1. Define conjugate stresses?
The stress acting on the conjugate planes is called conjugate stresses
2. How do you check the stability of retaining walls?

- The wall should be stable against sliding
- The wall should be stable against overturning
- The base of the wall should be stable against bearing capacity failure.

3. Define angle of repose?
Maximum natural slope at which the soil particles may rest due to their internal friction, if left unsupported for sufficient length of time.

4. Define theory of plasticity?
The theory on which the condition of the stress in a state of a plastic equilibrium is called as theory of plasticity.

5. What are the assumptions in coulomb wedge theory?
- the backfill is dry, cohesionless, isotropic, homogenous,
- the slip surface is plane which passes through the head of the wall.

6. How to prevent land sliding?
Sheet piles, retaining wall may be used to prevent the land sliding

7. Write down any two assumptions of Rankine"s theory?
- Semi infinite soil
- Cohesion-less backfill
- Homogenous soil
- The top surface is a plane which may be inclined or horizontal.

8. Distinguish Coloumb"s wedge theory from Rankine"s theory?
Rankine considered a soil particle at plastic equilibrium but Coulomb considered the whole soil mass.

9. What is meant by critical depth of vertical cut for a clay soil?
Due to negative pressure, a tension crack usually developed in the soil near the top of the wall, upto to a depth Z_0. Also, the total pressure upon a depth $2Z_0$ is zero. This means that a cohesive soil should be able to stand with a vertical face upto a depth $2Z_0$ without any lateral support. The critical height H_c of an unsupported vertical cut in cohesive soil is thus given by,

$$H_c = 2Z_0 = 4\frac{C \tan\alpha}{\gamma}$$

10. Why retaining walls are usually designed for active earth pressure?
From Rankine"s assumption, no-existence of frictional forces at the wall face, the resultant pressure must be parallel to the surface of the backfill. The existence of friction makes the resultant pressure inclined to the normal to the wall at an angle between the soil and the wall.

11. What do you understand by plastic equilibrium in soil?
A body of soil is said to be in plastic equilibrium, if every point of it is on the verge of failure.

12. What is critical failure plane?
Critical failure plane defined as the plane along which the failure occurs in which the shear stress on the plane is less than the maximum shear stress.

13. What is surcharge angle?
The angle of surcharge of a material is the angle to the horizontal, which the surface of the materials assumes, while the material is at rest on a moving conveyor belt. The surcharge angle is generally 5‟ to 15‟ less than the angle of repose.

14. What is earth pressure at rest?
The earth pressure at rest is defined as the intensity of lateral earth pressure when the lateral strain is zero and it is expressed as $P_R = K_R \cdot \gamma$‟ . Z, where K_R – coefficient of earth pressure.

15. Write the types of retaining wall.
The earth retaining walls are of following types:
(a) Gravity wall
    (i) Mass concrete or masonry wall
    (ii) Wall on wells
    (iii) Precast block wall
    (iv) Two row sheet pile wall
    (v) Crib wall
(b) Reinforced concrete wall
    (i) Cantilever type „T‟ wall or „L‟ wall
    (ii) Counterforted or butteressed wall
(c) Sheet pile wall
    (i) Cantilever sheet pile wall
    (ii) Anchored sheet pile wall or Anchored bulkhead.

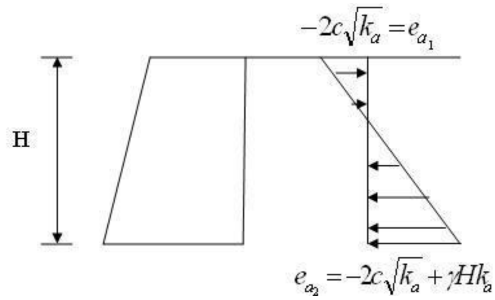
16. Write any three assumptions of Rankine‟s theory.
- The soil mass is semi-infinite, homogeneous, dry and cohesionless
- The ground surface is a plane which may be horizontally inclined
- The back of the wall is smooth and vertical.

17. List the assumptions common to Rankine and coulomb theory of earth pressures.

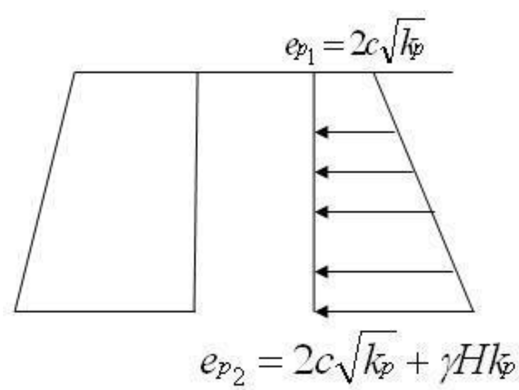
- Soil mass is semi-infinitive
- Ground surface is a plane
- The back of the wall is smooth and vertical.

18. Draw the lateral earth pressure diagram of clay depends for active and passive condition.

    The value of active earth pressure is

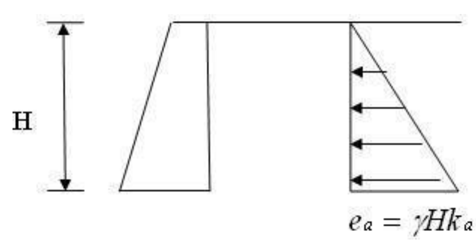


The value of passive earth pressure is

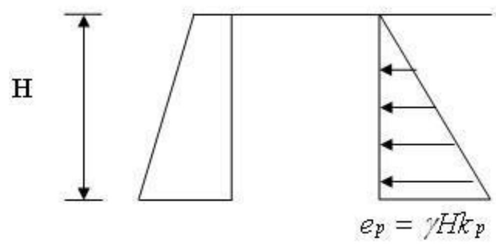


19. Draw the lateral earth pressure diagram of sand depends for active and passive condition.

The value of active earth pressure is



The value of passive earth pressure is



20. What are the assumptions in coulomb"s theory?
    - Uniform c – ϕ
    - Failure plane is straight
    - Failure wedge is a rigid body
    - Frictional force is developed along the wall boundary during the movement of wedge

21. Compare Rankine"s and Coulomb"s theory.

Rankine"s theory	Coulomb"s theory
The intensity of earth pressure at each depth is known. So point of application of the earth pressure is known at any depth	Only the total earth pressure value acting on the retaining structures can be calculated. The point of application of earth pressure can be calculated from Coulomb"s assumption that all points on the back of the retaining wall are essentially considered as feet of failure surface
Wall is smooth and vertical	Wall is rough and sloped
Wall moved sufficiently so soil is i9n plastic failure mass	Wall is rigid, straight failure plane and rigid failure wedge

22. Define plastic equilibrium
    A mass of soil is said to be in a state of plastic equilibrium if failure is incipient or imminent at all points within the mass.

23. What are the conditions to be satisfied while designing a retaining wall?
    Sliding resistance:

$$\text{Factor of safety} = \frac{Sum\ of\ resisting\ force}{Sum\ of\ driving\ force}$$

Factor of safety against sliding should be atleast 1.5 for sandy soil and 2.0 for clayey soil.

Overturning:

To avoid overturning the resultant thrust must fall within the middle third of the wall base.

$$\text{Factor of safety} = \frac{Sum\ of\ resisting\ force}{Sum\ of\ overturning\ \ force}$$

Factor of safety against overturning should be atleast 1.5 for sandy soil and 2.0 for clayey soil.

Bearing Capacity:

$$\text{Factor of safety} = \frac{Allowable\ \ bearing\ \ pressure}{Maximum\ \ contact\ \ pressure}$$

Factor of safety against bearing capacity should be atleast 2.5 for sandy soil and 3.0 for clayey soil.

24. Define coefficient of earth pressure.

$$\text{Co-efficient of earth pressure} = \frac{Horizontal\ \ stress}{Vertical\ stress}$$

$$K = \frac{\sigma k}{\sigma v}$$

25. Give the design criteria of gravity retaining wall

- 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
- No tension should be developed anywhere in the wall
- The wall must be safe against overturning and sliding.

16 MARKS

1. **A gravity retaining wall retains 10 m of a backfill, unit weight of soil =18 kN/m^{3,} angle of shearing resistance =30° with a horizontal surface. Assume the wall interface to be vertical, determine (i) the magnitude and point of application of the total active pressure (ii) if the water table is at a height of 5m, and how far do the magnitude and the point of the application of active pressure changed. Take submerged unit weight = 10kN/m^3.**

H= 10m, $\emptyset = 30°, \gamma = 18kN/m^2$, r_{sub} =10kN/m^2

$K_a = \frac{1-\sin \emptyset}{1+\sin \emptyset} = \frac{1-\sin 30°}{1+\sin 30°} = \frac{1}{3}$

Active pressure at base of wall $= \frac{1}{3}$ x 18 x 10 = 60 kN/m^2

∴ Total active thrust, $P_a = \frac{1}{2} K_a\, r\, H^2$

$P_a = \frac{1}{2} \times \frac{1}{3} \times 18 \times 10^2$ = 300 kN.

(ii) Water – table at 5m from surface:

$P_a = K_a\, r\, H_1 + K_a\, r'' H_2 + K_a\, r'' H$

$= [\frac{1}{3}$ x 18 x 5] + [1/2 x 10x 5] + (9.81 x 5)

= 104.05 kN/m^2 at base

P_1 = 1/2 x 1/3 x 18 x 5 x 5 = 75 kN

Y_1 =5/3 + 5 = 6.67m

P_2 =5 x 1/3 x18 x 5 = 150 kN

Y_2 = 5/2 = 2.5m

P_3 = ½ x 1/3 x 10 x 5 x 5 =41.67 kN

Y_3 = H / 3 =5/3 = 1.67m

P_4 = 1/3 X 9.81 X 5 X 5 =122.63 kN

Y_4 = H/3 = 1.67 m

Total thrust, $p_a = p_1 + p_2 + p_3 + p_4$

= 75 +150+41.67 +122.63

P_a = 389.3 kN per metre length of wall.

Taking moments about base

$P \times \bar{Y} = p_1 y_1 + p_2 y_2 + p_3 y_3 + p_4 y_4$

$389.3\bar{y} = (75 \times 6.67) + (150 \times 2.5) + (41.67 \times 1.67) + (122.63 \times 1.67)$

$\therefore \bar{y} = 2.95$ m

∴ Total thrust of 389.3 kN per metre length of wall will act at 2.95 m from base of wall.

2. **A retaining wall is 4 m high. Its back is vertical and it has got sandy backfill up to its top. The top of the fill is horizontal and carries a uniform surcharge of 85 kN/m^2. Determine the active pressure on the wall per metre length of wall. Water table is 1m below the top of the fill. Dry density of soil = 18.5 kN/m^3. Moisture content of soil above water table =12%. Angle of internal friction of soil = 30°, specific gravity of soil particles = 2.65. Porosity of backfill = 30°. The wall friction may be neglected.**

$e = \frac{n}{1-n} = 0.43$

$P = (1+w)\gamma_d = (1+0.12)\ 18.5 = 20.7$ kN/m^3

$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-0.5}{1+0.5} = 0.333$

(i) Due to soil above W.T

$P_1 = ½\ K_a\gamma H^2 + 3\ K_a\gamma H = 21.85$ kN/m

(ii) Due to submerged soil (k_{de})

$P_2 = ½ \times 0.333 \times 11.52 \times 9 = 17.3$ kN/m.

(iii) Due to water pressure (k_{ef})

$P_3 = ½ \times 10 \times 3^2 = 45$ kN/m.

∴ Total active pressure = P1 + P_2 + P_3 + P_4

$P_a = 21.58 + 17.3 + 45 + 113.2$

=197.08 kN/metre length of wall.

3. What are the different methods of soil stabilization? Explain with neat sketches?

Introduction:

Stabilization incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. Stabilization is used for a variety of engineering works, the most common application being in the construction of road & air-field pavements, where the main objective is to increase the strength or stability of soil & to reduce the construction cost by making best use of the locally available materials.

Mechanical stabilisation:

Mechanical stabilization involves two operations :(i) changing the composition of soil by addition or removal of certain constituents ,and

(ii) Densification or compaction .the particle size distribution and composition are the important factors governing the engineering behaviour of a Soil. Significant changes in the properties can be made by addition or removal of suitable soil fractions. For mechanical stabilizations where the primary purpose is to have a soil resistant to deformation and displacement under the loads, soil materials can be divided in two fractions: The granular fraction retained on a 75 microns

IS sieve and the fine soil fraction passing a 75 –microns sieve. The granular fraction imparts strength and hardness. The fine fraction provides cohesion or binding property, water – retention capacity and also acts as a filler for the voids of the coarse fraction.

Cement stabilization:

1. **Soil cements and its influencing factors**

The soil stabilized with cement (Portland) is known as soil cement.

The cementing action is believed to be the result of chemical reaction of cement with the siliceous soil during hydration. The binding action of individual particles through cement may be possible only in coarse-grained soils .in fine grained, cohesive soils, only some of the particles can be expected to have cement bonds, and the rest will be bonded through natural pollution. The important factors affecting soil cement are: nature of soil, cement content, condition of mixing, compaction and curing and admixtures.

2. **Construction methods**

The normal construction sequence for soil – cement bases is as follow: (i) shaping the sub-grade and scarifying the soil, (ii) Pulverising the soil, (iii) addition and mixing cements, (iv) adding and mixing water, (v) compacting, (vi) finishing, (vii) curing and (viii) adding wearing surfacing. There are three methods of carrying out these operations: (i) mix-in place method, (ii) travelling plant method and (iii) stationary plant method.

Lime stabilization:

Hydrated (or slaked) lime is very effective in treating heavy, plastic clayey soils . Lime may be used alone, or in combination with cement, bitumen or fly ash. Sandy soils can also be stabilized with these combinations. Lime has been mainly used for stabilizing the road bases and sub- grades on addition of lime to soil , two main types of chemical reactions occurs:

(i) Alteration in the nature of absorbed layer through Base Exchange phenomenon, and

(ii) Cementing or puzzolanic action. Lime reduces the plasticity index of highly plastic soils making them more friable and easy to be handled and pulverized. The plasticity index of soils of low plasticity generally increases. There is generally and increase in the optimum water content and a decrease in the maximum compacted density, but the strength and durability increase.

Bitumen stabilization:

Asphalts and tars are the bituminous materials which are used for stabilization of soil, generally for pavement construction. These materials are normally too viscous to be incorporated directly with soil .the fluidity of asphalts is increased by either heating, emulsifying or by cut-back process. Tars are heated or cut back. The bituminous materials when added to a soil impart cohesion or binding action and reduced water absorption. Thus either the binding action or the water proofing action or both the actions, may be utilized for stabilization. depending upon these actions and the nature of soils , bitumen stabilization is classified under the following four types :(i) sand-bitumen ,(ii)soil-bitumen ,(iii) water-proofed mechanical stabilization and (iv) oiled earth

Chemical stabilization:

There are a great many chemicals which are used for stabilization. Only the chemicals which are commonly used for stabilizing moisture in the soil and for cementation of particles will be described here,

1. Calcium chloride
2. Sodium chloride
3. Sodium silicate

Stabilization by heating:

Heating a fine grained soil to temperature of the order of 400-600®c causes irreversible changes in clay minerals. The soil becomes non – plastics, less water sensitive and non-expansive. Also the clay clods get converted into aggregates. Soil can be baked in kilns, or in –situ downwards draft slow moving furnaces. The artificial aggregates so produced can be used for mechanical stabilization.

Electrical stabilization:

The stability or shear strength of fine-grained soils can be increased by draining them with the passage of direct current through them. The process is also known as electro-osmosis. Electrical drainage is accompanied by electro- chemical composition of the electrodes and the deposition of the metal salts in the soils pores. There may also be some changed in the structure of soil. The resulting cementing of soil due to all these reactions, is also known as electro-chemical hardening and for these purpose the use of aluminium anodes is recommended.

4. Explain Rankine‟s theory for the cases of cohesion less backfill

ACTIVE EARTH PRESSURE: RANKINE'SS THEORY

As originally proposed Rankin‟s theory of lateral earth pressure is applied to uniform cohesionless soils only. Later, it was extended to include cohesive soils, by reseal (1910) and by bell (1915) .The theory has also been extended of the stratified, partially immersed and submerged soils. Following are the assumptions of the Rankin theory.

1. The soil mass is semi-infinite, homogenous, dry and cohesion less.
2. The ground surface is a plane which may be horizontal or inclined.
3. The back of the wall is vertical and smooth. In other words there are no shearing stresses between the wall and the soil and the stress relationship for any element adjacent to the wall is the same as for any other element far away from the wall.
4. The wall yields about the base and thus satisfies the deformation condition for plastic equilibrium.

   However the retaining walls are constructed of, masonry or concrete, and hence the back of the wall is never smooth. Due to this, frictional forces develop. As a consequence of Rankin‟s assumption of no-existence of frictional forces at the wall face, the resultant pressure must be parallel to the normal to the wall at an angle that approaches the friction angle between the soil and the wall.

The following cases of cohesion less backfill will now be constructed:

1. Dry or moist backfill with no surcharge.
2. Submerged backfill
3. Backfill with uniform surcharge.
4. Backfill with slopping surface.
5. Inclined back and surcharge.

1. DRY OR MOIST BACKFILL WITH NO SURCHARGE

Consider an element at a depth z below the ground surface, when the wall is at the point or moving outwards the active state of plastic equilibrium is established. The horizontal pressure σ_h is then the minimum principal stress σ3 and the vertical pressure σ_v is the major principal stress σ_1.

The total active earth pressure p_a or the resultant pressure per unit length of the wall is found by integrating or from the triangular pressure distribution.

2. SUBMERGED BACKFILL

In this case the sand fill behind the retaining wall is saturated with water. The lateral pressure is made up of two components.

1. Lateral pressure due to submerged weight ṛ of the soil
2. Lateral pressure due to water. Thus at any depth z below the surface.

The pressure at the base of the retaining wall (z=H)

If the free water stands to both sides of the wall thee water pressure need not be considered and the net lateral pressure.

$$P_a=K_a\text{ṛ}H$$

If the backfill is partly submerged, the backfill is moist to a depth H_1 below the ground level, and then it is submerged, the lateral pressure intensity at the base of the wall is given by

$$P_a=K_a\text{ṛ}H1+K_a\text{ṛ}H2+\text{ṛ}\ wH2$$

The above expression is on the assumption that the value of ℂ is the same for the moist as well as submerged soil .if it is different, say ℂ1 and ℂ2 respectively, the earth pressure coefficient, k_{a1} and k_{a2} for both the portions will be different.

3. BACKFILL WITH UNIFORM SURCHARGE

If the backfill is horizontal and carries a surcharge of uniform intensity q per unit area, the vertical pressure increment at any depth z will increase by q. The increase in the lateral pressure due to this will be k_a q. Hence the lateral pressure at any depth z.

$$P_a=k_a\ \text{ṛ}\ z+k_aq$$

This means that the effect of the surcharge of intensity q is the same as that of a fill of height z_e above the ground surface.

4. BACKFILL WITH SLOPING SURFACE:

Let the sloping surface behind the wall be inclined at an angle β with the horizontal; β is called the surcharge angle. In finding out the active earth pressure for this rankine"s theory an additional assumptions that the vertical and lateral stresses are conjugate is made. It can be shown that it is stress on a given plane at a given point is parallel to another plane; the stress on the latter plane at the same point must be parallel to the first plane. Such a plane is called the conjugate planes and the stresses acting on them are called conjugate stresses.

Consider a soil element at point A at a depth z within a backfill with a slopping surface, as shown. The top plane of the element is parallel to the ground plane, and the other plane conjugate to this is vertical .let σ and P is the conjugate stresses, σ being vertical pressure and p being parallel to the slopping backfill.

The Mohr‟s circle is the locus of a point that represents that resultant stress intensity at all planes passing through the point under consideration. Hence we can find the resultant stress intensities σ and P on two conjugate planes at a point A .the obliquity of σ and P is β. Hence through the origin O, draw the line at A_1andA_2 .

If the backfill is submerged, the lateral pressure due to the submerged weight of the soil will acct at β with horizontal, while the lateral pressure due to water will act normal to the wall

$$P_a=1/2K_a\gamma H^2$$

5. INCLINED BACK AND SURCHARGE:

It is a retaining wall with an inclined back supporting a backfill with horizontal ground surface. The total active pressure p1 is the first calculated on a vertical plane BC passing through the heel B. the total pressure P is the resultant of the horizontal pressure p1 and the weight w of the wedge ABC.

The active earth pressure is the first calculated on a vertical plane passing through the heel and intersecting the surface of the backfill or its extension in point C. the height H of vertical plane is represented by BC. The resultant of p is the vector sum of p1 and w1 where w is the weight of the soil contained in the triangle ABC .

(or)

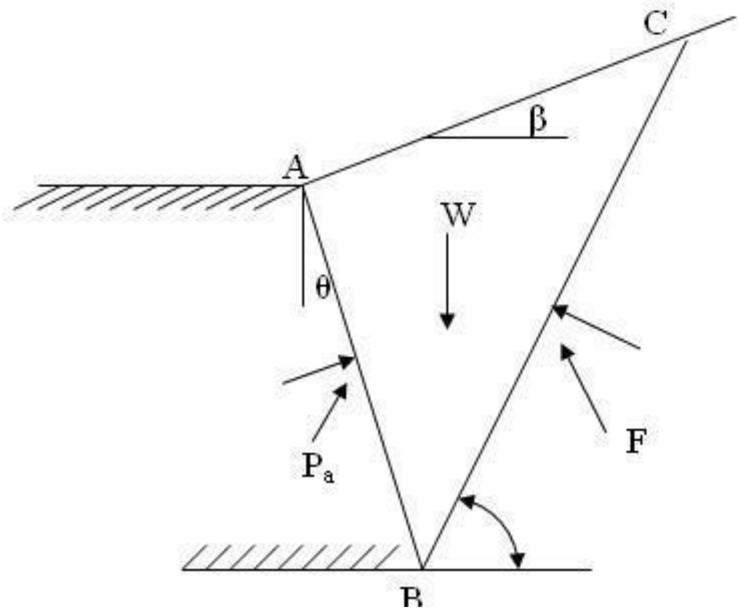
ACTIVE EARTH PRESSURE: RANKINE‟S THEORY

Rankine‟s theory of lateral earth pressure is applied to uniform cohesionless soils only. Later, it was extended to include cohesive soils, by Resal and by Bell. The theory has also been extended to stratified, partially immersed and submerged soils. Following are the assumptions of the Rankine‟s theory:

1. The soil mass semi-infinite, homogeneous, dry and cohesionless.
2. The ground surface is a plane which may be horizontal and inclined
3. The back of the wall is vertical and smooth. In other words, there are no shearing stresses between the wall and the soil and the stress relationship for any element adjacent to the wall is the same as for any other element fair away from the wall.
4. The wall yields about the base and thus satisfies deformation condition for plastic equilibrium.

The following cases of cohesionless back fill will now be considered :

1. Dry or moist backfill with no surcharge.
2. Submerged backfill.
3. Backfill with uniform surcharge.
4. Backfill with sloping surface.
5. Inclined back and surcharge.



DRY OR MOIST BACKFILL WITH NO SURCHARGES:

Consider an element at a depth z below the ground surface. When the wall is at the point of moving outwards, the active state of plastic equilibrium is established.

$$\sigma_1 = \sigma_3 \tan^2 (45 \quad \phi/2)$$

$$\sigma_3 / \sigma_1 = \sigma_h / \sigma_v = 1/ \tan^2 (45 + \phi/2)$$

$$= \cot^2 (45 \quad \phi/2)$$

Now,

σ_h= Lateral earth pressure = P_a

σ_v = Vertical pressure on the element = $\gamma.z$

$$P_a = \gamma.z \cot^2 (45 + \phi/2) = K_a \gamma.z$$

When

$\Phi = 30^\circ$; $K_a = 1- \sin30^\circ / 1+\sin30^\circ = 1/3$

The distribution of active earth pressure P over the retaining wall. At z = H, the earth pressure is

$$P_a = ½ K_a\gamma H^2$$

If the soil is dry, γ is the dry weight of the soil, if wet, γ is the moist weight.

SUBMERGED BACKFILL:

In this case, the sand fill behind the retaining wall is saturated with water. The lateral pressure is made up of two components:

1. Lateral pressure due to submerged weight γ'' of the soil.
2. Lateral pressure due to water. Thus, at any depth z below the surface

$$P_a = K_a\gamma''z + \gamma_w z$$

The pressure at the base of the retaining wall

$$P_a = K_a\gamma''z + \gamma_w z$$

If the free water stands to both sides of the wall, the water pressure need not be consider, and net lateral pressure is given by

$$P_a = K_a\gamma''z$$

If the backfill is partly submerged, ie, the backfill is moist to a depth H_1 below the ground level, and then it is submerged, the lateral pressure intensity at the base of the wall

$$P_a= K_a\gamma H_1 +K_a\gamma''H_2 + \gamma_w H_2$$

BACKFILL WITH UNIFORM SURCHARGE:

If the backfill is horizontal and carries a surcharge of uniform intensity q per unit area. The vertical pressure increment, at any depth z, will increase by q. the increase in the lateral pressure due to this will be $K_a q$.

$$P_a = K_a\gamma z+K_a q$$

At the base of the wall, the pressure intensity is

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

The two alternative method of plotting the lateral pressure diagram for this case. The lateral pressure increment due to the surcharges is the same at every point of the back of the wall and does not vary with depth z.

$$K_a\gamma z_e =K_a q$$

This means that the effect of the surcharge of intensity q is same as that of a fill of height $z_e$above the ground surface.

BACKFILL WITH SLOPING SURFACE:

Let the sloping surface behind the wall be inclined at the angle β with the horizontal; β is called the surcharge angle. In finding out the active earth pressure for this case by Rankine‟s theory, an additional assumption that the vertical and lateral stresses are conjugate is made. It can be shown that if the stress on the given plane at a given point is parallel to the another plane, the stress on the latter plane at the same point must be parallel to the first plane .such planes are called the conjugate planes the stresses acting on them are called conjugate stresses.

Consider a soil element at point A at depth z with in a backfill with a sloping surface. The top plane of the element is parallel to the ground plane and the other plane conjugate to this is vertical. Let σand p be the conjugate stresses, σ being vertical and p being the parallel to the sloping backfill. Being conjugate, both the vertical pressure and lateral pressure have the same angle of obliquity β, which is equal to the surcharge angle.

$$\sigma_1 - \sigma_3 / \sigma_1 + \sigma_3 = \sin\phi \quad \ldots\ldots (1)$$

Mhor circle corresponding to the principal stress intensity σ_1 and $\sigma_3$at A. OA_1 represents the resultant stress p and OA_2 represents the resultant stress σ. Draw OB perpendicular to $A_1 A_2$.

$$OB = OC \cos\beta \quad \ldots\ldots (2)$$

$$BC = OC \sin\beta = \sin\beta\,(\sigma1 + \sigma3)/2 \quad \ldots\ldots (3)$$

$$A_1B = BA_2 = \sqrt{(A_1C^2 - BC^2)} = \sqrt{((\sigma_1 - \sigma_3)/2)^2 - (\sigma_1 + \sigma_3)/2)^2 \sin^2\beta)}$$

From (1) ,

$$A_1B = BA_2 = (\sigma1 + \sigma3)/2\ \sqrt{(\sin^2\phi - \sin^2\beta)} \quad \ldots\ldots (4)$$

Now stress

$$\sigma = OB + BA_2$$

$$= (\sigma1 + \sigma3)/2 \cos\beta + (\sigma1 + \sigma3)/2\ \sqrt{(\sin^2\phi - \sin^2\beta)} \quad \ldots (5)$$

And stress $p = OB - A_1B$

$$= (\sigma1 + \sigma3)/2 \cos\beta - (\sigma1 + \sigma3)/2\ \sqrt{(\sin^2\phi - \sin^2\beta)} \quad \ldots (6)$$

Dividing (5)&(6) we get,

$p/\sigma=K=\cos\beta - \sqrt{(\sin^2\phi-\sin^2\beta)}/\cos\beta+ \sqrt{(\sin^2\phi-\sin^2\beta)}$

$$K= \cos\beta - \sqrt{(\cos^2\beta-\cos^2\phi)}/\cos\beta+ \sqrt{(\cos^2\beta-\cos^2\phi)}$$

The ratio K is called conjugate ratio.

For the present case, $\sigma=(\gamma.z.b\cos\beta/b)$

$$=\gamma.z.\cos\beta$$

$P_a=\gamma.z.\cos\beta\ (\cos\beta - \sqrt{(\cos^2\beta-\cos^2\phi)}/\cos\beta+ \sqrt{(\cos^2\beta-\cos^2\phi)})$

$P_a=K_a\gamma.z$

$K_a=\cos\beta\ (\cos\beta - \sqrt{(\cos^2\beta-\cos^2\phi)}/\cos\beta+ \sqrt{(\cos^2\beta-\cos^2\phi)})$

$K_a=(1-\sin\phi)/(1+\sin\phi)$

The total active pressure P_a for the wall of height H is given by

$P_a=1/2\ K_a\gamma.H^2$

If the backfill is submerged, the lateral pressure due to the submerged weight of the soil will act at β with horizontal, while the lateral pressure due to water will act normal to the wall.

<u>INCLINED BACK AND SURCHARGE</u>:

A retaining wall with an inclined back supporting a backfill with horizontal ground surface. The total active pressure P_1 is first calculated on a vertical plane BC passing through the heel B. the total pressure P is the resultant of the horizontal pressure P_1 and the weight W of the wedge ABC:

$$P=\sqrt{(P_1^2+W^2)}$$

Where,

$$P_1=1/2\ K_a\gamma.H^2$$

The active earth pressure is first calculated on a vertical plane passing throughthe heel and intersecting the surface of the backfill or it‟s extension in point C. the height H of vertical plane is represented by BC. The resultant of P is the vector sum of P_1 and W, where W is the weight of the soil contained in the triangle ABC.

5. Explain with neat sketch the culmann‟s method of calculating active earth pressure.

CULMANN'S GRAPHICAL METHOD FOR ACTIVE PRESSURE:

Culmann (1866) also gave a graphical solution to evaluate the active pressure and can be conveniently used for ground surface of any shape, for various types of surcharging loads, and for a layered backfill of different densities.

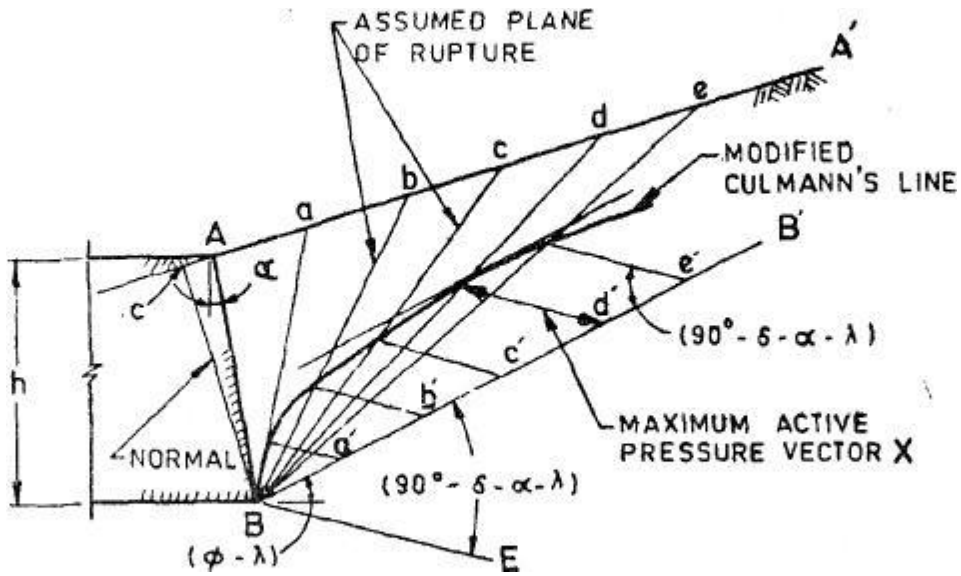
PROCEDURE:

1. Draw the ground line ℂ line and the ψ line as usual
2. Take a slip plane BC1 .calculate the weight of the wedge ABC1and plot it as BE1to some scale on the ℂ line.
3. Through E1, draw E1,F1 parallel to the line ψ, to cut the slip plane BC_2 IN F_1.
4. Similarly take another slip plane BC_2 , calculate the weight of wedge ABC_2 and plot it as BE_2 on the line. Draw E_2F_2 parallel to the line cut the slip plane BC_2 in F_2
5. Take number of such slip planes $BC_{3,}$ BC4. Plot the weight of the corresponding wedge s on the ψ line and obtain point‟s f3, f4.
6. Draw a smooth curve through points B, F1, F2, F3, F4 etc. This curve is known as the culmann‟s line.
7. Draw a tangent to the culmann‟s line parallel to the ℂ line .the maximum value of the earth pressure is represented by the intercept EF, on the adopted scale. EF being drawn through the points of tangency parallel to the line ψ line. BFC represents the critical slip plane.
8. To locate the points of application of the resultant pressure, draw a line parallel to the critical slip plane BC, through the centre of gravity of the sliding wedge ABC and obtain its intersection on the back AB.

   When the ground line is a plane, the weights of the wedges ABC1, AC1 (=L3), etc. since the height of soil wedge is constant being equal to H1, . Hence the weights of these wedges are plotted as their base lengths L1, L2, L3, etc. on the ℂ line.

P_a=1/2ṛH_1(EF)

If the backfill also carries a surcharge of intensity q, ṛ1



Determination of Active Earth Pressure by Graphical Method

EFFECT OF LINE LOAD:

Culmann‟s graphical method can also be used to take into account the running parallel to the retaining wall. A line load of intensity q per unit length, acting at a point C1, distant from the top of the wall. BEF1, F_n shows the culmanns line and BC is the failure plane in absence of the line load. Let w1 be the weight of the wedge ABC1 which is plotted as BE1 on the line ℂ and point F1 is obtained if there were no line load. However when the line load is there the weight of the wedge ABC1 increases by q. thus BE^I represents and a point change in the culmann line the change being proportional to q. for all other failure wedges to the right , the weight q is added to the weight of the wedge and then plotted on the ℂ line. The modified culmann‟s line is thus represents by BFF_1FF_n. when the slip plane is BC the pressure on the wall is represented by EF and when the slip plane is BC1, the pressure is represented by E,aF. if E^IF^I<EF slip occurs along BC^I and the pressure on the wall is increased

The culmann line BFF_2 is plotted by ignoring the line load .the modified culmann line $BF^IF^I_2$is then plotted by taking into account the line load, when the load q is added to the weight of each soil wedge considered. By drawing tangents to two culmann‟s lines parallel to ℂ line, intercepts FE and F^IE^I are obtained. The intercept E^IF gives the greatest value of pressure due to backfill acted upon by q, whereas FE gives the maximum pressure in the absence of the line load. If the tangent at F is prolonged to meet the modified culmann line in F^I_2 the intercept $E^I_2 F^I_2$ equals to FE. This means that if the line is placed beyond C_2, there is no effect of the line load on the pressure .for the other plotted. it will be seen that is maximum when the load is just at face of the wall , it remains constant with the position of q up to point c1 and then decreases gradually to zero at C_2.

For load positions beyond C_2 .the pressure on the wall is not due to q. This method is very much used in locating the position of the railway line or the footing of building on the backfill at such a safe distance that the earth pressure on the (existing) wall does not increase.

6. Explain the coulomb‟s Wedge theory of earth pressure with a neat sketch.

COULOMB'S WEDGE THEORY.

Instead of considering the equilibrium of an element within the mass of the material, Coulomb (1776) considered of equilibrium of whole of the material supported by a retaining wall when the wall is on the point of moving slightly away from the filling. The wedge theory of earth pressure is based on the concept of a sliding wedge which is torn off from the rest of the backfill on movement of the wall. In the case of active earth pressure, the sliding wedge moves downwards on a slip surface relative to the intact backfill and in the case of passive earth pressure, the sliding wedge moves upwards and inwards. The pressure on the wall is, in fact, a force of reaction which it has to exert to keep the sliding wedge in equilibrium. Factors such as well friction, irregular soil surfaces and different soil strata can easily by taken into account in this method. Following are the basic Assumptions of the wedge theory:

1. The backfill is dry, cohesionless, homogenous, isotopic and elastically underformable but breakable.
2. The slip surface is plane which passess through the heel of the wall.
3. The sliding wedge itself acts as a rigid body and the value of earth pressure is obtained by considering the limiting equilibrium of the sliding wedge as a whole.
4. The position and direction of the resultant earth pressure are known. The resultant pressure acts on the back of the wall at one-third the height of the wall from the base and is inclined at an angle δ (called the angle of wall friction) to the normal to the back. (The assumption means that the pressure distribution is hydrostatic, i.e., triangular). The back of wall is rough and a relative movement of the wall and the soil on the back takes place which develops frictional forces that influence the direction of the resultant pressure.

The forces acting on a wedge of soil are: its weight W, the reaction R along the plane of sliding and the active thrust Pa against the retaining wall. R will act at an angle $\emptyset$ to the normal of the plane of sliding. The pressure P is inclined at an angle of wall friction δ to the normal which is considered positive as marked in Fig. 20.20 Both R and P will be inclined in a direction so as to oppose the movement of the wedge. For the condition of the yield of the wall from the backfill the most dangerous or the critical slip surface is that for which the wall reaction is maximum, i.e., the wall must resist the maximum lateral pressure before it moves away from the fill.

Condition for maximum pressure from a sliding wedge. BD shows a plane inclined at an angle ϕ to the horizontal at which the soil is expected to stay in the absence of any lateral support. The line BD, therefore, is called the natural slope line, repose line or the $\emptyset$ – line. AD, inclined at β to the horizontal, is called the ground line or surcharge line. Plane BC, inclined at angle λ (to be determined) is the line or rupture plane or slip plane; the angle λ is called the critical slip angle. The reaction R inclined at an angle ϕ to the normal to the slip line; R is also inclined at an angle (λ-ϕ) to the vertical. The wall reaction P_a is inclined at an angle to the normal to the wall. The inclination of P_a to vertical is represented by angle $\psi = 90^{\circ} - \theta - \delta$ (= constant for given value of θ and δ). The value of P_a depends upon the slip angle λ. P_a is zero when $\lambda = \phi$. As λ increases beyond ϕ, P also increases and after reaching a maximum value it again reduces to zero when λ equals $90 + \theta$. Thus, the critical slip plane lies between the line and back of the wall.

In order to derive the condition for maximum active pressure P_a from the sliding wedge, draw line CE at an angle ψ to the ϕ –line. Let x and n be the perpendicular distance of points C and A from the ϕ -line, and m be the length of line BD. It will be seen triangle BCE and the force triangle similar.

Hence $\frac{Pa}{W} = \frac{C\,E}{B\,E}$ ——————————————(1)

Now, CE = x cosec ψ = A_1 x (where A_1 = cosec ψ = constant)

BE = BD – (DF - FE) = m – x {cot ($\phi - \beta$) – cot ψ} = m – A_2 x

A_2 = [cot ($\phi - \beta$) – cot ψ] = constant.

W = $\gamma(\Delta ABD) = \gamma(\Delta ABD - \Delta BCD) = 0.5\,\gamma\, m\,(n - x)$

Subsituting the value of CE, BE and W in (1), we get

$P_a = 0.5m\, A_1 \frac{nx - x2}{m - A2x}$ ——————————————(2)

In the above expression x is the only variable which depends upon the position of slip plane BC. For maxima $dP_a/dx = 0$

$(n-2x)(m - A_2\, x) = - A_2\,(n\,x - x^2)$

$mn – mx = mx - A_2\, x^2 = x\,(m - A_2\, x)$

$\Delta ABC = \Delta BCE$

Thus the criterion for maximum active pressure is that the slip plane is so chosen that ΔABC and ΔBCE are equal in area.

(OR)

The assumptions are:

- The soil is isotropic and homogeneous.
- The surface of rupture is a plane.
- The failure wedge is a rigid body.
- There is friction between and the wall.
- Back of wall need not be vertical.
- Failure is two dimensional.
- The soil is cohesionless.
- Coulomb‟s equation of shear strength is valid.

Coulomb made his derivation based on limit equilibrium approach.

Active Case

Figure below shows the cross section of a retaining Wall. Equilibrium analysis of failure wedge ABC involves:

- Weight of wedge ABC (magnitude and direction known)
- P_a (direction known, magnitude unknown)
- R (direction known, magnitude unknown)

Hence, from the triangle of forces can be drawn and P_a can be determined.

Weight of wedge ABC
From Δ ABC,
Area of Δ ABC = ½ AD × BC

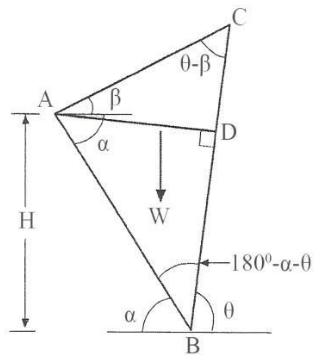


Fig 2 Weight of Wedge ABC

BC/AB = {sin(α + β)/ sin(Θ - β)}

BC = AB {sin(α + β)/ sin(Θ - β)}

Again, AD = AB sin[180^0 – (α + Θ)] = AB sin(α + Θ)

$$\text{Area of } \Delta ABC = \frac{1}{2} AB \sin(\alpha + \Theta) \times AB \frac{\sin(\alpha + \beta)}{\sin(\Theta - \beta)}$$

$$\Delta ABC = \frac{H^2}{2\sin^2 a}\left[\sin(\alpha+\Theta)\frac{\sin(\alpha+\beta)}{\sin(\Theta-\beta)}\right]$$

$$W = \gamma \times V = \frac{\gamma H^2}{2\sin^2 a}\left[\sin(\alpha+\Theta)\frac{\sin(\alpha+\beta)}{\sin(\Theta-\beta)}\right]$$

Triangle of Forces for W, P_a and R

From the sine rule,

$$\frac{P_a}{\sin(\theta - \phi)} = \frac{W}{\sin[180^0 - \{(\theta - \phi) + (\alpha - \delta)\}]}$$

Substituting the value of W from the equation into we get,

$$P_a = \frac{\gamma H^2}{2\sin^2\alpha}\left\{\sin(\alpha+\Theta)\frac{\sin(\alpha+\beta)}{\sin(\Theta-\beta)}\right\}\frac{\sin(\theta - \phi)}{\sin(180^0 - \Theta + \phi - \alpha + \delta)}$$

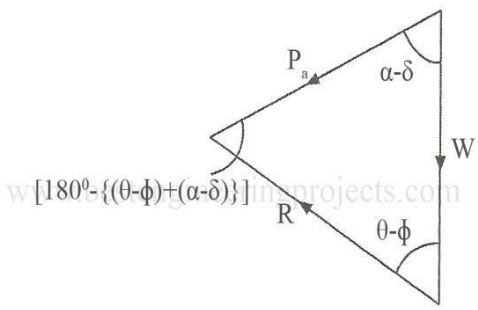


Fig 2 Triangle of Force for W, P_a and R

In order to get the maximum value of P_a,

$$\frac{\partial P_a}{\partial \theta} = 0$$

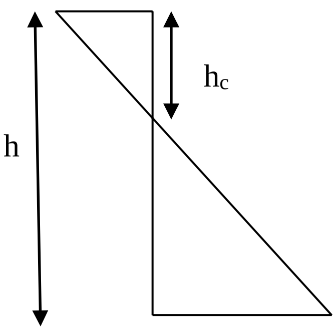
$$P_a = \frac{\gamma H^2}{2}\left[\frac{\sin^2(\phi+\alpha)}{\sin^2\alpha\sin(\alpha-\delta)\left\{1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\alpha-\delta)\sin(\alpha+\beta)}}\right.}\right]$$

$$P_a = K_a\frac{\gamma H^2}{2}$$ Where,

$$K_a = \left[\frac{\sin^2(\phi+\alpha)}{\sin^2\alpha \sin(\alpha-\delta)\left\{1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\alpha-\delta)\sin(\alpha+\beta)}}\right.} \right]$$

Note: When, $\beta = 0$ (leveled backfilled), $\delta = 0$ (no wall friction), then $k_a = K_a = (1 - \sin\phi)/(1 + \sin\phi)$. The point of application of P_a is at a distance of H/3 above the base of the wall.

7. What is meant by tension cracks? Explain



In clay under undrained condition at climatic temperature variation and due to water drain in season‟s soil volume shrinkage, cause compression due to soil self weight, surcharge and live load, cause tensile stress and spilt or fracture in the clay mass especially.

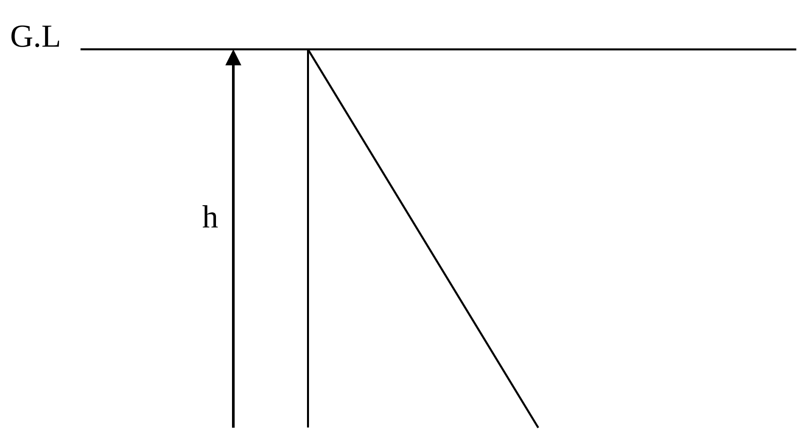
Hence in figure the depth of the tension zone was given the symbol h_c. It is possible for cracks to develop over this depth and a value for h_c is obtained as

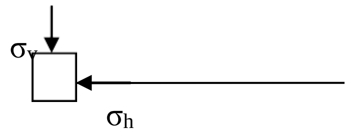
From active earth pressure theory, $h_c = 2C / \gamma$

8. What are the different types of earth pressure? Give examples. Derive an equation for determining the magnitude of earth pressure at rest.

Different types of earth pressure:

1. Earth pressure at rest
2. Active earth pressure
3. Passive earth pressure





Derivation for magnitude of earth pressure:

1. Consider walls are at rest (not moving in or out)
2. So soil in its back is not moving.
3. At rest a cube of soil is under vertical pressure σ_v and a horizontal stress $\sigma_{h.}$ This ratio is termed at rest earth pressure coefficient K_0

   $\sigma_v = \gamma h \qquad \sigma_h = K_0 \gamma h$
4. The vertical stress and lateral stress at rest
5. The total pressure at rest $P_0 = 0.5 K_0 \gamma H^2$
6. From elastic theory, $K_0 = \mu/(1-\mu)$ where μ is poisson‟s ratio.

9. What are different modes of failure of retaining wall?
   1. Failure against sliding
   2. Failure against overturning
   3. Failure against bearing capacity

Failure against sliding

(a) Ths soil in front of the wall provides active and passive pressure resistance as the wall tends to slide.

(b) Use of a key beneath the base provides additional sliding stability.

(c) The sliding resistance along the base $F_R = \mu R$, where R includes all the vertical forces, including the vertical components of P_a, acting at the base and μ the coefficient of wall friction.

$$\text{Factor of safety} = \frac{Sum\ of\ resisting\ force}{Sum\ of\ driving\ force}$$

Factor of safety against sliding should be atleast 1.5 for sandy soil and 2.0 for clayey soil.

Failure against overturning:

For a wall to be stable the resultant thrust must be within the base. Most walls are so designing that the thrust is within the middle third of the wall base. It is to avoid loss of contact of base with soil.

$$\text{Factor of safety} = \frac{Sum\ of\ resisting\ force}{Sum\ of\ overturning\ \ force}$$

Overturning is usually considered with respect to toe and the factor of safety should be at least 1.5 for sandy soil and 2.0 for clayey soil. The resisting moments are normally due to vertical component of all the forces namely weight of wall, weight of soil overbase, vertical component active pressure and passive pressure.

Failure against Bearing Capacity:

$$\text{Factor of safety} = \frac{Allowable\ \ bearing\ \ pressure}{Maximum\ \ contact\ \ pressure}$$

Vertical load causes uniform contact pressure at the base. Over turning moment causes compressive pressure at toe and tensile pressure at heel. The sum contact pressure is maximum at toe. Factor of safety against bearing capacity should be atleast 2.5 for sandy soil and 3.0 for clayey soil.