

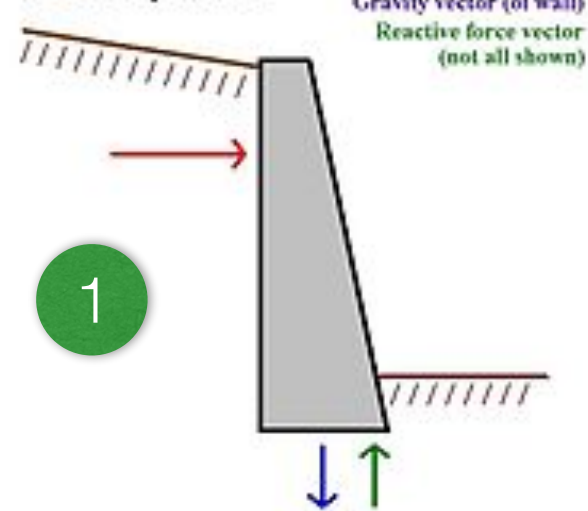
Retaining Walls

Text: Das, 2010. Chapter 13

Retaining walls, basement foundations and bulkheads are common structures that support sloping or vertical earth masses. An understanding of lateral earth pressure is essential here, as in understanding hydrostatic pressure for reservoir design.

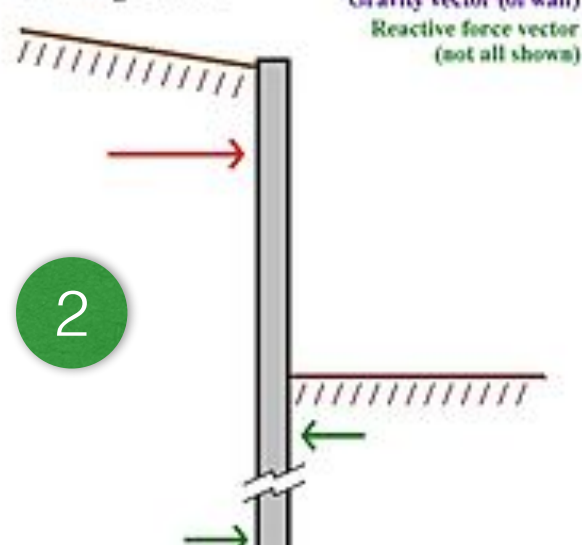
Simplified explanation of typical retaining walls

Gravity wall



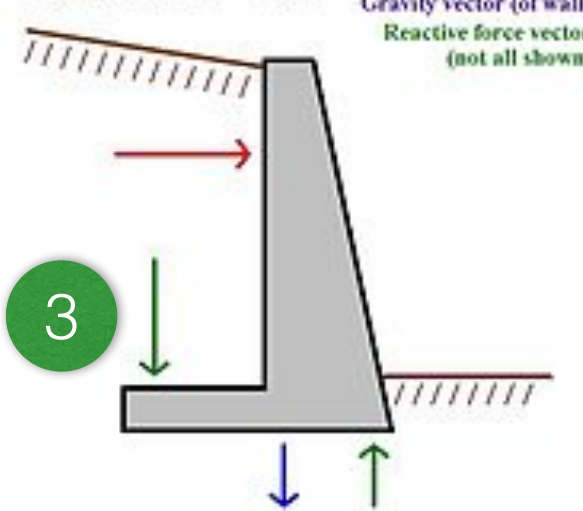
1 Standard wall type that holds the earth mainly through its own weight. Can pivot and topple relatively easily, as the internal leverage of the earth pressure is very high.

Piling wall



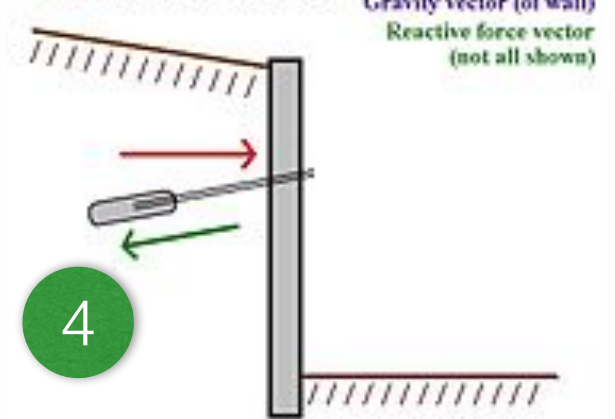
2 Using long piles, this wall is fixed by soil on both sides of its lower length. If the piles themselves can resist the bending forces, this wall can take high loads.

Cantilever wall



3 The cantilever wall (which may also extend in the other direction) uses the same earth pressure trying to topple it to stabilize itself with a second lever arm.

Anchored wall



4 This wall keeps itself from toppling by having cables driven into the soil or rock, fixed by expanding anchors (can be combined with other types of walls).

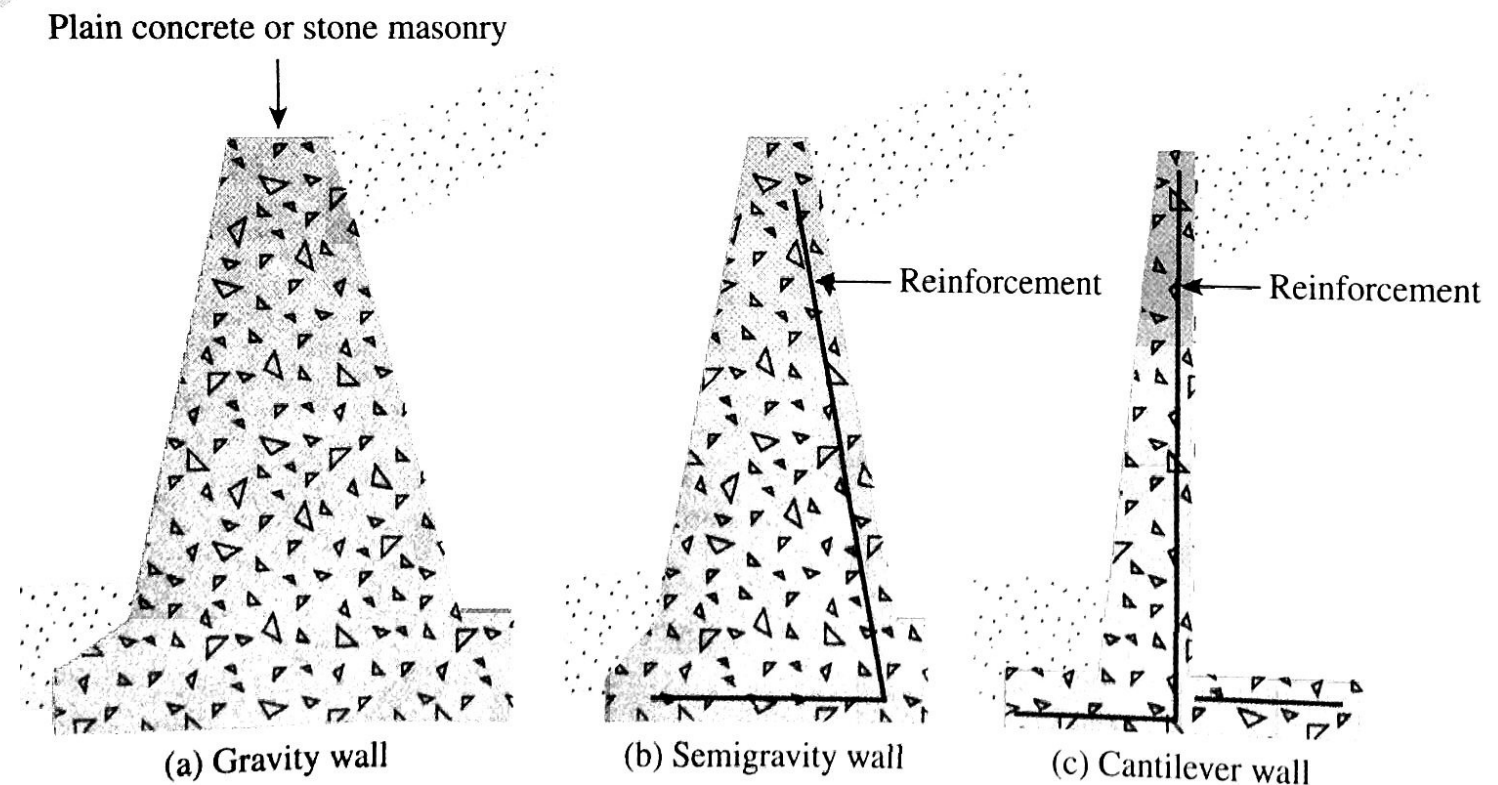
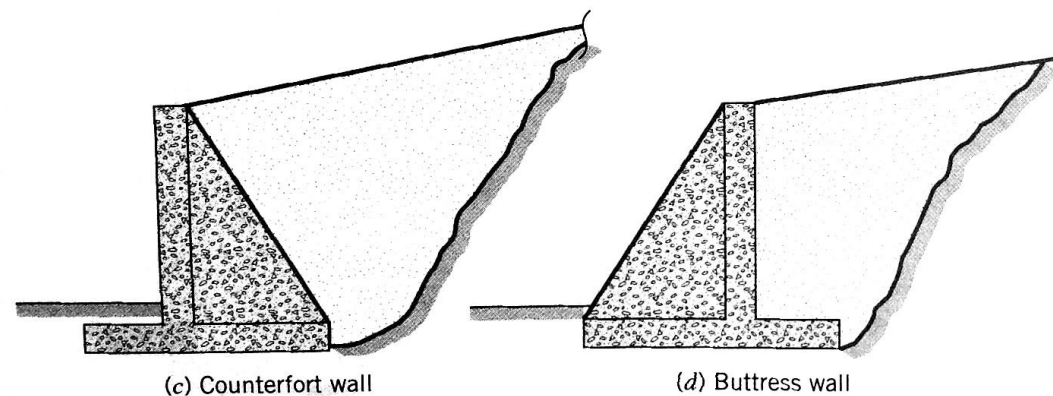
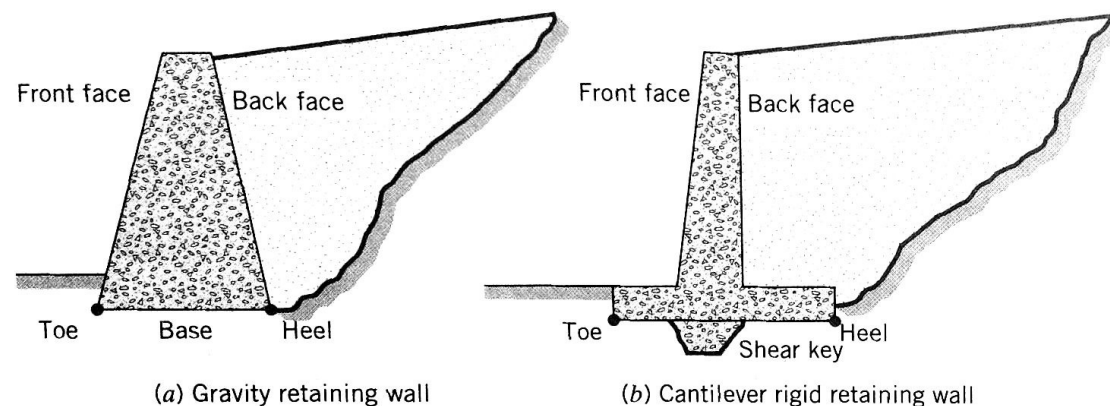
Types of Retaining Walls

There are two general types of retaining walls:

- Rigid
- Flexible

Rigid retaining walls typically involve monolithic reinforced or plain concrete construction and are less common these days.

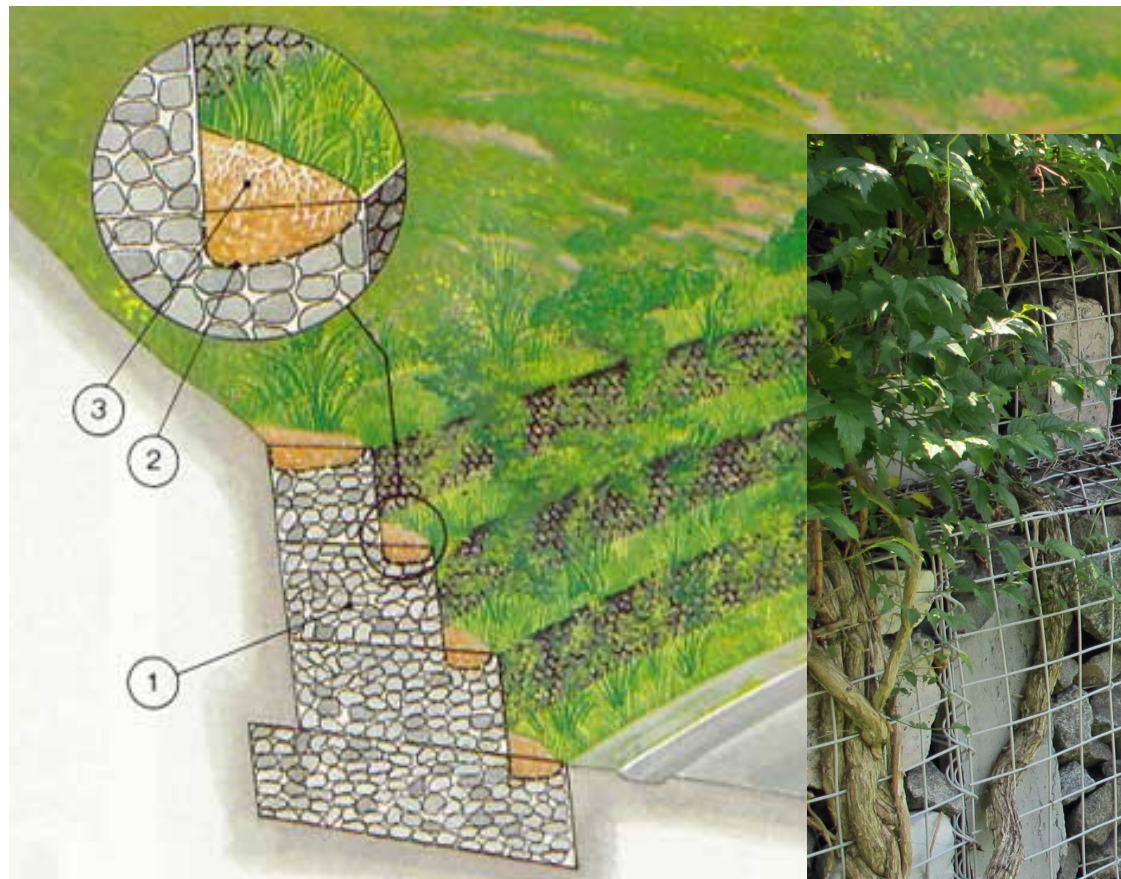
Rigid walls are uneconomical for high lifts. This can be improved somewhat by the use of reinforcing (semi-gravity wall) to reduce the volume of mass concrete.



Types of Retaining Walls

Flexible retaining walls can be prefabricated in units as gabions, cribs or facing panels. These are easier to construct and maintain than gravity walls.

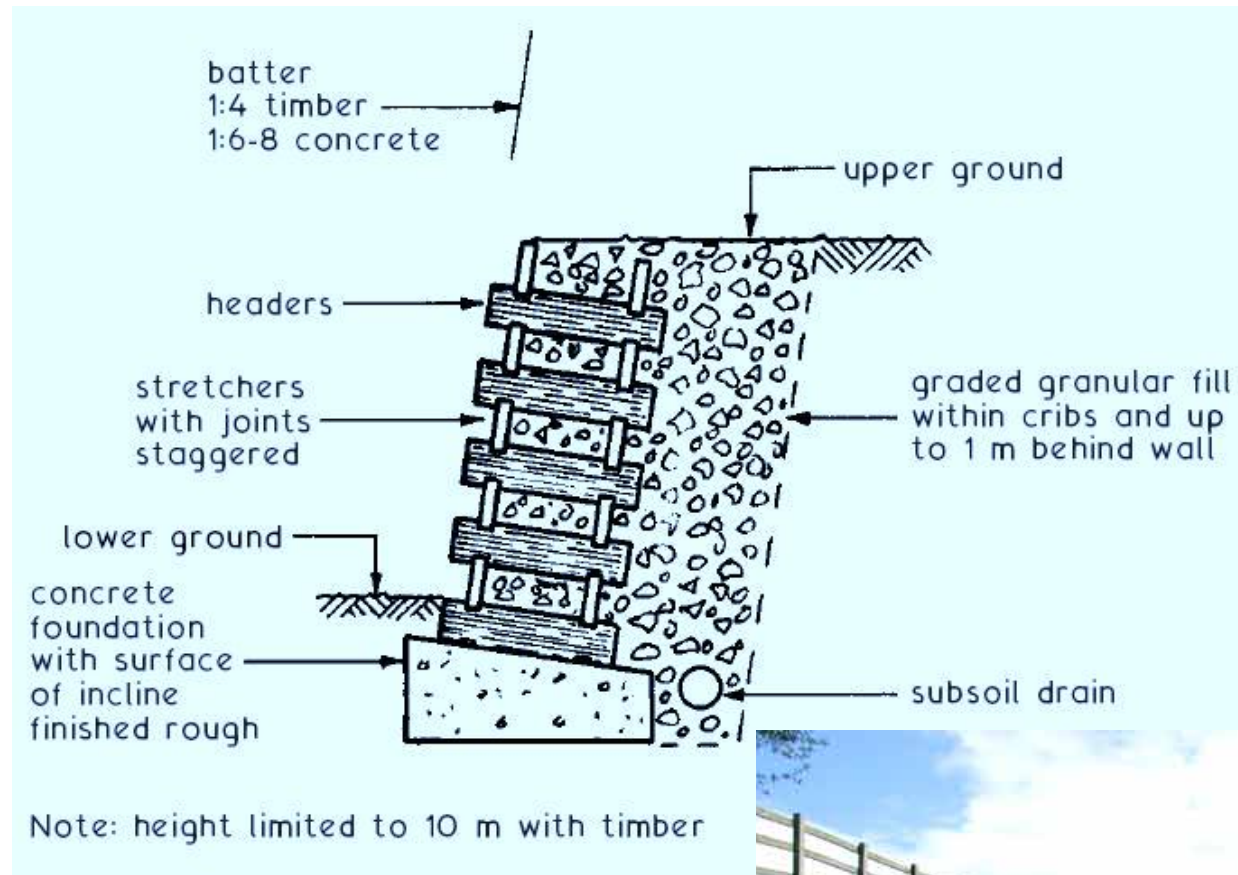
Gabions are blocks of rock rubble in a wire cage. Gabions have excellent drainage and can be manually prefabricated to any required size for handling and fitting. They are very common in domestic construction or to minimise cost.



1. Gabions
2. Geotextile
3. Soil

Types of Retaining Walls

Cribs are prefabricated concrete or treated timber units that fit together into a flexible wall which is backfilled with granular soil as construction proceeds.



Types of Retaining Walls

Mechanically Stabilised Earth (MSE) walls: Facing panels of lightweight precast reinforced concrete are tied into the backfill by galvanised steel or geotextile strips. Ties are sized in a manner similar to concrete reinforcing to ensure sufficient bond development and to interrupt the shear failure surface.



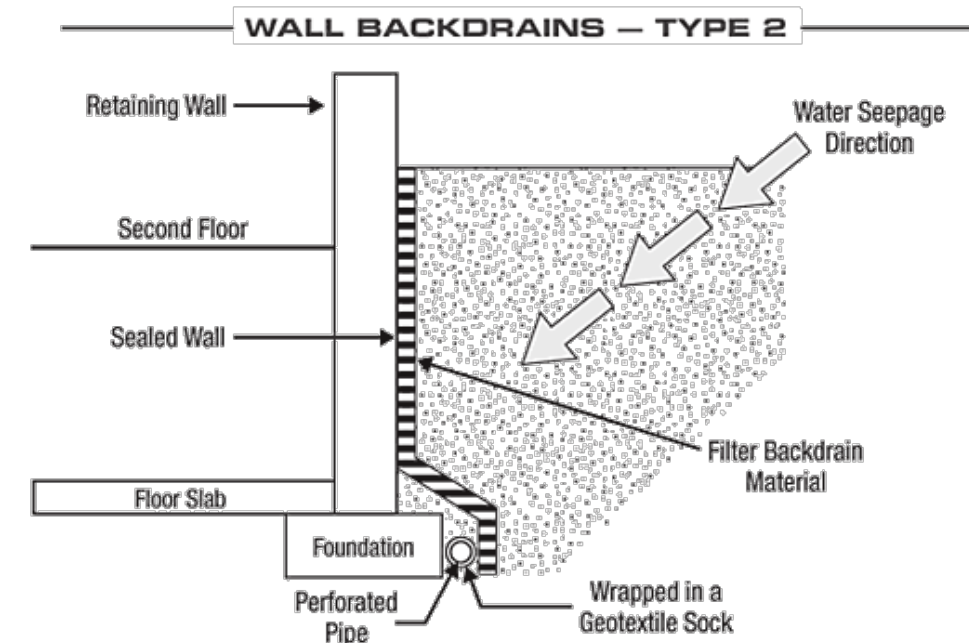
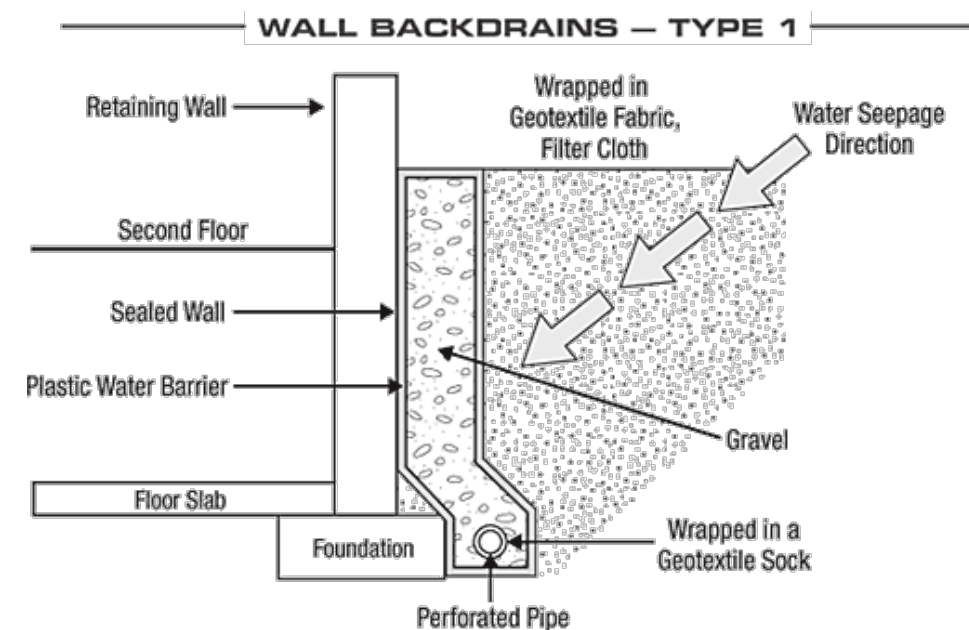
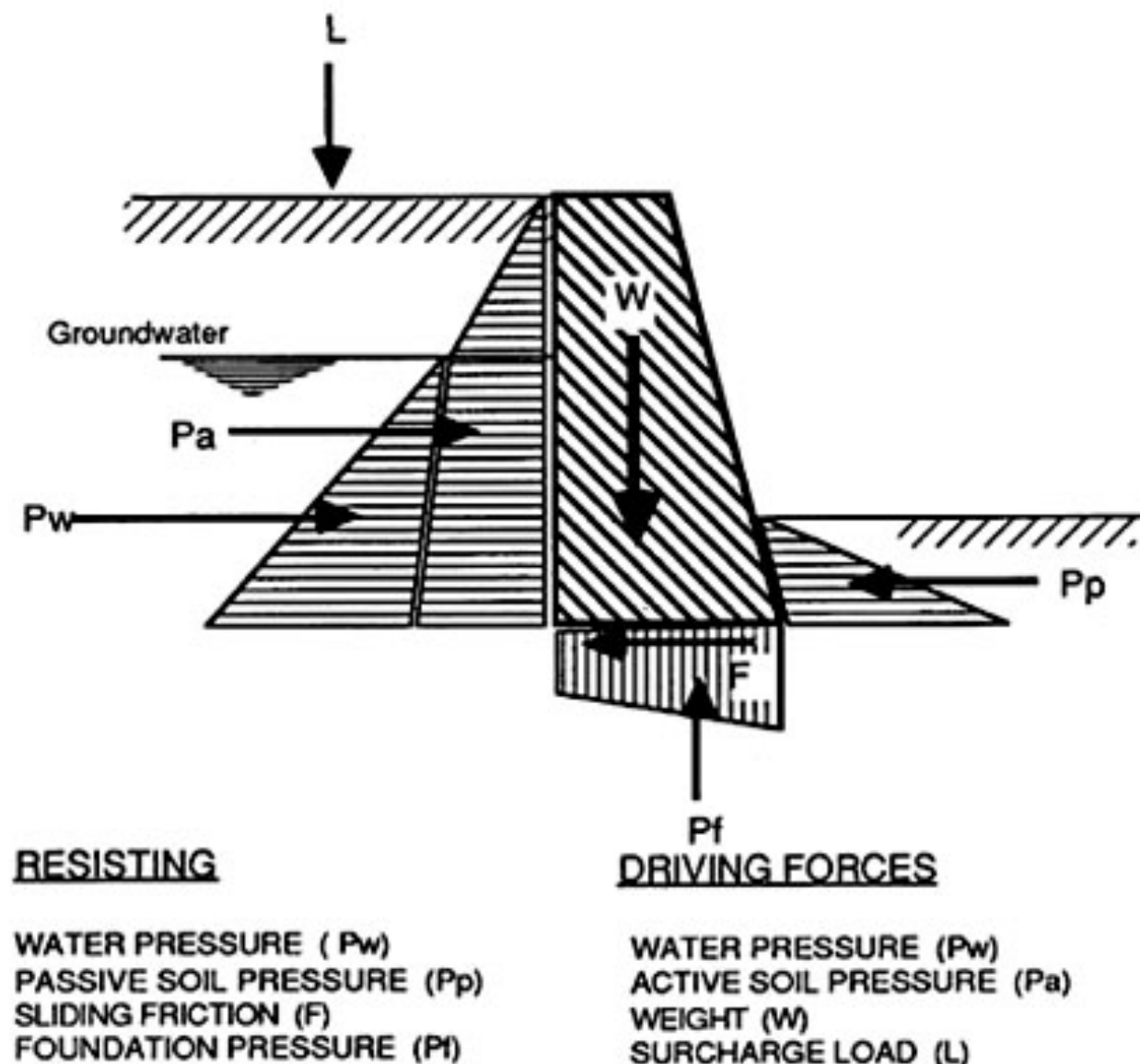
Galvanised steel
geogrid (mesh) or strips



Forces on Retaining Walls

Retaining wall design is based on equilibrium of the structure assuming directed earth pressure (including soil water pressure) on all faces.

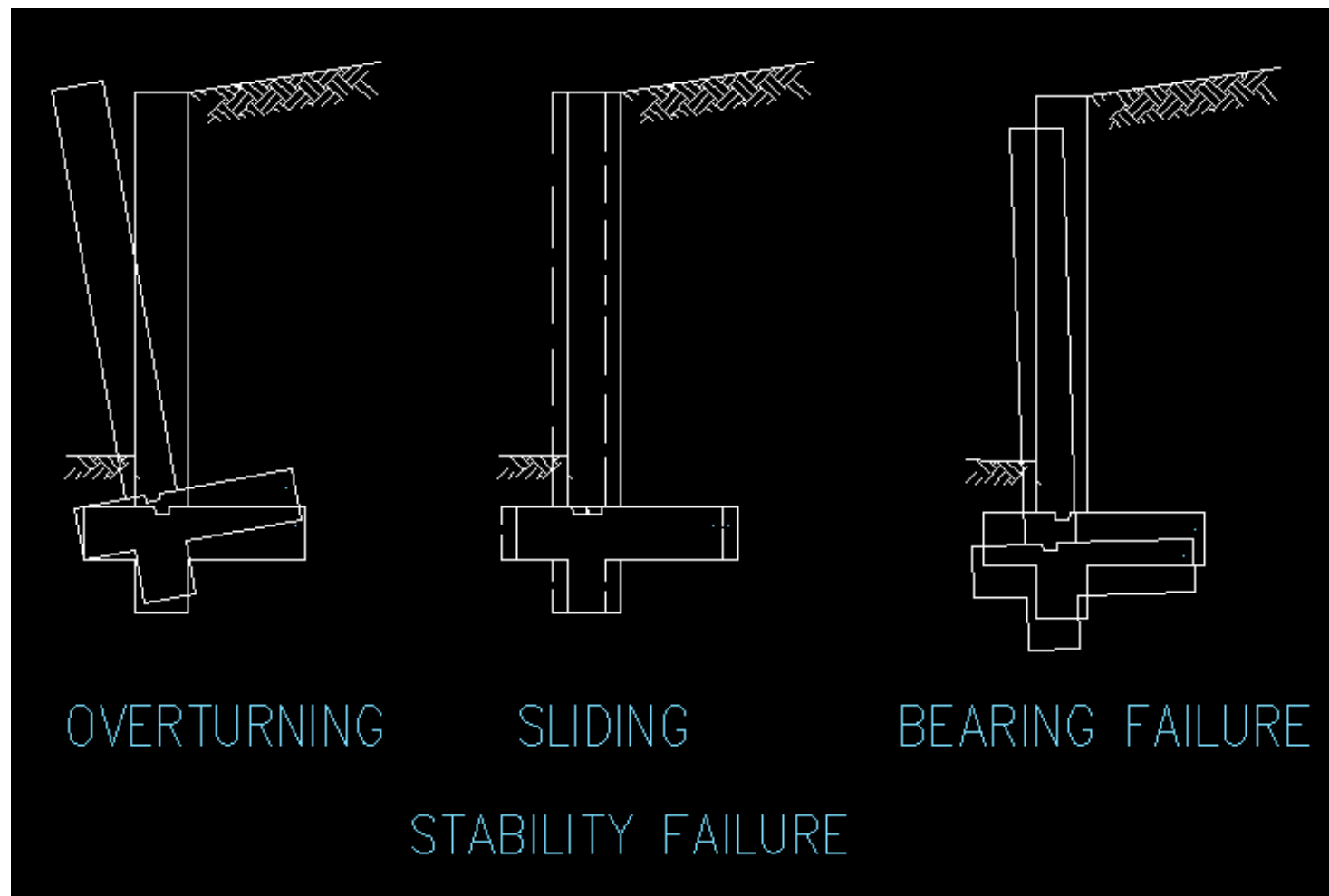
An important consideration is drainage behind the wall, including maintenance of drainage works.



Wall Failure

Retaining walls may fail by a number of mechanisms in response to applied forces.

The main failure mechanisms are rotation (overturning), translation (sliding), settlement (bearing failure), and structural failure of the wall itself:



Wall Failure

The development of movement in a retaining wall does not necessarily indicate that the wall has failed.

Failure may usually be defined in serviceability terms, ie excess deflection that causes alarm with no real risk, or occasionally in structural terms with real (as opposed to perceived) danger:



At-rest, Active and Passive Earth Pressure

Lateral pressure depends on how effectively a retaining structure prevents the retained earth from moving in the lateral direction.

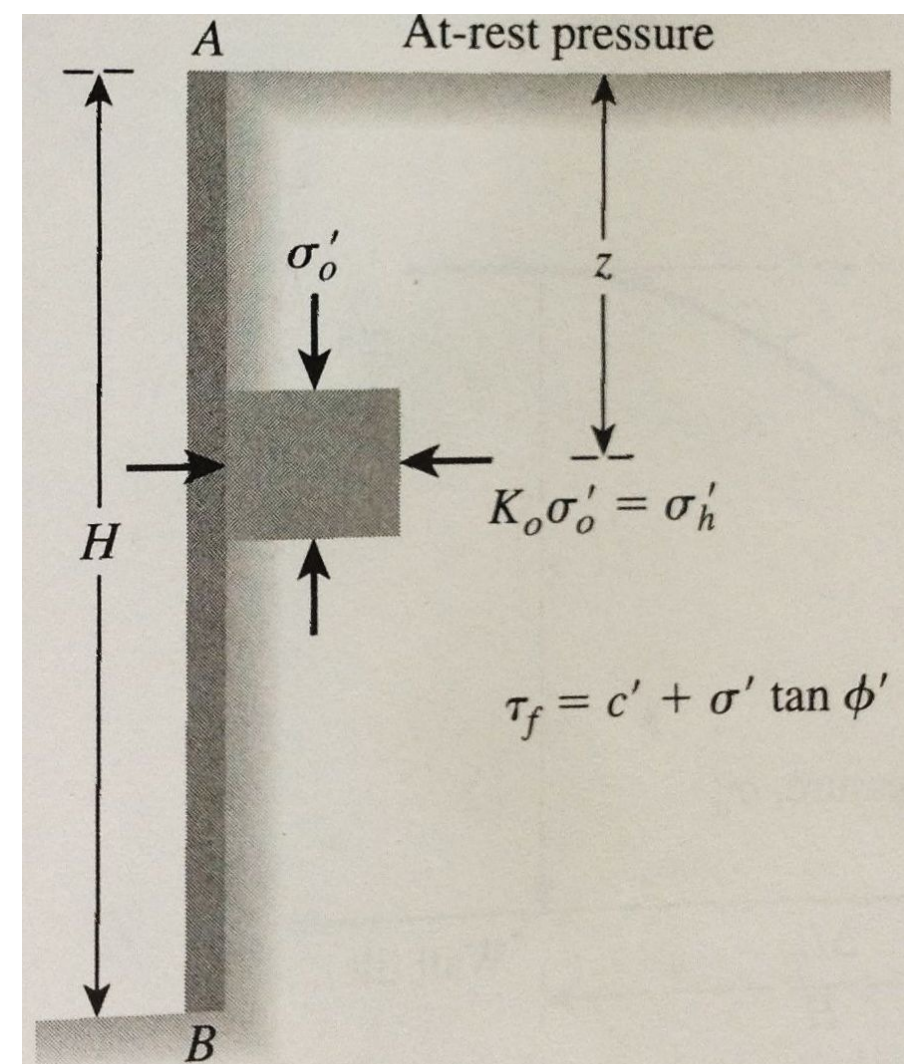
Consider a mass of soil as in the figure. The mass is supported by a frictionless wall of height H . A soil element at depth z is subjected to a vertical effective pressure σ'_o and a horizontal effective pressure σ'_h . There are no shear stress on the horizontal and vertical planes, so σ'_o and σ'_h are principal stresses.

We can define the ratio of horizontal to vertical stresses by an *earth pressure coefficient* K :

$$K = \frac{\sigma'_h}{\sigma'_o}$$

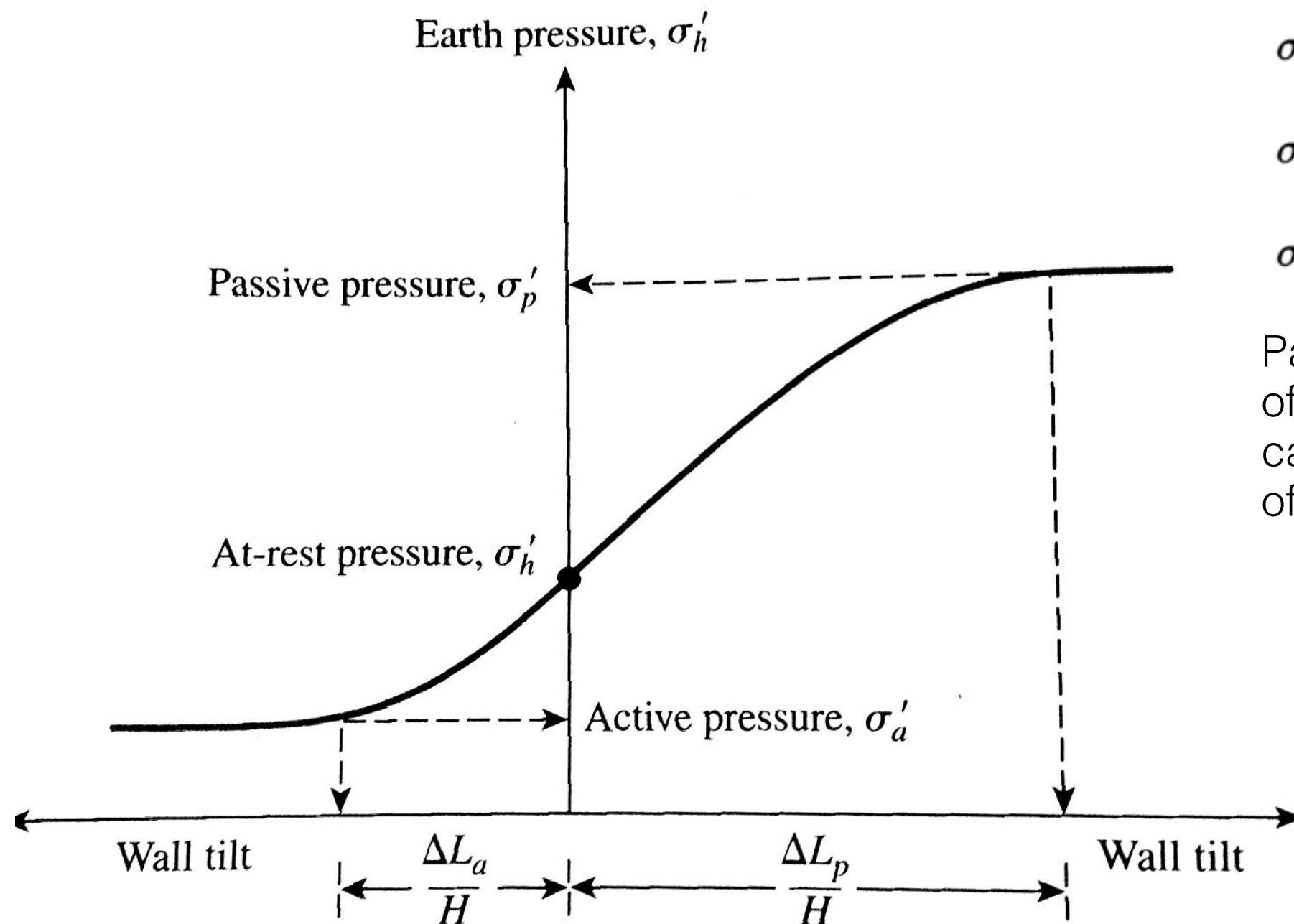
First devised by Rankine (1857), the Rankine Earth Pressure Coefficient depends on the movement (or prevention of movement) of the wall and soil mass:

- If the wall is fixed (no movement) we use an at-rest coefficient $K_o < 1$
- If the wall moves outwards (reduces retaining pressure), the active coefficient $K_a < K_o$ is used
- If the wall moves inwards (increases retaining pressure), the passive coefficient $K_p > 1$



At-rest, Active and Passive Earth Pressure

At-rest soil masses are not easily constructed and may develop either active or passive coefficients as a structure ages. There is no clear dividing line between states - worst case extremes are usually considered.

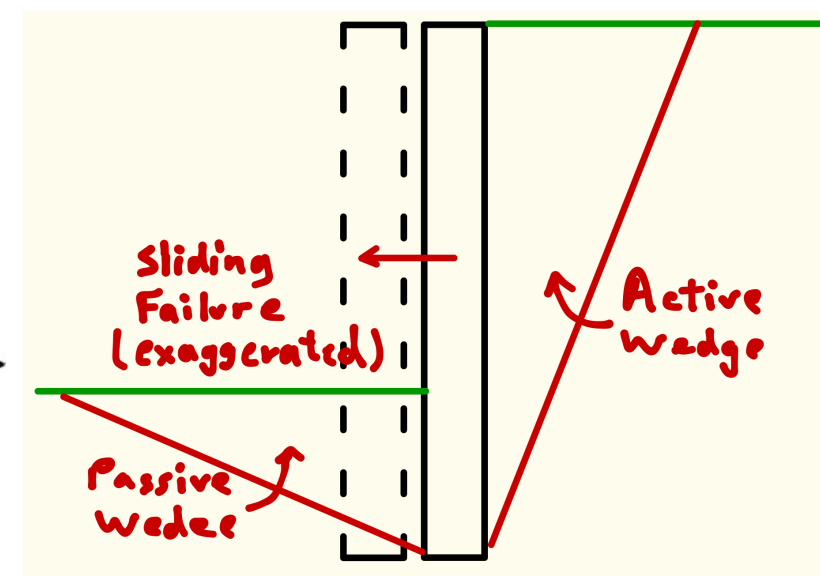


$$\sigma'_h = K_o \sigma'_o \quad \text{At-rest}$$

$$\sigma'_h = K_a \sigma'_o \quad \text{Active}$$

$$\sigma'_h = K_p \sigma'_o \quad \text{Passive}$$

Passive earth pressure often arises due to cantilevering of the base of a retaining structure:



At-rest Earth Pressure

The at-rest coefficient is a function of the effective friction angle ϕ' and the overconsolidation ratio.

Rankine's original theoretical model of at-rest pressure has been replaced by empirical models that account for the effect of these two factors in field situations.

A number of competing empirical models are available. All should be considered in design. No attempt is made here to derive the at-rest coefficient. Validity rests on empirical data which is still open to investigation:

$$K_o = (1 - \sin(\phi'))(OCR)^{\sin(\phi')}$$

or

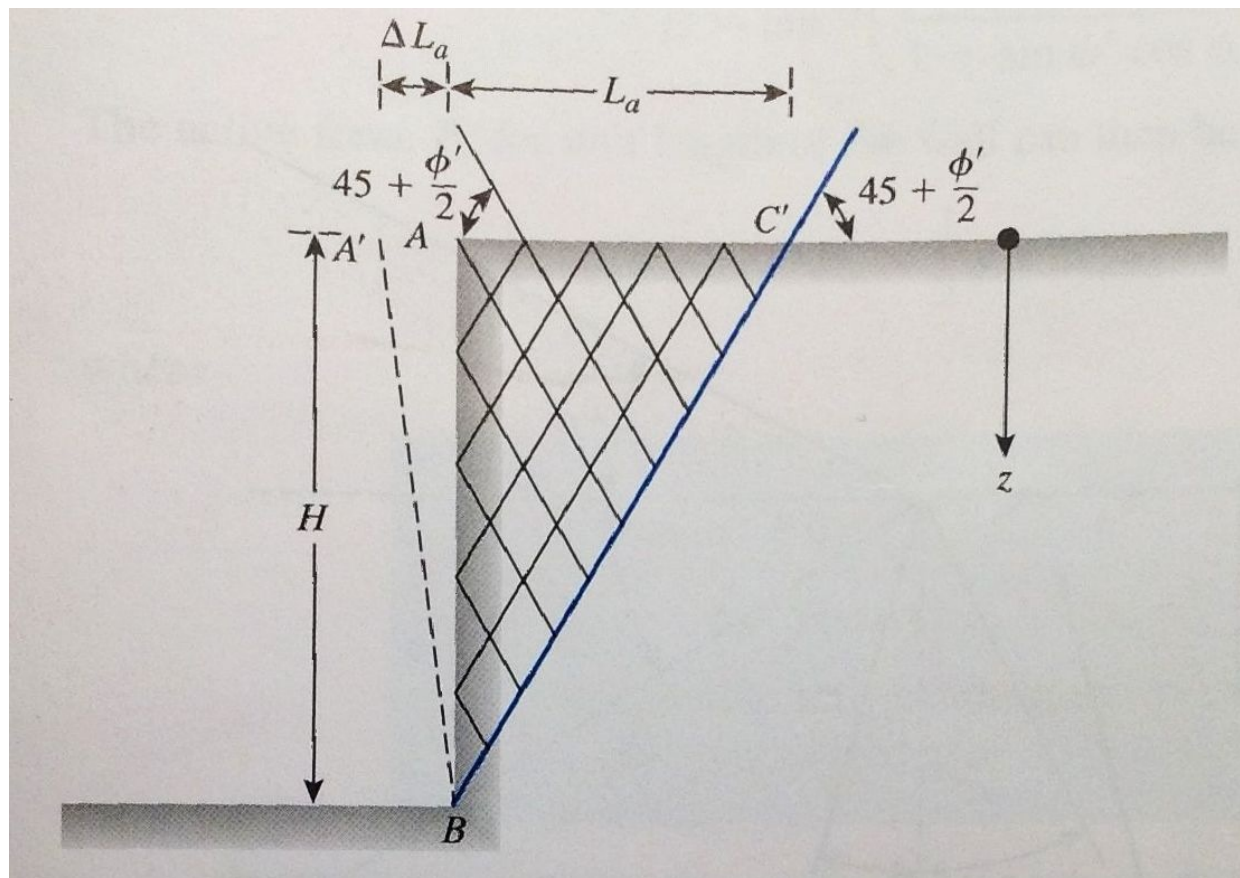
$$K_o = (1 - \sin(\phi'))\sqrt{OCR}$$

Both of these should be evaluated and the worst case (usually the larger) adopted for the design circumstances.

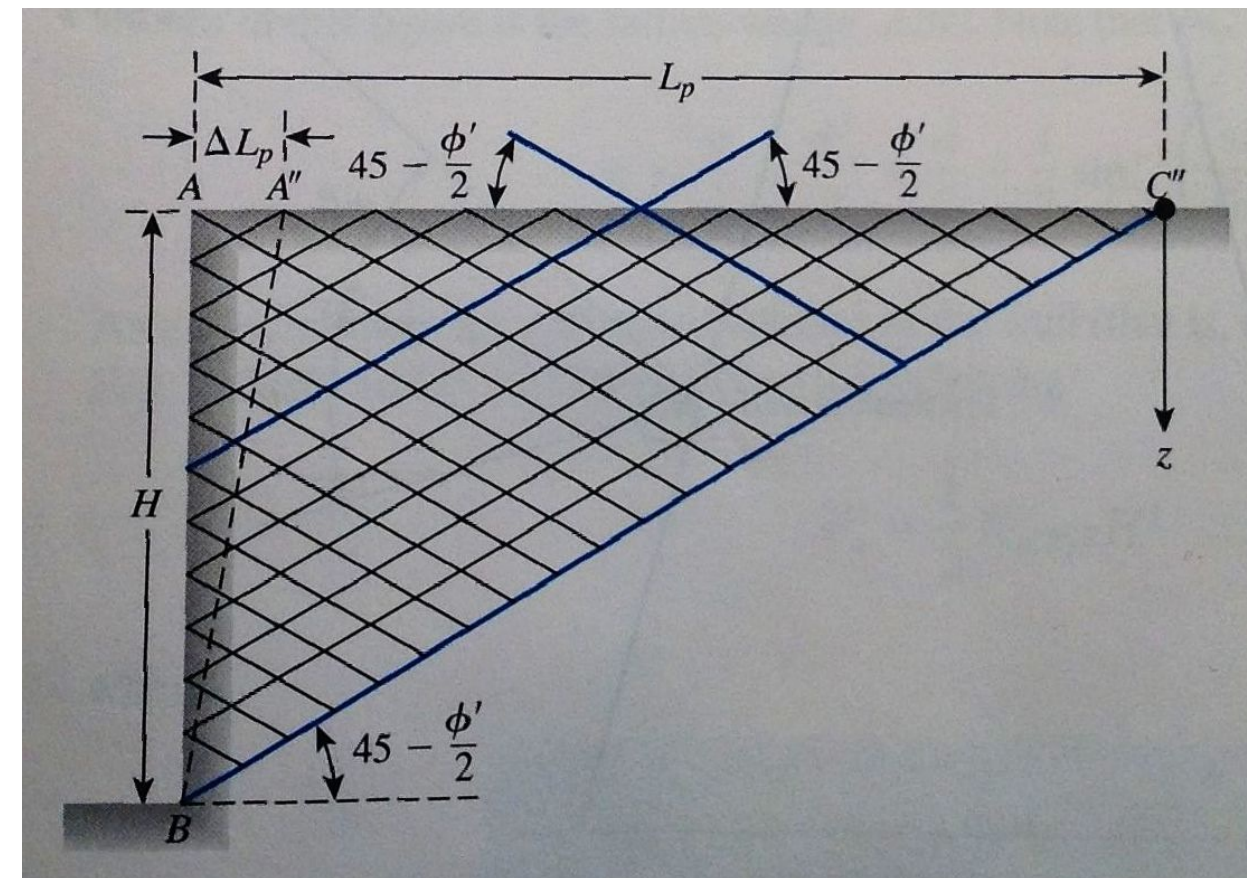
Active and Passive Earth Pressure

The active and passive coefficients are also functions of the effective friction angle ϕ' , and to some extent the cohesion c' . Unlike the at-rest coefficient, Rankine's theoretical active and passive models agree with empirical data.

Rankine's approach was to consider soils in a state of plastic equilibrium, defined as a stress state where every point in the mass is on the verge of failure. This reflects the tendency of soil masses to fail as a block.

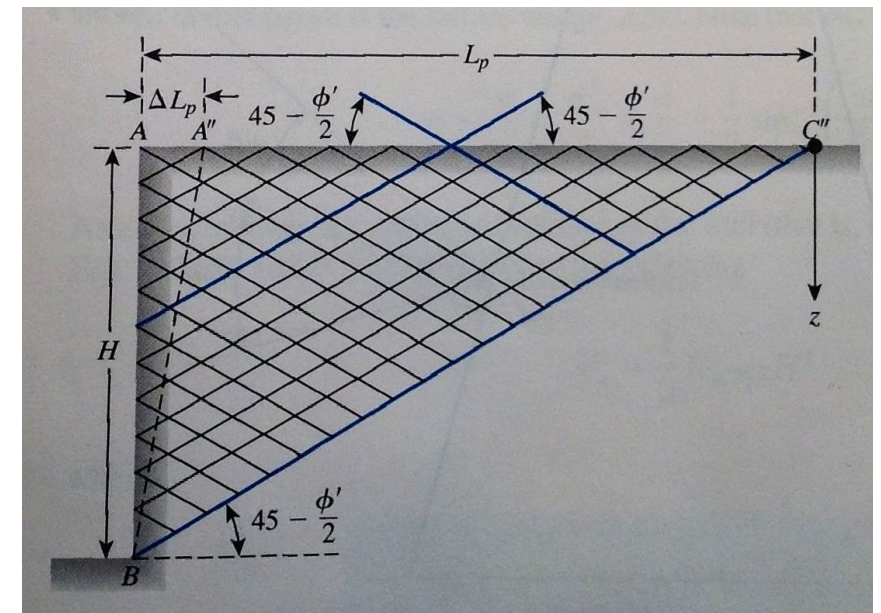
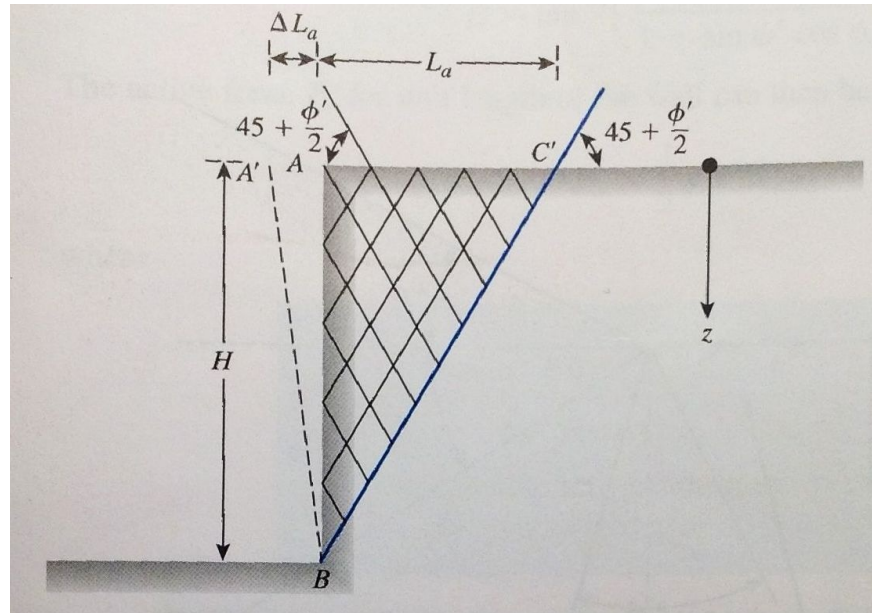


Active state failure eg gravity wall

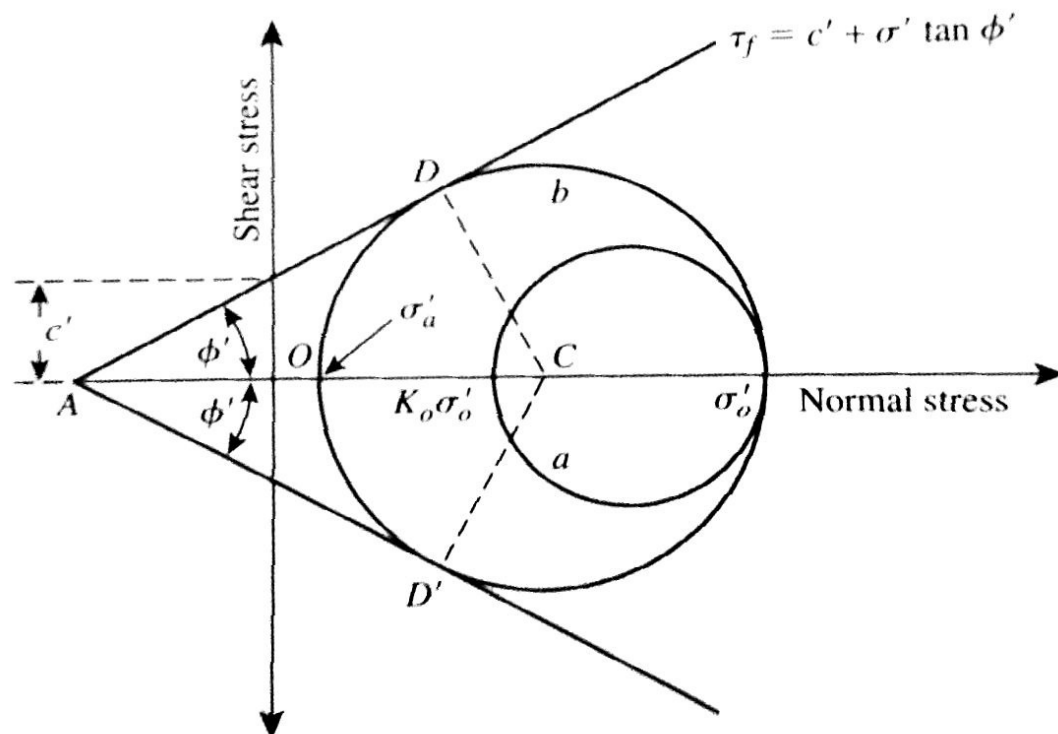


Passive state failure eg base of sheet pile wall (inverted view)

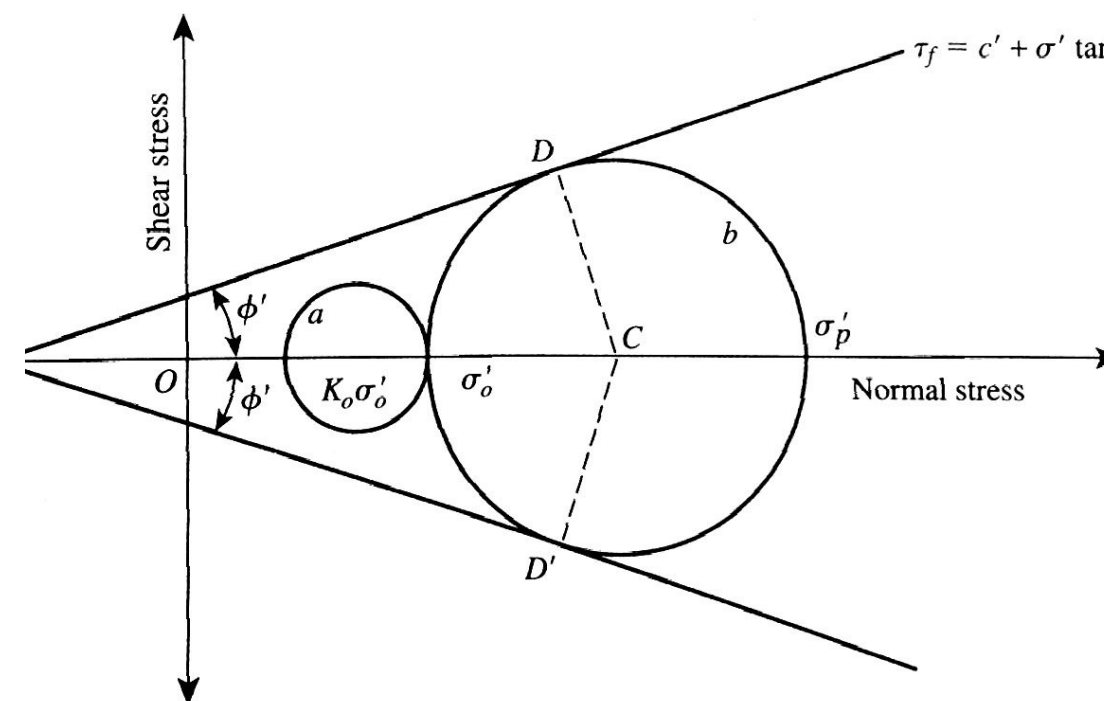
Active and Passive Earth Pressure



In either case, the vertical stress depends only on the density and depth. The horizontal stress however is decreased (active) or increased (passive) to reflect decreased or increased lateral constraint:

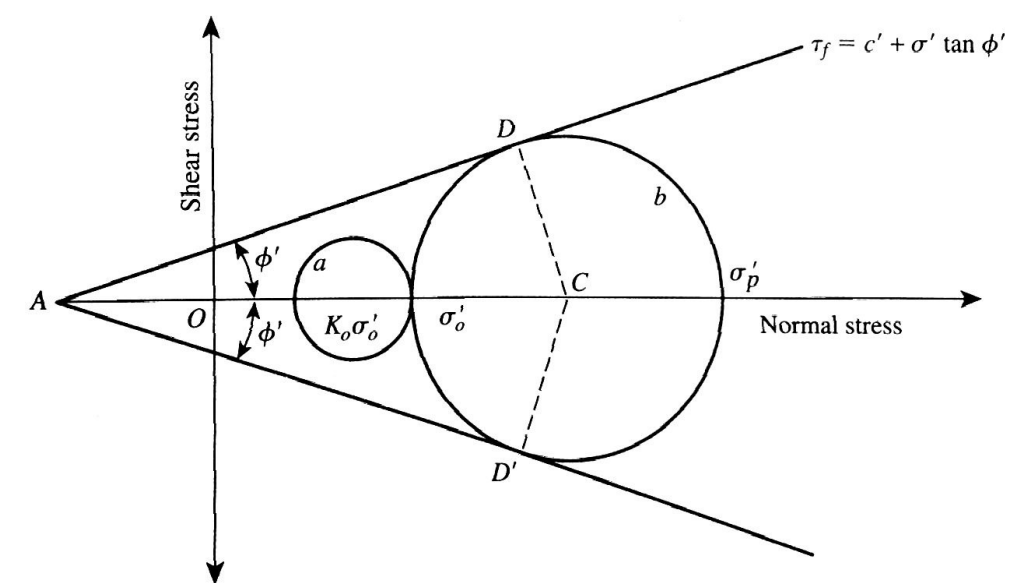
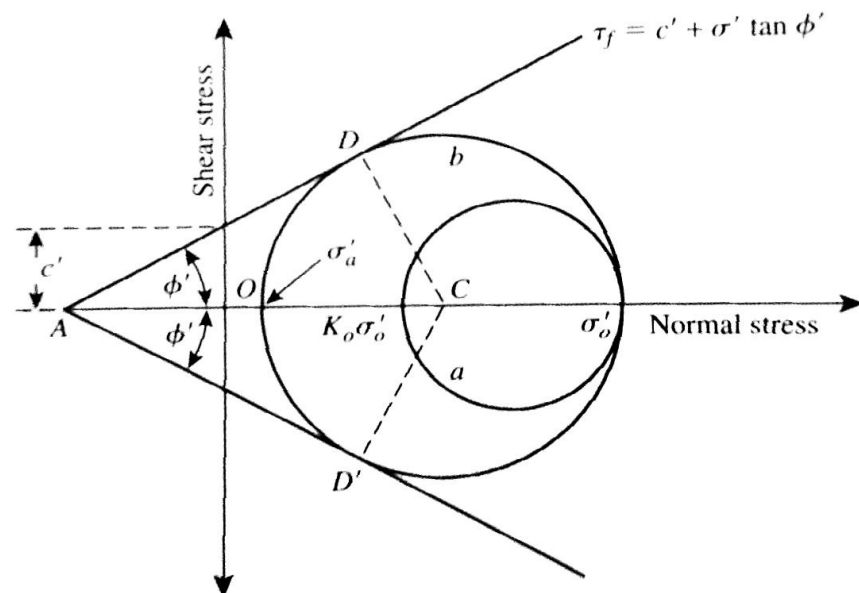


Active state failure (horizontal stress decreases as constraint is relaxed)



Passive state failure (major principal stress shifts from vertical to horizontal)

Active and Passive Earth Pressure



The derivation (see text) is based on the geometry of the assumed failure surface (blocks in static equilibrium) and of Mohr's circle. The result is:

$$\sigma'_a = \sigma'_o \tan^2 \left(45 - \frac{\phi'}{2} \right) - 2c' \tan \left(45 - \frac{\phi'}{2} \right) \quad \sigma'_p = \sigma'_o \tan^2 \left(45 + \frac{\phi'}{2} \right) + 2c' \tan \left(45 + \frac{\phi'}{2} \right)$$

Active state failure (horizontal stress decreases as constraint is relaxed)

Passive state failure (horizontal stress increases to above σ'_o , ie $K_p > 1$)

The agreement of these equations with empirical data is one of the great successes of geotechnical engineering. The equations are highly symmetric, intuitively accessible and apply to all soils; cohesive, non-cohesive, normally consolidated and overconsolidated soils.

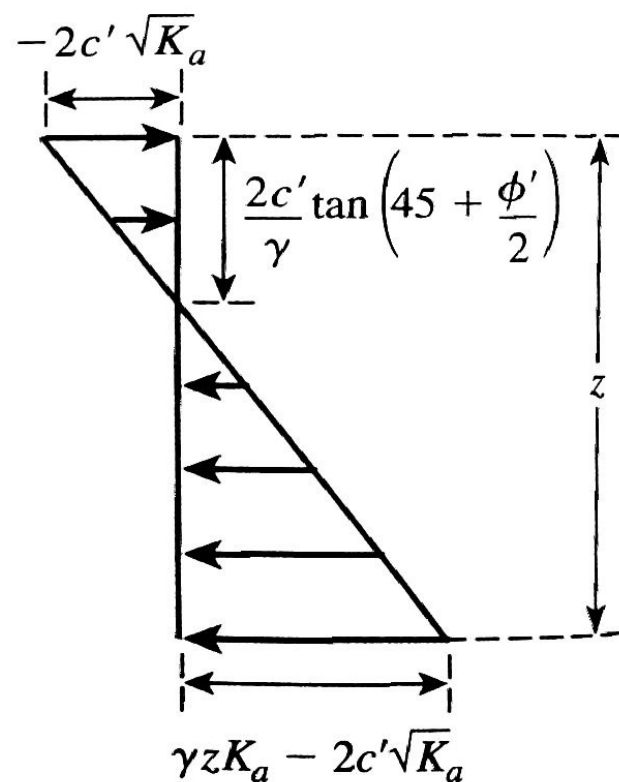
A number of different forms of these equations appear in the literature. If in doubt, use the equations provided in AS4678 - Earth Retaining Structures (available through Dixson library)

Active and Passive Earth Pressure

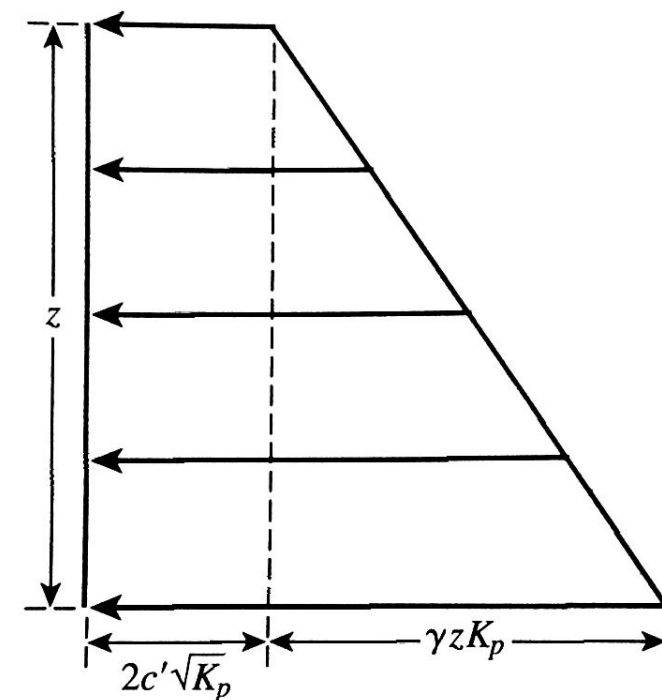
$$\sigma'_a = \sigma'_o \tan^2 \left(45 - \frac{\phi'}{2} \right) - 2c' \tan \left(45 - \frac{\phi'}{2} \right) \quad \sigma'_p = \sigma'_o \tan^2 \left(45 + \frac{\phi'}{2} \right) + 2c' \tan \left(45 + \frac{\phi'}{2} \right)$$

Both equations depend partly on the variable vertical stress σ'_o and a constant term based on the cohesion. The result, for soils with constant density and friction parameters, is a straight line graph increasing with depth and either positive or negative at the surface.

Negative tension in cohesive soils under active pressure will develop a crack in the soil surface at the top of the wall, to a depth which is a function of the cohesion and friction angle:

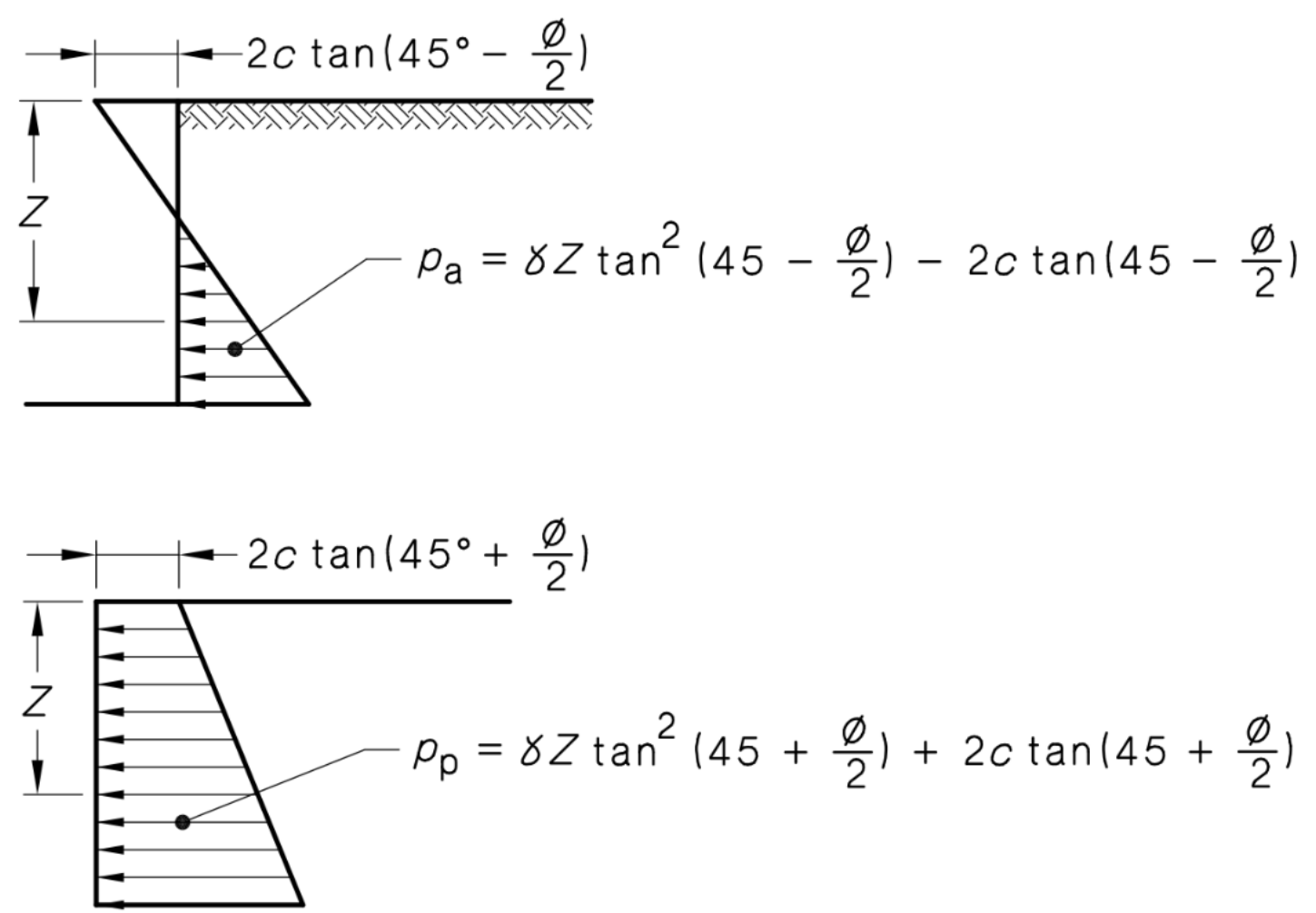


$$K_a = \tan^2 \left(45 - \frac{\phi'}{2} \right)$$



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

Note that these equations apply only to level soil behind a frictionless retaining wall. More complex models will be covered in the next lecture.



(b) Cohesive soil

FIGURE E2 RANKINE-BELL DESIGN MODEL

Earth Pressure Force Resultants

As with reservoir or dam walls, retaining walls are designed to support both the horizontal force resultant and its moment of action around the base or failure hinge point of the structure.

The figure shows the distribution of lateral earth pressure at rest on a wall of height H retaining a non-saturated soil having a bulk unit weight of γ . We assume an earth pressure coefficient K which may be at-rest, active or passive.

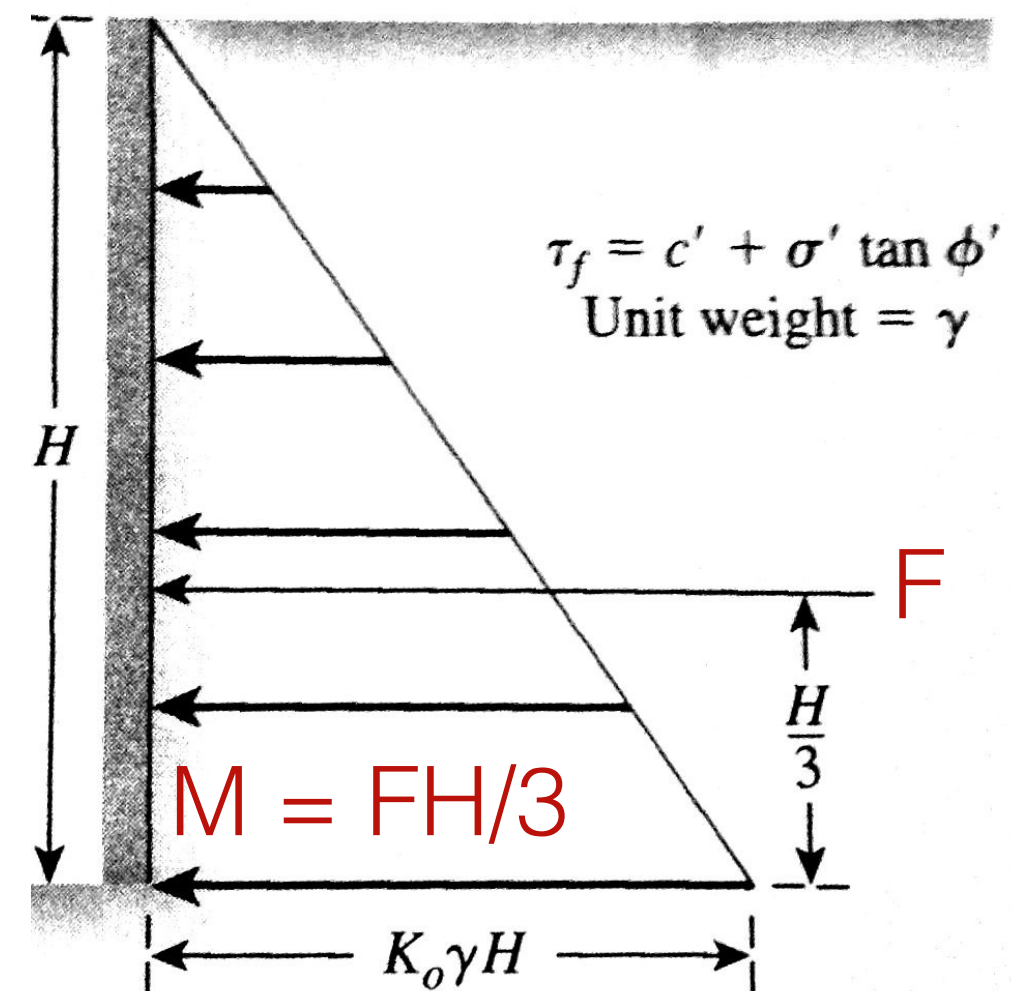
The total force per unit width of wall (into the page) is equal to the area of the pressure diagram, so:

$$F = \frac{1}{2} K \gamma_b H^2$$

The earth pressure force acts at a distance $H/3$ from the base. The moment exerted around the toe is:

$$M = \frac{1}{6} K \gamma_b H^3$$

This model applies only to soils of constant bulk density. Stratified soils must be integrated with variable density.



Saturated Earth Pressure Forces

It is not unusual for retaining walls to also retain water in saturated soils. The saturated and effective unit weights are used below the water table and must be integrated in layers of variable density.

The figure shows a wall with the water table located at a depth H_1 . For $z < H_1$ the bulk unit weight is used as $P = \gamma_b H_1$. For $z > H_1$ the effective and total stresses can be calculated separately by the saturated and effective unit weights.

The wall supports the total force consisting of horizontal effective stress and pore water pressure:

Vertical effective stress:

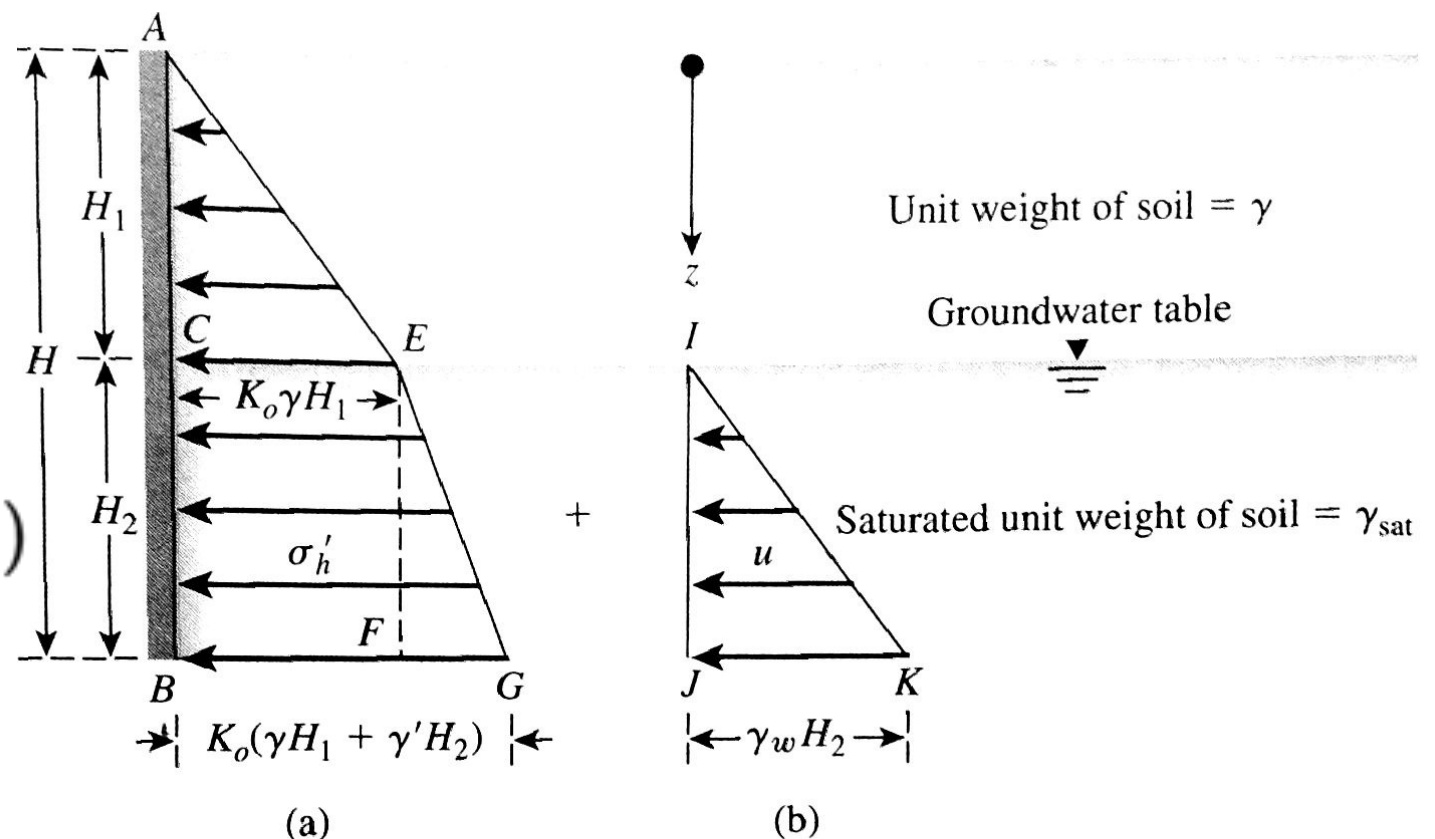
$$\sigma'_o = \gamma_b H_1 + \gamma'(z - H_1)$$

Horizontal effective stress:

$$\sigma'_h = K \sigma'_o = K(\gamma_b H_1 + \gamma'(z - H_1))$$

Pore water pressure:

$$u = \gamma_w(z - H_1)$$



$$\gamma_{sat} = \gamma_w \frac{G + e}{1 + e} \quad \gamma' = \gamma_{sat} - \gamma_w$$

Saturated Earth Pressure Forces

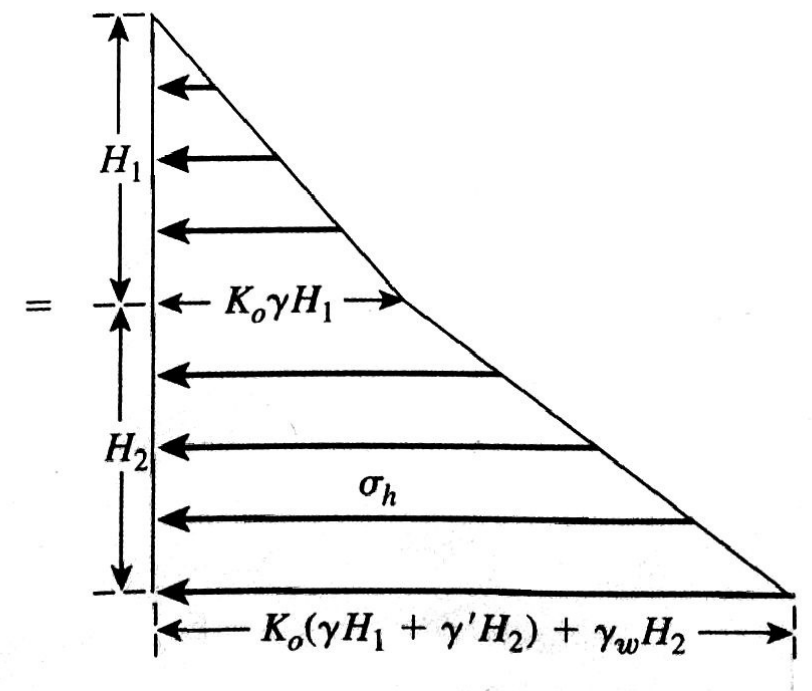
Total pressure, force and moment are calculated from the areas of the pressure diagram:

Horizontal total stress:

$$\begin{aligned}\sigma_h &= \sigma'_h + u \\ &= K [\gamma_b H_1 + \gamma'_b (z - H_1)] + \gamma_w (z - H_1)\end{aligned}$$

Horizontal force resultant:

$$F = \frac{1}{2} K \gamma_b H_1^2 + K \gamma_b H_1 H_2 + \frac{1}{2} (K \gamma' + \gamma_w) H_2^2$$



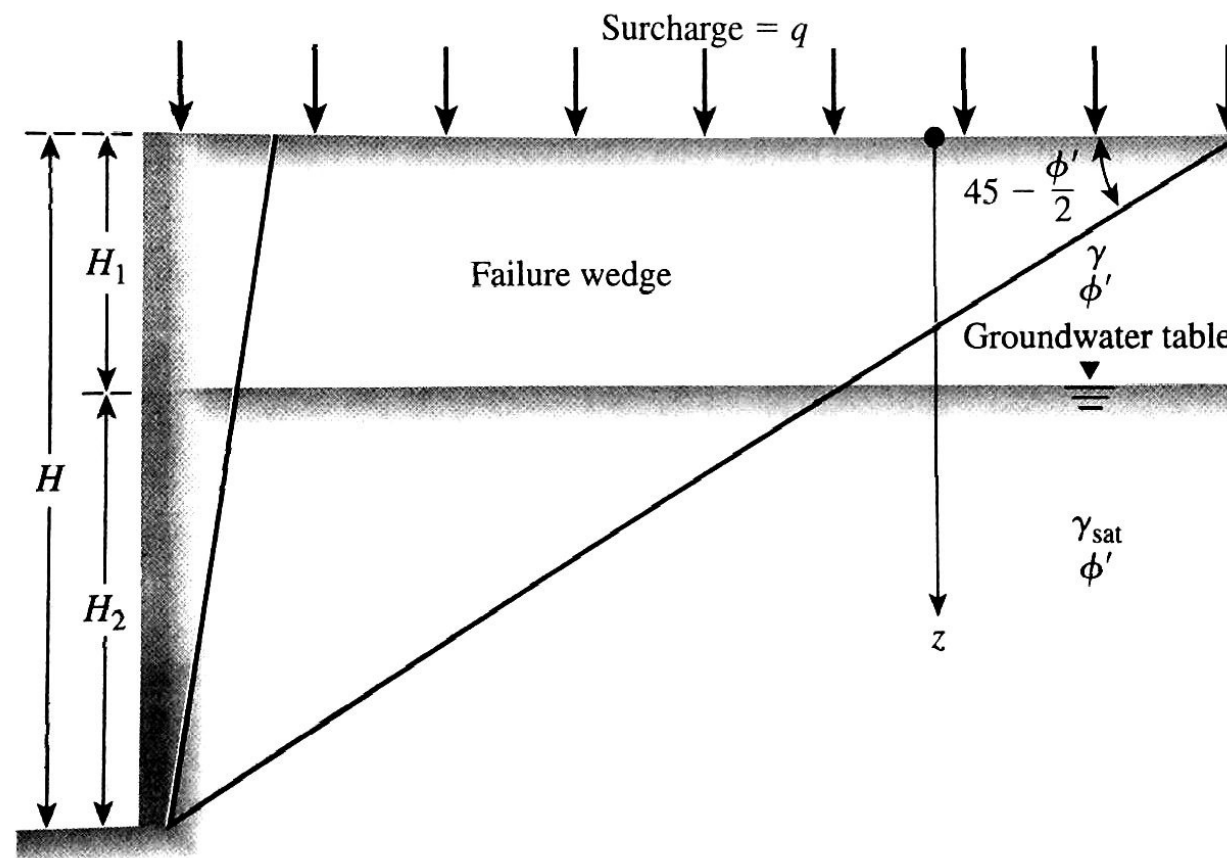
The force resultant can still be regarded as approximately located at $H/3$, so the overturning moment is:

$$M = FH/3$$

Sliding forces and overturning moments must be resisted by structural actions both internally (ie walls reinforced to resist the load) and externally (ie soil bearing pressure not exceeded).

Surcharge

Surcharge (q , kPa) is any additional vertical pressure other than soil pressure applied to a geotechnical system. In retaining wall design, surcharge must be added to earth pressure, force and moment:



$$F = F_0 + KqH$$

$$M = M_0 + Kq\frac{H^2}{2}$$

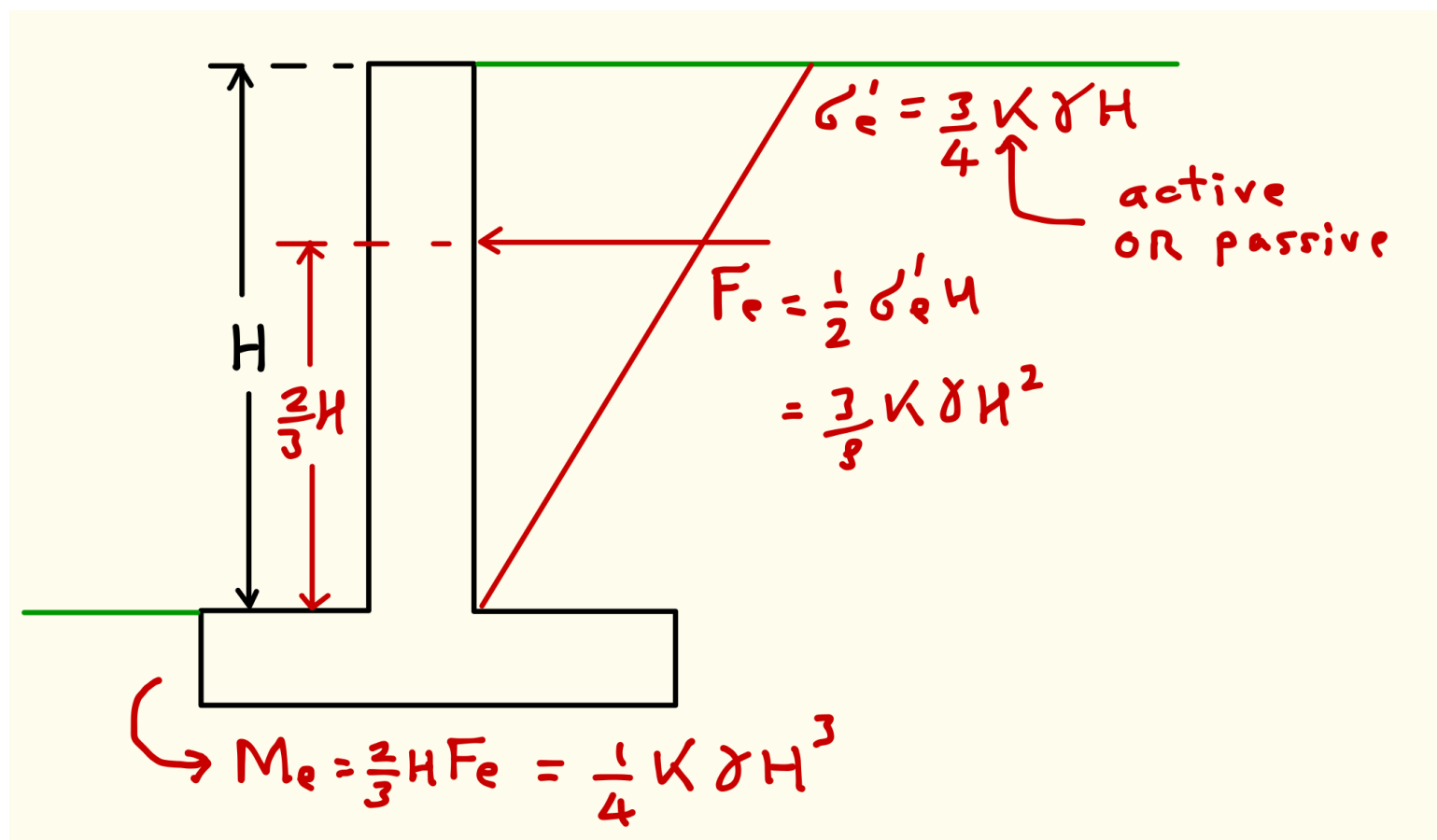
Where F_0 and M_0 are the horizontal pressure force resultant and overturning moment due to soil pressure alone.

Earthquake

Earthquake loads are rare but not unprecedented in Australia. Das (2010) provides design techniques suited to high risk zones such as the Pacific rim.

Australian earthquake design lacks data on the recurrence interval of earthquakes of any given magnitude. In view of this, earthquake design in Australia uses simplified methods.

Horizontal earthquake loads are an inverted triangle with the dominant load at the top of the wall. Earthquake pressure coefficients are taken as 3/4 of active or passive coefficients. The resultant force applies at 2/3 of the wall height:



Earthquake loads and moments are again simply added to actions due to surcharge, earth pressure and pore water pressure.

Readings

Chapter 13 Das

Smith, D.W. 1992. Retaining Systems (Reading 9)

