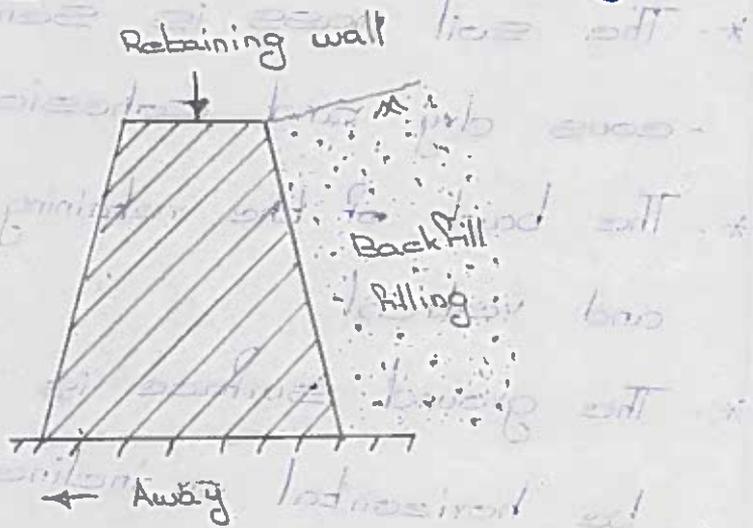


UNIT - III EARTH PRESSURE

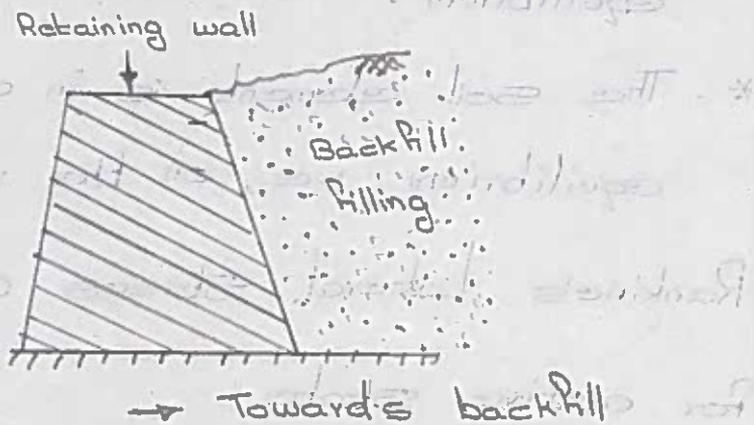
THEORIES AND RETAINING WALLS

Introduction to Earth Pressure

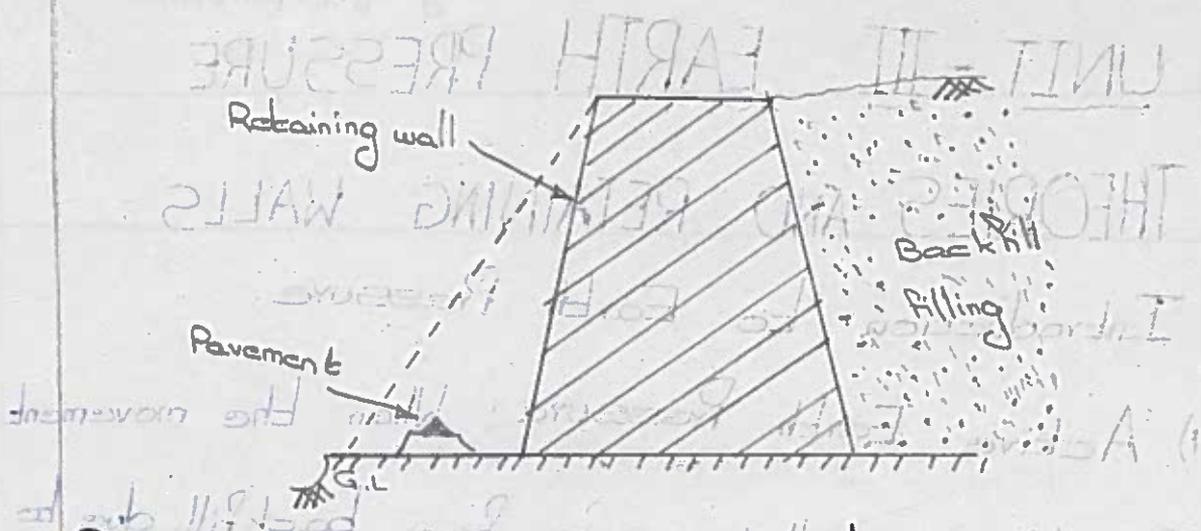
1) Active Earth Pressure: When the movement of retaining wall is away from backfill due to some pressure exerted on retaining wall



2) Passive Earth Pressure: When the movement of retaining wall is towards the backfill as such as the soil tends to compress horizontally.



3) Lateral Earth Pressure: A force exerted by a soil with any vertical or inclined face of a structure is known as lateral earth pressure.



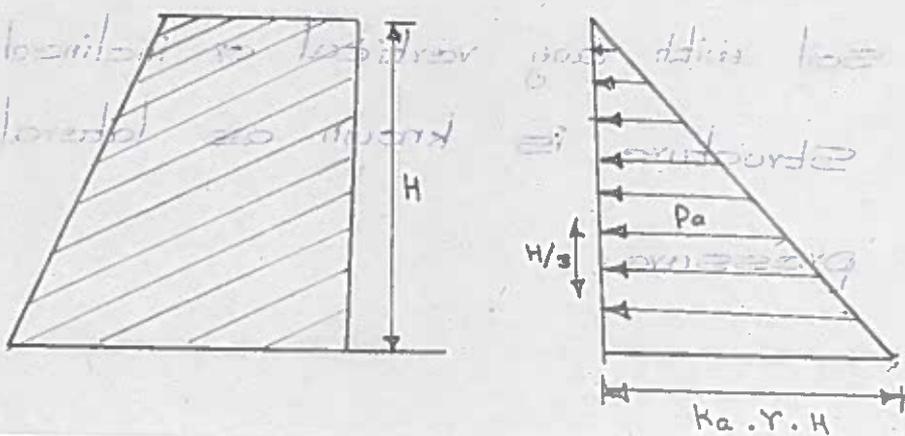
Rankine's earth pressure theory

- * The soil mass is semi-infinite, homogeneous dry and cohesionless
- * The back of the retaining wall is smooth and vertical
- * The ground surface is plane, which may be horizontal or inclined
- * The wall yields about the base thus satisfies deformation condition for plastic equilibrium.
- * The soil element is in a state of plastic equilibrium i.e., on the verge of failure

Rankine's Lateral Stress distribution theory

For active state

- * Dry backfill with no surcharge shown in fig



* Thus the pressure distribution at base is

$P_a = k_a \cdot \gamma \cdot H$

where as, $k_a =$ Coefficient of active earth

$k_a = \frac{1 - \sin \phi}{1 + \sin \phi}$

$\gamma =$ Unit weight of soil

$\phi =$ Angle of internal friction of soil

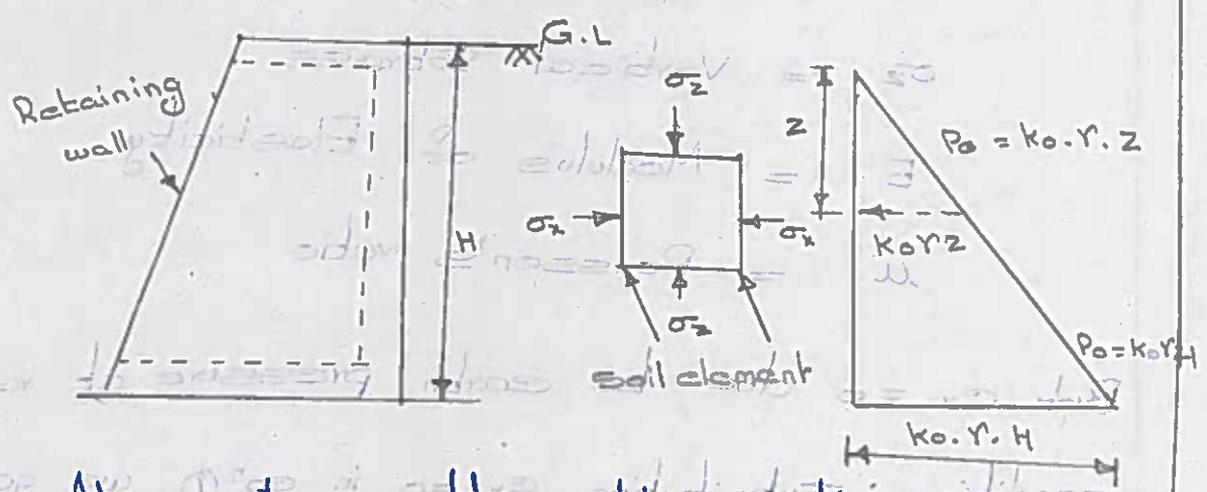
* Total active earth pressure per unit length

of wall $P_a = \frac{1}{2} k_a \gamma \cdot H^2$

acting at $\frac{H}{3}$ above the base of wall

Earth Pressure at Rest

* Earth pressure at rest is the earth pressure when the soil mass is not subjected to any lateral movement.



* At rest condition, the earth pressure is expressed as follows:

$P_0 = k_o \cdot \sigma_z$

where, K_0 = Coefficient of earth pressure

σ_z = Effective vertical stress at depth

where $K_0 = \frac{\sigma_x}{\sigma_z}$ = Coefficient of earth pressure
 $\therefore \sigma_z = \gamma \cdot z$

As γ = Unit weight of soil

* Consider the soil element at a depth "z" subjected to horizontal direction is given stress (σ_x) and vertical stress (σ_z).

* The strain (e_x) in the horizontal direction is given by the following expression

$$e_x = \frac{\sigma_x}{E} - \frac{\mu \sigma_x}{E} - \frac{\mu \sigma_z}{E}$$
$$= \frac{1}{E} (\sigma_x - \mu \sigma_x - \mu \sigma_z)$$

$$e_x = \frac{1}{E} [\sigma_x - \mu (\sigma_x + \sigma_z)] \quad \text{--- (1)}$$

where e_x = Lateral strain in horizontal direction

σ_x = Horizontal stress

σ_z = Vertical stress

E = Modulus of Elasticity

μ = Poisson's ratio

But $e_x = 0$ due to earth pressure at rest condition. Substituting $e_x = 0$ in eqⁿ (1) we get.

$$0 = \frac{1}{E} [\sigma_x - \mu (\sigma_x + \sigma_z)]$$

$$\therefore 0 = \sigma_x - \mu (\sigma_x + \sigma_z)$$

$$\therefore \sigma_x = \mu (\sigma_x + \sigma_z) = \mu \sigma_x + \mu \sigma_z$$

$$\sigma_x + \mu \sigma_x = \mu \sigma_z$$

$$\sigma_x (1 - \mu) = \mu \sigma_z$$

$$\sigma_x = \frac{\mu}{1 - \mu} \sigma_z \quad \text{--- (2)}$$

$$\frac{\sigma_x}{\sigma_z} = \frac{\mu}{1 - \mu}$$

$$k_0 = \frac{\mu}{1 - \mu} \quad \dots \quad k_0 = \frac{\sigma_x}{\sigma_z}$$

The relation for lateral earth pressure in active state for submerged cohesionless backfill

- * The retaining wall with backfill submerged with water
- * The lateral earth pressure consists of two components
- * These are as follows: i) Lateral pressure due to submerged weight γ_b of the soil
- ii) Lateral pressure due to water
- * Thus, at any depth z below the surface

$$P_a = k_a \cdot \gamma_b \cdot z + \gamma_w \cdot z$$

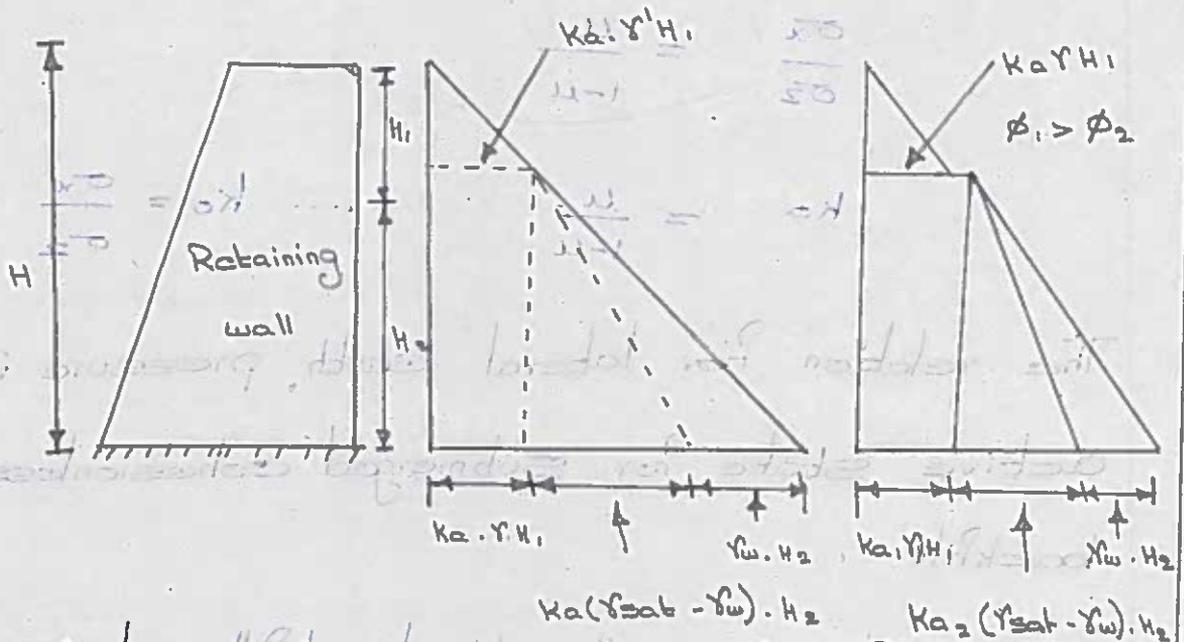
when $z = 0, P_a = 0$

when $z = H, P_a = k_a \cdot \gamma_b \cdot H + \gamma_w \cdot H$

- * If the backfill is partly submerged: The backfill is moist to a depth H , i.e., below the ground level and then

it is submerged. The lateral pressure intensity at the base of wall will be

$$P_a = K_a \cdot \gamma H_1 + K_a [\gamma_{sat} - \gamma_w] H_2 + \gamma_w \cdot H_2$$



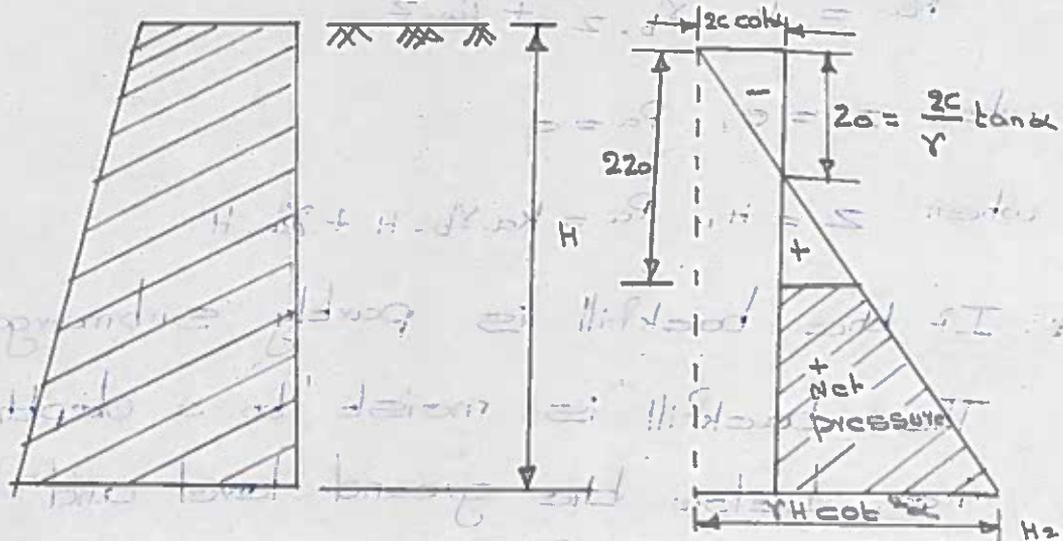
Showing retaining wall with backfill submerged with water

RAI: Expression for the vertical cut that can stand unsupported in a purely cohesive soil

Consider a smooth vertical retaining wall with a horizontal backfill. At any depth

z , we have $\sigma_1 = \sigma_2 = \gamma \cdot z$ and

$\sigma_3 =$ Lateral Pressure, P_a



The principal stress relationship on a failure plane is given by the equation

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

Substituting σ_1 and σ_3 in equation (i) we have

$$\gamma \cdot z = P_a \tan^2 \alpha + 2c \tan \alpha$$

where, $\alpha = 45 + \frac{\phi}{2}$

$$\text{or } P_a = \gamma \cdot z \cot^2 \alpha - 2c \cot \alpha$$

At $z = 0$, $P_a = -2c \cot \alpha$

This shows that negative pressure [i.e. tension] is developed at the top level of the retaining wall.

At a point where $P_a = 0 = \gamma \cdot z \cot^2 \alpha - 2c \cot \alpha$

$$\gamma z = 2c \cot \alpha$$

\therefore when $P_a = 0$, $z = z_0 = \frac{2c}{\gamma} \cot \alpha$

Hence tension decreases to zero at a depth

$$z_0 = \frac{2c}{\gamma} \cot \alpha$$

At $z = H$, $P_a = \gamma H \cot^2 \alpha - 2c \cot \alpha$

The total net pressure is given by

$$P_a = \int P_a \cdot dz$$

$$P_a = \frac{1}{2} H^2 \cot^2 \alpha - 2cH \cot \alpha$$

Due to negative pressure, a tension crack is usually developed in the soil

near the top of the wall upto a depth z_0 . Also, the total net pressure at depth $2z_0$ is zero. This means that a cohesive soil should be able to stand with a vertical face, upto a depth of $2z_0$, without any lateral support. The lateral height H_c of an unsupported vertical cut in a cohesive soil is thus given by

$$H_c = 2z_0 = \frac{4c}{\gamma} \tan \alpha$$

$$\text{or } H_c = \frac{4c}{\gamma} \frac{1}{\sqrt{k_a}}$$

$$\text{where, } k_a = \cot^2 \alpha$$

For soft saturated clay, $\phi = 0$, $k_a = 1$

$$H_c = \frac{4c}{\gamma}$$

As the crack develops in the soil upto depth z_0 , the soil does not remain adhered to the top portion of the wall, upto z_0 .

Hence the total lateral thrust is given by integrating equation (ii) between limits z_0 to H

$$P_a = \int_{z_0}^H [\gamma z \cot^2 \alpha - 2c \cot \alpha] dz$$

$$\text{or } P_a = \frac{1}{2} \gamma [H^2 - z_0^2] \cot^2 \alpha - 2c [H - z_0] \cot \alpha$$

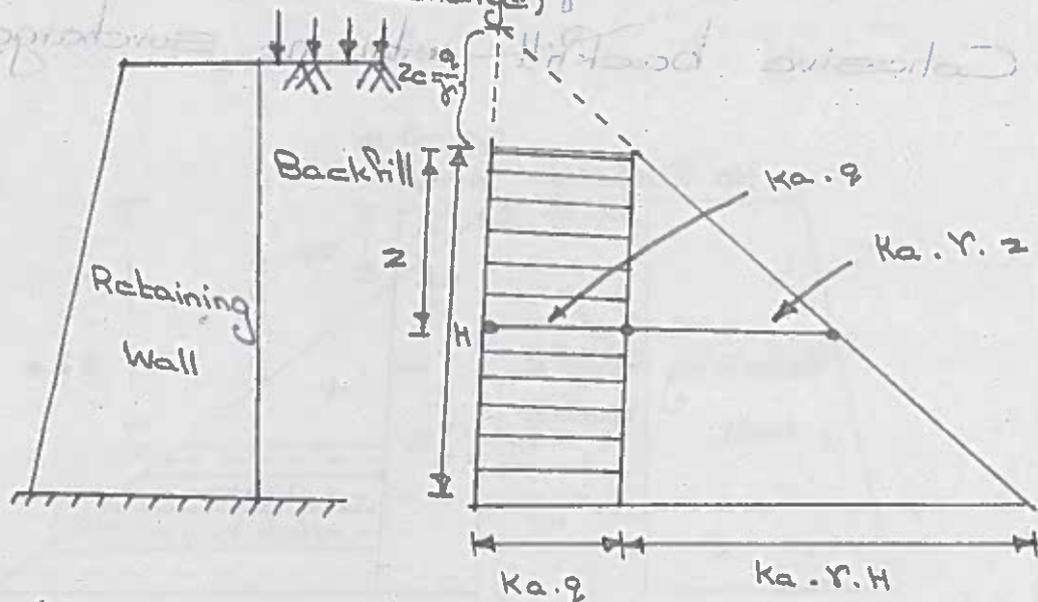
From equation (iii)

$$z_0 = \frac{2c}{\gamma} \tan \alpha$$

Substituting for Z_0 in equation (iv) we get

$$P_a = \frac{1}{2} \gamma H^2 \cot^2 \alpha - 2cH \cot^2 \alpha + \frac{2c^2}{\gamma}$$

Showing retaining wall with backfill carrying uniform surcharge (q)



* The retaining wall with horizontal backfill carrying a surcharge of uniform intensity " q " per unit area

* The vertical pressure increment at any depth z , will increase by q

* Thus the increase in the lateral pressure due to this will be $K_a \cdot q$.

* Hence, the lateral pressure at any depth z is given by

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

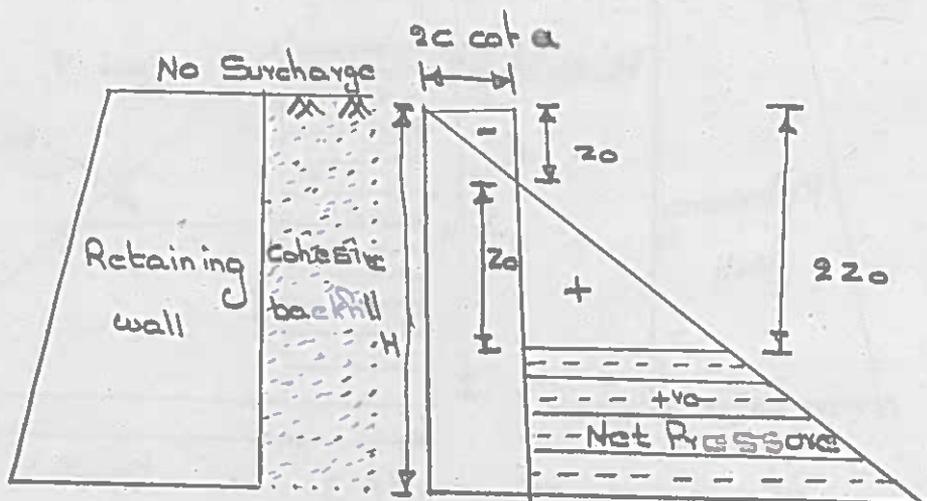
* The height of backfill z_c equivalent to

the uniform surcharge intensity is given

by
$$k_a \cdot \gamma \cdot z_c = k_a \cdot q$$

where
$$z_c = \frac{q}{\gamma}$$

Cohesive backfill with no surcharge



* Consider a smooth vertical retaining wall with a horizontal backfill. The principal stress relationship on a failure plane is given by the equation,

$$\sigma_1 = \sigma_3 \tan^2 \left(45 + \frac{\phi}{2} \right) + 2c \tan \left[45 + \frac{\phi}{2} \right] \quad \text{--- (1)}$$

At any depth z , we know

$$\sigma_1 = \sigma_v = \gamma \cdot z \quad \text{and}$$

$$\sigma_3 = P_a \quad (\text{lateral pressure})$$

Now substituting the values σ_1 & σ_3 in eqⁿ (1)

$$\gamma z = P_a \tan^2 \alpha + 2c \tan \alpha$$

OR,
$$P_a = \gamma \cdot z \cdot \cot^2 \alpha - 2c \cot \alpha \quad \text{--- (2)}$$

B) At $z = 0$

$$P_a = -2c \cot \alpha \quad \text{--- (3)}$$

Here -ve pressure is set up at top level of retaining wall i.e., tension is developed

at the top level of wall

C) When $P_a = 0$,

$$0 = \gamma \cdot z \cdot \cot^2 \alpha - 2c \cot \alpha$$

$$\gamma \cdot z = 2c \tan \alpha \quad \text{--- (4)}$$

D) Thus equation shows that tension decreases to zero at a depth z_0

$$z_0 = \frac{2c}{\gamma} \tan \alpha$$

$$z = H$$

$$P_a = \gamma H \cot^2 \alpha - 2c \cot \alpha$$

E) Therefore total net pressure is given by

$$P_a = \int P_a \cdot dz$$

$$\text{OR } P_a = \frac{1}{2} H^2 \cot^2 \alpha - 2cH \cot \alpha$$

A tension crack is usually developed in the soil due to -ve pressure at the top of wall upto z_0 . The total net pressure at depth $2z_0$ is zero.

F) H_c = Critical height for an unsupported vertical cut in a cohesive soil

$$H_c = 2z_0 = 2 \times \frac{2c \tan \alpha}{\gamma}$$

$$\text{OR } H_c = \frac{4c}{\gamma} \tan \alpha = \frac{4c}{\gamma} \cdot \frac{1}{\sqrt{K_a}}$$

where $k_a = \cot^2 \alpha$

For soft saturated clay, $\phi = 0$, $k_a = 1$

$$\therefore H_c = \frac{Hc}{\gamma}$$

G) The total lateral thrust is given by integrating equation (ii) between limits z_0 to H

$$\therefore P_a = \int_{z_0}^H (\gamma \cdot z \cot^2 \alpha - 2c \cot \alpha) dz$$

$$\text{OR } P = \frac{1}{2} \gamma [H^2 - z_0^2] \cot^2 \alpha - 2c [H - z_0] \cot \alpha \quad \text{--- (5)}$$

Substituting for z_0 in equation (5) we get

$$P_a = \frac{1}{2} \gamma H^2 \cot^2 \alpha - 2cH \cot \alpha + \frac{2c^2}{\gamma}$$

MSE Walls

* Mechanically Stabilized earth walls, (MSE) are constructed by artificial reinforcing of soil and they are generally used as retaining walls, dikes, bridges abutments etc.

* They stabilize the unstable slopes and retain the soil on steep and under crest load

* Installation and construction of MSE is easy and quick.

* They does not require any framework curing scaffolding.

Coulomb's Earth Pressure Theory

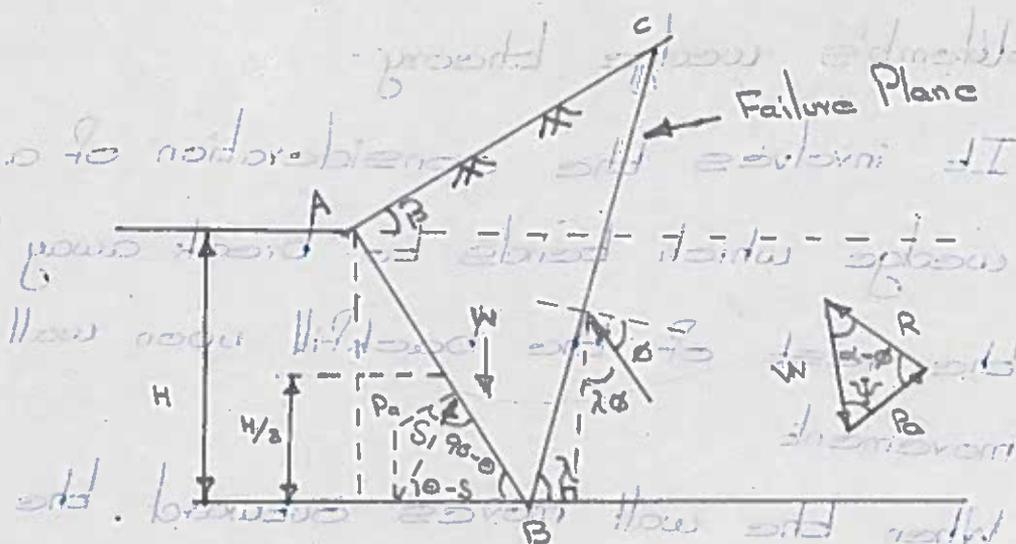
Coulomb's wedge theory:

- * It involves the consideration of a sliding wedge which tends to break away from the rest of the backfill upon wall movement
- * When the wall moves outward, the sliding wedge moves downwards and outwards. The sliding wedge moves upward and inwards when the wall is pushed towards the backfill.

Assumptions ::

- * Soil is homogeneous, isotropic, semi-infinite, dry, elastic and cohesionless
- * The face of the wall is in contact with the backfill is vertical, inclined & rough
- * The failure wedges acts as a rigid body and the stresses acting over it are uniform
- * Failure is two dimensional. Failure surface is planar and passes through the heel of the wall.

Active State



θ = Angle made by inclined face of wall with vertical

S = Angle of friction between soil and wall

λ = Angle made by failure plane with the horizontal

ϕ = Frictional angle of the soil

β = Surcharge angle

In this theory:

- Self weight of the wedge ABC acting vertically downward
- Resultant thrust between the wall and soil acting at a downward angle of S with the normal to the inclined face of the wall
- Resultant reaction R , between the two portions of the soil mass on either side of the failure plane acting as a downward angle of ϕ with the normal to failure plane

Active earth pressure on soil A *

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

$$\text{where } K_a = \left[\frac{\sec \theta \cos(\phi - \theta)}{\sqrt{\cos(\theta + \delta) + \sqrt{\frac{\sin(\delta + \phi) \sin(\phi - \beta)}{\cos(\beta - \theta)}}}} \right]^2$$

If $\beta = 0^\circ$, $\theta = 0^\circ$ and $\delta = \phi$

$$K_a = \left[\frac{1 \cdot \cos \phi}{\sqrt{\cos \phi + \sqrt{\frac{\sin 2\phi \sin \phi}{1}}}} \right]^2 = \frac{\cos \phi}{(1 + \sqrt{2} \sin \phi)^2}$$

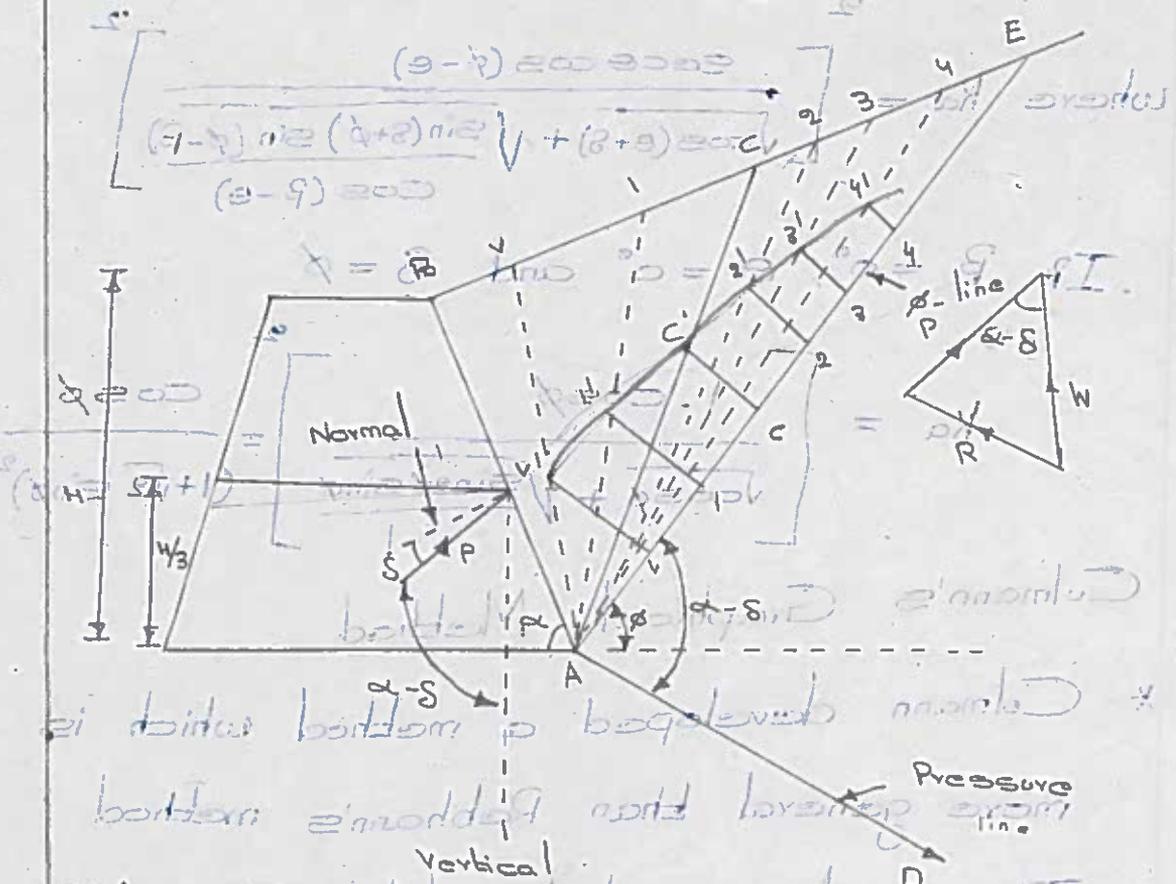
Culmann's Graphical Method

- * Culmann developed a method which is more general than Rankine's method
- * It can be used to determine Coulomb's earth pressure for ground surface of any configuration for various types of surcharge loads and layered backfills.

Procedure

- * Draw the retaining wall BA to the scale
- * Draw the ϕ -line AE
- * A line AD is drawn at an angle ψ with line AE, such that $\psi = \alpha - \delta$
- * A failure surface AC is assumed and the weight (W) of failure wedge ($\gamma \cdot BAC$)

* A line cc' is drawn from point c parallel to AD to intersect the surface AC & c' .



Culmann's graphical construction active case

* The length cc' represents the magnitude of P_a required to maintain equilibrium for assumed failure plane

* Several other failure planes A_1, A_2, A_3 , etc. are assumed and the procedure is repeated. Thus, the points v', z', y' are obtained

* A smooth curve is drawn joining points v', z', y', c', z', y' , etc. The curve is called Culman's line.

* A line (x,y) (dotted) is drawn tangential to the culman line and parallel to AE . Point i' is the point of tangency.

* The magnitude of the largest value of P_a is measured from drawing a line $i'i'$ on AE and parallel to AD. It is equal to Coulomb's pressure (P_a).

* The actual failure plane passes through the point i' . (dotted).

Types of Retaining Wall

i) Gravity retaining wall:

* It consists of mass of concrete or masonry

* Its dead weight is more to give stability against thrust of retained earth

* Its base is so proportioned that are no tensile stresses developed

* Little reinforcement is required in this type of wall



2) Cantilever retaining Wall

* Most common and widely used retaining wall

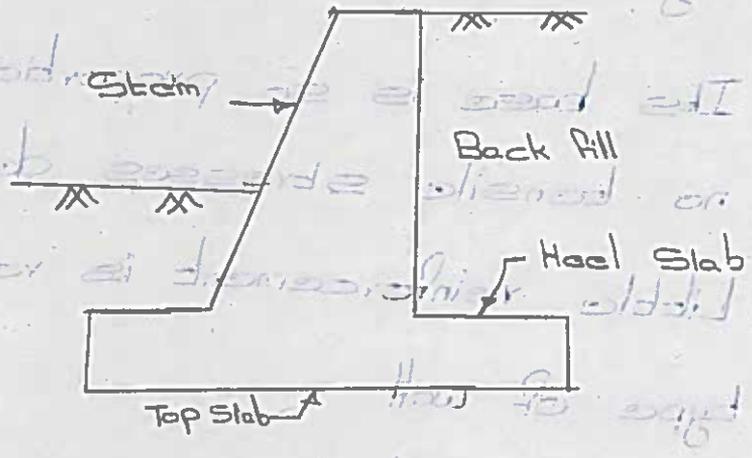
* Vertical stem resisting earth pressure

From one side and the slab bends like a cantilever.

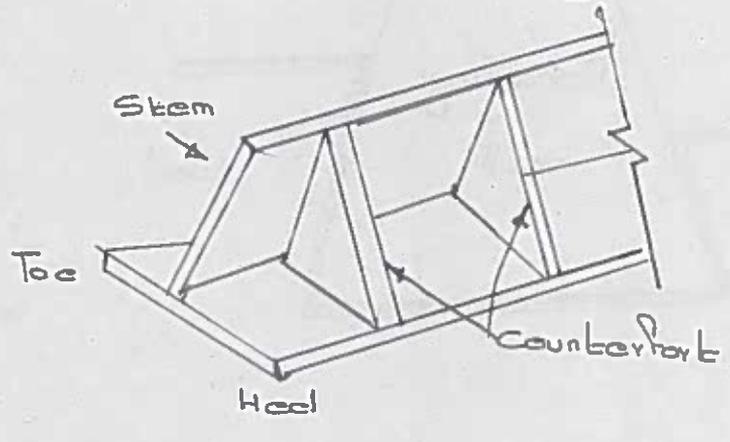
* Depending upon the soil pressure thickness of stem slab varies

* Bottom slab is called toe slab and heel slab. They act as a horizontal cantilever

* It is adopted for small to medium height upto 5 m.



3) Counterfort retaining wall



*. The counterforts act as support to stem and heel slab

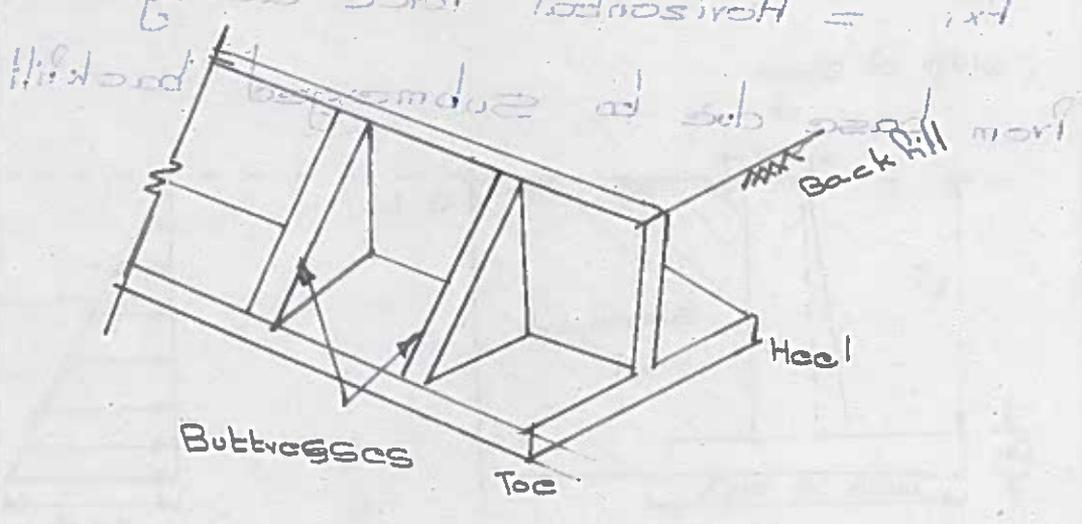
*. Therefore, stem and heel slab are designed as continuous slab supported over counterforts

*. The size of concrete components and the steel reinforcement shall be reduced as the bending moments are less than that in case of cantilever retaining wall

4) Buttressed Retaining Walls

*. When the counterforts are provided on the front of the wall and not on the soil side, it is known as buttressed retaining wall.

*. It reduces the clearance in front of the wall. Contribution of backfill is less towards the stability of the wall because heel projection is small.



The active earth Pressure diagram on a T-Shaped retaining wall showing the expression for maximum earth pressure for the following conditions

- i) Backfill is a completely submerged soil with top surface horizontal and
- ii) Backfill is a completely submerged soil and Backfill is horizontal with uniform surcharge W_s / unit run

A. i) Backfill is a completely submerged soil with top surface horizontal
 K_a = Active earth pressure coefficient

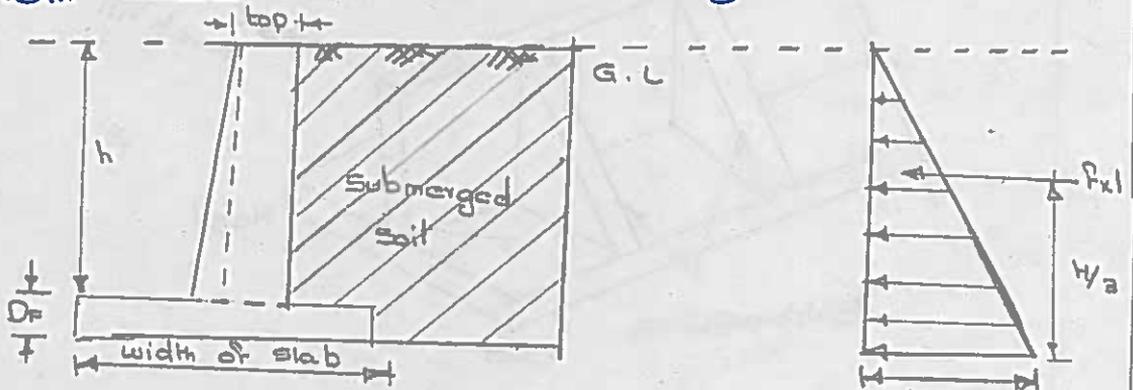
h = Height of stem

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

ϕ = Angle of repose

F_{x1} = Horizontal force acting at $H/3$

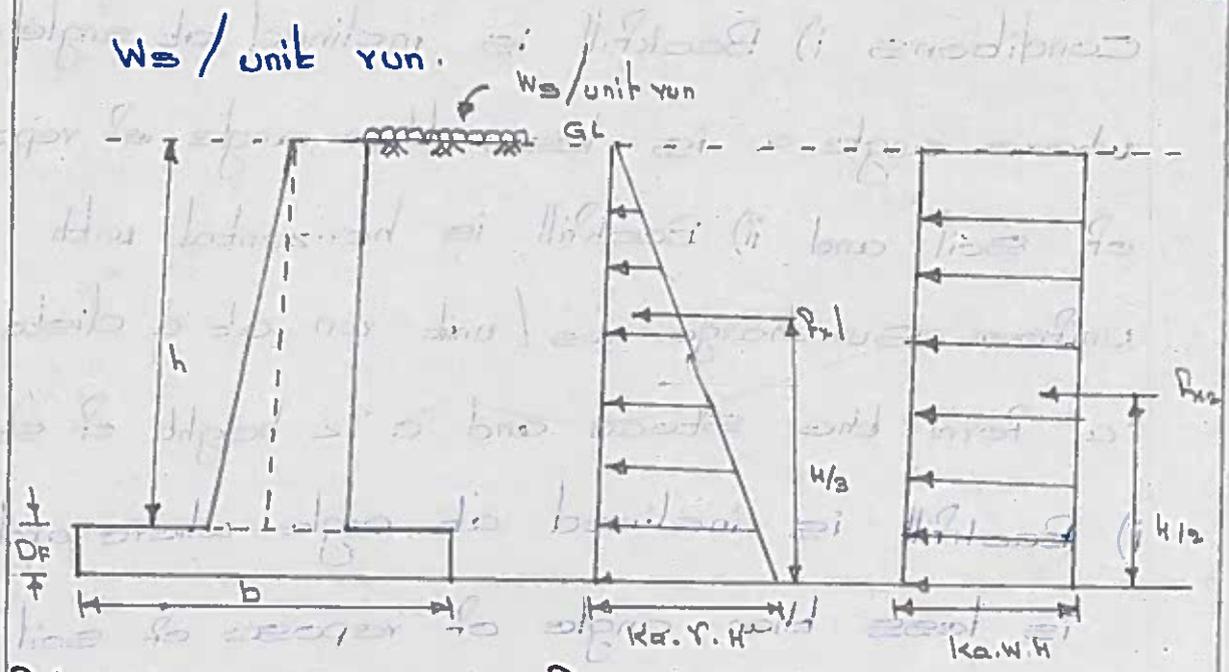
From base at width of stem due to submerged backfill.



Retaining wall

Pressure distribution diagram

ii) Backfill is horizontal with uniform surcharge



Retaining Wall

Pressure distribution (Backfill)

Pressure distribution (uniform surcharge)

h = Height of stem

D_f = Depth of base slab

b = Width of base slab

W = Surcharge load

γ = Unit weight of soil

$$K_a = \left[\frac{1 - \sin \phi}{1 + \sin \phi} \right]$$

ϕ = Angle of repose

P_{x1} = Horizontal force due to backfill

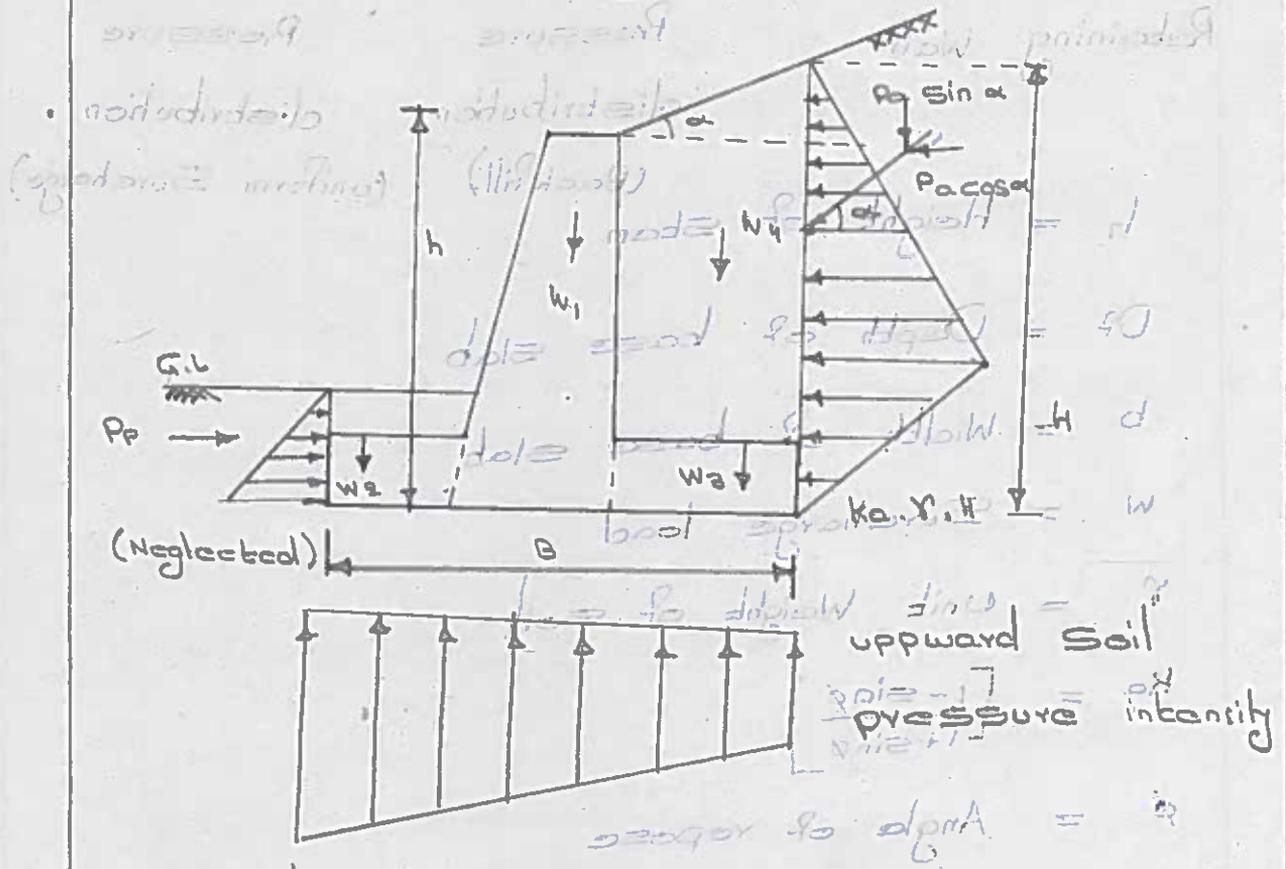
$$= \frac{K_a \cdot \gamma \cdot H^2}{2}$$

P_{x2} = Horizontal force due to surcharge

$$= K_a \cdot W \cdot H$$

maximum earth pressure for the following conditions i) Backfill is inclined at angle α , where angle α is less than angle of repose of soil and ii) Backfill is horizontal with uniform surcharge w_s / unit run at a distance "a" from the stem and "a" < height of stem

i) Backfill is inclined at angle where angle α is less than angle of repose of soil



* The general relation for the coefficient of active earth pressure based on Rankine's theory is given by

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

ϕ = Angle of repose

α = Surcharge angle

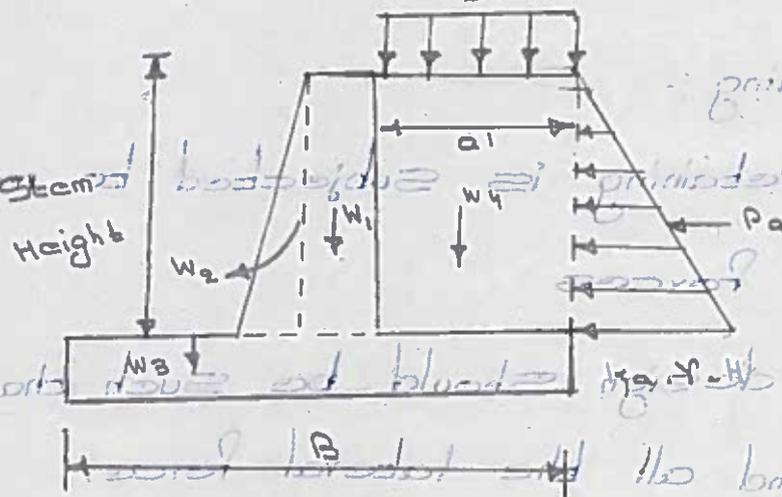
ii) Backfill is horizontal with uniform sur-charge W_s / unit run at a distance "a" from the stem and "a" < height of stem

Equation for coefficient of active earth

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

ϕ = Angle of repose.

W_s/m



Principles of the design of retaining walls

A) Overbaking:

* Due to rotational forces that are acted on retaining wall, an overbaking moment is developed

* Thus, to overcome such moment, a factor of safety of 1.5 is considered in design

B) Bearing Capacity

* Factor of safety of 2 is considered while designing

C) Tension

- * The design should be such that, there exists no tension at the base of wall
- * If the eccentricity (e) $> b/6$, then the tension is developed at heel.

D) Sliding :-

- * A retaining is subjected to many horizontal forces
- * The design should be such that, it withstand all the lateral force.
- * A factor of safety of 1.5 is considered while design.

Stability of Retaining walls against overturning, sliding and bearing capacity.

A) Stability against overturning

- * The overturning effect is calculated about the retaining wall
- * The factor of safety against overturning is calculated as follows

$$F.O.S = \frac{\sum M_R}{\sum M_O}$$

Where ΣMR = Summation of all the resisting moments about toe

ΣMo = Summation of all the overturning moments about toe

* Generally, the resisting moments are developed by the section or gravity wall

* The overturning moments are developed due to the earth pressure, friction at base etc.

* The wall should be safe against overturning and the factor of safety against overturning ranges between 1.5 - 2

B) Stability against Sliding:

* It is calculated as,

$$F.O.S = \frac{\mu R_v}{R_H}$$

where, μ = Coefficient of friction between the soil and the wall

R_v = Summation of all the forces in vertical direction

R_H = Summation of all the forces in horizontal direction

* Vertical forces mainly include weight of

* Factor of safety should not be less than 1.5.

C) Stability against bearing Capacity

* The pressure exerted at the toe due to the total vertical force should be less than the allowable bearing capacity of soil.

$$F.O.S = \frac{T_{na}}{P_{max}}$$

where $P_{max} = \frac{R_v}{b} \left[1 + \frac{6e}{b} \right]$

b = Width of the base

e = Eccentricity of force

T_{na} = Allowable bearing capacity

P_{max} = Maximum pressure

* Factor of Safety should not be less than 3 for safe design.

Methods used for drainage of the backfill

A) Weep holes:

* These are provided in the walls

* The diameter of weep holes is

block the backfill material

* The weep holes have a spacing which varies from 1.5 m to 3m in the transverse direction

B) Drainage Filters

* Fine grained soils, cause large earth pressure against retaining walls, which is used as a backfill material

* The granular material should be applied in the sliding wedge portion of the wall for good draining.

* By placing coarse permeable material behind the retaining wall, the development of excessive pore water pressure is controlled

* The two types of drainage filters commonly used are (1) Vertical Filter (2) Inclined Filter

* The percolated water in the filter gets discharged from the weep holes.

* The vertical filter is less effective when compared to the inclined filter

*. It discharge water collected by
backfill

*. The filter material is positioned around
the perforated pipes.

Determine the passive pressure by

Rankine's theory per unit run for a

retaining wall 4m high, with $i = 15^\circ$, $\phi' = 30^\circ$
and $\gamma = 19 \text{ kN/m}^3$. The back face of wall

is smooth and vertical

A. Given

Height of retaining wall, $H = 4\text{m}$

$\phi' = 30^\circ$, $i = 15^\circ$, $\gamma = 19 \text{ kN/m}^3$

$$K_p = \cos i \times \frac{\cos i + \sqrt{\cos^2 i - \cos^2 \phi'}}{\cos i - \sqrt{\cos^2 i - \cos^2 \phi'}}$$

$$= \cos 15^\circ \times \frac{\cos 15^\circ + \sqrt{\cos^2(15^\circ) - \cos^2(30^\circ)}}{\cos 15^\circ - \sqrt{\cos^2(15^\circ) - \cos^2(30^\circ)}} = 2.45$$

Passive earth pressure

$$P_p = \frac{1}{2} K_p \gamma H^2 = \frac{1}{2} \times 2.45 \times 19 \times 4^2 = 372.4 \text{ kN}$$

$$P_p = 372.4 \text{ kN}$$

A retaining wall was a smooth vertical back and is 8.5 m in height. It retains a horizontal backfill of sand with $\phi = 33^\circ$. Find out the total active earth pressure per meter length of wall. If $\gamma = 18 \text{ kN/m}^3$ and

$$\gamma_{\text{sat}} = 20 \text{ kN/m}^3$$

a. The water table is far below the base of the wall

b. The water table rises upto 4.0 m level above the base

1. Horizontal Soil Surface:

$$K_a = \frac{(1 - \sin \phi)}{(1 + \sin \phi)} = \frac{1 - \sin 33^\circ}{1 + \sin 33^\circ} = 0.294$$

$$P_{a1} = \frac{1}{2} K_a \gamma H^2 = \frac{1}{2} \times 0.294 \times 18 \times 8.5^2 = 191.17 \text{ kN/m}$$

2. Slopping Soil surface

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

$$\beta = \phi = 33^\circ$$

$$K_a = \cos 33^\circ \frac{\cos 33^\circ - \sqrt{(\cos 33^\circ)^2 - (\cos 33^\circ)^2}}{\cos 33^\circ + \sqrt{(\cos 33^\circ)^2 - (\cos 33^\circ)^2}} = 0.838$$

$$P_{a2} = \frac{1}{2} K_a \gamma H^2 = \frac{1}{2} \times 0.838 \times 18 \times 8.5^2 = 611.17 \text{ kN/m}$$

Calculate the Factor of Safety with respect to cohesion of a clay slope laid at $1 \text{ in } 2$ to a height of 10 m , if the angle of internal friction $\phi = 10^\circ$, $c = 25 \text{ kN/m}^2$ and $\gamma = 19 \text{ kN/m}^3$.

What will be the critical height of the slope in this soil?

A. $i = \tan^{-1} \frac{1}{2} = 26.5^\circ$

$i = 26.5^\circ$, $\phi = 10^\circ$, $S_n = 0.064$

$$S_n = \frac{c}{F_c \gamma H}$$

$$F_c = \frac{c}{S_n \gamma H} = \frac{25}{0.064 \times 19 \times 10} = 2.06$$

The critical height H_c is given by

$$H_c = F_c H = 2.06 \times 10 = 20.6 \text{ m}$$

Alternatively, $H_c = \frac{c}{\gamma \sqrt{S_n}} = \frac{25}{19 \times 0.064} = 20.6 \text{ m}$

$$H_c = 20.6 \text{ m}$$