GATE – CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

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9.2 Earth Pressure Theories

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9.2 EARTH PRESSURE THEORIES

- Soil exerts a lateral pressure on any structure with which it is in contact.
- Lateral earth pressure is the force exerted by the soil mass upon the earth retaining structure.
- The magnitude of lateral earth pressure depend on the
  - Displacement of retaining structures
  - Nature of soil
  - Boundary conditions
- Backfill is the material retained by the structure
- 'Surcharge' is the backfill lies above the horizontal plane at the elevation of the top of the structure.
- Surcharge angle: Inclination of the surcharge to the horizontal

Real view of Earth Retaining wall structures

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Types of lateral earth Pressure

depends on the movement of the retaining wall with respect to soil retained.

a. Earth pressure at rest

- Earth pressure at rest is the pressure exerted due to backfill at zero movement of the retaining wall
- Soil mass is not subjected to any lateral yielding or movement.
- At rest condition, the soil is in a state of elastic equilibrium.

$$\sigma_0 = K_0.\gamma.H$$

K_0: Coefficient of earth pressure at rest.

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

μ : Poisson's ratio of soil

Jackey's formula

Applicable to cohesionless soil.

$K_0 = (1-\sin\phi)$, ϕ : Angle of internal friction of soil

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b. Active earth pressure

- The retaining wall tends to more away from the backfill.
- Active earth pressure is the pressure exerted due to backfill at the instant of the retaining wall moves away from the backfill.
- Stretching of the soil mass takes place.
- It is the state of plastic equilibrium as the entire soils mass is on the verge of failure.

c. Passive earth pressure

- The retaining wall tends to move towards the backfill due to any natural cause.
- Passive earth pressure is the pressure exerted due to backfill at the instant of the retaining wall moves towards the backfill.
- The soil tends to compress horizontally
- It is the state of plastic equilibrium.
- The surface over which the sheared off wedge tends to slide is referred to as ‘sliding’ or ‘rupture’.

- Bridge abutment, Basement wall is designed for pressure at rest condition only because wall cannot move away from soil due to deck slab.
- Retaining walls are designed for active earth pressure only
- Passive earth pressure will be taken into account when the sheet pile is driven.

Conditions in the Active earth pressure case

Conditions in the Passive earth pressure case

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Types of lateral earth Pressures

Rankine's theory:

Assumptions

- The soil is homogeneous and semi-infinite
- The soil is dry and cohesionless (c = 0)
- The face of the wall in contact with the backfill is vertical and smooth- friction between the wall and backfill is neglected.
- The soil element is in the state of plastic equilibrium ie at the wedge of failure.
- The ground surface is plane, which may be horizontal or inclined.

Earth pressure at rest (p_0)

$$p_0 = K_0.\gamma.H$$

K_0: Coefficient of earth pressure at rest

$$K_0 = \frac{\mu}{1-\mu}, \quad \mu : \text{Poisson's ratio of soil}$$

$$K_0 = (1-\sin\phi), \quad \phi : \text{Angle of internal friction of soil}$$

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Active Earth pressure (p_a): $\boxed{p_a = K_a.\gamma.H}$

K_a : Coefficient of active earth pressure $= \dfrac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45^0 - \dfrac{\phi}{2}\right)$

Passive Earth pressure (p_p): $\boxed{p_p = K_p.\gamma.H}$

K_p : Coefficient of passive earth pressure $= \dfrac{1+\sin\phi}{1-\sin\phi} = \tan^2\left(45^0 + \dfrac{\phi}{2}\right)$

$K_p = \dfrac{1}{K_a}$, For $\phi = 30^0$; $K_a = \dfrac{1}{3}$; $K_p = 3$; $\dfrac{K_p}{K_a} = 9 \Rightarrow K_p = 9.K_a$

Retaining wall with cohesionless soil backfill and Active pressure distribution

Retaining wall with cohesionless soil backfill and Passive pressure distribution

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a) Submerged backfill
Effect of submergence on lateral earth pressure

b) Wall with submerged backfill
Water on the other side

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a) Partly submerged backfill

b) Lateral pressure for partly submerged backfill

c) Partly submerged backfill with different friction angles above and below WT

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(a) Wall with uniform surcharge

(b) Lateral pressure diagram

(c) Alternative manner of showing lateral pressure

Effect of uniform surcharge on lateral pressure

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Inclined surcharge $\sigma = K_a.\gamma.H$

$$K_a = \cos\beta.\frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} \; ; K_p = \cos\beta.\frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}$$

P_{av} : Lateral pressure on the imaginary vertical face through the heel of the wall.

W :Weight of the soil wedge acting at its center of gravity

P_a :Total (Resultant) thrust on the back of the wall.

Active Earth pressure of cohesive soils

- Cohesive soil is a partially self supporting soil and exerts a smaller pressure on a retaining wall than a cohesionless soil with the same angle of friction.
- Rankine's theory is for cohesionless soils only
- In cohesive soils, the failure envelope has a cohesion intercept whereas that for cohesionless soils is zero.

Plastic equilibrium equation

$$\sigma_1 = \sigma_3.N_\phi + 2c.\sqrt{N_\phi}$$

$$\sigma_1 = \gamma.z \qquad \sigma_3 = \sigma_h \qquad N_\phi : \tan^2\left(45 + \frac{\phi}{2}\right) = \text{Flow value}$$

$$\sigma_3 = \frac{\sigma_1}{N_\phi} - \frac{2c}{\sqrt{N_\phi}}$$

$$\sigma_h = \frac{\gamma.z}{N_\phi} - \frac{2c}{\sqrt{N_\phi}}$$

$$K_a = \frac{1}{N_\phi} \text{ : Coefficient of active earth pressure}$$

At the surface $z = 0, H = 0;$ $\quad \sigma_h = -\frac{2c}{\sqrt{N_\phi}}$

Active pressure distribution for a cohesive soil

- The negative values of active pressure upto a depth equal to half of the critical depth indicate suction effect or tensile stresses.
- Cracks occur over the entire depth of the tension zone, making the backfill soil loose contact with the wall in that zone.

z_c may be obtained by $\sigma_3 = 0$

$$\sigma_3 = \frac{\gamma z_c}{N_\phi} - \frac{2c}{\sqrt{N_\phi}} = 0 \quad ; \quad z_c = \frac{2c}{\gamma}.\sqrt{N_\phi}$$

Critical depth , $h_c = 2.z_c$

Unsupported depth of soil, $h_c = \frac{4c}{\gamma}.\sqrt{N_\phi}$

If $\phi = 0$; $h_c = \frac{4c}{\gamma}$

Passive earth pressure of cohesive soil

$$\sigma_1 = \sigma_3 N_\phi + 2c\sqrt{N_\phi}$$

$$\sigma_1 = \sigma_h \quad , \quad \sigma_3 = \gamma.z$$

$$\sigma_h = \gamma z.N_\phi + 2c.\sqrt{N_\phi}$$

$K_p = N_\phi$: Coefficient of passive earth pressure

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Coulomb's Wedge Theory:

Assumptions:

1. The backfill is dry, cohesionless, homogeneous, isotropic and ideally plastic material. The rupture surface is a plane which passes through the heel of the wall
2. The sliding wedge acts as a rigid body. The magnitude of earth pressure is obtained by considering the equilibrium.
3. The wall surface is rough. The resultant earth pressure on the wall is inclined at an angle 'δ' to the normal to the wall, where is angle of friction between the wall and backfill.
4. The friction is distributed uniformly on the rupture surface.The back face of the wall is a plane
   - The coulomb's theory is applicable to inclined wall faces, irregular backfill, sloping wall , surcharge loads etc.,
   - Coulomb's theory considers the soil behind the wall as a whole instead of as an element in the soil.

- The triangular mass of soil between the plane of failure and the back of the wall is 'sliding wedge'.
- It is also called wedge theory.
- The coulomb's theory is applicable to inclined wall faces, to a wall with broken face, to a sloping backfill, curved backfill surface, broken backfill surface and to concentrated or distributed surcharge loads.
- The main deficiency in coulomb's theory is that it does not satisfy the static equilibrium condition occurring in nature.
- The method in also extended for cohesive soils
- Coulomb's theory is more general than the Rankine's theory
- This method can be used for active and passive cases.

Forces acting on the sliding wedge are

1. Weight of the sliding wedge, W
2. Soil reaction on the rupture surface, R
3. Earth pressure ie., Reaction from the wall, P_a

Stability of Retaining wall

1. The base width of the wall must be such that the maximum pressure exerted on the foundation soil does not exceed the safe bearing capacity of the soil.

$$\sigma_{max} = \frac{\Sigma W}{b}\left(1+\frac{6e}{b}\right)$$

$e < \frac{b}{6}$, the base of the retaining wall is totally compressive.

$e = \frac{b}{6}$, the pressure at toe is compressive and at heel is equal to zero.

$e > \frac{b}{6}$, the pressure at toe is compressive and at heel is tensile.

2. Tension should not be developed anywhere in the wall.

$$\sigma_{min} = \frac{\Sigma W}{b}\left(1-\frac{6e}{b}\right) \quad , \quad e > \frac{b}{6}$$

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3. The wall must be safe against sliding

$$F.S = \frac{\mu.\Sigma W}{P}$$

ΣW : Algebraic sum of the vertical forces

P : Algebraic sum of the horizontal forces

$F.S > 2.0$, if the passive resistance is considered.

$F.S \geq 1.5$, if the passive resistance is ignored.

4. The wall must be safe against overturning

$$F.S = \frac{\Sigma M_R}{\Sigma M_O}$$

ΣM_R :Algebraic sum of the resisting moments about the toe

ΣM_O :Algebraic sum of the overturning moments about the toe

$F.S > 1.5$ for granular soils

$F.S > 2.0$ for cohesive soils

EARTH PRESSURE THEORIES

Numerical Questions

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1. A retaining wall is to be provided to retain the soil of 4 m depth with angle of internal friction ϕ=30^0 and unit weight of soil γ=18 kN/m^3.

i. The magnitude of the total thrust on the wall when the top of the wall is free to yield is ……..

Ans: 48 kN, 72 kN, 432 kN

i. Intensity of pressure at bottom,

Horizontal Thrust, $P_a = K_a \gamma h$

$$P_a = \frac{1}{2}.K_a.\gamma.H.H$$

$$= \frac{1}{2}.\frac{1}{3} \times 18 \times 4 \times 4$$

$$P_a = 48 \text{kN/m}^2$$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30^0}{1+\sin 30^0} = \frac{1}{3}$$

ii. When the wall is restrained against yielding, the horizontal thrust on the wall is …….

$$K_0 = \text{Coeffiecient of earth pressure}$$

$$=1\text{-}\sin\phi=1\text{-}\sin30^0 = 0.5$$

$$P_a = \frac{0.5\times18\times4^2}{2}$$

$$P_a = 72\text{kN/m}^2$$

iii. The total passive resistance of the wall is …….

$$P_P = \text{Total pasive resistance}$$

$$= \frac{K_P.\gamma.H^2}{2}$$

$$= \frac{3\times18\times4^2}{2} \Rightarrow P_P = 432\text{kN/m}^2$$

2. A retaining wall retains cohesionless soil of 6 m height. The angle of internal friction is 30^0 and the unit weight of soil is 16 kN/m^3. A surcharge load of 36 kN/m^2 is acting over the soil immediately behind the wall.

Ans: 168 kN, 2.43 m, 44 kN, 201 kN.

i. The horizontal thrust exerted on the wall is …..

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30^0}{1+\sin 30^0} = \frac{1}{3}$$

$$P_a = K_a qH + \frac{K_a.\gamma.H^2}{2}$$

$$= \frac{1}{3}\times 36\times 6 + \frac{\frac{1}{3}\times 16\times 6^2}{2} = 72+96$$

$$P_a = 168\text{kN/m}^2$$

ii. The position of resultant thrust on the wall from bottom is …….

y: Distance of resultant thrust from bottom

$$= \frac{P_1 y_1 + P_2 y_2}{P_1 + P_2} = \frac{72 \times 3 + 96 \times \frac{6}{3}}{72 + 96}$$

$$\bar{y} = 2.43m$$

iii. The intensity of the horizontal stress at the base of wall is ……

$$P_a = K_a q + K_a . \gamma . H$$

$$= \frac{1}{3} \times 36 + \frac{1}{3} \times 16 \times 6 = 12 + 32 \Rightarrow P_a = 44 \text{kN/m}^2$$

iv. If the ground water level increases up to 3 m from the ground surface (Saturated unit weight of soil is 18 kN/m^3), the total horizontal thrust on the wall is …….

$$P_a = P_1 + P_2 + P_3 + P_4 + P_5$$

$$= K_a qH + \frac{K_a.\gamma.H^2}{2} + K_a \gamma_1 h_1 + ...$$

$$= 12 \times 6 + \frac{1}{2} \times 3 \times 16 + 3 \times 16 + \frac{1}{2} \times 8 \times 3 + \frac{1}{2} \times 30 \times 3$$

$$P_a = 201 \text{kN/m}^2$$

3. At a particular site, a retaining wall is to be provided to maintain a difference of level of 4 m. The backfill is dry cohesionless soil with angle of internal friction $\phi = 35^0$ and unit weight of soil $\gamma = 16$ kN/m^3.

Ans: 34.68 kN to 472.32 kN and 67 kN (increase).

i. The range of earth resistance on the wall is ……

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 35^0}{1+\sin 35^0} = 0.271$$

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} = \frac{1+\sin 35^0}{1-\sin 35^0} = 3.69$$

Range of earth resistance of soft wall: P_a to P_P

P_a : Active earth resistance on wall

$$= \frac{K_a.\gamma.H^2}{2} = \frac{0.271\times 16\times 4^2}{2} = 34.68\text{kN}$$

$$P_P = \frac{K_p.\gamma.H^2}{2} = \frac{3.64 \times 16 \times 4^2}{2} = 472.32\text{kN}$$

Range of earth resistance of wall: 34.68 to 472.32 kN

$$\frac{P_P}{P_a} = \frac{\frac{K_p.\gamma.H^2}{2}}{\frac{K_a.\gamma.H^2}{2}} = \frac{K_p}{K_a} = \frac{3.69}{0.371} = 13.61$$

ii. If the ground water table rises up to the ground surface (Saturated unit weight of soil is 20 kN/m^3), the change in active earth pressure is ……..

$$\gamma' = \gamma_{sat} - \gamma_w = 20 - 10 = 10\text{kN/m}^2$$

$$K_a.\gamma'.H = 0.271 \times 10 \times 4 = 10.84\text{kN/m}^2$$

$$\gamma_w h = 10 \times 4 = 40\text{kN/m}^2$$

$$P_a = \frac{1}{2} \times 10.84 \times 4 + \frac{1}{2} \times 40 \times 4$$

$$= 101.68\text{kN}$$

Change in active earth pressure $= 101.68 - 34.68 = 67\text{kN}$

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4. The properties of soil behind the retaining wall are as shown in figure.

i. The intensity of active earth pressure at the bottom of wall is ….

$$\phi_1 < \phi_2 \Rightarrow k_{a1} > k_{a2}$$

Intensity of stress at the base of the wall

$$P_a = K_{a1}.\gamma_1.h_1 + K_{a2}.\gamma_2.h_2$$

$$= 0.271 \times 16 \times 4 + 0.271 \times 18 \times 2$$

$$= 17.34 + 9.6$$

$$P_a = 27.1 \text{kN/m}^2$$

ii. Total horizontal active earth thrust on the wall is …….

$$P_a = P_1 + P_2 + P_3$$

$$P_a = \frac{1}{2} K_{a1}.\gamma_1.h_1 \times h_1 + K_{a2}.\gamma_1.h_1 \times h_2 + \frac{1}{2} K_{a2}.\gamma_2.h_2 \times h_2$$

$$= \frac{1}{2} \times 24.34 \times 4 + 17.3 \times 2 + \frac{1}{2} \times 9.6 \times 2$$

$$P = 87.12\text{kN}$$

iii. The resultant of the active earth thrust on the wall from base is ……

$\overline{y}$: Distance of resultant active thrust from the base.

$$= \frac{P_1 y_1 + P_2 y_2 + P_3 y_3}{P_1 + P_2 + P_3}$$

$$\bar{y} = \frac{42.68 \times 3.333 + 34.68 \times 1 + 9.76 \times 0.667}{87.12}$$

$$\bar{y} = 2.1m$$

$$y_1 = 2 + \frac{4}{3} = 3.33m$$

$$y_2 = \frac{2}{2} = 1m$$

$$y_2 = \frac{2}{3} = 0.667m$$

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5. A retaining wall 6 m high with smooth vertical side retains a clay backfill with c'=18 kN/m^3, ϕ'=16^0 and γ = 18 kN/m^3.

i. The total active thrust on the wall is ……

Intensity of active earth pressure, $\sigma_h = \frac{\gamma.z}{N_\phi} - \frac{2C}{\sqrt{N_\phi}}$

$$\frac{1}{N_\phi} = K_a \qquad N_\phi = \tan^2\alpha$$

$$= \tan^2 53^0$$

$$\alpha = 45 + \frac{\phi}{2} = 45 + \frac{16}{2} = 53^0 \qquad N_\phi = 1.76$$

$$K_a = 0.567$$

$$At\ z=0, \quad \sigma_h = 0 - 2\times18\sqrt{0.567} = 27.1\text{kN/m}^2$$

$$At\ z=6, \quad \sigma_b = 0.567\times18\times6 - 2\times18\sqrt{0.567} = 34.12\text{kN/m}^2$$

ii. The depth of tension crack is …….

$$z_c = \text{depth of tension crack}$$

$$= \frac{2c}{\gamma} . \frac{1}{\sqrt{K_a}} \quad \text{(or)} \quad \frac{2c}{\gamma} . \tan\alpha$$

$$= \frac{2 \times 18}{18} \tan 53^0$$

$$z_c = 2.65m$$

- The soil upto the depth of tension crack will not cause horizontal thrust on wall due to the soil from the wall. Therefore the horizontal thrust on the wall is due to the soil below the tension crack.

$$P_a = \frac{1}{2} \times 34.12 \times 3.35$$

$$P_a = 57.15$$

iii. The unsupported depth of soil is …….

$$\text{Unsupported depth of soil} = 2 \times z_c$$

$$= 2 \times 2.65$$

$$h_C = 5.3m$$

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6. An excavation was made in saturated soft clay with sides vertical. The sides caved in when the depth of excavation reached 5 m. Unit weight of soil is 18 kN/m^3. The value of cohesion of the soil is ……

Ans: 22.5 kN/m^2

Unsupported depth of clay $h_C = \frac{4c}{\gamma}\tan\alpha$

$$h_C = \frac{4c}{\gamma}\times 1$$

$$5 = \frac{4c}{18}$$

$$c = 22.5\text{kN/m}^3$$

$\phi = 0$ for soft clay

$$\tan\alpha = \tan\left(45 + \frac{\phi}{2}\right) = 1$$

7. The soil properties of the backfill behind the retaining wall are as shown in the figure. The intensity of active earth pressure at the base of retaining wall is ……

Ans: 29.3 kN/m^2

Intensity of active earth pressure

$$BC = K_{a1}.\gamma_1.h_1$$

$$= \frac{1}{3} \times 16 \times 3 = 16\text{kN/m}^2$$

$$BD = K_{a2}.\gamma_1.h_1 + K_{a2}.\gamma.z - 2c\sqrt{K_a}$$

$$= 0.588 \times 16 \times 3 + \left[0 - 2 \times 20\sqrt{0.588}\right] = 28.22 - 30.67$$

$$BD = -2.45\text{kN/m}^2$$

$$EF = K_{a2}.\gamma_1.h_1 + K_{a2}.\gamma_2.h_2 - 2c\sqrt{K_a}$$

$$= 0.588 \times 16 \times 3 + \left[0.588 \times 18 \times 3 - 2 \times 20 \times \sqrt{0.588}\right] = 28.22 + (31.75 - 30.67)$$

$$EF = 29.3\text{kN/m}^2$$

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8. A retaining wall of height 8 m with smooth vertical back retains backfill. The properties of soil backfill are:

c =18 kN/m^2, ϕ =20^0 and γ =20 kN/m^3. The depth of tension crack is---------

$$\text{Depth of tension crack} = z_c = \frac{2c}{\gamma}\tan\alpha$$

$$\alpha = 45^0 + \phi/2$$

$$= \frac{2\times 18}{20}\tan 55^0$$

$$z_c = 2.57m$$

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9. An excavation for foundation is carried out in plastic clay with a unit weight of 20 kN/m^3, failure occurs at a depth of 6.2 m reach. The value of cohesion of soil is …… Ans: 31 kN/m^2

$$h_c = \frac{4c}{\gamma}.\tan\alpha$$

$$\phi = 0, \tan\alpha = 1$$

$$6.2 = \frac{40}{20}.1$$

$$c = 31\text{kN/m}^2$$

10. A retaining wall with smooth vertical back retains purely cohesive soil. Height of wall =8 m, γ =20 kN/m^3 and c =80 kN/m^2.

i. At what depth the intensity of stress is zero.

ii. The total active thrust at the base is …….

iii. The point of application of resultant thrust from the base is ……

$$z_c = \frac{2c}{\gamma}\tan\alpha$$

$$\tan\alpha = 1 \text{ if } \phi = 0$$

$$= \frac{2\times 80}{20}$$

$$z_c = 8m$$

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EARTH PRESSURE

Previous GATE Questions

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1. A vertical retaining wall of 5 m height has to support soil having unit weight of 18 kN/m^3, effective cohesion of 12 kN/m^2, and effective friction angle of 30°. As per Rankine's earth pressure theory and assuming that a tension crack has occurred, the lateral active thrust on the wall per mater length (in kN/m, round off to two decimal places), is….

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Ans .21.71

Depth of tension crack, $z_c = \frac{2C}{\gamma}\tan\alpha$

$$z_c = \frac{2\times 12}{18}\tan\left(45^o + \frac{30}{2}\right) = 2.31\,m$$

Intensity of pressure at the bottom,

$$P = K_a.\gamma H - 2C\sqrt{K_a}$$

$$P = \frac{1}{3}\times 18\times 5 - 2\times 12\times\sqrt{\frac{1}{3}} = 16.14 kN/m^2$$

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If the tension crack occurs, soil does not necessarily adhered to the top position of wall up to height z_c. Thus the negative pressure diagram is neglected and considered only positive pressure diagram.

Total active thrust on the wall per meter length, $P_a = \frac{1}{2} \times 16.14 \times 2.69$

$= 21.71$ kN/m

2. A 5 m high vertical wall has a saturated clay backfill. The saturated unit weight and cohesion of clay are 18 kN/m^3 and 20 kPa, respectively. The angle of internal friction of clay is zero. In order to prevent development of tension zone, the height of the wall is required to be increased. Dry sand is used as backfill above the clay for the increased portion of the wall. The unit weight and angle of internal friction of sand are 16 kN/m^3 and 30°, respectively. Assume that the back of the wall is smooth and top of the backfill is horizontal. The prevent the development of tension zone, the minimum height (in m, round off to one decimal place) by which the wall has to be raised, is ….GATE CE 2020

Ans. 2.5m

To prevent the development of the tension zone, the pressure in the clay at the junction of clay and sand will be zero.

$$2C\cot\alpha = K_a.r.h$$

$$2\times 20\times 1 = 1\times 16\times h \Rightarrow h = 2.5m$$

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03. A retaining wall of height H with smooth vertical back face supports a backfill inclined at an angle β with the horizontal. The backfill consists of cohesionless soil having angle of internal friction ϕ If the active lateral thrust acting on the wall is P_a, which one of the following statements is TRUE? CE1 2019

a. P_a acts at a height H/2 from the base of the wall and at an angle β with the horizontal

b. P_a acts at a height H/2 from the base of the wall and at an angle ϕ with the horizontal.

c. P_a acts at a height H/3 from the base of the wall and at an angle β with the horizontal

d. P_a acts at a height H/3 from the base of the wall and at an angle ϕ with the horizontal.

Ans. c

The active earth pressure P_a acts at a height of H/3 from the base of the wall at an angle of β with the horizontal.

04. A 3 m high vertical earth retaining wall retains a dry granular backfill with angle of internal friction of 30^0 and unit weight of 20 kN/m^3. If the wall is prevented from yielding (no movement), the total horizontal thrust (in kN per unit length) on the wall is CE2 2018

a. 0 b. 30 **c.** 45 d. 270

Ans. c

Height of earthfill, H = 3m

Angle of internal friction of backfill, $\phi = 30^0$

Unit weight of backfill, γ=20 kN/m^3

The wall is prevented from yielding (no movement) ie., wall is at rest.

K_0:coefficient of earth pressure at rest $= 1 - \sin\phi = 1 - \sin 30^0$

=0.5

Intensity of earth pressure at the base $=K_0\ \gamma H$=30 kN/m^2

Total horizontal thrust, $P_0 = \frac{1}{2} \times 30 \times 3$ = 45 kN/m Length

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05. A rigid smooth retaining wall of height 7m with vertical backface retains saturated clay as backfill. The saturated unit weight and undrained cohesion of the backfill are 17.2kN/m^3 and 20kPa, respectively. The difference in the active lateral forces on the wall (in per meter length of wall, up to two decimal places), before and after the occurrence of tension cracks is… CE1 2018

Ans. 46.52

Height of retaining wall, H= 7 m

Saturated unit weight of soil, γ_{sat} = 17.2 kN/m^3

Undrained cohesion, C_u= 20 kPa

For clay $\phi = 0$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 0}{1+\sin 0} = 1$$

Before occurrence of tension crack:

Intensity of pressure at top $= -2c\sqrt{N_\phi} = 2\times 20\times\sqrt{1}$ = - 40 kPa

Intensity of pressure of bottom $= \frac{\gamma H}{N_\phi} - 2C\sqrt{N_\phi} = \frac{17.2 \times 7}{1} - 2 \times 20\sqrt{1}$ = 80.4 kPa

Depth of tension crack, $z_c = \frac{2C}{\gamma}\sqrt{N_\phi} = \frac{2 \times 20}{17.2}\sqrt{1}$ =2.326 m

Active earth pressure before occurrence of tension crack,

$$P_{a1} = \frac{40 + 80.4}{2} \times 2.348 \quad = 141.35 \text{ kN/m}$$

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Active earth pressure after occurrence of tension crack,

$$P_{a2} = \frac{1}{2} \times 80.4 \times 4.674 = 187.90 \text{ kN/m}$$

Difference, $P_{a2} - P_{a1} = 187.90 - 141.35 = 46.52$ kN

OR

Difference of active earth pressure on the wall before and after occurrence of tension crack.

$$= \frac{1}{2} \times 40 \times 2.326 = 460.52 \text{ kN/m}$$

06. Consider a rigid retaining wall with partially submerged cohesionless backfill with a surcharge. Which one of the following diagrams closely represents the Rankine's active earth pressure distribution against this wall? CE2 2017

a.

b.

c

Ans. c

07. The soil profile at a site consists of a 5 m thick sand layer underlain by a $c-\phi$ soil as shown in 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 …… CE2 2016

Ans. 69.67

$$K_{a1} = \frac{1-\sin 32^0}{1+\sin 32^0} = 0.307 \qquad K_{a2} = \frac{1-\sin 24^0}{1+\sin 24^0} = 0.422$$

P_a: total active earth pressure at A

$$= \sigma.K_a - 2C\sqrt{K_a} + \gamma_{w.}h = \sigma.\cot^2\alpha - 2c\cot\alpha + r_w.h$$

$\sigma =$ Intensity of stress at A

$$= \gamma h_1 + \gamma'.h_2 + \gamma'.h_3 = 16.5\times 1 + (19-9.81)4 + (18.5-9.81)3 = 79.33\text{kPa}$$

$$P_a = 79.33\times 0.422 - 2\times 25\times\sqrt{0.422} + 9.81\times 7 = 69.67 \text{ kPa}$$

08. 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.

The minimum weight of the wall (expressed in kN per m length) required to prevent it from overturning about its toe (Point P) is CE1 2016

a. 120 b. 180 c. 240 d. 360

Total active earth force, $p_a = \frac{1}{2} \times 40 \times 6 \quad = 120 \text{ kN}$

To prevent the gravity retaining wall from overturning about toe (point P),

$$\sum M_p = 0 \Rightarrow W \times 2 - 120 \times 2 = 0 \Rightarrow W = 120 \text{kN}$$

07. 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

CE1 2016

a. $\frac{4c}{\gamma\sqrt{K_p}}$ b. $\frac{2c\sqrt{K_p}}{\gamma}$ c. $\frac{4c\sqrt{K_a}}{\gamma}$ d. $\frac{4c}{\gamma\sqrt{K_a}}$

Ans. d

10. 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, $\phi = 30^0$ while the bottom layer is 3m 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… CE2 2015

a. 150 b. 216 c. 156 d. 196

Ans. a

Active earth pressure coefficient for top layer, $k_{a_1} = \frac{1-\sin 30^0}{1+\sin 30^0} = \frac{1}{3}$

Active earth pressure coefficient for bottom layer, $k_{a_2} = \frac{1-\sin 0}{1+\sin 0} = 1$

For the top layer,

Earth pressure at B, $p_B = k_{a_1}\gamma_1 H_1 = \frac{1}{3}\times 18\times 3$ =18 kN/m^2

For the bottom layer,

Earth pressure at B, $p_B = k_{a_2}\gamma_1 H_1 - 2C\sqrt{k_{a_2}} = 1\times 18\times 3 - 2\times 20\sqrt{1}$ = 14 kN/m^2

Earth pressure at C, $p_c = k_{a_2}\gamma_1 H_1 + k_{a_2}\gamma_2 H_2 - 2c\sqrt{k_{a_2}} = 1\times18\times(3+3) - 2\times20\sqrt{1}$ = 68 kN/m^2

Total active earth pressure per unit length of wall,

$$p_a = \frac{1}{2}\times18\times3 + 14\times3 + \frac{1}{2}\times54\times3 = 150 \text{ kN/m}^2$$

11. Surcharge loading required to be placed on the horizontal backfill of a smooth retaining vertical wall so as to completely eliminate tensile crack is . CE2 2015

a. $2C$ b. $2Ck_a$ c. $2C\sqrt{k_a}$ **d.** $\frac{2C}{\sqrt{k_a}}$

Ans. d

12. Two different soil types (Soil 1 and Soil 2) 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 wall is 2013

a. 31.7 **b.** 35.2 c. 51.8 d. 57.0

Ans. b

Soil 1:

$\gamma_t = 15\,\text{kN/m}^2,\ c' = 0\ ,\phi' = 30^0$

$$k_{a1} = \frac{1-\sin 30^0}{1+\sin 30^0} = 0.333$$

Intensity of pressure at B, $p_B = k_{a_1}.\gamma.H$ =0.333x15x2=10kN/m^2

Soil 2:

$\gamma_t = 20\,\text{kN/m}^2,\ c' = 0,\ \phi' = 40^0$

$$k_{a2} = \frac{1-\sin 40^0}{1+\sin 40^0} = 0.2596$$

Intensity of pressure at B, $p_B = K_{a2}.\gamma.H$ =0.2596x15x2=7.79kN/m^2

Intensity of pressure at C due to soil 2, $p_C = k_{a2}.\gamma.H$= 0.2596x15x2=10.834kN/m^2

Resultant active earth pressure $= \frac{1}{2}\times 10\times 2 + 7.79\times 2\times 10.384\times 2$ = 35.964kN/m

13. 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 2012

a. parallel to the wall face and acting downwards

b. normal to the wall face

c. oblique to the wall face acting downwards

d. oblique to the wall face acting upwards.

Ans. b

Passive earth pressure exerts when the movement of wall is towards the backfill. The major principal stress is which is normal to the wall face.

14. 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 2010

a. $\frac{\sigma_h}{\sigma_v}$ b. $\frac{\sigma_h}{\sigma'_v}$ c. $\frac{\sigma_v}{\sigma_h}$ d. $\frac{\sigma_v}{\sigma'_h}$

Ans. a

σ_h : Total horizontal stress

σ_v : Total vertical stress

σ'_h : Effective horizontal stress

σ'_v : Effective vertical stress

The coefficient of earth pressure at rest is the ratio of intensity of earth pressure at rest to the vertical stress at a specified depth.

$K_0 = \frac{\sigma_h}{\sigma_v}$ For a saturated soil, $K_0 = \frac{\sigma'_h}{\sigma'_v}$

15. When a retaining wall moves away from the back-fill, the pressure exerted on the wall is termed as 2008

a. Passive earth pressure b. Swelling pressure

c. Pore pressure **d.** Active earth pressure

Ans. d

When a retaining wall moves away from the backfill, the pressure exerted on the wall is termed as active earth pressure. When a retaining wall moves towards the backfill, the pressure exerted on the wall is termed as passive earth pressure.

Swelling pressure is the pressure exerted by the soil on the overlying structure if free swelling of the soil is restrained by the placement of a structure over the soil. Pore water pressure is the pressure exerted due to the pore water. It is equal to the product of the depth at which pore water pressure is required and unit weight of water.

16. Figure given below shows a smooth vertical gravity retaining wall with cohesionless 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 2006

a. vertical stress at the base. b. vertical stress at a height *H/3* from the base

c. lateral earth pressure at the base.

d. lateral earth pressure at a height *H/3* from the base.

Ans. a

From the Mohr's diagram, the length OP represent vertical stress at the base.

17. 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 30^0. 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(=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 2005

Ans. a

Coefficient of active earth pressure, $k_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30^0}{1+\sin 30^0} = \frac{1}{3}$

Active earth pressure at the base, $p_1 = k_a.\gamma.H = \frac{1}{3}\times 18\times 3$ = 18kN/m^2

When the water table rises up to the surface, the thrust due to water will also be added to the active earth pressure.

Active earth pressure at the base, $p_2 = k_a \gamma' H + \gamma_\omega H$

$$= \frac{1}{3} \times (18-10) \times 3 + 10 \times 3 = 8+30 = 38 \text{kN/m}^2$$

The active earth pressure increases from 18 kN/m^2 to 38 kN/m^2

Change in active earth pressure = 38-18 = 20 kN/m^2

18. A retaining wall of height 8 m retains dry sand. In the initial state, the soil is loose sand has a void ratio of 0.5, γ_d = 17.8 KN/m^3 and ϕ = 30^0. Subsequently, the backfill is compacted to a state where void ratio is 0.4, γ_d =18.8 KN/m^3 and ϕ=35^0. The ratio of initial passive thrust to the final passive thrust, according to Rankine's earth pressure theory, is 2004

a. 0.38 b. 0.64 **c.** 0.77 d. 1.55

Ans. c

k_{P_1} : Coefficient of passive earth pressure for loose sand

$$= \frac{1+\sin\phi}{1-\sin\phi} = \frac{1+\sin 30^0}{1-\sin 30^0} \quad =3$$

P_{p_1} : Passive earth pressure for loose sand

$$P_{p_1} = \frac{1}{2}.k_{P_1}.\gamma H^2 = \frac{1}{2}\times 3\times 17.8\times 8^2 = 1708.8 \text{ kN/m}$$

k_{P_2} : Coefficient of passive earth pressure for compacted sand

$$k_{P_2} = \frac{1+\sin 35^0}{1-\sin 35^0} = 3.69$$

P_{p_2} : Passive earth pressure for compacted sand

$$P_{p_2} = \frac{1}{2}.k_{P_2}.\gamma H^2 = \frac{1}{2}\times 3.69\times 18.8\times 8^2 = 2219.9 \text{ kN/m}$$

$$\frac{P_{p_1}}{P_{p_2}} = \frac{1708.8}{2219.9} = 0.77$$

19. An unsupported excavation is made to the maximum possible depth in a clay soil having γ = 18 kN/m^3, C = 100 kN/m^2, ϕ=30^0. The active earth pressure, according to Rankine's theory, at the base level of the excavation is 2004

a. 115.47 kN/m^2 b. 54.36 kN/m^2 c. 27.18 kN/m^2 d. 13.0 kN/m^2

Ans. a

Density of soil, γ= 18 kN/m^3

Cohesion, C = 100 kN/m^2

Angle of internal friction, ϕ= 30^0

The excavation is unsupported which means the maximum possible depth upto which the clay soil can be excavated is $2z_c$.

The active earth pressure at the base level of the excavation, $p_a = 2c.\sqrt{K_a}$

$$=2\times100\times\sqrt{\frac{1-\sin 30^0}{1+\sin 30^0}} = 115.47\,\text{kN/m}^2$$

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20. Using $\phi_u = 0$ analysis and assuming planar failure as shown, the minimum factor of safety against shear failure of a vertical cut of height 4 m in a pure clay having C_u =120 KN/m^2 and γ_{sat} = 20 KN/m^3 is 2004

a. 1 **b.** 6 c. 10 d. 20

Ans. b

Factor of safety against shear failure = F_s

Height of vertical cut off, h = 4 m

Angle of shearing resistance, $\phi_u = 0$

Cohesion, C_u = 120 kN/m^2

Saturated unit weight of soil, γ_{sat} = 20 kN/m^3

Critical depth of vertical cut, $h_c = 2.z_0 = \dfrac{4.c}{\gamma\sqrt{k_a}}$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 0}{1+\sin 0} = 1$$

$$h_c = \frac{4\times 120}{20\sqrt{1}} = 24\text{m}$$

Actual height of vertical cut = 4m

Factor of safety, $F_s = \dfrac{\text{Critical depth of vertical cut}}{\text{Actual height of vertical cut}} = \dfrac{24}{4} = 6$

21. A braced cut, 5 m wide and 7.5 m deep is proposed in a cohesionless soil deposit having effective cohesion $c' = 0$ and effective friction angle, $\phi' = 36^0$. The first row of struts is to be installed at a depth of 0.5 m below ground surface and spacing between the struts should be 1.5 m. If the horizontal spacing of struts is 3m and unit weight of the deposit is 20 kN/m^3, the maximum strut load will be 2003

a. 70.87 kN b. 98.72 kN **c.** 113.90 kN d. 151.86 kN

Ans. c

Width of braced cut = 5 m

Depth of braced cut = 7.5 m

Effective cohesion, $c' = 0$

Effective friction angle, $\phi' = 36^0$

Spacing between struts = 1.5 m

Unit weight of soil, γ=20 kN/m^3

K_a = Coefficient of active earth pressure

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$$= \frac{1-\sin\phi'}{1+\sin\phi'} = \frac{1-\sin 36^0}{1+\sin 36^0} = 0.2596$$

Uniform pressure on the side cut = $0.65 K_a.\gamma.H$

$$= 0.65 \times 0.2569 \times 20 \times 7.5 = 25.31 \text{kN/m}^2$$

Area covered by strut 1 $= 3 \times (0.5 + 0.75)$ = 3.75m^2

Area covered by strut 2 to 5 $= 3(0.75 + 0.75)$ = 4.5m^2

Maximum force will be carried by strut 2 and other downward struts=25.31x4.5

=113.90 kN

22. To have zero active pressure intensity at the tip of a wall in cohesive soil, one should apply a uniform surcharge intensity of 2000

a. $2c\tan\alpha$ b. $2c\cot\alpha$ c. $-2c\tan\alpha$ d. $-2c\cot\alpha$

Ans. a

The relationship between the principal stresses is given by $\sigma_1 = \sigma_3 . N_\phi + 2c.\sqrt{N_\phi}$

For active earth pressure on cohesive soil, $\sigma_1 = q = \gamma.z$ and $\sigma_3 = \sigma_h$

q: Uniform surcharge intensity

$$q = \sigma_h . N_\phi + 2c.\sqrt{N_\phi}$$

$$\sigma_h = \frac{q}{N_\phi} - \frac{2c}{\sqrt{N_\phi}}$$

$\sigma_h = 0$ at the tip of the wall

$$0 = \frac{q}{N_\phi} - \frac{2c}{\sqrt{N_\phi}} \Rightarrow q = 2c.N_\phi$$

$$q = 2c.\tan\alpha$$

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23. Cohesion in soil 1999

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

Ans. a

The relationship between the principal stresses is given by $\sigma_1 = \sigma_3 . N_\phi + 2c.\sqrt{N_\phi}$

For active earth pressure on cohesive soil, $\sigma_1 = q = \gamma.z$ and $\sigma_3 = \sigma_h$

$$\sigma_h = \frac{q}{N_\phi} - \frac{2c}{\sqrt{N_\phi}} = k_a.q - 2c.\sqrt{k_a}$$

Therefore, cohesion decreases the active earth pressure.

For passive earth pressure on cohesive soil,

$\sigma_1 = \sigma_h$ and $\sigma_3 = q$

$$\sigma_h = q.N_\phi + 2c\sqrt{N_\phi} = k_p.q + 2c\sqrt{k_p}$$

Therefore, cohesion increases the passive earth pressure.

24. The total active thrust on a vertical wall 3 m high retaining a horizontal sand backfill (unit weight = 20 KN/m^3, angle of shearing resistance $\phi' = 30^0$), when the water table is at the bottom of the wall, will be : 1998

a. 30 kN/m b. 35 kN/m c. 40 kN/m d. 45 kN/m

Ans. a

Height of retaining wall, H = 3m

Unit weight of back fill, γ = 20 kN/m^3

Angle of shearing resistance, $\phi = 30^0$

Coefficient of active earth pressure, $k_a = \dfrac{1-\sin\phi}{1+\sin\phi}$

$$= \frac{1-\sin 30^0}{1+\sin 30^0} = \frac{1}{3}$$

Total active thrust on vertical wall, $P = \dfrac{k_a.\gamma.H^3}{6} = \dfrac{1}{3}\times\dfrac{1}{6}\times 20\times 3^3$ =10kN/m

25. In cohesive soils the depth of tension crack (Z_{cr}) is likely to be 1998

a. $Z_{cr} \geq \frac{2c}{\gamma}\sqrt{\tan\left(45^0 - \frac{\phi}{2}\right)}$ b. $Z_{cr} \geq \frac{2c}{\gamma}\sqrt{\tan\left(45^0 + \frac{\phi}{2}\right)}$

c. $Z_{cr} \geq \frac{4c}{\gamma}\sqrt{\tan\left(45^0 - \frac{\phi}{2}\right)}$ d. $Z_{cr}\ \frac{4c}{\gamma}\sqrt{\tan\left(45^0 + \frac{\phi}{2}\right)}$

Ans. b

The relationship between the principal stresses is given by $\sigma_1 = \sigma_3 . N_\phi + 2c.\sqrt{N_\phi}$

For active earth pressure on cohesive soil, $\sigma_1 = q = \gamma h,\ \sigma_3 = \sigma_h$

$$\sigma_h = \frac{\gamma h}{N_\phi} - \frac{2c}{\sqrt{N_\phi}}\ ,\ N_\phi = \tan^2\alpha$$

$$= \gamma h \cot^2\alpha - 2c.\cot\alpha$$

z_{cr} : Depth of tension crack

When $\sigma_h = 0,\ h = z_{cr} = \dfrac{2c}{\gamma}.\tan\alpha$

$$z_{cr} = \frac{2c}{\gamma}.\tan\left(45^0 + \frac{\phi}{2}\right)$$

26. The depth of tension crack in a soft clay($\phi_u = 0$) is 1997

a. $\frac{4c_u}{\gamma}$ **b.** $\frac{2c_u}{\gamma}$ c. $\frac{c_u}{\gamma}$ d. $\frac{c_u}{2\gamma}$

Ans. b

Depth of tension crack, $z_c = \frac{2c_u}{\gamma.k_a}$

$\phi_u = o, k_a = 1 \quad z_c = \frac{2c_u}{\gamma}$

27. Coulomb's theory of earth pressure is based on 1997

a. the theory of elasticity b. the theory of plasticity

c. empirical rules **d.** wedge theory

Ans. d

Coulomb's theory of earth pressure is based on 'wedge theory'.

Rankine's theory of earth pressure is based on the 'theory of plasticity'.

28. The wall shown in figure has failed. The cause of failure or the error made in the design of the failed wall is 1996

a. deep slip surface failure
b. overturning
c. no proper drainage in the clay backfill
d. translational failure

Ans. b

The retaining wall may fail due to overturning and sliding.

29. For the determination of earth pressure, Coulomb's wedge theory assumes that

a. the back of wall is smooth and vertical 1996

b. the soil is non homogeneous and anisotropic

c. the slope surface is circular

d. the wall surface is rough

Ans. d

Assumptions in Coulomb's wedge theory for the determination of earth pressure.

i. The back fill is dry, cohesionless, homogeneous, isotropic and ideally plastic material.

ii. The rupture surface is a plane which posses through the heel of the wall.

iii. The sliding wedge acts as a rigid body.

iv. The wall surface is rough.

v. The friction is distributed uniformly on the rupture surface.

vi. The back face of the wall is a plane.

30. A vertical wall 6 m high above the water table, retains a 20^0 soil slope, the retained soil has a unit weight of 18 kN/m^3, the appropriate shear strength parameters are C = 0 and ϕ = 40^0. The coefficient of active earth pressure to be used in estimating the active pressure acting on the wall is……. 1994

Ans. 0.1726

Height of retaining wall, h=6m

Slope of soil, $\beta = 20^0$

Unit weight of soil, $\gamma = 18\ \text{kN/m}^3$

Cohesion, C =0

Angle of internal friction, ϕ= 40^0

K_a : Coefficient of active earth pressure

$$= \cos\beta . \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} = \cos 20^0 . \frac{\cos 20^0 - \sqrt{\cos^2 20^0 - \cos^2 40^0}}{\cos 20^0 + \sqrt{\cos^2 20^0 - \cos^2 40^0}}$$

$K_a = 0.1726$

31. The earth pressure for the design of bridge abutments is taken as 1993

a. active thrust b. passive thrust

c. thrust in at rest condition d. None of the above

Ans. c

Bridge abutment is designed for pressure at rest condition only because it can not move away from soil due to deck slab.