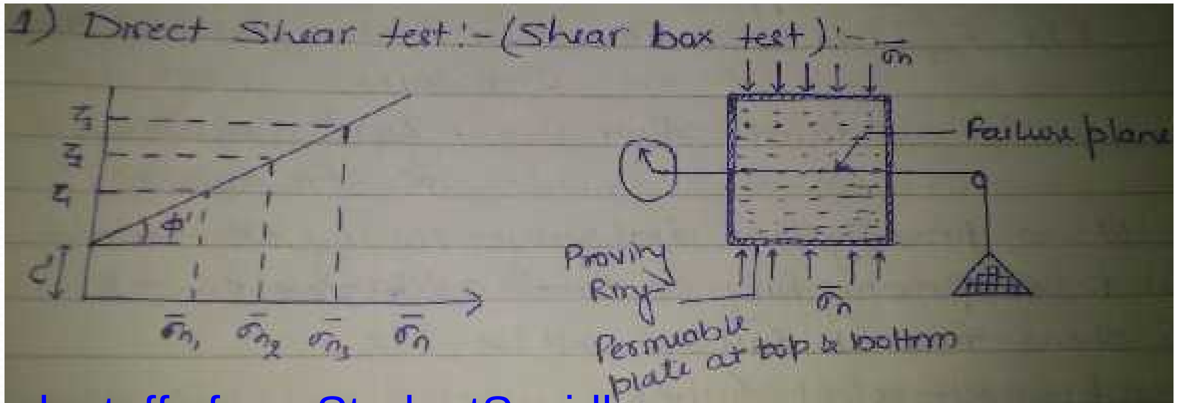
TYPES OF SHEAR TEST

- UU Test
  - In this test neither water is permitted to leave the soil during cell pressure state nor during shear stage/ deviator stage
  - This is a quick test and requires 5 to 7 mins and it is suitable for saturated clays in which rate of loading is fast
- CU Test
  - In this test drainage is permitted in 1^{st} Stage (During consolidation stage) but during 2^{nd} stage (Shear stage) water is not allowed to flow out, hence soil remains undrained in 2^{nd} stage
  - This test is performed to investigate stability analysis of earthen dams due to sudden drawdown
- CD Test
  - In this test drainage is permitted in both stages, hence shear stage is applied only when consolidation is completed
  - This test is suitable for saturated sands or for long term analysis of stability of soils

TEST TO DETERMINE SHEAR STRENGTH OF SOIL

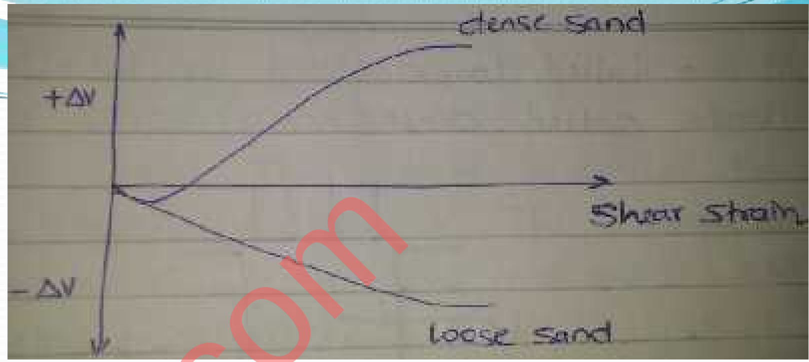
- Direct Shear Test
  - The shear box is either square or circular having size 60 or 90mm
  - There is no mechanism to measure pore pressure, hence this test should be conducted under drained condition only so that applied normal stress will be effective stress
  - At certain normal stress, shear stress at failure is found and test is repeated on similar soil with changed value of Normal stress
  - A graph is plotted between normal stress and shear stress at failure which is called failure mohr envelop. from the graph c’ and ϕ’ are obtained
  - The shear strength on any plane in which effective normal stress σ_n is given by

$$S = C' + \bar{\sigma}_n (\tan \phi')$$

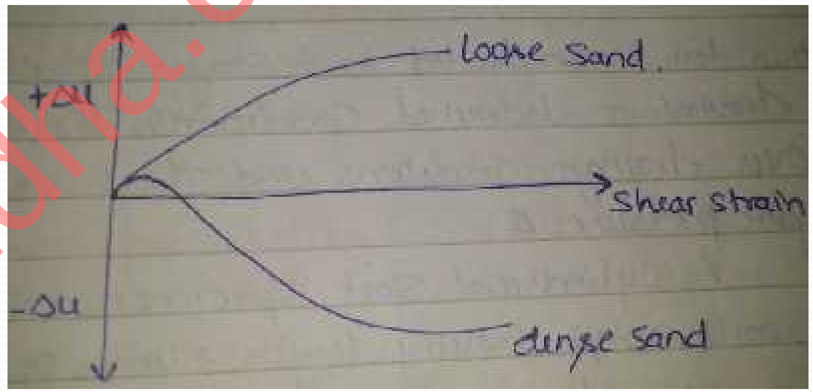


LIMITATIONS

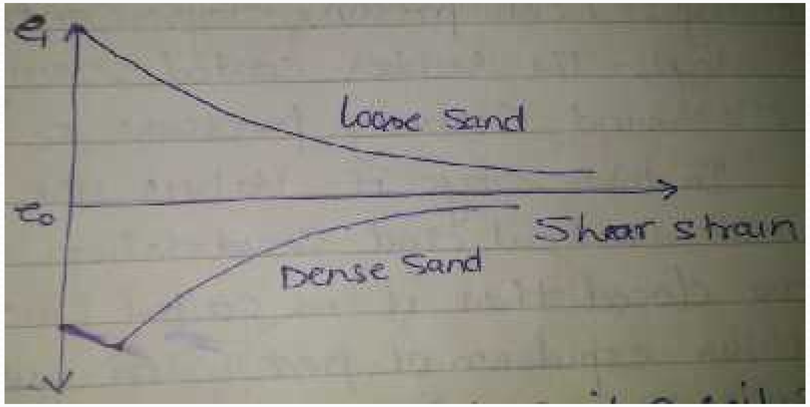
- Failure plane is predetermined which may not be the weakest plane
- The stress conditions are known only at failure and it is difficult to draw mohr circle
- There is no mechanism to measure pore pressure
- There is no control on drainage condition
- The distribution of stresses on failure plane is not uniform
- Note :- This test is suitable for sandy soils
- Graph b/w Volume change and shear strength
  - In dense sands interlocking fails at 4-6% os a strain hence before failure of interlocking volume decreases or after failure of interlocking volume increases and soil enters into trivial stage
  - In loose sands volume continuously decreases and when volume decrease is large corresponding to 15 -20% of shear strain then failure is assumed to occur



- Graph b/w pore pressure change Vs shear strain curve



- Graph b/w void ratio Vs shear strain curve
  - Critical void ratio is that void ratio at which if a soil is sheared then there will be minimum volume change, it means there will be negligible change in void ratio



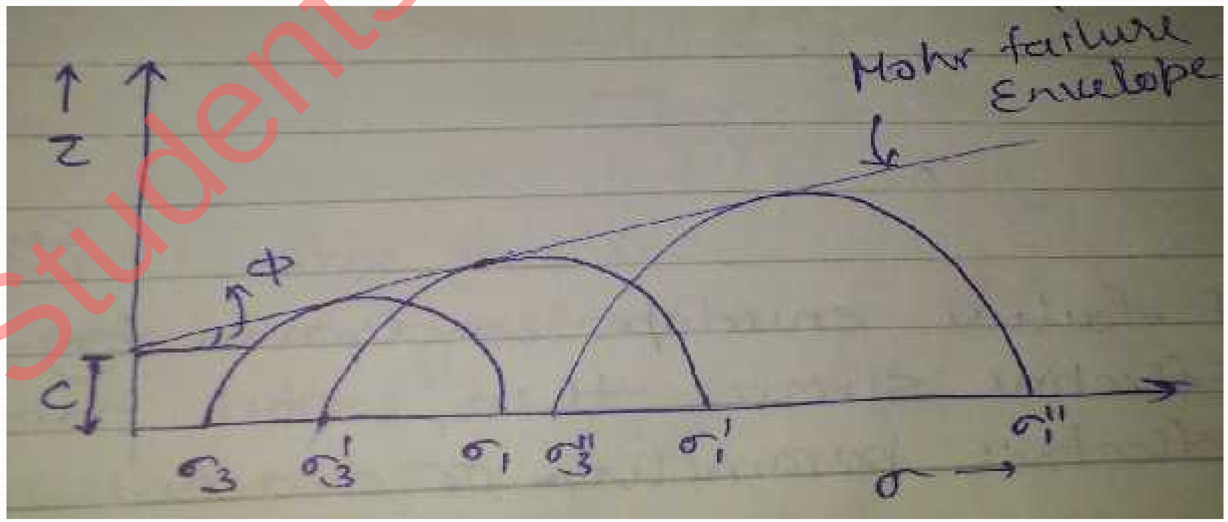
TRIAXIAL SHEAR TEST

- This test is conducted in 2 stages which may be under drained or undrained conditions
- There is complete control over drainage conditions and there is provision to measure pore pressure
  - 1st Stage (Consolidation stage):- The rubber coated sample is subjected to all round confining pressure $\sigma_c=\sigma_3$
  - In this stage if valves are open then pore water will flow out and consolidation will occur and if valves are closed then it is called unconsolidated stage and when expulsion of pore water will be stopped, consolidation will be completed
  - 2nd Stage :- The cell pressure is kept constant and vertical stress is increased till the soil fails in shear. This stage is called back pressure stage. The deviator stress at failure at constant confining pressure is called confined compressive strength

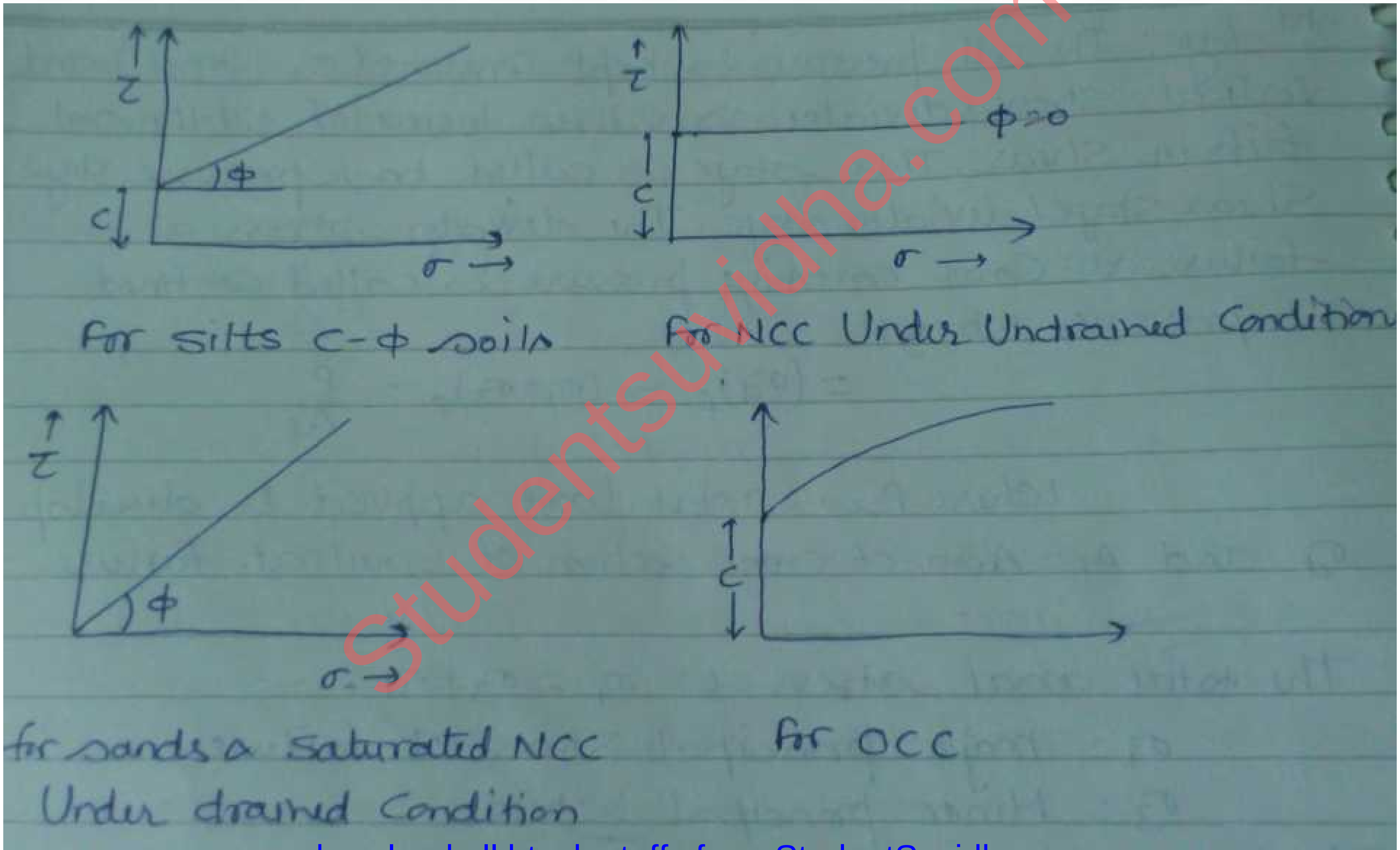
$$(\sigma_d)_f = (\sigma_1 - \sigma_3)_f$$

TRIAXIAL SHEAR TEST

- If during 2nd Stage drainage valves are open then shearing will be in drained conditions and if valves are closed then shearing will be in Undrained conditions
- To find shear parameters, test is repeated for different values of cell pressure and axial stress at failure is found
- The mohr circle for each condition at failure is drawn and a common tangent to all mohr circles represents mohr's failure envelop from which c and ϕ can be obtained

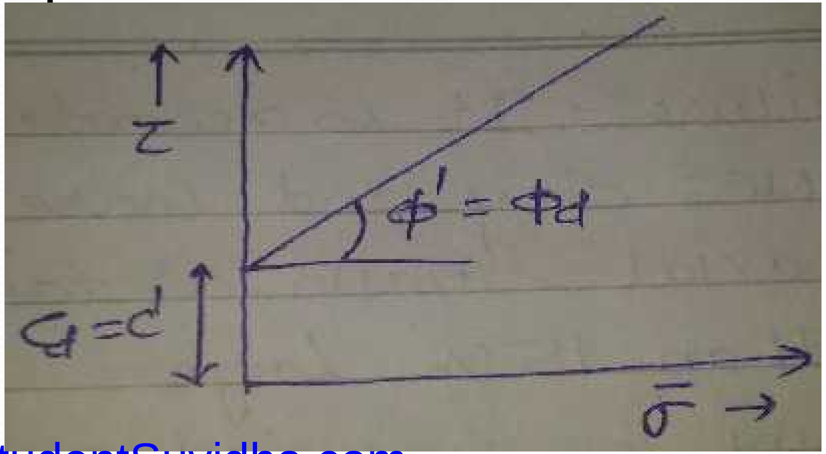


FAILURE ENVELOP FOR DIFFERENT SOIL TYPE



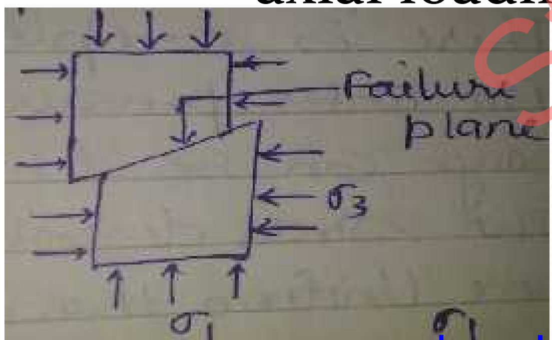
TRIAXIAL SHEAR TEST

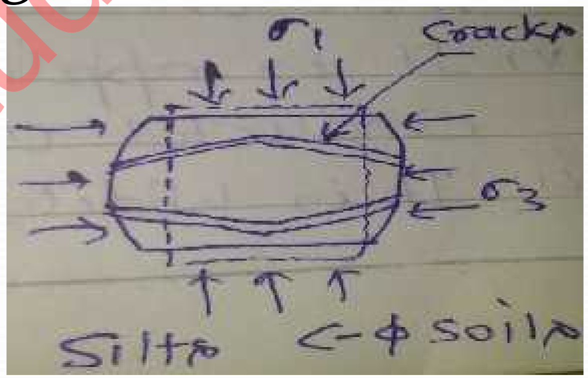
- If test is conducted under Undrained condition (UU) then applied cell pressure is total stress and axial stress at failure is total normal axial stress at failure
- In this condition pore pressure will develop, let at failure pore pressure is u then
- If are used to draw mohr circle then failure envelop will correspond to total stress condition hence the cohesion and friction obtained will be total or drained values
- If failure envelop is drawn by taking effective stresses then soil parameters will be effective or drained parameters

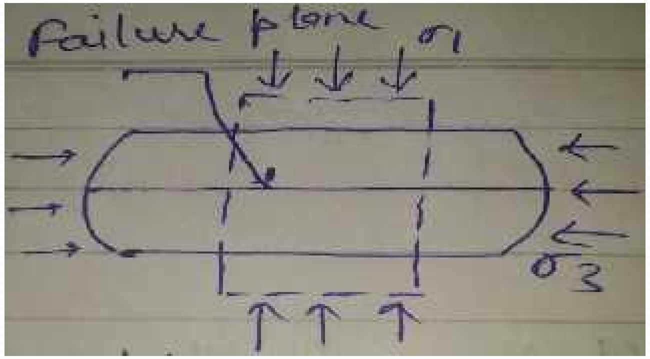


TYPES OF FAILURE DURING TRIAXIAL TEST

- Brittle Failure
  - It is the case of dense sands and over consolidated clays. The failure plane is inclined and shear crack is very clear
- Semi brittle failure/Semi plastic failure
  - In this case axial strain is greater than previous case and lateral bulging is recorded. It is the case of c-ϕ soils
- Plastic failure
  - It is recorded in soft clays/NCC and loose sands. Large lateral bulging is recorded and failure plane is normal to axial loading





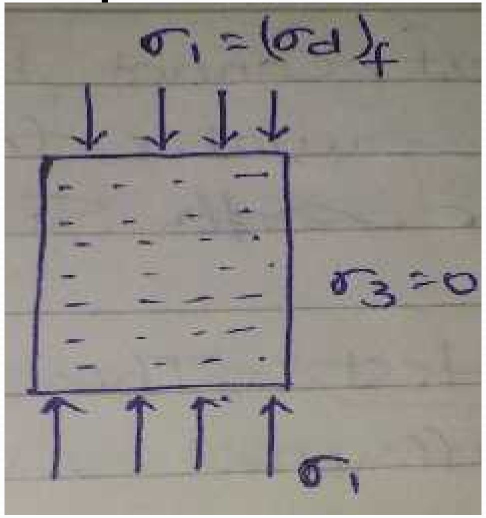


MERITS OF TRIAXIAL TEST

- Failure plane is not predetermined and it is the weakest plane
- There is complete control over drainage conditions
- Pore water pressure can be measured and volume change can be determined
- The stress distribution in failure plane is much more uniform than in direct shear test
- It is applicable for all type of soil and can be conducted under any drainage condition
- It is widely adopted and most versatile test

UNCONFINED COMPRESSION TEST

- It is an special case of triaxial test in which confining pressure is zero, it means there is no cell pressure stage
- The load applied is only axial and axial stress at failure (Deviator stress) is called Unconfined compressive strength



$$qu = (\pm_d)_f = 2C \tan(45 + \frac{¤}{2})$$

- For pure Clays ϕ=o
- At failure mohr circle passes

  through origin for pure clays

VANE SHEAR TEST

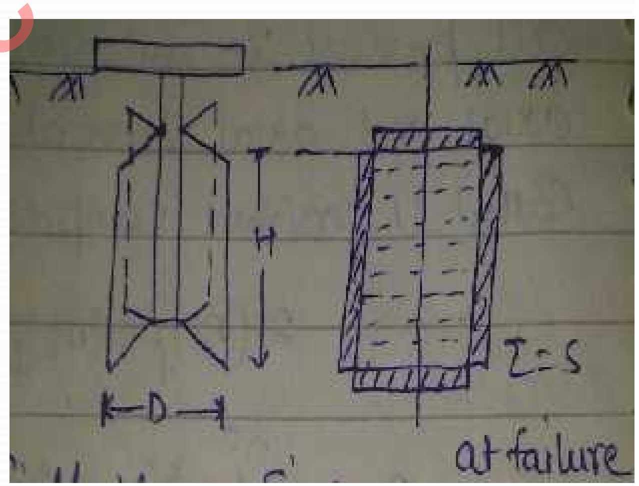
- There is no mechanism of drainage and no provision to measure pore pressure, hence this test is essentially under undrained condition
- It is suitable for soft saturated clay and highly plastic clay under undrained condition only
- The vane is punched into the soil and the torque is applied manually at the rate of 6°/min. The torque is measured by the calibrated torsional spring of torsional constant K. The torque at failure is Kθ where is angle of rotation of vane at failure condition
- Depending on penetration of vane into soil there may be following two condition
    - When Vane is penetrated fully inside the soil such that shearing of soil occurs at sides, top and bottom

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

VANE SHEAR TEST

- When vane is punched into the soil such that the top surface of vane is at Ground level, it means shear will occur at bottom and sides only

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



- Limitations
  - No mechanism to measure pore pressure
  - Not suitable for sands and dry soils
  - No facility of drainage condition

PORE PRESSURE PARAMETERS

- If it is not possible to measure pore pressure by practical means then theoretical approach given by skempton can be used
- The pore pressure parameters represents the response of pore pressure change due to change in lateral and vertical stresses under undrained condition
- The pore pressure can be classified in 2 stages
  - Cell Pressure
    - The parameter B represents the ratio of change in pore pressure due to the change in cell pressure
    - For fully saturated soil B=1
    - For dry soil B=0

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

PORE PRESSURE PARAMETERS

- Deviator Stress
  - The parameter A is defined in terms of another parameter $\overline{A}$ which represents change in pore pressure due to change in deviator stress

$$\overline{A} = A.B$$

$$\overline{A} = \frac{\Delta u_d}{\Delta \pm_d}$$

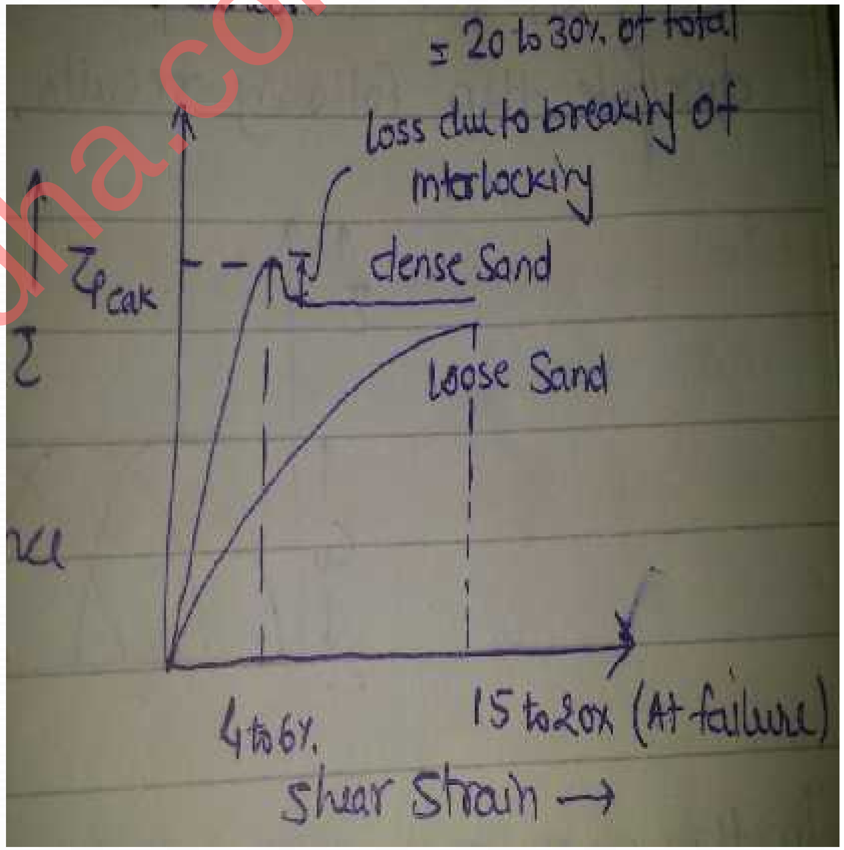
  - The parameter A depends on strain, degree of saturation, over consolidation ratio and stratification of soil. It may be as low as -0.5 for OCC Soils with high OCR to as high as 2 to 3 for loose saturated sands
- If cell pressure and deviator stress both are changed then pore pressure is $\Delta u = \Delta u_c + \Delta u_d$

$$\Delta u = B \Delta \pm_3 + \overline{A} \Delta \pm_d$$

$$\Delta u = B \Delta \pm_3 + AB\ (\Delta \pm_1 - \Delta \pm_3)$$

SHEAR CHARACTERISTIC OF SOIL

- Shear characteristic of sands
  - In dense sands interlocking resistance is 20-30% of total and due to shear failure interlocking resistance is destroyed. The peak shear strength occurs at 4 to 6% of shear strain. After breaking the interlocking soil becomes loose and frictional resistance still remains.
  - In loose sands there is no clear point of failure, when shear strain is high 15-20% then failure is assumed to occur.

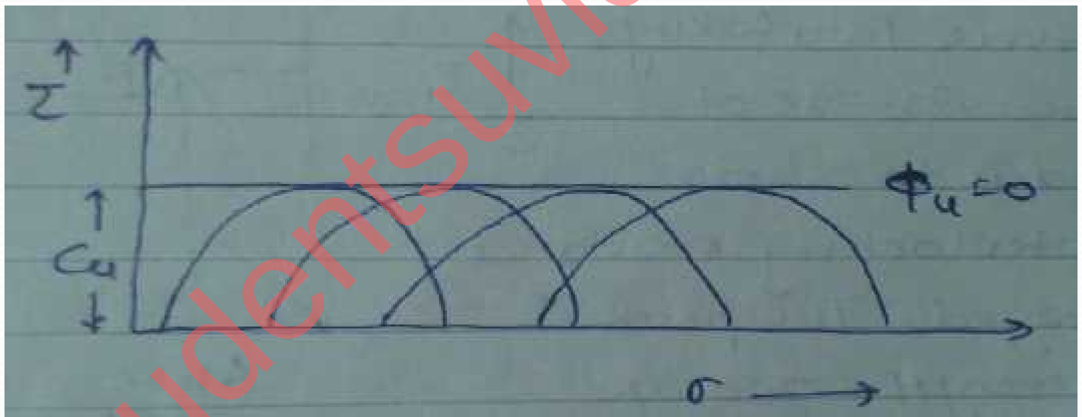


SHEAR CHARACTERISTIC OF SOIL

- Shear characteristic of sands
  - In loose saturated sand due to shear disturbances volume of soil decreases therefore pore pressure increases then effective shear strength decreases. The sudden loss in shear strength due to earthquake & other dynamic effect occurs in loose saturated sands because high pore pressure is built up as a result pore water strats flowing out at rapid rate & excessive settlement are recorded due to shear failure. Such a condition is called liquefaction of sands.
  - In dense saturated sands due to shear failure volume of soil increases therefore pore pressure become negative, consequently shear stress increases due to increase in effective stress

SHEAR CHARACTERISTIC OF SOIL

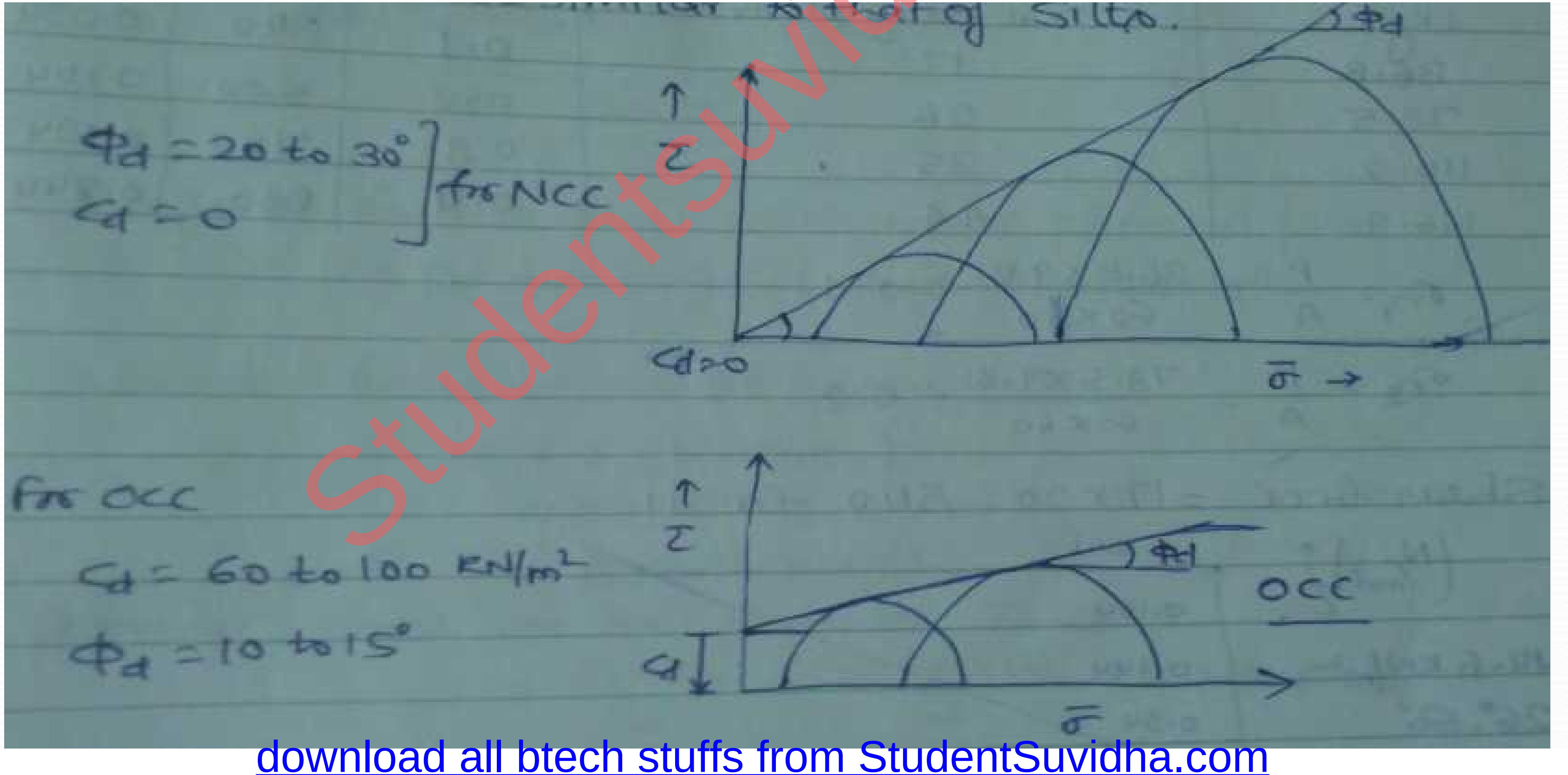
- Shear characteristic of Clays
  - Saturated Clays under Un-drained Conditions
    - If UU test is conducted on saturated clays in which loading is fast and pore pressure is not allowed to dissipate then following results are obtained



  - In this case each mohr circle is found to have equal radius Cu = 25 to 30kN/m², ϕ_u =0 for NCC and Cu = 100 to 200kN/m², ϕ_u = 0 for OCC

SHEAR CHARACTERISTIC OF SOIL

- Shear characteristic of Clays
  - Saturated clays under drained Conditions
    - If CD test is conducted on saturated clays then results of NCC are similar to that of sands and results of OCC are similar to that of silts



SHEAR CHARACTERISTIC OF SOIL

- Shear characteristic of Clays
  - Partially Saturated clays
    - The partially saturated clays under drained and undrained condition both behaves similar to the silts