Chapter 9

Earth Pressure Theories

CHAPTER HIGHLIGHTS

- *Introduction*
- *Definition of lateral earth pressure*
- *Types of lateral earth pressure*
- *Rankine's earth pressure theory*
- *Coulomb's wedge theory*
- *Rehbann's method*

Introduction

The present chapter outlines the concept of determination of magnitude and location of the lateral earth pressure proposed by various theories. The magnitude of lateral earth pressure is very important in the design of retaining wall and it also depends on various factors, such as the movement of wall, the flexibility of the wall, the properties of the soil and the drainage conditions.

Definition of Lateral Earth Pressure

Lateral earth pressure is the force exerted by the soil mass upon an earth retaining structure, such as retaining wall.

Types of Lateral Earth Pressure

Depending upon the movement of wall with respect to soil retained (known as backfill) there are three types of lateral earth pressures. These are:

1. At rest earth pressure
2. Active earth pressure
3. Passive earth pressure

At Rest Pressure

- The lateral earth pressure is called at rest pressure when there is no movement of wall with respect to backfill soil.
- At rest pressure, soil mass is not subjected to any lateral yielding or movement.
- At rest pressure, the retaining wall is firmly fixed its top without any lateral movement or rotation.
- At rest pressure, elastic equilibrium condition prevails.

Examples:

1. Basement retaining walls which are restrained against the movement by basement slab at their tops.
2. Bridge abutment wall which is restrained at its top by bridge slab.
   - Theory of elasticity is used for analysis.

At rest earth pressure,

$$\boxed{\sigma_n = K_0\sigma_v}$$

Where

K_0 = Coefficient of earth pressure at rest

= Ratio of intensity of earth pressure at rest to the vertical stress at a specified depth

σ_v = Vertical stress = $\gamma \cdot z$

$$K_0 = \frac{\mu}{1-\mu}$$

$$K_0 = 1 - \sin\phi$$

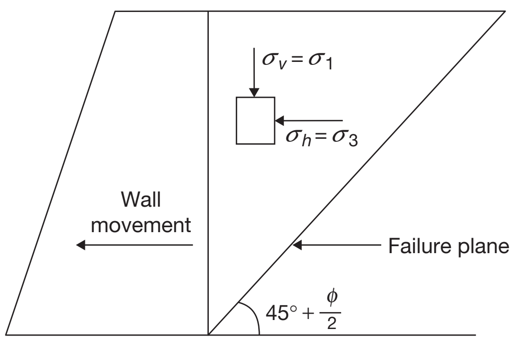
Where

μ = Poisson's ratio of a soil

ϕ = Angle of shearing resistance or angle of internal friction

Active Pressure

- The state of active pressure exists when a retaining wall moves away from the backfill.
- In case of active pressure, soil mass yields and it tends to stretch horizontally.
- In active pressure case, plastic equilibrium condition prevails as the entire soil mass is on verge of failure.
- In this case, failure wedge or sliding wedge moves downwards and outwards.
- The lateral earth pressure exerted on the wall is minimum as compared to the other lateral pressures.

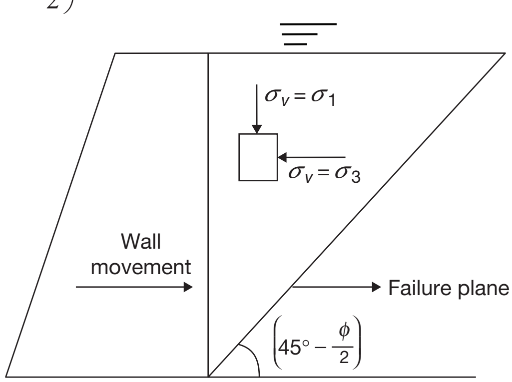


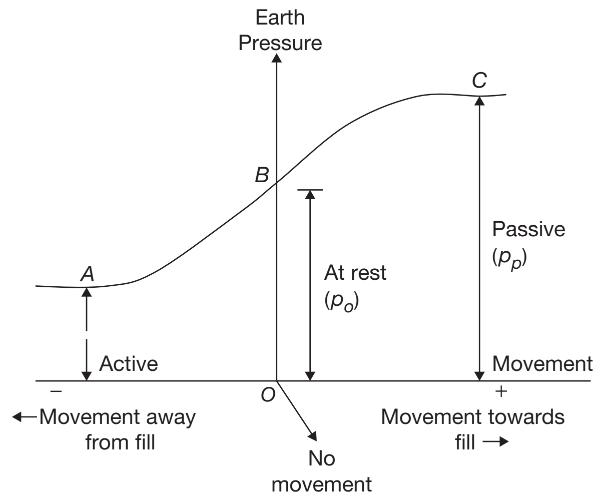
Active state

- In active state, failure plane is inclined at an angle $\left(45° + \frac{\phi}{2}\right)$ with horizontal.

Passive Pressure

- The state of passive pressure exists when a retaining wall moves towards the backfill.
- In case of passive pressure, the soil mass tends to compress horizontally.
- In case of passive pressure also, plastic equilibrium condition prevails.
- In this case, failure wedge or sliding on the wall is maximum as compared to other lateral pressures.
- In passive case, failure plane is inclined at an angle $\left(45° - \frac{\phi}{2}\right)$ with horizontal.





Variation of pressure

Rankine's Earth Pressure Theory

Rankine earth pressure theory is based on the equilibrium of a soil element with in a soil mass.

Assumptions

1. Soil is homogeneous, semi-infinite, dry and cohesionless.
2. The ground surface is plane, which may be horizontal or inclined.
3. The retaining wall back is smooth and vertical.
4. The soil element is in a state of plastic equilibrium.

Plastic Equilibrium

At plastic equilibrium, the following equation is used:

$$\boxed{\sigma_1 = \sigma_3 \tan^2\alpha_f + 2c\tan\alpha_f}$$

Where $\tan^2\alpha_f$ = flow ratio (N_ϕ)

$$\alpha_f = 45° + \frac{\phi}{2}.$$

If the stresses in soil mass satisfy the above failure criterion, the soil mass is said to be in state of plastic equilibrium and the failure is imminent at this condition.

1. **Active earth pressure:**
   - Horizontal pressure is given by,

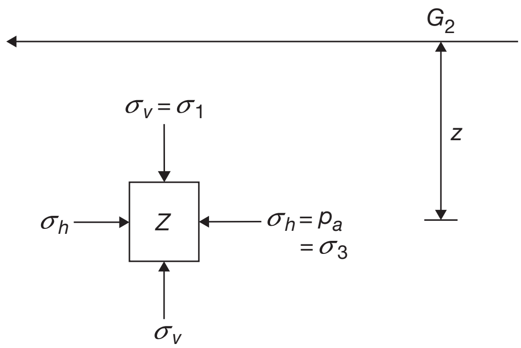
$$\boxed{\sigma_h = \sigma_a = K_a\sigma_v}$$

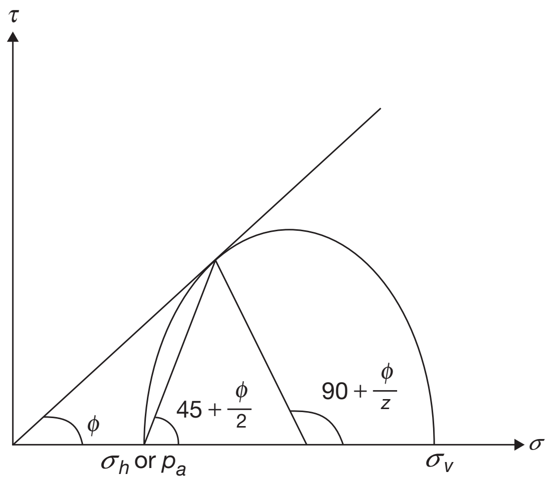
Where

K_a = Coefficient of active earth pressure

$$\boxed{K_a = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45 - \frac{\phi}{2}\right)}$$

σ_v = Vertical stress at a depth 'z' = γz



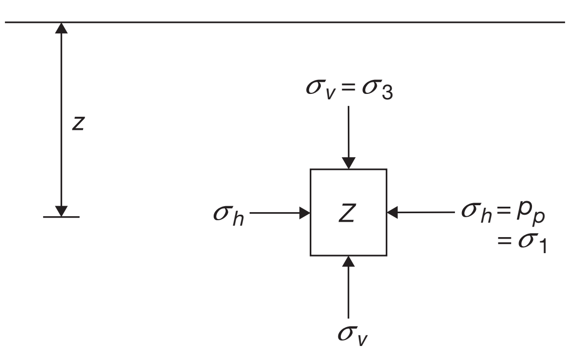


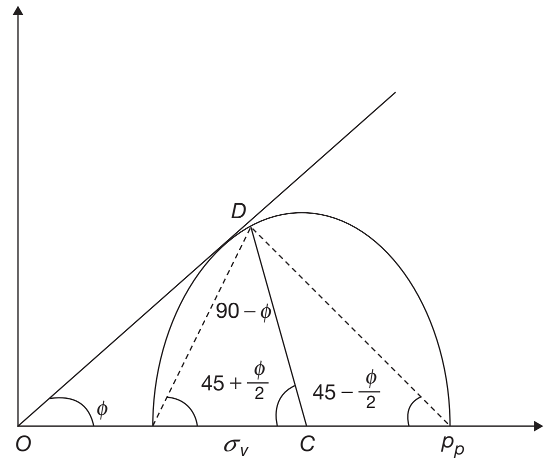
σ_3 and σ_1 are minor and major principal stresses.

- Failure plane is inclined at an angle $\left(45° + \frac{\phi}{2}\right)$ with horizontal.

2. Passive earth pressure:

- As the wall is moving towards the backfill in passive case, it laterally compresses the soil. Due to this, the horizontal stress is increased, whereas the vertical stress remains constant.
- In this case, major principal stress develops in horizontal direction while minor principal stress develops in vertical direction.
- The following figure shows the stress element and Mohrs circle at passive case.





Passive earth pressure (p_p) is given by,

$$p_p = k_p \sigma_v$$
$$p_p = K_p \cdot \gamma \cdot z$$

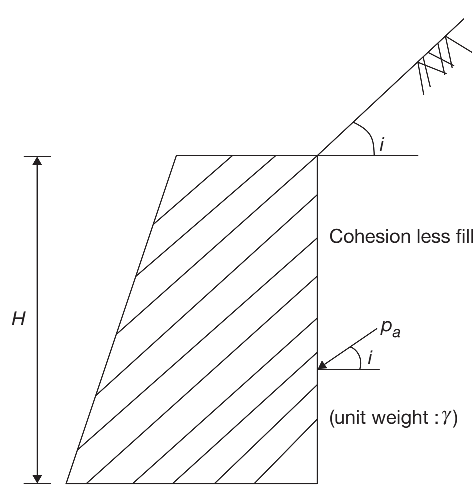
Where, K_p = Coefficient of passive earth pressure, given by:

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} = \tan^2\left(45 + \frac{\phi}{2}\right)$$

$$K_p = \frac{1}{K_a}$$

- The failure plane makes an angle of $\left(45 + \frac{\phi}{2}\right)$ with the major principal plane which is vertical and makes an angle of $\left(45 - \frac{\phi}{2}\right)$ with horizontal, i.e., with respect to minor principal plane.

Rankine's Earth Pressure When Surface is Inclined



i = Angle of inclination of soil surface (unit weight) with horizontal

Active case:

$$p_a = K_a \gamma \cdot H$$

Where

$$K_a = \cos i \left[\frac{\cos i - \sqrt{\cos^2 i - \cos^2 \phi}}{\cos i + \sqrt{\cos^2 i - \cos^2 \phi}} \right]$$

Passive case:

$$p_p = k_p \gamma H$$

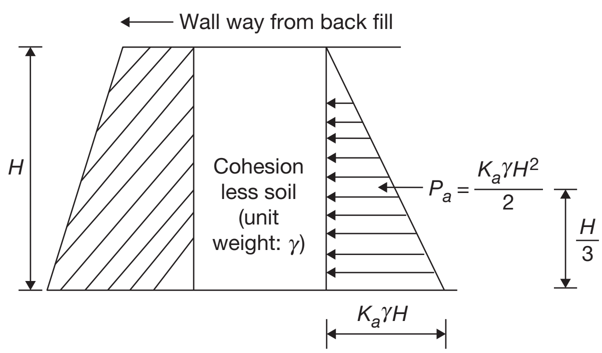
Where

$$K_p = \cos i \left[\frac{\cos i + \sqrt{\cos^2 i - \cos^2 \phi}}{\cos i - \sqrt{\cos^2 i - \cos^2 \phi}} \right]$$

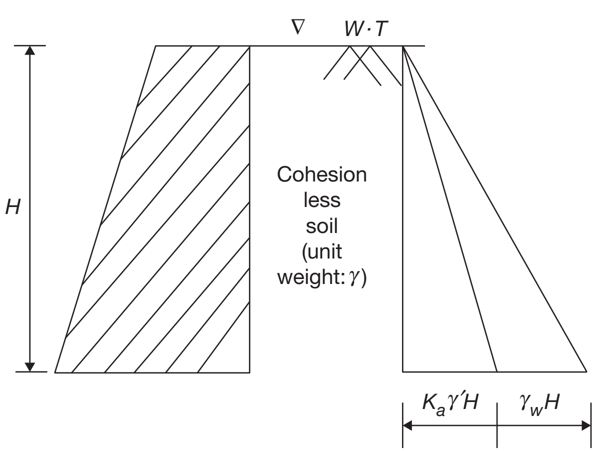
Pressure Distribution Diagrams

Active Case

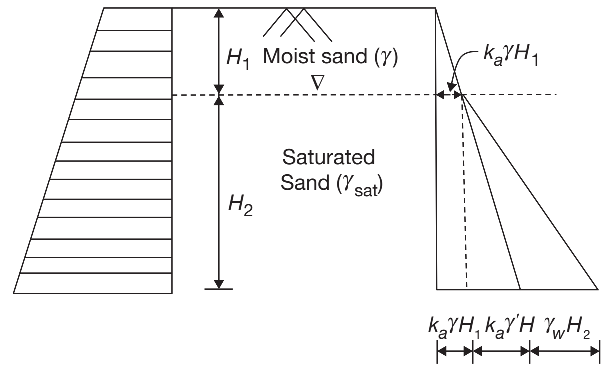
1. **Dry cohesion less soil:**



2. **Effect of submergence:** In case of saturated or submerged backfill, lateral earth pressure will be due to the submerged unit weight of the backfill and also due to pore water.

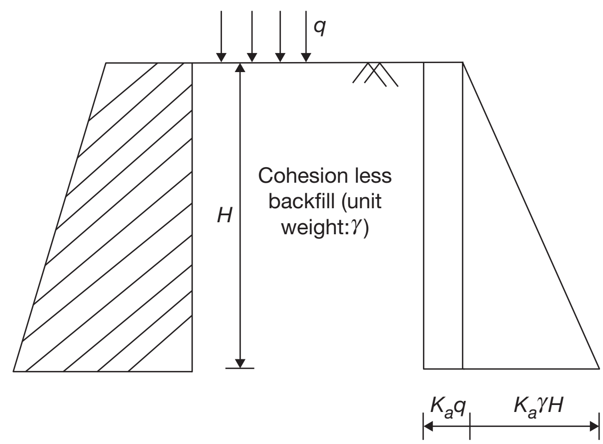


3. **If water table is at a depth H_1 from GL:**



The resultant pressure P acting on the wall is determined from pressure distribution diagram.

4. **Effect of uniform surcharge:**



NOTE

The pressure distribution diagrams are same for passive and at rest cases also, except replace k_a by k_p and k_0, respectively.

Earth Pressure in Cohesive Soils

- It is an extension of Rankine's theory for cohesionless soil by Resal and Bell.
- The basic difference is that the failure envelope has a cohesion intercept in case of cohesive soil, whereas it is zero in case of cohesionless soil.

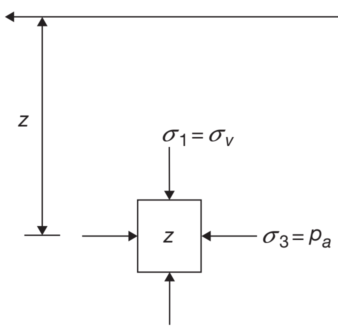
Active Case

Active pressure,

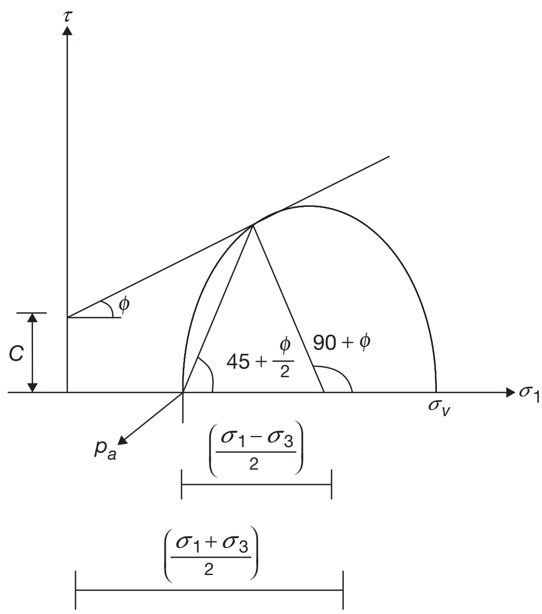
$$p_a = K_a \gamma z - 2c\sqrt{K_a}$$

[Hint: The above equation is obtained by substituting $\sigma_1 = \sigma_v$ and $\sigma_3 = p_a$ in plastic equilibrium condition.]

- The Mohr's circle for active case for cohesive soils is shown in the following figure.



Stress Conditions



Mohr's Circle for Active Case

Pressure distribution: At top $z = 0$; $p_a = -2C\sqrt{K_a}$

- The negative sign shows that pressure is negative (tension) and this tensile stress decrease with an increase in depth and becomes zero at z_c.
- The depth z_c is known as depth of tensile crack.

  At $z = z_c$; $p_a = 0 \Rightarrow 0 = k_a\gamma(z_c) - 2Ck_a$

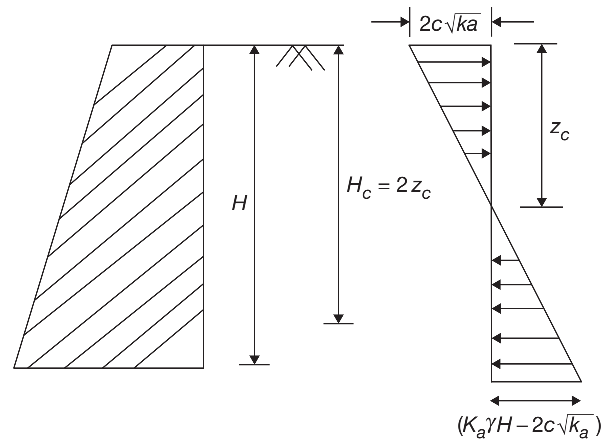
$$\boxed{z_c = \frac{2C}{\gamma\sqrt{k_a}}}$$

- For a purely cohesive soil ($\phi = 0$),

$$\boxed{z_c = \frac{2C}{\gamma}}$$

At bottom, $z = H$; $p_a = k_a\gamma H - 2Ck_a$

The pressure distribution diagram is shown in the following figure:



Total active force:

1. Before the formation of tensile crack;

$$\boxed{P_a = k_a\frac{\gamma H^2}{2} - 2C\sqrt{K_a}}$$

[Equal to total area of pressure diagram.]

2. After the occurrence of tensile crack,

$$\boxed{P_a = k_a\frac{\gamma H^2}{2} - 2C\sqrt{K_a}H + \frac{2c^2}{\gamma}}$$

[Neglect tensile stress.]

- It acts at a height of $\left(\frac{H - z_c}{3}\right)$.

Critical height or unsupported vertical cut (H_c):

- The depth up to which the total earth pressure is zero is known as critical height.
- $H_c = 2z_c$

$$= 2\left(\frac{2C}{\gamma\sqrt{K_a}}\right)$$

$$\boxed{H_c = \frac{4C}{\gamma\sqrt{K_a}}}$$

For pure cohesive soil ($\phi = 0$),

$$\boxed{H_c = \frac{4C}{\gamma}}$$

- It is the depth up to which the soil can withstand without any lateral movement.

SOLVED EXAMPLE

Example 1

An unsupported excavation is made to the maximum possible depth a clay soil having $\gamma_t = 18$ kN/m^3, $C = 100$ kN/m^2, $\phi = 30°$. The active earth pressure, according to Rankine's theory, at the base level of excavation is: **[GATE, 2004]**

(A) 115.47 kN/m^2 (B) 54.36 kN/m^2
(C) 27.18 kN/m^2 (D) 13 kN/m^2

Solution

Given,

$$\gamma_t = 18 \text{ kN/m}^3,\ C = \text{k/m}^2,\ \phi = 30°.$$

Critical height or depth of unsupported vertical cut (H_c).

$$H_c = \frac{2C}{\gamma\sqrt{k_a}}$$

Where,
$$K_a = \frac{1-\sin\phi}{1+\sin\phi}$$
$$= \frac{1-\sin 30°}{1+\sin 30°}$$
$$K_a = \frac{1}{3}$$
$$\therefore H_c = \frac{2\times 100}{18\times\sqrt{\frac{1}{3}}}$$
$$H_c = 38.5 \text{ m}$$

Active earth pressure is given by

$$p_a = k_a\gamma H_c - z_c\sqrt{K_a}$$
$$p_a = (0.333)(18)(38.5) - 2\times 100\times\sqrt{0.333}$$
$$p_a = 115.4 \text{ kN/m}^2$$

Hence, the correct answer is option (A).

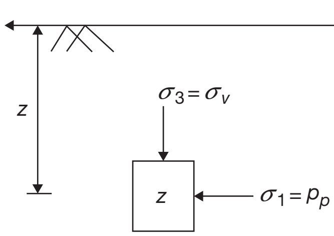
Passive Case

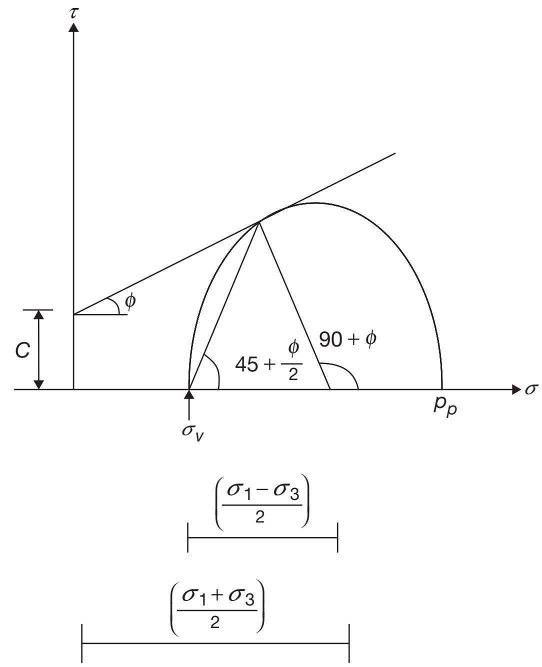
Passive pressure for a cohesive soil can be determined by the following expression

$$p_p = \gamma z k_p + 2C\sqrt{k_p}$$

[**Hint:** The above expression can be derived by substituting $\sigma_1 = p_p$ and $\sigma_3 = \sigma_v$ in plastic equilibrium condition].

The mohr's circle for passive case for cohesive soils is shown in the following figure:

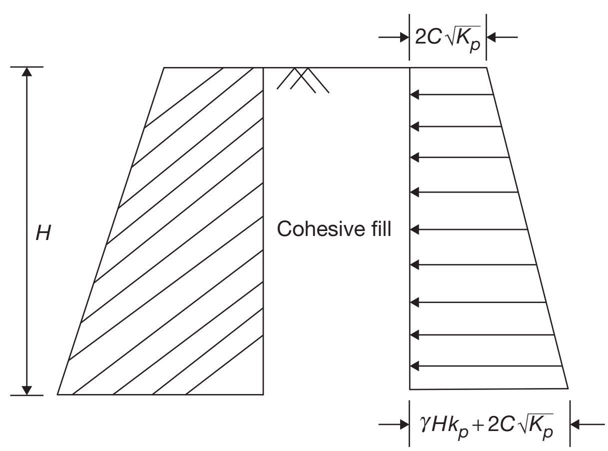




- The failure plane makes an angle of $\left(45° + \frac{\phi}{2}\right)$ with horizontal (minor principal plane).

Pressure distribution: At top $z = 0$, $p_p = +2C\sqrt{k_p}$

At Bottom $z = H$; $p_p = \gamma \cdot Hk_p + 2C\sqrt{k_p}$



- The pressure, unlike active case, is positive throughout the depth.

The total passive force on the retaining wall of height 'H' is given by,

$$p_p = k_p\frac{\gamma H^2}{2} + 2C\sqrt{K_p}H$$

NOTE

The effect of cohesion is to reduce active pressure everywhere by $2C\sqrt{K_p}$ and to increase the passive pressure by $2C\sqrt{K_p}$.

Coulomb's Wedge Theory

Coulomb carried out the analysis by considering the equilibrium of sliding wedge as a whole.

Assumptions

1. The backfill is dry, cohesionless, homogeneous, isotropic and ideally, plastic material.
2. The slip surface is a plane which passes through the heel of the wall.
3. The wall surface is rough. The resultant earth pressure on wall is inclined at an angle 'δ' normal to the wall, where 'δ' is the angle of friction between the wall and the backfill.
4. The sliding wedge itself acts as a rigid body.

Important Points

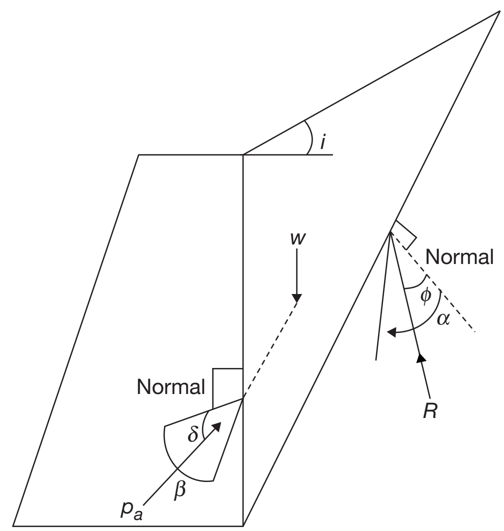
1. In Coulomb's theory, a plane trial failure surface is assumed and the trial surface which gives the largest force for the active case and the smallest force for the passive case is the actual failure surface.
2. This method readily accommodates the friction between the wall and the backfill, irregular backfill, sloping wall, surcharge loads, etc.
3. Coulomb's theory is more general than Rankine theory as it is used for wet soils and cohesive soils as well.
4. The wall friction angle is determined by means of directs shear test. The approximate values of 'δ' are given below.

   (a) For concrete walls, $\delta = \frac{2\phi}{3}$

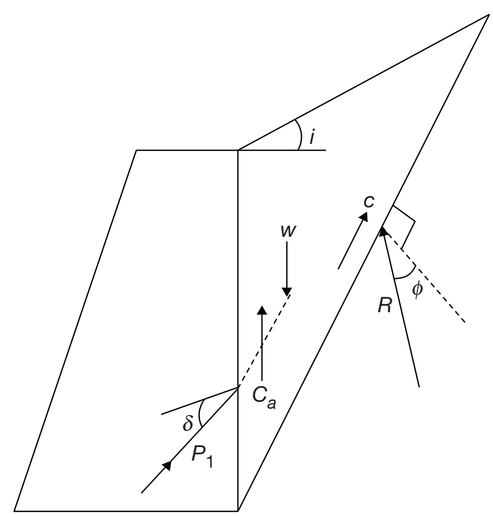
   (b) For smooth walls, $\delta = \frac{\phi}{3}$

   (c) For rough walls with well drained backfill $\delta = \frac{3\phi}{4}$

   (d) Backfill subjected to vibrations, $\delta = 0$
5. Coulomb's method does not give the point of application of resultant earth pressure. But, however it is assumed that the pressure distribution diagram is hydrostatic on the back of the wall and resultant pressure p_a is assumed to act at one-third of the height of the wall from the base.
6. In case of Coulombs active pressure in cohesionless soils, the sliding wedge is in equilibrium under three forces, i.e., weight of wedge (W), reaction R on the slip surface and reaction p_a from the wall whereas the coulombs active earth pressure in cohesive soil, in addition to the above, two additional forces acts on the failure wedge.



(a) Coulomb's active pressure in cohesionless soil



(b) Coulombs active pressure in cohensive soil

Rehbann's Method

- This is a graphical method, also known as Poncelet's method.
- Used for the determination of total active pressure according to Coulomb's theory.

Exercises

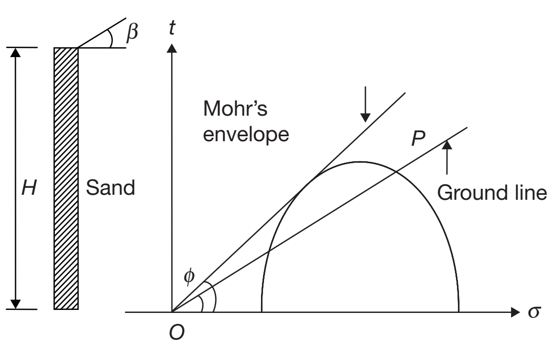
1. Coulomb's theory of earth pressure is based on
(A) the theory of elasticity.
(B) the theory of plasticity.
(C) empirical rules.
(D) wedge theory.

2. The depth of tension crack in a soft clay ($\phi_u = 0$) is
(A) $\frac{4C_u}{\gamma}$ (B) $\frac{2C_u}{\gamma}$
(C) $\frac{C_u}{\gamma}$ (D) $\frac{C_u}{2\gamma}$

3. In cohesive soils the depth of tension crack (Z_{cr}) is likely to be
(A) $Z_{cr} \geq \frac{2C}{\gamma}\tan\left(45° - \frac{\phi}{2}\right)$
(B) $Z_{cr} \geq \frac{2C}{\gamma}\tan\left(45° + \frac{\phi}{2}\right)$
(C) $Z_{cr} \geq \frac{4C}{\gamma}\tan\left(45° - \frac{\phi}{2}\right)$
(D) $Z_{cr} \geq \frac{4C}{\gamma}\tan\left(45° + \frac{\phi}{2}\right)$

4. Cohesion in soil
(A) decreases active pressure and increases passive resistance.
(B) decreases both active pressure and passive resistance.
(C) increases the active pressure and decreases the passive resistance.
(D) increases both active pressure and passive resistance.

5. Figure given below shows a smooth vertical gravity retaining wall cohesion less soil backfill having an angle of internal friction ϕ. In the graphical representation of Rankine's active earth pressure for the retaining wall shown in figure, length OP represents



(A) vertical stress at the base.
(B) vertical stress at a height $\frac{H}{3}$ from the base.
(C) lateral earth pressure at the base.
(D) lateral earth pressure at a height $\frac{H}{3}$ from the base.

6. The total active thrust on a vertical wall 3 m high retaining a horizontal sand backfill (unit weight γ_t =20 kN/m^3, angle of shearing resistance = ϕ' = 30°) when the water table is the bottom of the wall, will be
(A) 30 kN/m (B) 35 kN/m
(C) 40 kN/m (D) 45 kN/m

7. To have zero active pressure intensity at the tip f a wall in cohesive soil, one should apply a uniform surcharge intensity of
(A) $2c\tan\alpha$ (B) $2c\cot\alpha$
(C) $-2c\tan\alpha$ (D) $-2c\cot\alpha$

8. Consider the following statements:
I. Coulomb's earth pressure theory does not take the roughness of wall into consideration.
II. In case of non-cohesive soils, the coefficients of active earth pressure and earth pressure at rest are equal.
III. Any movement of retaining wall away from the fill corresponds to active earth pressure condition.

Which of these statements is/are correct?
(A) I alone (B) I and II
(C) II alone (D) III alone

9. Given that $c = 2t/\text{m}^2$, $\phi = 0°$ and $\gamma = 2t/\text{m}^2$, the depth of tension crack developing in a cohesive soil backfill would be
(A) 1 m (B) 2 m
(C) 3 m (D) 4 m

10. The correct sequence of the given parameters in descending order of earth pressure intensity is
(A) active, passive, at rest.
(B) passive, active, at rest.
(C) passive, at rest, active.
(D) at rest, passive, active.

11. If the coefficient of active earth pressure is $\frac{1}{3}$, then what is the value of the coefficient of passive earth pressure?
(A) $\frac{1}{9}$ (B) $\frac{1}{3}$
(C) 3 (D) 1

12. The earth pressure behind a bridge abutment is
(A) active
(B) passive
(C) at rest
(D) constant always and everywhere

13. An unsupported excavation is made to the maximum possible depth in a clay soil having γ_t = 18 kN/m^3, c = 100 kN/m^2, ϕ = 30°. The active earth pressure, according to Rankine's theory, at the base level of the excavation is

(A) 115.47 kN/m^2 (B) 54.36 kN/m^2
(C) 27.18 kN/m^2 (D) 13 kN/m^2

14. A retaining wall of height 8 m retains dry sand. In the initial state, the soil is loose and has a void ratio of 0.5, γ_d = 17.8 kN/m^3 and ϕ = 30°. Subsequently, the backfill is compacted to a state where void ratio is 0.4 γ_d = 18.8 kN/m^3 and ϕ = 35°. The ratio of initial passive thrust to the final passive thrust, according to Rankine's earth pressure theory, is

(A) 0.38 (B) 0.64
(C) 0.77 (D) 1.55

15. A 3 m high retaining wall is supporting a saturated sand (saturated due to capillary action) of bulk density 18 kN/m^3 and angle of shearing resistance 30°. The change in magnitude of active earth pressure at the base due to rise in ground water table from the base of the footing to the ground surface shall (γ_w = 10 kN/m^3)

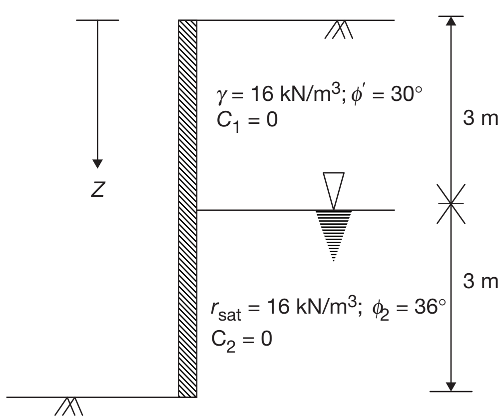
(A) increase by 20 kN/m^2.
(B) decrease by 20 kN/m^2.
(C) increase by 30 kN/m^2.
(D) decrease by 30 kN/m^2.

16. Compute the intensity of passive earth pressure at a depth of 8 m in a cohesion less sand with an angle of internal friction of 30° when water table rises to the ground level. Saturated unit weight of sand is 21 kN/m^3, γ_w = 9.81 kN/m^3.

17. A vertical excavation was made in a clay deposit having unit weight of 22 kN/m^3. It caved in after the digging reached 4 m depth. Assuming ϕ = 0, calculate the magnitude of cohesion.

Direction for questions 18 and 19:

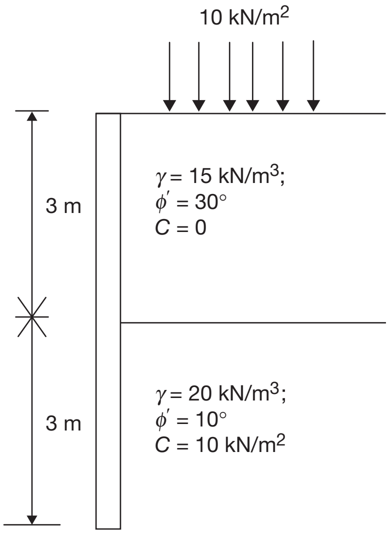
For the retaining wall shown in the given figure assume that the wall can yield sufficiently to develop active stage. Use Rankine's active earth pressure theory and determine:



18. Active force per metre of the wall.

19. The location of the resultant line of action.

20. A retaining wall with a stratified backfill and a surcharge load is shown in the following figure. Draw the earth pressure diagram detailing the values at critical points. Also estimate the resultant thrust on the wall and its position.



21. Under active pressure condition the failure wedge moves

(A) towards right.
(B) towards left.
(C) towards upward.
(D) towards downward.

22. Westergaard's theory is applicable for which type of soils?

(A) Sandy soils (B) Startified soils
(C) Humus soils (D) Gravel

23. The unsupported vertical cut of the embankment if C = 40 kN/m^2, γ = 30 kN/m^3 and k_a = 1 is

(A) 5.23 m (B) 5.33 m
(C) 5.43 m (D) 5.53 m

24. A retaining wall of height 10 m retains dry sand. The soil is loose and has a void ratio of 0.8, γ_d = 18.8 kN/m^3 and ϕ = 50°. The backfill is compacted to a state of 0.5, γ_d = 20.8 kN/m^3 and ϕ = 65°. The ratio of initial passive thrust to the final passive thrust according to Rankine's earth pressure theory is

(A) 0.35 (B) 2.9
(C) 0.33 (D) 2.7

25. I. In Rankine's theory the retaining wall is assumed to be smooth and vertical.
II. In Coulomb's wedge theory the retaining wall is assume to be rough.

(A) I is true, II is false.
(B) I is false, II is true.
(C) I and II are true.
(D) I and II are false.

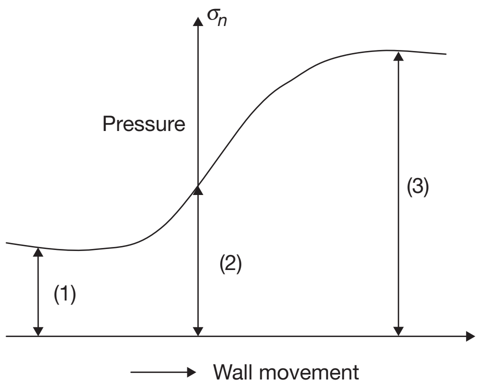
26. The term mobilized shear strength is referred to as

(A) shear strength.
(B) maximum shear stress.

(C) applied shear stress.
(D) None of these

27. If uniform surcharge of 120 kN/m^2 is placed on the backfill with ϕ = 30°, the increase in pressure is (in kN /m^2)

28.



Identify the correct one from the following: (p_0, p_a, p_p indicates at rest, active and passive earth pressures respectively)

(A) (1) – p_0, (2) – p_a, (3) – p_p
(B) (1) – p_a, (2) – p_0, (3) – p_p
(C) (1) – p_p, (2) – p_0, (3) – p_a
(D) (1) – p_0, (2) – p_p, (3) – p_a

29. A vertical wall of 5 m high above the water table, retains a 20° soil slope, the retained soil has a unit weight of 20 kN/m^3, the appropriate shear strength parameters are C = 0 and ϕ = 30°. The coefficient of active earth pressure to be used in estimating the active pressure acting on the wall is _______ (upto two decimal).
(A) 0.5
(B) 0.31
(C) 0.42
(D) 0.65

30. A 5 m high retaining wall having a smooth vertical back face retains a layered horizontal backfill. Top 3 m thick layer of the back fill is sand having an angle of internal friction ϕ = 30° while the bottom is 2 m thick clay with cohesion, C = 15 kPa. Assure unit weight for both sand and clay as 20 kN/m^3. The total active earth pressure per unit length of wall (in kN/m) is _______.
(A) 130 (B) 150
(C) 160 (D) 175

31. An electric pole of 5 m high is fixed into the foundation. It carries a wire at the top and is free to move sideways. The effective length of the pole is
(A) 3.25 m (B) 4.0 m
(C) 5.0 m (D) 10.0 m

32. The active pressure caused by a cohesionless backfill on a smooth vertical retaining wall may be reduced by _______.
(A) providing surcharge on the backfill
(B) compacting the backfill
(C) saturating the backfill with water
(D) All of these

33. A retaining wall of height 6 m retains dry sand. In initial state, the soil is loose and has a void ratio of 0.5, γ_d = 17.8 kN/m^3 and ϕ = 30°. Subsequently, on compaction of backfill if the void ratio becomes 0.4, γ_d becomes 18.8 kN/m^3 and ϕ becomes 35°. What will be the ratio of initial passive thrust to final passive thrust?
(A) 0.38
(B) 0.64
(C) 0.77
(D) 1.55

34. A 8 m thick layer of saturated clay of γ=19 kN/m^3 is underlain by a layer of sand. The sand is under a artesian pressure of 5 m. Calculate the maximum depth of cut that can be made without causing a heave.
(A) 4.32 m
(B) 5.42 m
(C) 6.72 m
(D) 8 m

Previous Years' Questions

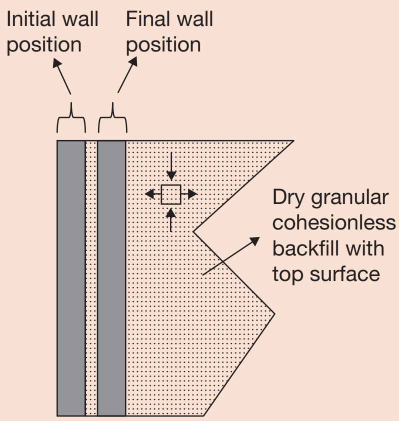
1. When a retaining wall moves away from the backfill, the pressure exerted on the wall is termed as **[GATE, 2008]**
(A) passive earth pressure.
(B) swelling pressure.
(C) pore pressure.
(D) active earth pressure.

2. If σ_h, σ_v, σ'_h and σ'_v represent the total horizontal stress, total vertical stress, effective horizontal stress and effective vertical stress on a soil element, respectively, the coefficient of earth pressure at rest is given by **[GATE, 2010]**

(A) $\dfrac{\sigma_h}{\sigma_v}$ (B) $\dfrac{\sigma'_h}{\sigma'_v}$

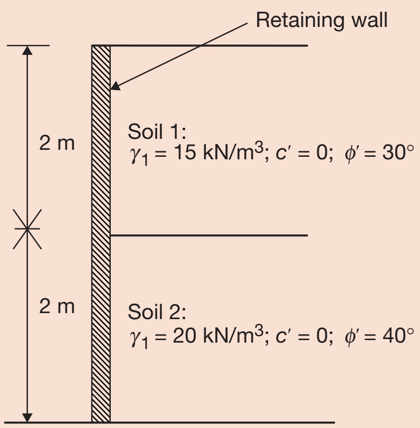
(C) $\dfrac{\sigma_v}{\sigma_h}$ (D) $\dfrac{\sigma'_v}{\sigma'_h}$

3. A smooth rigid retaining wall moves as shown in the sketch causing the backfill material to fail. The backfill material is homogeneous and isotropic, and obeys the Mohr–Coulomb failure criterion. The major principal stress is **[GATE, 2012]**



(A) parallel to the wall face and acting downwards.
(B) normal to the wall face.
(C) oblique to the wall face and acting downwards.
(D) oblique to the wall face acting upwards.

4. Two different types (soil 1 and soil 2) soil are used as backfill behind a retaining wall as shown in the figure, where γ_t is total unit weight, and c' and ϕ' are effective cohesion and effective angle of shearing resistance. The resultant active earth force per unit length (in kN/m) acting on the all is **[GATE, 2013]**



(A) 31.7 (B) 35.2
(C) 51.8 (D) 57.0

5. Surcharge loading required to be placed on the horizontal backfill of a smooth retaining vertical wall so as to completely eliminate tensile crack is **[GATE, 2015]**

(A) $2c$ (B) $2ck_a$

(C) $2c\sqrt{k_a}$ (D) $\dfrac{2c}{\sqrt{k_a}}$

6. A 6 m high retaining wall having a smooth vertical back face retains a layered horizontal backfill. Top 3 m thick layer of the backfill is sand, having an angle of internal friction, $\phi = 30°$, while the bottom layer is 3 m thick clay with cohesion, $c = 20$ kPa. Assume unit weight for both sand and clay as 18 kN/m^3. The total active earth pressure per unit length of the wall (in kN/m) is **[GATE, 2015]**

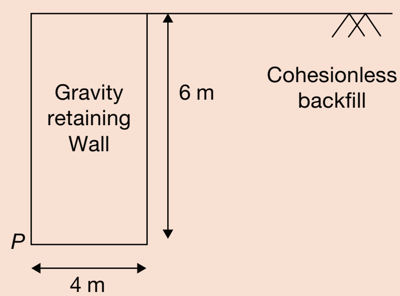
(A) 150 (B) 216
(C) 156 (D) 196

7. A vertical cut is to be made in a soil mass having cohesion c, angle of internal friction ϕ, and unit weight γ. Considering K_a and K_p as the coefficients of active and passive earth pressures, respectively, the maximum depth of unsupported excavation is **[GATE, 2016]**

(A) $\dfrac{4c}{\gamma\sqrt{K_p}}$ (B) $\dfrac{2c\sqrt{K_p}}{\gamma}$

(C) $\dfrac{4c\sqrt{K_a}}{\gamma}$ (D) $\dfrac{4c}{\gamma\sqrt{K_a}}$

8. A homogeneous gravity retaining wall supporting a cohesionless backfill is shown in the figure. The lateral active earth pressure at the bottom of the wall is 40 kPa. **[GATE, 2016]**



The minimum weight of the wall (expressed in kN per m length) required to prevent it from overturning about its toe (Point P) is

(A) 120 (B) 180
(C) 240 (D) 360

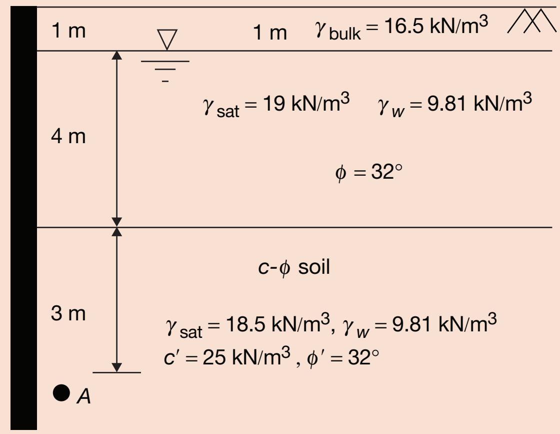
9. The results of a consolidation test on an undisturbed soil, sampled at a depth of 10 m below the ground level are as follows. **[GATE, 2016]**

Saturated unit weight :	16 kN/m^3
Pre-consolidation pressure :	90 kPa

The water table was encountered at the ground level. Assuming the unit weight of water as 10 kN/m^3, the over-consolidation ratio of the soil is

(A) 0.67 (B) 1.50
(C) 1.77 (D) 2.00

10. The soil profile at a site consists of a 5 m thick sand layer underlain by a *c*-ϕ soil as shown in the figure. The water table is found 1 m below the ground level. The entire soil mass is retained by a concrete retaining wall and is in the active state. The back of the wall is smooth and vertical. The total active earth pressure (expressed in kN/m^2) at point A as per Rankine's theory is __________. **[GATE, 2016]**



Answer Keys

Exercises

1. D **2.** B **3.** B **4.** A **5.** A **6.** A **7.** A **8.** D **9.** B **10.** C
11. C **12.** C **13.** A **14.** C **15.** A **16.** 347 kN/m^2 **17.** 22 kN/m^2
18. 113.46 kN/m^2 **19.** 1.80 m from bottom **20.** 161.67 kN/m, 1.83 m **21.** D **22.** B
23. B **24.** C **25.** C **26.** C **27.** 40 **28.** B **29.** C **30.** A **31.** D **32.** B
33. C **34.** B

Previous Years' Questions

1. D **2.** B **3.** B **4.** A **5.** D **6.** 150 **7.** D **8.** A **9.** B
10. 69.65