Lateral Earth Pressures and Retaining Walls

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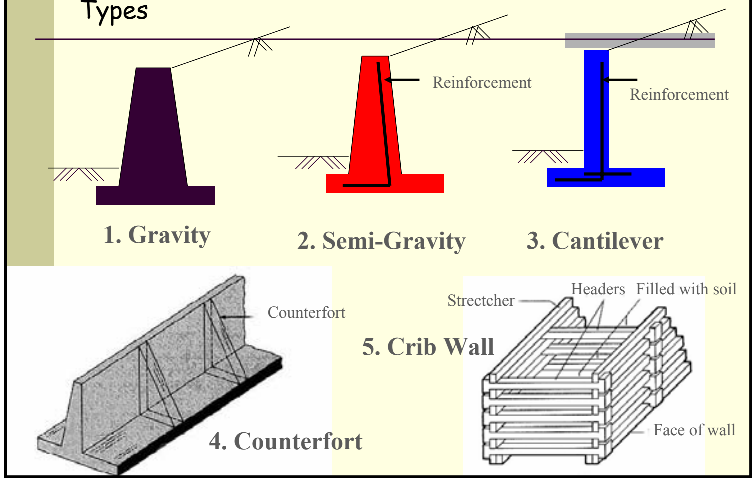
RETAINING WALLS

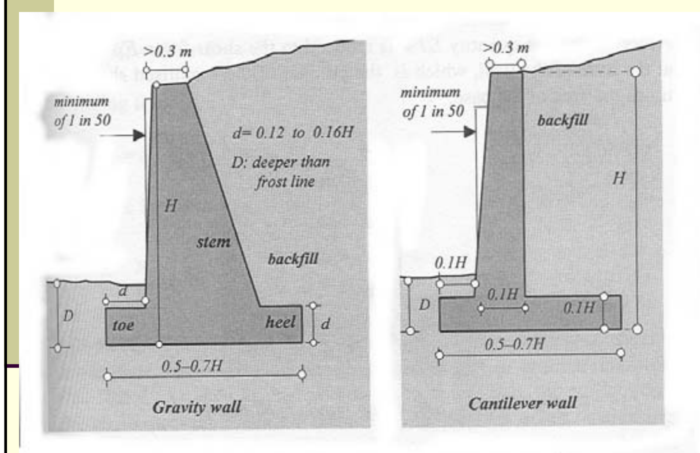
are usually built to hold back soil mass

Types



Design

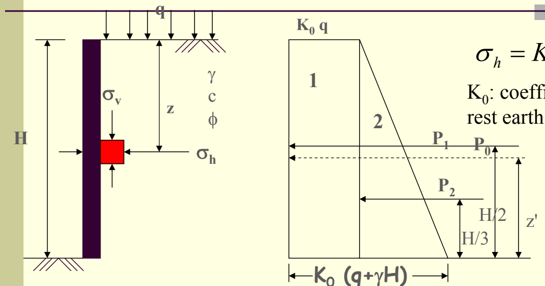
- Basic soil parameters;
  - Unit weight of soil
  - Angle of friction
  - Cohesion
- Then the lateral pressure distribution will be known.
- There are 2 phases in the design of a retaining wall;
  - The retaining wall is checked for stability: overturning, sliding and bearing capacity failures.
  - Each component of the retaining wall is checked for adequate strength and the steel reinforcement.



Empirical relationships related to the design of walls (Azizi, 2000)

Lateral Earth Pressure

At Rest



$$\sigma_h = K_0 \sigma'_v + u$$

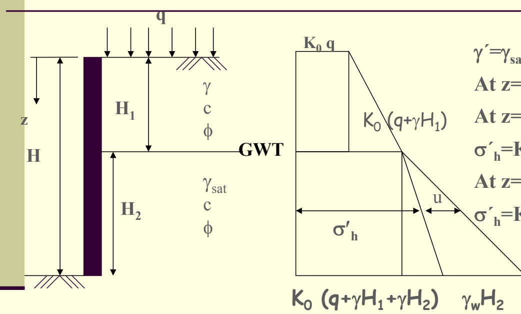
K_0: coefficient of at-rest earth pressure

The total force: $P_0 = P_1 + P_2 = qK_0H + \frac{1}{2}H^2K_0\gamma$ where $K_0 = 1 - \sin\phi$

$$z' = \frac{P_1\left(\frac{H}{2}\right) + P_2\left(\frac{H}{3}\right)}{P_0}$$

for normally consolidated soil

- If the water table is located at depth z<H, the at-rest pressure diagram will be as shown.



$\gamma' = \gamma_{sat} - \gamma_w$

At z=0, $\sigma'_h = K_0\sigma'_v = K_0 q$

At z=H$_1$,

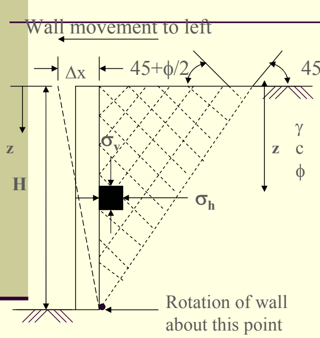
$\sigma'_h = K_0\sigma'_v = K_0(q+\gamma H_1)$

At z=H$_2$,

$\sigma'_h = K_0\sigma'_v = K_0(q+\gamma H_1+\gamma' H_2)$

$$P_0 = K_0 q H_1 + \frac{1}{2}K_0 H_1^2\gamma + K_0(q + H_1\gamma)H_2 + \frac{1}{2}K_0 H_2^2\gamma' + \frac{1}{2}\gamma_\omega H_2^2$$

Rankine Active Earth Pressure



The Mohr's circle will touch the Mohr-Coulomb failure envelope representing the failure condition in the soil mass. $\sigma_h = \sigma_a$, where σ_a is the Rankine active pressure.

The Mohr-Coulomb failure envelope is defined by;

$\tau = c + \sigma \tan\phi$

- Relating the principal stresses for a Mohr's circle that touches the Mohr-Coulomb failure envelope;

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

$\sigma_1 = \sigma_v$ and $\sigma_3 = \sigma_a$

Thus $\sigma_v = \sigma_a \tan^2\left(45 + \frac{\phi}{2}\right) + 2c\tan\left(45 + \frac{\phi}{2}\right)$

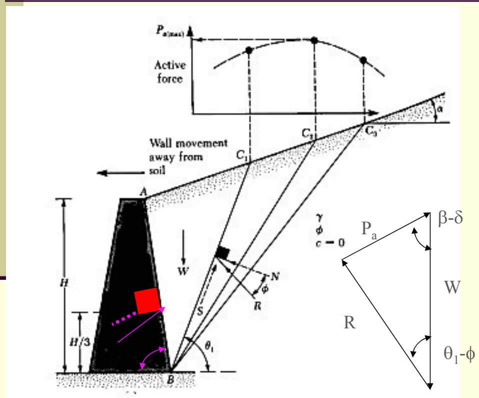
$\sigma_a = \sigma_v K_a - 2c\sqrt{K_a}$

where $K_a = \tan^2(45 - \phi/2)$; Rankine active pressure coefficient

However the active earth pressure condition will be reached only if the wall is allowed to 'yield' sufficiently.

The amount of outward displacement of the wall necessary is about 0.001H to 0.004H for granular soil backfills and about 0.01H to 0.04H for cohesive backfills.

Coulomb's Active Earth Pressure



β is the angle, the back face of the retaining wall makes with the horizontal.

α is the angle that the backfill makes with the horizontal.

δ is the angle of friction between the soil and the wall.

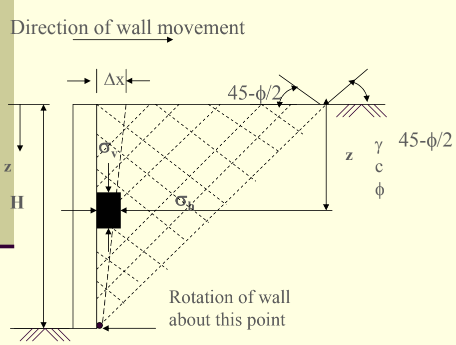
- The active force per unit length of the wall, P_a will be inclined at an angle of δ to the normal to the back face of the wall.

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

H: height of wall

The value of the wall friction angle, δ is between ϕ/2 and 2ϕ/3.

Rankine Passive Earth Pressure

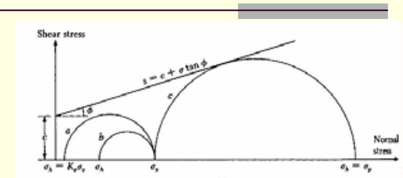


The horizontal stress σ_h at this point is referred to as the Rankine passive pressure,

$\sigma_p = \sigma_v K_p + 2c\sqrt{K_p}$

where $K_p = \tan^2(45+\phi/2)$; Rankine passive earth pressure coefficient

Rankine Passive Earth Pressure

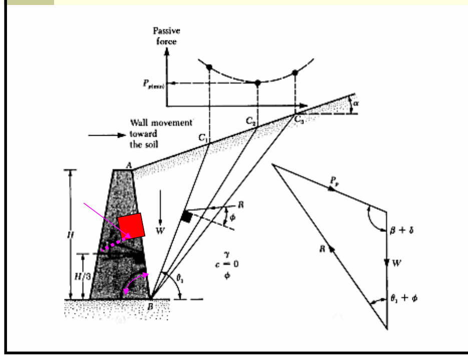


The magnitude of the wall movements, Δx required to develop failure under passive conditions are;

Soil Type	Δx (for passive condition)
Dense sand	0.005H
Loose sand	0.01H
Stiff clay	0.01H
Soft clay	0.05H

Coulomb's Passive Earth Pressure

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

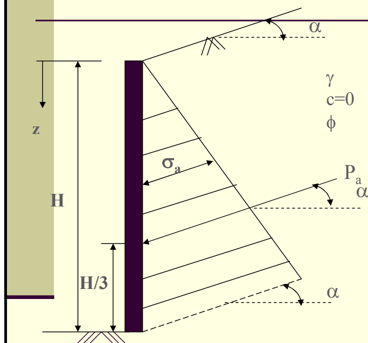


K_p: Coulomb's passive pressure coefficient

Range of Wall Friction Angle

Backfill material	δ(°)
Gravel	27-30
Coarse sand	20-28
Fine sand	15-25
Stiff clay	15-20
Silty clay	12-16

Rankine Active and Passive Earth Pressure for Inclined Granular Backfill



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

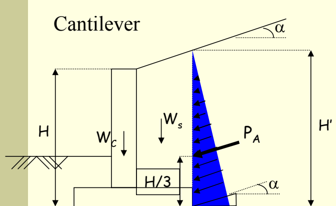
$$K_a = \frac{\cos\alpha-\sqrt{\cos^2\alpha-\cos^2\phi}}{\cos\alpha+\sqrt{\cos^2\alpha-\cos^2\phi}}\cos\alpha$$

$$P_p = \frac{1}{2}\gamma H^2 K_p$$

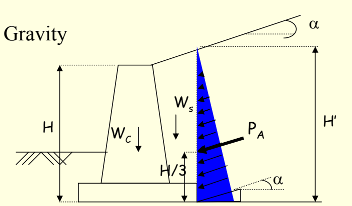
$$K_p = \frac{\cos\alpha+\sqrt{\cos^2\alpha-\cos^2\phi}}{\cos\alpha-\sqrt{\cos^2\alpha-\cos^2\phi}}\cos\alpha$$

Application of Lateral Earth Pressure Theories to Design

Cantilever

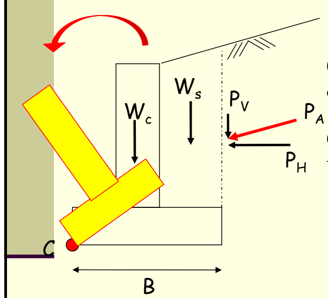


Gravity



Retaining Wall Stability

1) Safety Against Overturning (Rotational stability) :



Consider forces W_C, W_S, P_V, P_H
Take moment w.r.t '**C**' (TOE)
clockwise : resisting (M_R) (W_C, W_S, P_V) a.clockwise :overturning (M_O) (P_H)

if not increase the base 'B' ;use piles ;increase wall dimensions.

- F_s=2 (for cohesive backfill) and 1.5 (for granular backfill)

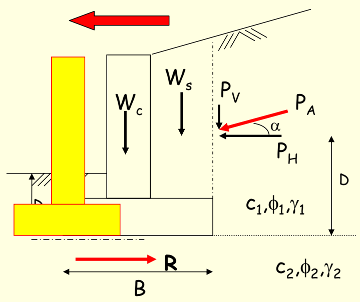
Retaining Wall Stability

2) Safety Against Base Sliding :

Driving Force : P_H
Ignore : P_V
Resisting force : R

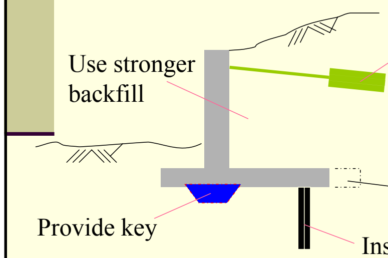
$$R = c_2 B + (\Sigma V)\tan\phi_2 + P_p$$

$$Fs = \frac{c_2 B + (\Sigma V)\tan\phi_2 + P_p}{P_A \cos\alpha} \geq 1.5$$



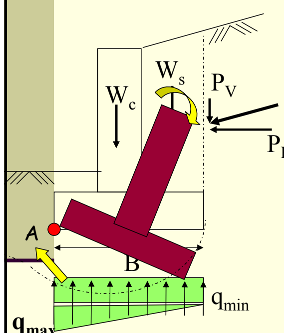
If base key : $P_p = \frac{1}{2}\gamma_2 D_1^{\,2} K_p + 2c_2 D_1\sqrt{K_p}$

use reduced c_2 and ϕ_2 (ϕ_{design}=(0,5~0,67) ϕ_2 , c_{design}= =(0,5~0,67) c_2)
if not increase B ; provide key ;stronger backfill (import soil ∴ expansive) ; install tiedown anchors

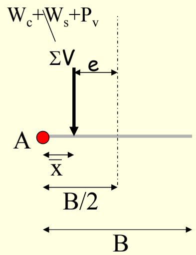


3) Bearing capacity failure. F_s=3=q_u/q_{max}

Base Pressures :



q_{all} : allowable bearing capacity of foundation soil



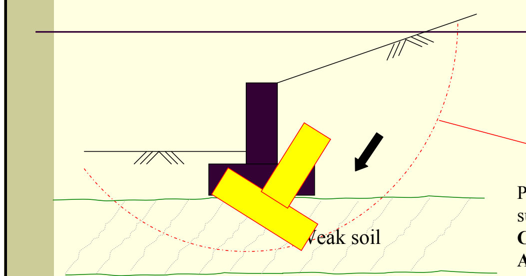
$$\bar{x} = \frac{\Sigma M_R - \Sigma M_D}{\Sigma V}$$

$$e = \frac{B}{2} - \bar{x}$$

$$q_{\substack{max \\ min}} = \frac{\Sigma V}{B*1}\left(1 \pm \frac{6e}{B}\right)$$

$q_{min} > 0$ (no tension)
$q_{max} < q_{all}$

4) Deep Seated Shear Failure :



Possible failure surface
CONVENTIONAL ANALYSIS

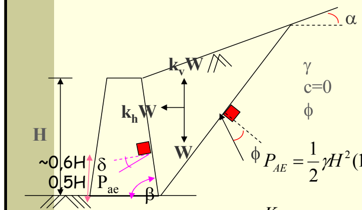
5) CHECK FOR SETTLEMENTS (Conventional) :
6) REINFORCEMENT DESIGN (Structural Design) :

Comments Relating to Stability

- The lateral force of the backfill will depend on (Casagrande, 1973);
  - Effect of temperature (freeze and thaw),
  - Groundwater fluctuation,
  - Readjustment of the soil particles due to creep and prolonged rainfall,
  - Tidal changes,
  - Heavy wave action,
  - Traffic vibration,
  - Earthquakes.

Gravity Retaining-Wall Design for Earthquake Conditions

Coulomb's active earth pressure theory can be extended to take into account the forces caused by an earthquake.



$$k_h = \frac{horizontal\ \ EQ\ \ acc.comp.}{acc.due\ \ to\ \ gravity\ \ ,g}$$

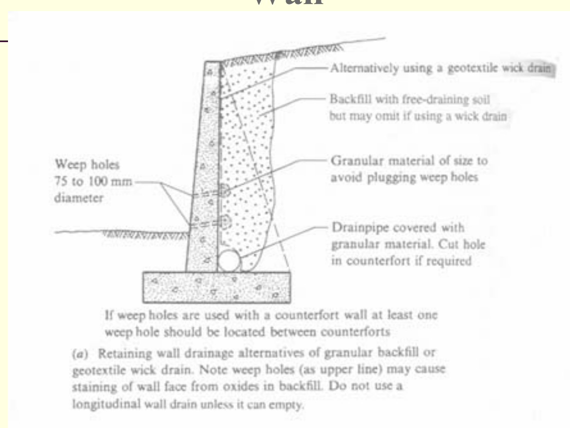
$$k_v = \frac{vertical\ \ EQ\ \ acc.comp.}{g}$$

$$P_{AE} = \frac{1}{2}\gamma H^2(1-k_v)K_{AE}$$

$$K_{AE} = \frac{\sin^2(\phi+\beta-\theta)}{\cos\theta\sin^2\beta\sin(\beta-\theta-\delta)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta-\alpha)}{\sin(\beta-\delta-\theta)\sin(\alpha+\beta)}}\right]^2}$$

$$\theta = \tan^{-1}\left[\frac{k_h}{1-k_v}\right]$$

Drainage from the Backfill of the Retaining Wall



Bowles, 1997

Sheet Pile Walls

➢are widely used for both large and small waterfront structures.

➢used for

➢Beach erosion protection

➢Stabilizing ground slopes

➢Shoring walls of trenches and other excavations and for cofferdams.

Sheet Pile Walls

Types:

- Wooden
- Precast concrete
- Steel

Construction Methods:

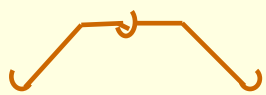
1. Backfilled structure
2. Dredged structure

Sheet Piles can be categorised as:

a) Cantilever
b) Anchored

Sheet pile connections:

a) Thumb and finger type



b) Ball and socket type

Sheet Pile Walls

Cantilever Sheet Pile Walls

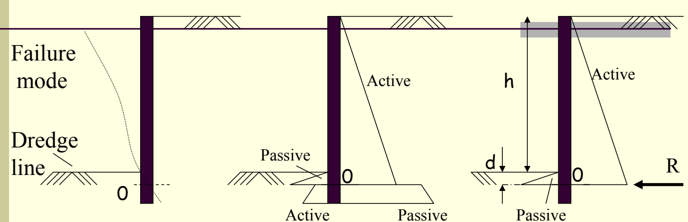
-Used for small retaining height (20 ft ≅ 6 m above dredge line)

Permanent : sands, gravels

Temporary : other soils

-Stability of cantilever sheet pile wall : due to passive resistance developed below the lower soil surface

Cantilever Sheet Pile Walls



*fixing moment at 0

Design Idealisation

Net Passive Resistance below '0' : given with '**R**' .

⇒ design : $\Sigma M_c = 0$ → determine 'd'.

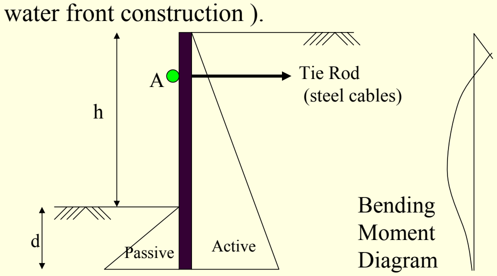
Then 'd' is increased arbitrarily by %20 to allow for simplification of procedure . (1.2d : embedment)

$\Sigma F_h = 0$ → determine R

(Check $P_p \geq R$ / over 0,2d)

Anchored Sheet Pile Walls

Additional support to sheet pile walls can be given by backs (anchored) near the top of the wall (Used in deep excavation & water front construction).



Note: depth of tension crack < depth of tie.

Anchored Sheet Pile Walls

DESIGN PROCEDURE:

1- Calculate Active & Passive Pressures in terms of (unknown) depth of embedment , ‘d’ .

2- Usually Fs=2 is applied to passive pressures

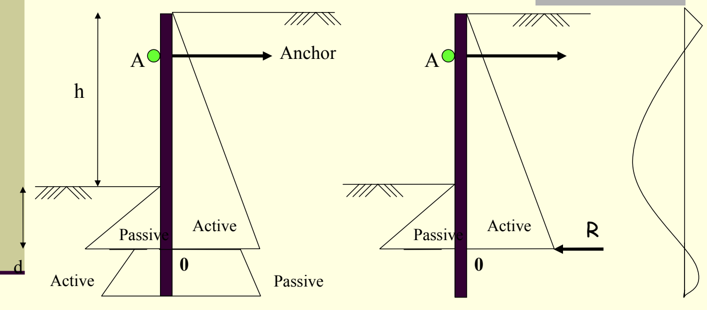
3- Take $\Sigma M_A = 0$; obtain cubic equation in terms of ‘d’. Solve for ‘d’. Increase d by 20% in quay walls.

4- Take $\Sigma F_h = 0$; solve for T.

5- Plot moment diagram & determine maximum bending moment. Determine required cross section.

Sheet Piles with Anchors

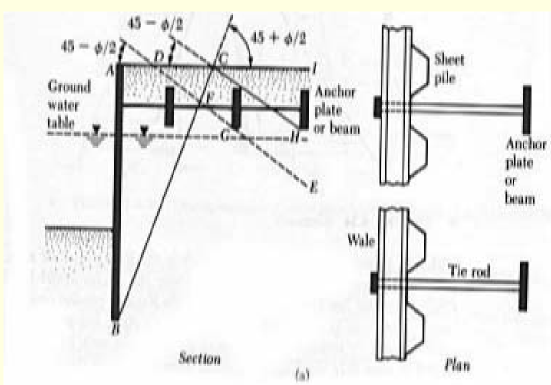
When there is a deep excavation



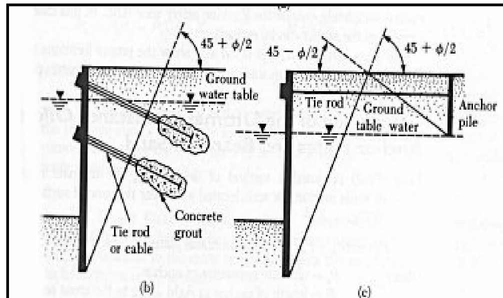
Note: Solved with equivalent beam method.

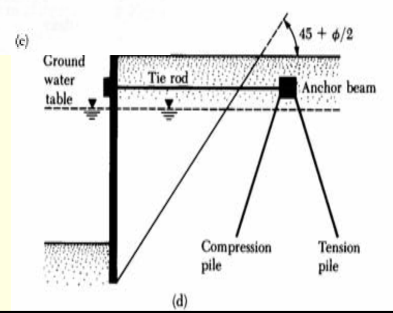
Types of anchor used in sheet pile walls are:

1. Anchor plates and beams
2. Tie backs
3. Vertical anchor piles
4. Anchor beams supported by batter (compression and tension) piles



Das, 1995



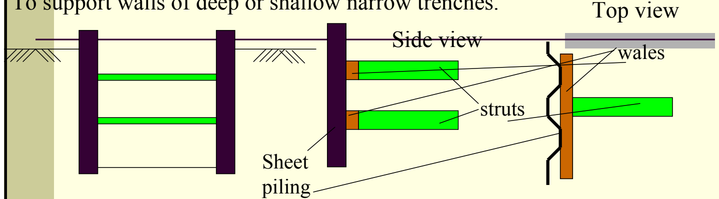


Das, 1995

Braced Cuts (Braced Excavations)

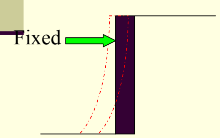
Systems to support the sides of excavations

To support walls of deep or shallow narrow trenches.

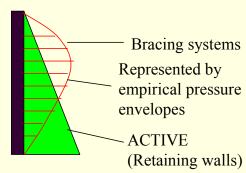


EARTH PRESSURES AGAINST BRACING SYSTEMS

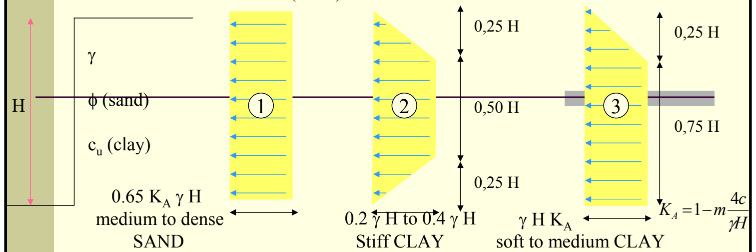
Braced Cuts:



Earth Pressure function of Wall Displacement:



TERZAGHI & PECK (1967) EMPIRICAL PRESSURE DIAGRAMS



TERZAGHI & PECK (1967) EMPIRICAL PRESSURE DIAGRAMS

1) 0,65 Times Rankine Active

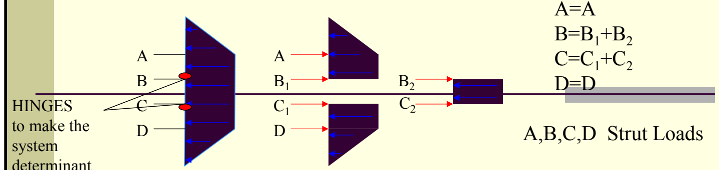
2) N:stability number $N = \frac{\gamma H}{c_u}$ if $N < 4$ (elastic equilibrium)

3) $N > 4$ plastic equilibrium at the bottom ($N = \gamma H / c_u > 4$)

m is usually 1,0 , but m=0,4 for soft NC clays.

4) $N > 7$ Heaving

Strut Loads:



A=A

$B = B_1 + B_2$

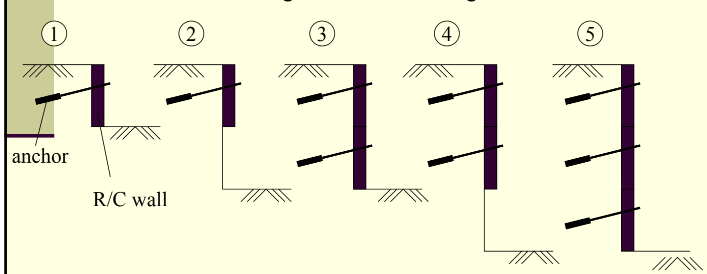
$C = C_1 + C_2$

D=D

A,B,C,D Strut Loads

Braced Cuts

Wall construction & anchorage installation in stages.



REINFORCED EARTH

Reinforced earth is a construction material comprising soil that has been strengthened by tensile elements such as metal rods and/or strips, nonbiodegradable fabrics (geotextiles), geogrids.

The beneficial effects of soil reinforcement derive from

a) soil's increased tensile strength and

b) the shear resistance developed from the friction at the soil-reinforcement interfaces.

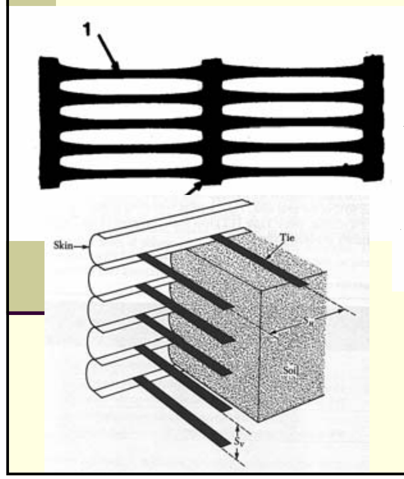
REINFORCED EARTH

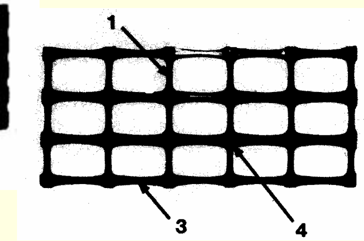
Geotextiles have four primary uses in foundation engineering:

1. Drainage
2. Filtration
3. Separation
4. Reinforcement – increases the load-bearing capacity of the soil

REINFORCED EARTH

Two types of geogrids: a) Biaxial and b) Uniaxial





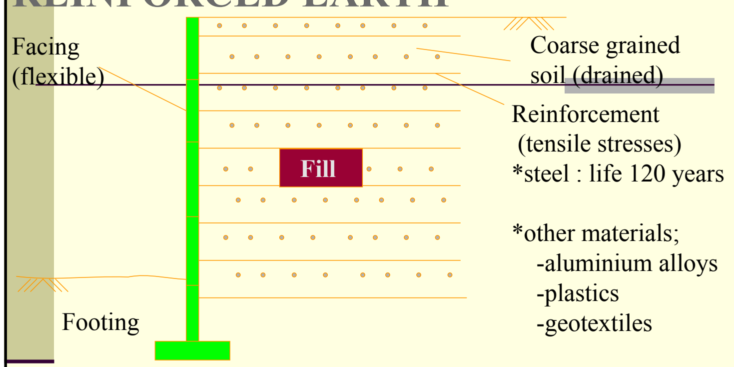
1.Longitudinal rib

2.Transverse bar

3.Transverse rib

4. Junction

REINFORCED EARTH



FACING : *Pre-cast concrete units (limited relative movement)
*U-shaped steel sections arranged horizontally

COST : *more economic than concrete cantilever retaining wall

FAILURE : *Tensile failure of one element leads to progressive collapse of the entire structure

*Local slipping leads to redistribution of tensile stress and gradual deformation of structure (not necessarily collapse)

REINFORCED EARTH