Day 06

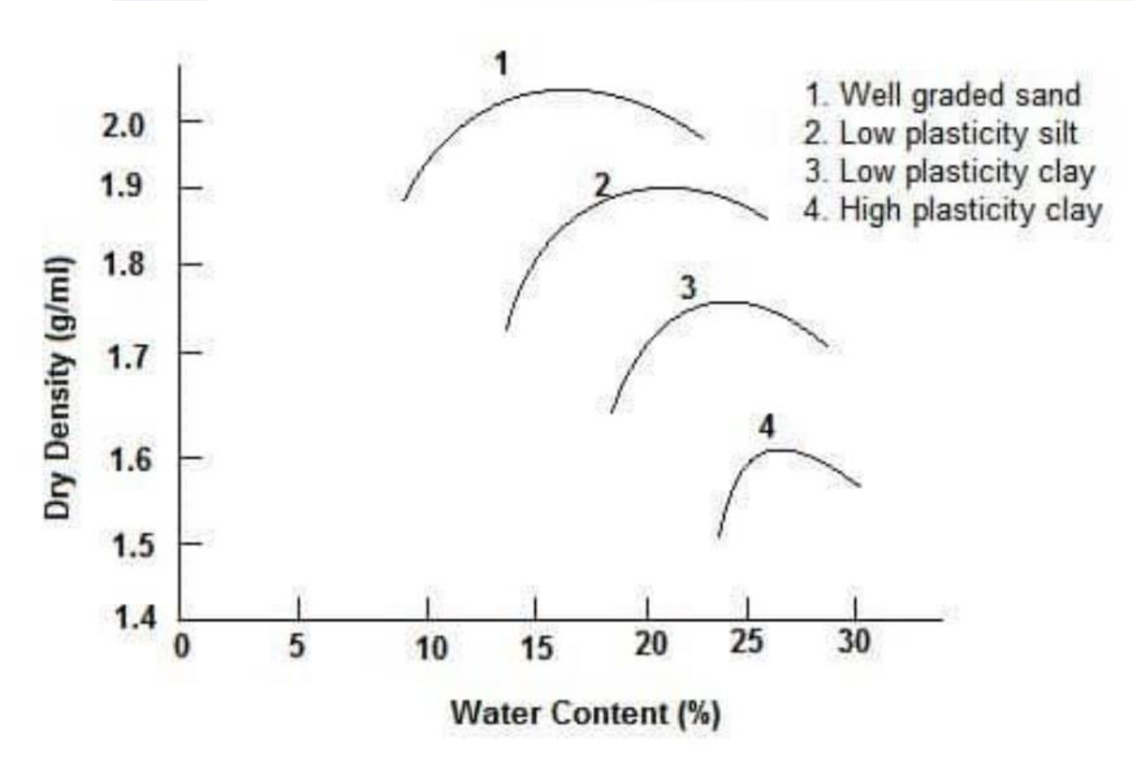
Compaction	Consolidation
It is almost instantaneous	It is time dependent.
It occurs due to reduction of air voids.	It occurs due to expulsion of pore water from voids.
Soil is unsaturated.	Soil is saturated.
For a specified compaction energy, the compaction of a solid takes place only upto a certain limiting water content.	No limiting value of moisture content for the consolidation.

Compaction test: It includes determining optimum moisture content (OMC) with respect to corresponding maximum dry density. Normal range of OMC for sand is around 6 to 10%, whereas it is 14 to 20% for clay.

	Standard Proctor Test	Modified Proctor Test
Rammer mass	2.6 kg	4.89 kg
Layers of compaction	3 layers	5 layers
Drop height	310 mm	450 mm

Factors affecting compaction:

- Water content
  - ✓ For a given compactive effort the dry density of soil first increases with increase in water content. Beyond a certain value of water content, the trend is reversed.
  - ✓ The maximum value of dry density is obtained at optimum moisture content.
- Amount of compaction
  - ✓ Increase in the compaction energy will result in an increase in the maximum dry density (M.D.D) and a decrease in the Optimum moisture content (O.M.C).
- Type of soil
  - ✓ In general, coarse-grained soil can be compacted to higher dry density than fine-grained soil.
- Method of compaction
  - ✓ MDD can be increased by kneading action.
- Admixture
  - ✓ Addition of lime, cement, etc. improves compaction characteristics of soil.



Soil Compressibility

When a surcharge (load) is placed on top of soil, the load will be transferred to the soil and will be stressed. The foundation on the soil if is not properly designed may fail either in shear or in settlement. Here, settlement of soil will occur because of the rearrangement of soil particles themselves in a closer state to enable the soil to sustain the applied stress. In saturated soil, closer state of particles is possible if the water is pushed out of the soil. **Compression** means the decrease in volume of soil mass under stress. The decrease in volume per unit increase in pressure is defined as "**COMPRESSIBILITY**" of the soil.

Consolidation

The compression consists of

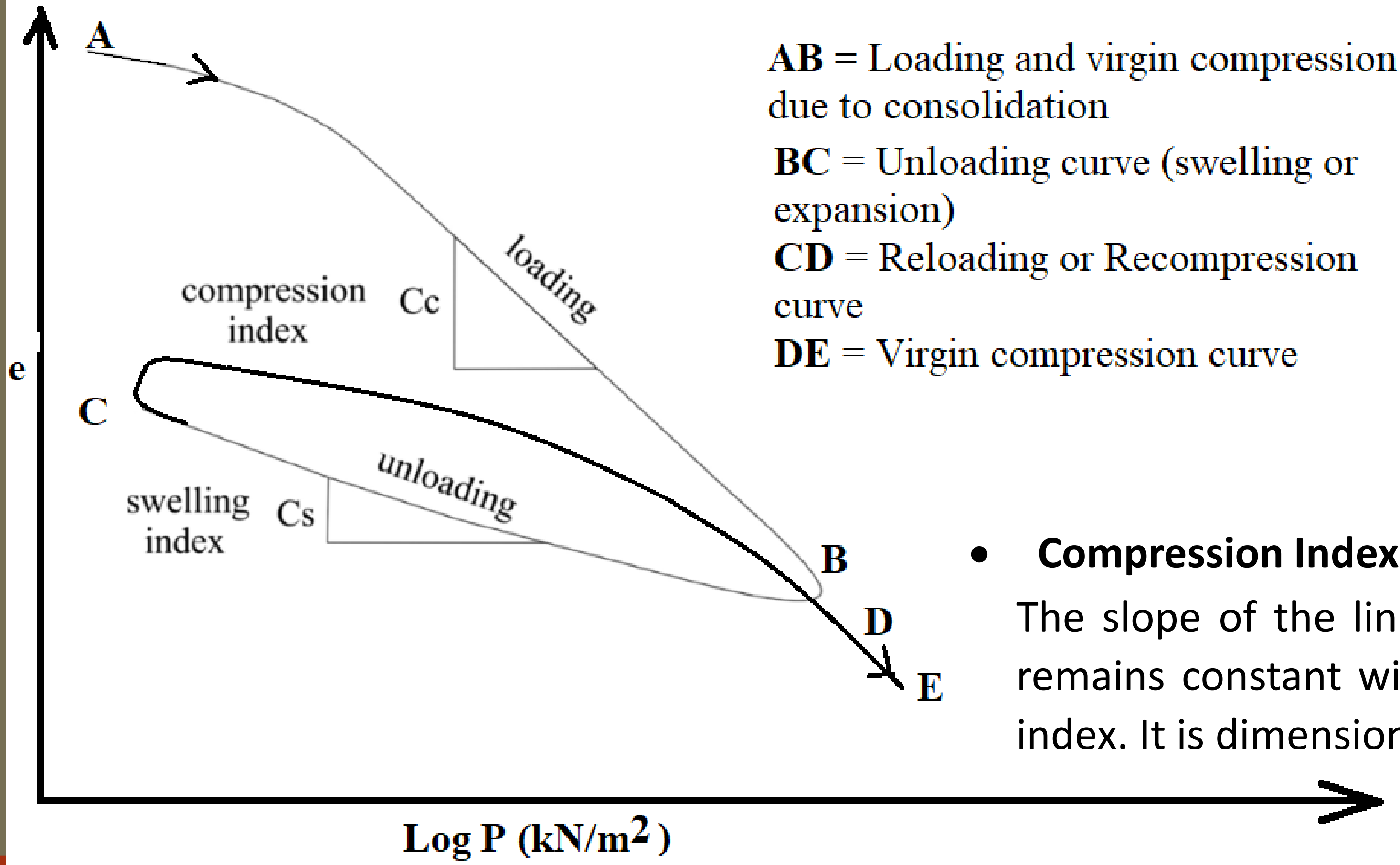
(i) Elastic or immediate compression,

(ii) Primary compression and

(iii) Secondary compression.

Normally Consolidated and Over Consolidated soil:

$$OCR = \frac{Pre - consolidation\ pressure}{Present\ effective\ overburden\ pressure} = \frac{\mathrm{P}_c}{\mathrm{P}_0}$$



- **Compression Index (C_c):**

The slope of the linear portion of the pressure void ration curve, which remains constant within a fairly range of pressure, is called compression index. It is dimensionless.

$$C_c = \frac{e_o - e}{log_{10}\left(\frac{P}{P_0}\right)}$$

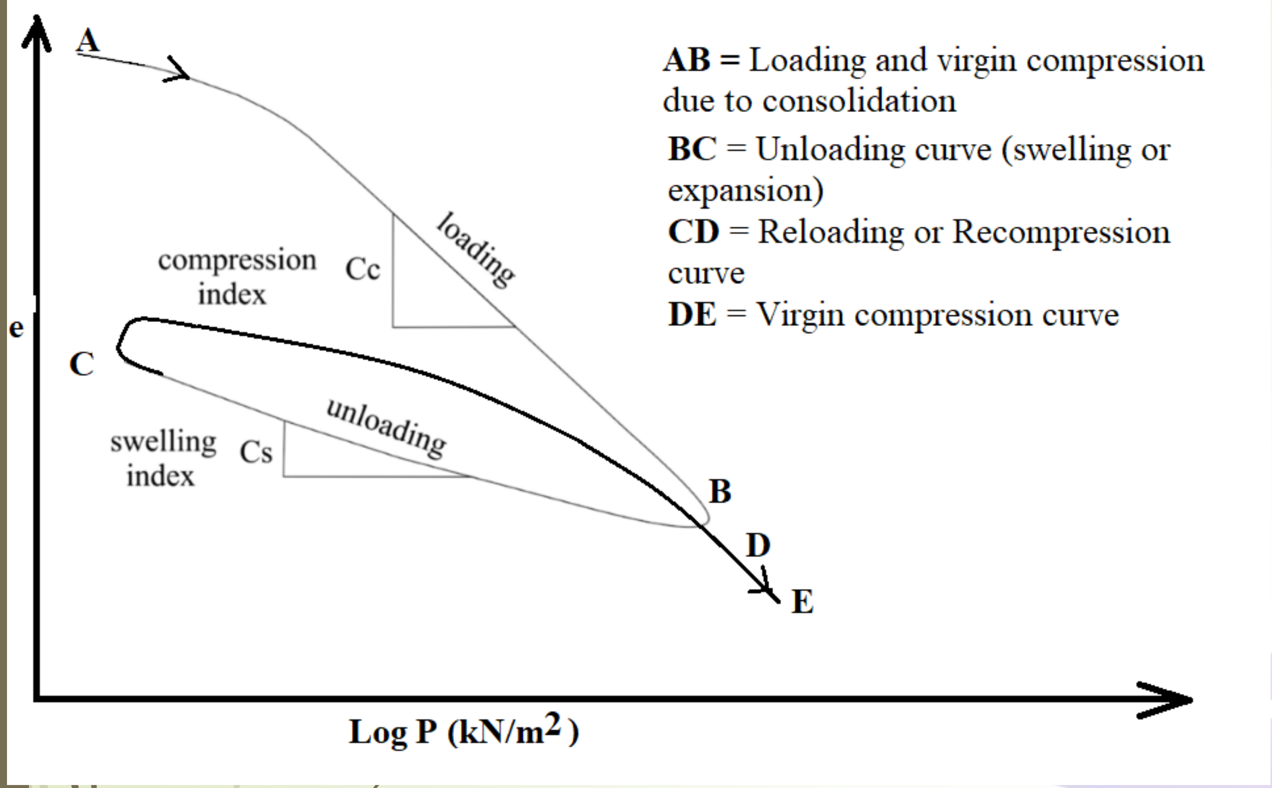
Where, e_o = initial void raito e= final void ratio

P_0 = initial pressure P = final pressure

$$C_C = 0.09\ (W_L - 10) \text{ for undisturbed soil.}$$

$$C_C = 0.007\ (W_L - 10) \text{ for remoulded soil.}$$

$$C_C\ (undisturbed\ or\ field\ sample) = 1.3 C_C\ (remoulded\ sample)$$



- **Swelling Index (C_S):**

  The behavior of unloading of the soil sample represented by portion BC of the curve can be used for defining the swelling characteristics of the soil. The slope of this line indicates swelling index.

$$C_S = \frac{e_i - e_f}{log_{10}\left(\frac{P_i}{P_f}\right)}$$

- **Coefficient of compressibility (a_v):**

  It is the decrease in voids per unit increase in pressure. If Δ_v or Δ_e be change in volume (or void ratio) with increase in pressure by Δ_P, then

$$a_v = -\frac{\Delta_v}{\Delta_P}$$

The negative sign indicates that when the pressure increases the volume (or void ratio) decreases. It is also the secant slope of the effective stress and void ratio curve

- **Coefficient of volume change or coefficient of volume compressibility (m_v):**

The change in volume of a soil per unit initial volume due to given increase in pressure is called coefficient of volume change.

$$m_v = -\frac{(\Delta_v/v)}{\Delta_P} = \frac{a_v}{1+e_o}$$

It can also be defined as the compression of a soil layer per unit of original thickness due to a given unit increase in pressure.

$$m_v = -\frac{(\Delta_H/H)}{\Delta_P}$$

$$\boldsymbol{Settlement}\ (\Delta_{\boldsymbol{H}}) = \boldsymbol{m_v H}\Delta_{\boldsymbol{P}}$$

Also, we have,

$$\frac{\Delta_H}{H} = \frac{\Delta e}{1+e_o} \Rightarrow \Delta_H = \frac{\Delta e}{1+e_o} H$$

$$C_c = \frac{\Delta e}{log_{10}\left(\frac{P}{P_0}\right)} \Rightarrow \Delta e = C_c.\, log_{10}\left(\frac{P}{P_0}\right)$$

$$Settlement\ (\Delta_{\boldsymbol{H}}) = \frac{C_c.\, H}{1+e_o} log_{10}\left(\frac{P}{P_0}\right)$$

- **Coefficient of consolidation**:

  It is adopted to indicate combined effects of permeability and compressibility of soil on the rate of volume change. It is expressed in C_v and unit is cm^2/s.

$$C_V = \frac{k}{m_v \gamma_w} = \frac{k(1+e_o)}{a_v \gamma_w}$$

Where, k= coefficient of permeability

m_v = coefficient of volume change

- **Degree of consolidation (U_z)**:

  The downward movement of the surface of a consolidation layer at any time (t) during the process is called consolidation settlement. The ratio of settlement of full thickness of clay at the given instant to the ultimate or final settlement when the process of consolidation is complete, is known as degree of consolidation (U). It is expressed as a percentage.

$$U_Z = \frac{S}{S_f} = 1 - \frac{U}{U_i}$$

Where, S = settlement at that time

S_f = final settlement at 100% consolidation

U = pore pressure at that time

U_i= initial pore pressure (at the start of consolidation)

- **Time factor (T_v)**

It is dimensionless constant and is defined by the equation

$$T_v = \frac{C_V \, . \, t}{d^2}$$

$$t = \frac{d^2 . \, T_v}{C_v}$$

Since, T_v is constant for given degree of consolidation and given boundary conditions; the time t required to attain certain degree of consolidation is directly proportional to the square of its drainage path and inversely proportional to the coefficient of consolidation. Here, drainage path (d) is half of depth of layer (H) if double drainage is provided and is equal to the depth of the layer for single drainage.

When the degree of consolidation U is less than 60%, then the time factor is given by,

$$T_V = \frac{\pi}{4}\left(\frac{U}{100}\right)^2$$

When U is greater than 60%,

$$T_V = -0.933 \log_{10}\left(1 - \frac{U}{100}\right) - 0.085$$

BCDDC

25. The decrease in void ratio per unit increase in pressure is called:
    a. Coefficient of Permeability
    b. Coefficient of Compressibility
    c. Coefficient of volume compressibility
    d. Coefficient of Curvature
26. The ratio of settlement at any time (t) to the final settlement is known as:
    a. Compression index
    b. Coefficient of consolidation
    c. Degree of consolidation
    d. None of these
27. The time factor for the clay layer is:
    a. A dimensionless parameter
    b. Directly proportional to permeability
    c. Directly proportional to the drainage path
    d. Both a and b
28. Time factor corresponding to 25% degree of consolidation is given by:
    a. $\pi/8$
    b. $\pi/16$
    c. $\pi/32$
    d. $\pi/64$
29. The coefficient of consolidation of a soil is affected by:
    a. Compressibility
    b. Permeability
    c. Both a and b
    d. None of these

AACBC

30. Compression of soils occurs rapidly if voids are occupied by:
    a. Air
    b. Water
    c. Partly air and partly water
    d. Can't decide
31. Standard Procter test is used for determining
    a. Optimum moisture content (OMC)
    b. Void Ratio
    c. Coefficient of consolidation
    d. Pavement Thickness
32. Compaction of soil is aimed at:
    a. Decreasing dry density
    b. Increasing porosity
    c. Decreasing void ratio
    d. Decreasing Shear strength
33. The process of compaction of a soil involves:
    a. Expulsion of pore water
    b. Expulsion of air voids
    c. Expulsion of both pore water and air voids
    d. None
34. Compaction of a soil
    a. Increases dry density
    b. Decreases porosity
    c. Both (a) and (b)
    d. None

CBDBD

35. For the same soil, increase in compaction effort
    a. Does not affect OMC
    b. Increases OMC
    c. Decreases OMC
    d. Decreases Dry Density
36. Select the correct statement:
    a. Increase in the compaction effort will decrease the dry density of the soil
    b. Irrespective of the compaction effort, a soil cannot reach the zero air voids condition
    c. Both (a) and (b)
    d. None
37. The most important method of compacting sand is by using?
    a. Pneumatic Rollers
    b. Sheep Foot Rollers
    c. Steel Tyred Rollers
    d. Vibration
38. The soil involved in the compaction is:
    a. Perfectly saturated soil
    b. Partly Saturated soil
    c. Submerged soil
    d. None
39. Compaction process may be accompanied by
    a. Rolling
    b. Tamping
    c. Vibration
    d. All of the above

CCD

40. For a particular loading condition unsaturated clay layer undergoes 30% consolidation in a period of 180 days. What would be the additional time required for further 20% consolidation to occur?
    a. 320 days
    b. 220 days
    c. 280 days
    d. 160 days

41. Under a given load a clay layer attains 30% degree of consolidation in 100 days. The time taken by the same clay layer to attain 60% degree of consolidation will be:
    a. 1600 days
    b. 800 days
    c. 400 days
    d. 200 days

42. In a consolidation test, when the load is changed from 50 kN/m^2 to 100 kN/m^2, then the void ratio changes from 0.80 to 0.60. The coefficient of compressibility will be
    a. 0.002 m^2/kN
    b. 0.003 m^2/kN
    c. 0.001 m^2/kN
    d. 0.004 m^2/kN

$$T_V = \frac{\pi}{4}(U)^2,\ when\ U \le 60\%$$

T_V = (-0.9332 $\log_{10}$ (1 - U) – 0.0851) when U > 60%

$$T_V = \frac{C_v t}{d^2}$$

For U_1 = 30% then t_1 = 180 days

It is said further 20% consolidation So U2 = 50% then t_2 = ?

$$\frac{t_2}{t_1} = \left(\frac{U_2}{U_1}\right)^2$$

$$t_2 = \left(\frac{50}{30}\right)^2 \times 180 = 500\ days$$

∴ The additional time required = 500 – 180 = 320 days

Given,

Δe = 0.2

$\bar{\sigma}_o = 50$ kN/m²

$\bar{\sigma}_1 = 100$ kN/m²

C_c = 0.664 m²/kN

$$a_v = \left|\frac{\Delta e}{\bar{\sigma}_o - \bar{\sigma}_1}\right| = \frac{0.2}{50} = 0.004$$

∴ a_v = 0.004 m²/kN

Calculation:

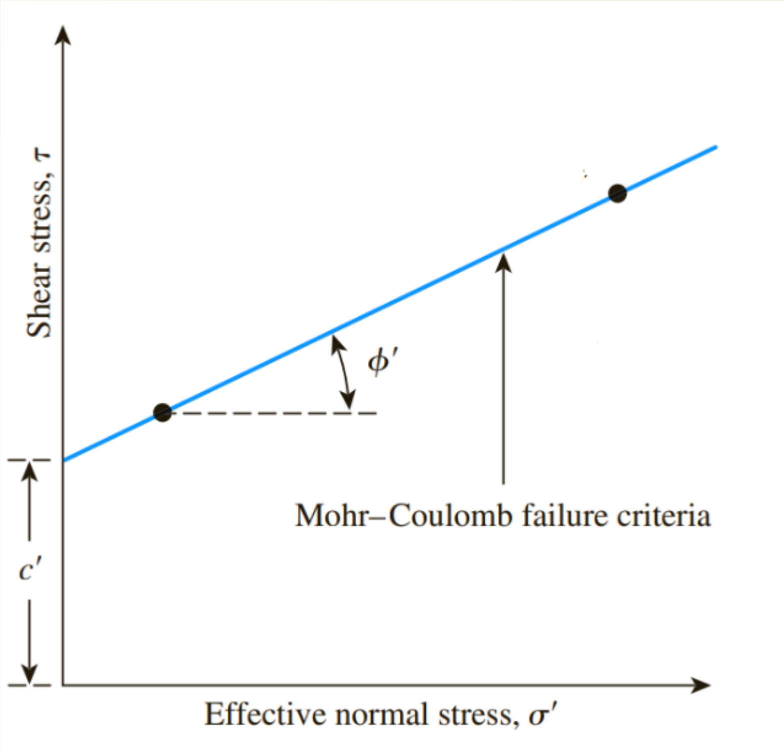
For a given c_v, and d ⇒ u ∝ √t

$$\frac{u_1}{u_2} = \sqrt{\frac{t_1}{t_2}} \Rightarrow \frac{30}{60} = \sqrt{\frac{100}{t_2}}$$

⇒ t_2 = 400 days

∴ Time taken for 60% consolidation is 400 days.

2.3 Shear strength of soil and stability of slopes: Concept of shear strength, principal planes and principal stresses; Mohr-Coulomb theory of shear strength; calculation of normal and shear stresses at different planes; relation of principle stress at failure condition; types of shear tests; stability of slopes. (ACiE0203)



Shear strength of soil (τ)

Cohesion (C):

Angle of internal friction:

 # Mohr-Coulomb theory of shear strength

$$\tau_f = c + \tan\phi$$

Limitations of Mohr-Column Theory:

- It neglects the effect of intermediate principal stress.
- It approximates the curved failure envelop by a straight line.
- For some clayey soil, there is no fixed relationship between the normal and shear stresses on the plane of failure. The theory cannot be used for such soils.

 # Principle plane and Principle stresses

If a plane is inclined at angle θ to major principle plane,

Normal stress (σ) is given by, $\sigma = \frac{\sigma_1 + \sigma_3}{2} + \frac{\sigma_1 - \sigma_3}{2} \cos 2\theta$

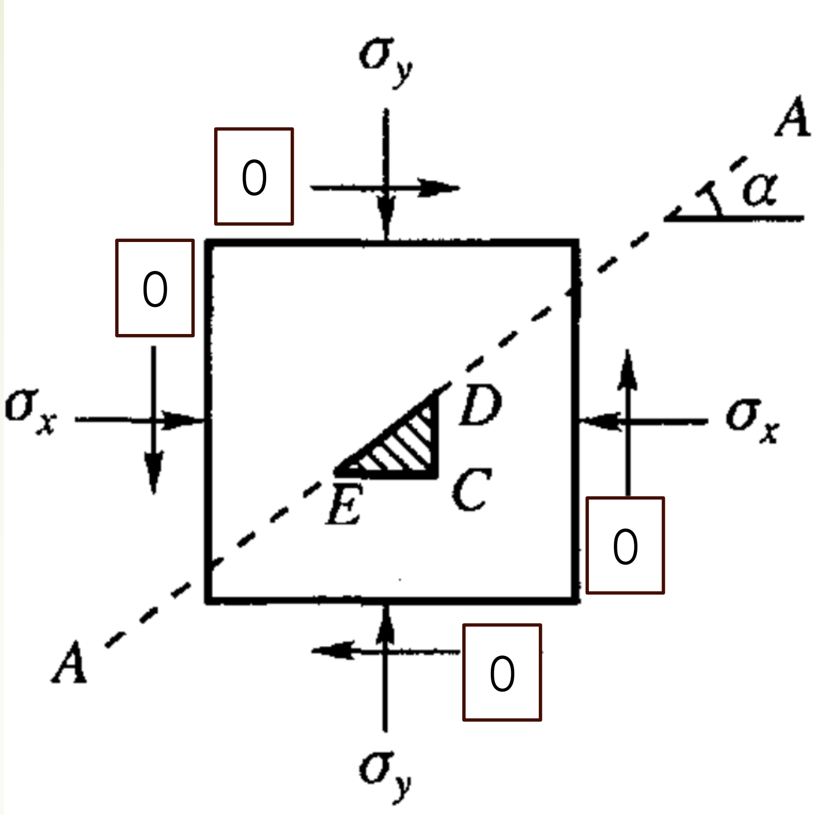
Shear stress (τ) = $\frac{\sigma_1 - \sigma_3}{2} \sin 2\theta$

Maximum shear stress (τ_{max}) = $\frac{\sigma_1 - \sigma_3}{2}$, occurs at 45^0 to principle plane

Where, σ_1 = major principle stress

σ_3 = minor principle stress

Θ = 45 + Ø/2

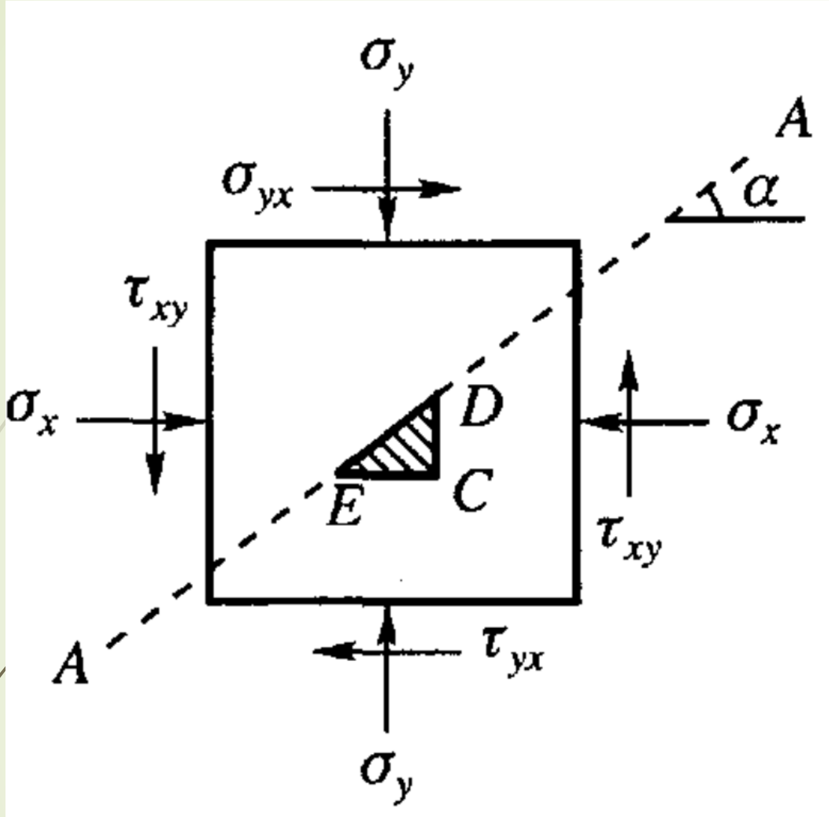


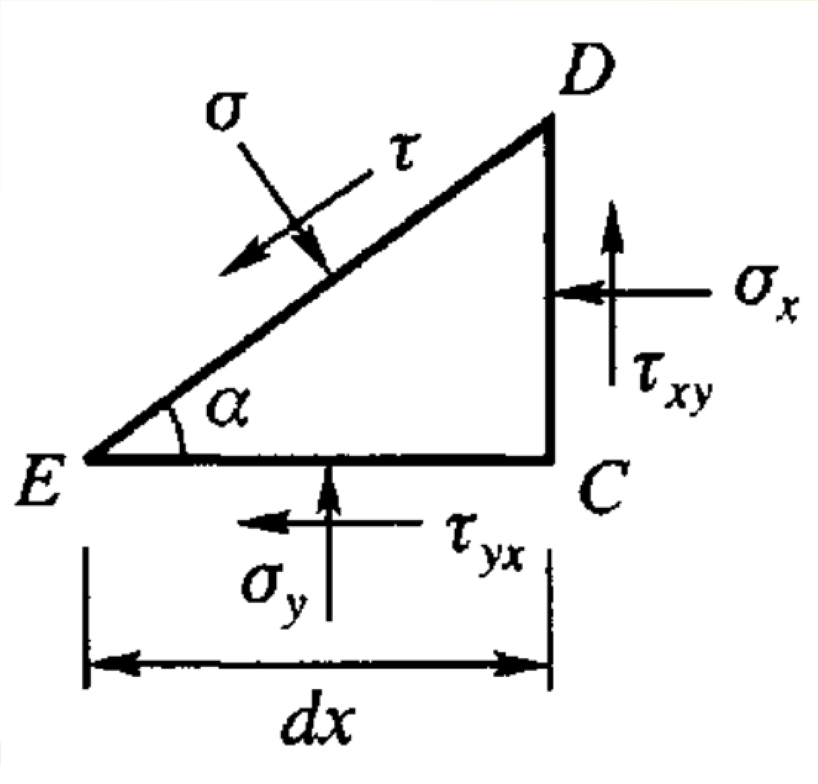
Mohr-Column failure criterion is given by the following relation. This gives the **relation between principal stresses**, cohesion and angle of friction at **failure condition**. $\mathrm{Tan}^2\left(45 + \frac{\phi}{2}\right) = N_\phi$ is called flow ratio.

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

Failure plane makes $45 + \frac{\phi}{2}$ with major principal plane.

Calculation of normal and shear stresses at different planes





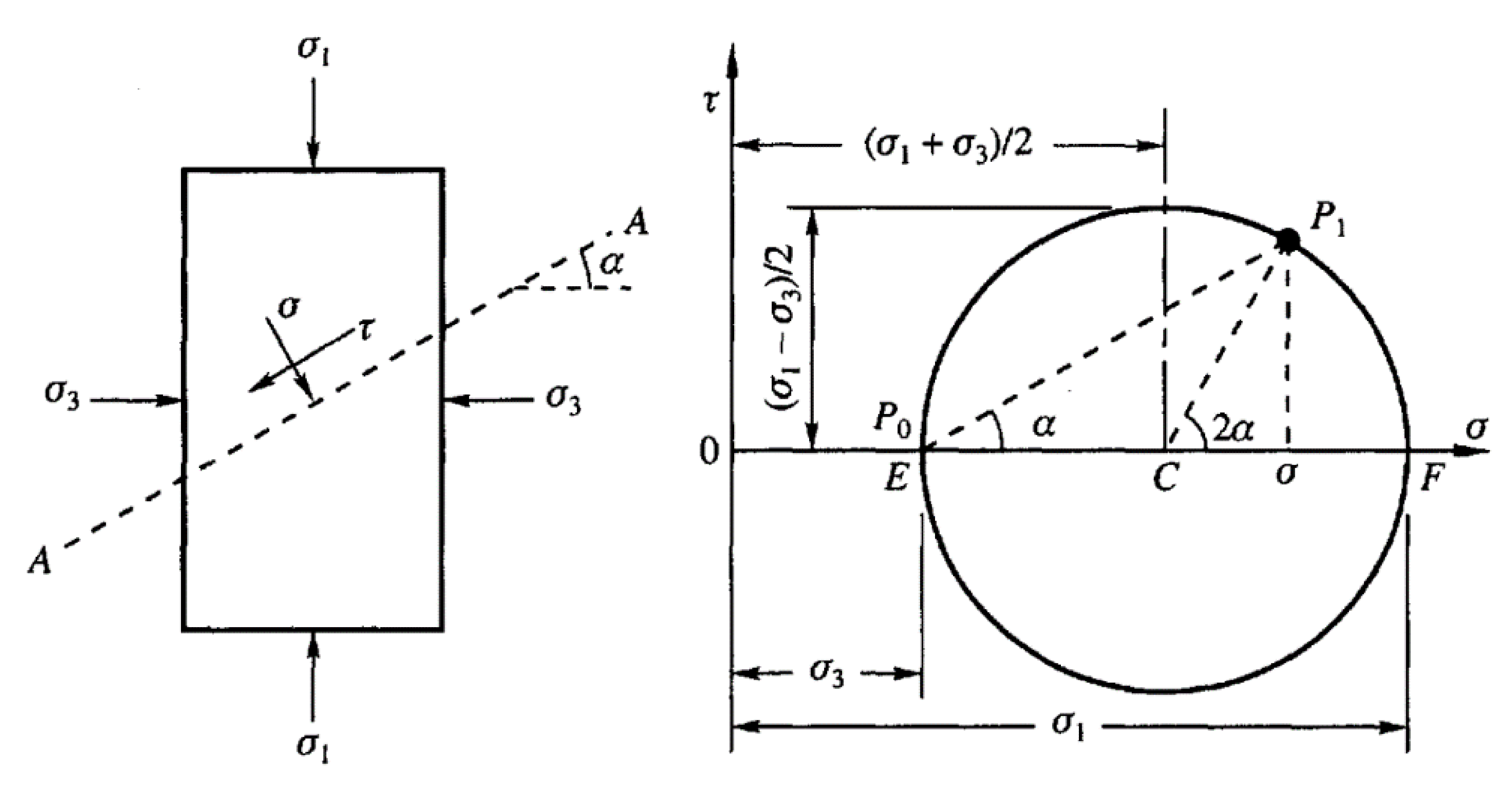
$$\sigma = \frac{\sigma_y + \sigma_x}{2} + \frac{\sigma_y - \sigma_x}{2}\cos 2\alpha + \tau_{xy}\sin 2\alpha$$

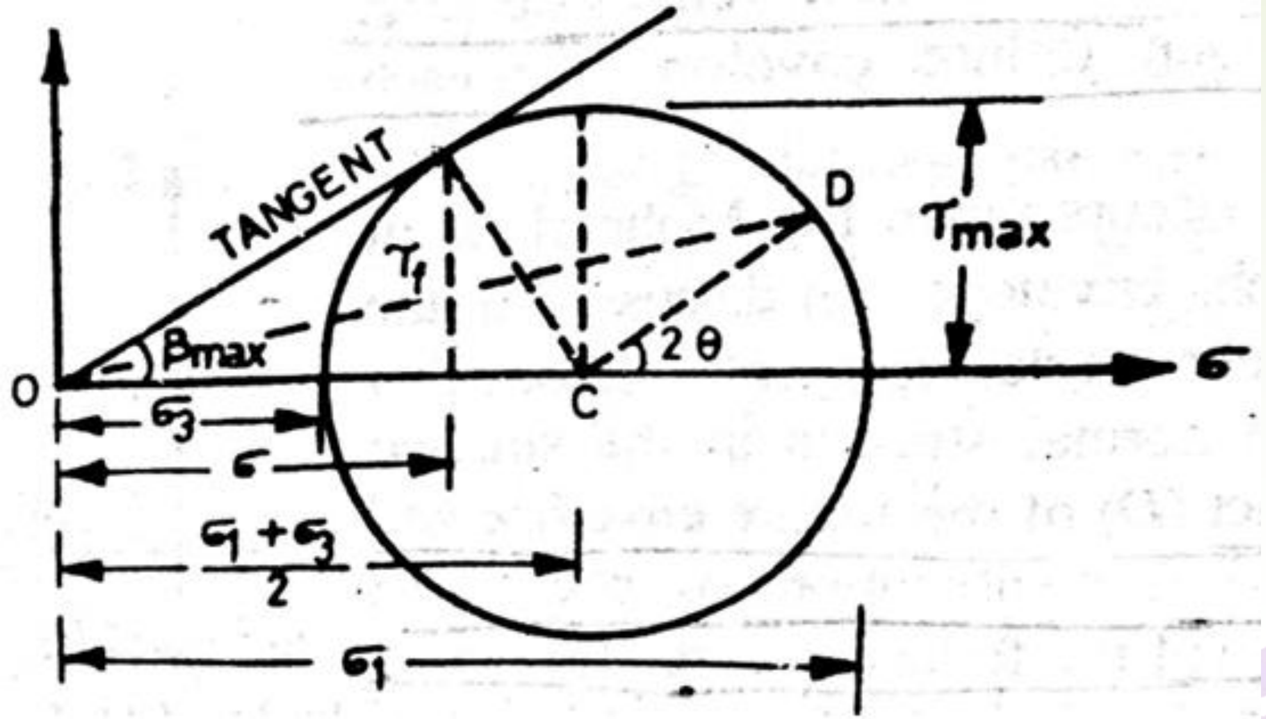
$$\tau = \frac{\sigma_y - \sigma_x}{2}\sin 2\alpha - \tau_{xy}\cos 2\alpha$$

Orientation of principal plane:

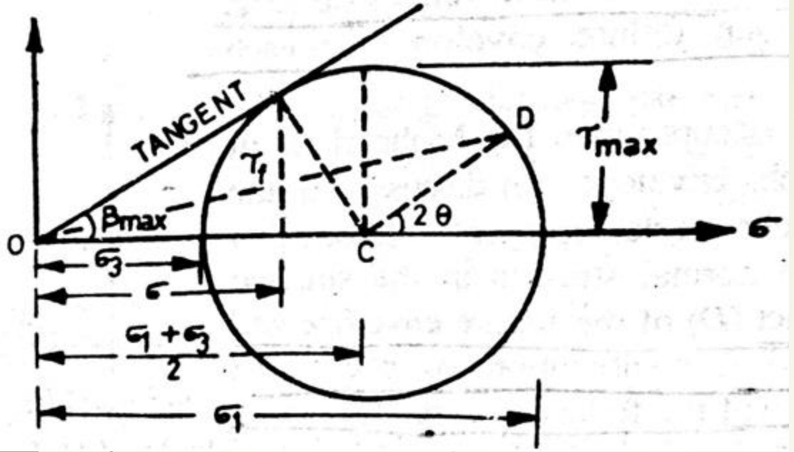
$$\tan 2\alpha = \frac{2\tau_{xy}}{\sigma_y - \sigma_x}$$

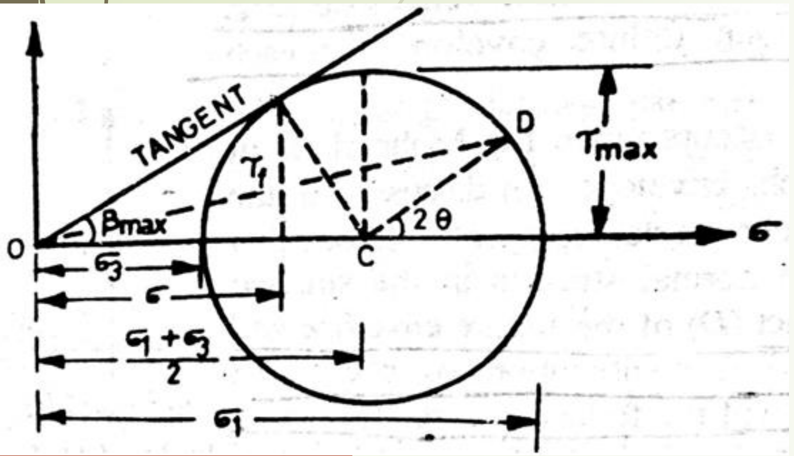
Mohr’s Circle of Stress

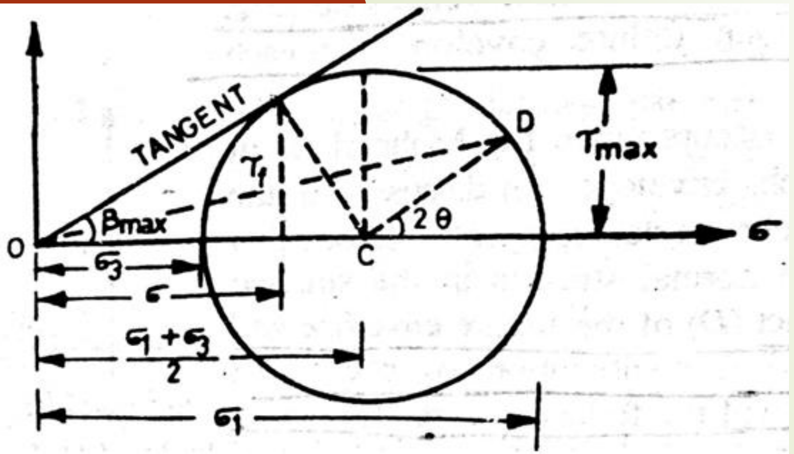




- The maximum shear stress τ_{max} is numerically equal to $\frac{\sigma_1 - \sigma_3}{2}$ (i.e., radius of Mohr's circle) and it occurs in a plane inclined at 45^0 to the principal planes.







- The point D on the Mohr circle represents the stresses (σ, τ) on a plane making an angle θ with the major principal plane.
  The resultant stress on that plane is equal to $\sqrt{\sigma^2 + \tau^2}$ and its angle of obliquity with the normal of the plane is equal to angle β, given by:

$$\beta = \tan^{-1}(\tau/\sigma)$$

- The maximum angle of obliquity β_{max} is obtained by drawing a tangent to the circle form origin O.

$$\beta_{max} = \sin^{-1}\frac{\frac{\sigma_1 - \sigma_3}{2}}{\frac{\sigma_1 + \sigma_3}{2}} = \sin^{-1}\frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$$

- The shear stress τ_f on the plane of the maximum obliquity is less than the maximum shear stress τ_{max}.
- Shear stress on the plane right angle to each other are numerically equal but are of opposite sign.

There is no need to be rigid about sign convention for plotting the shear stresses in Mohr's circle. These can be plotted either upward or downward. Although the sign convention is required for locating the orientation of the planes, the numerical results are not affected.