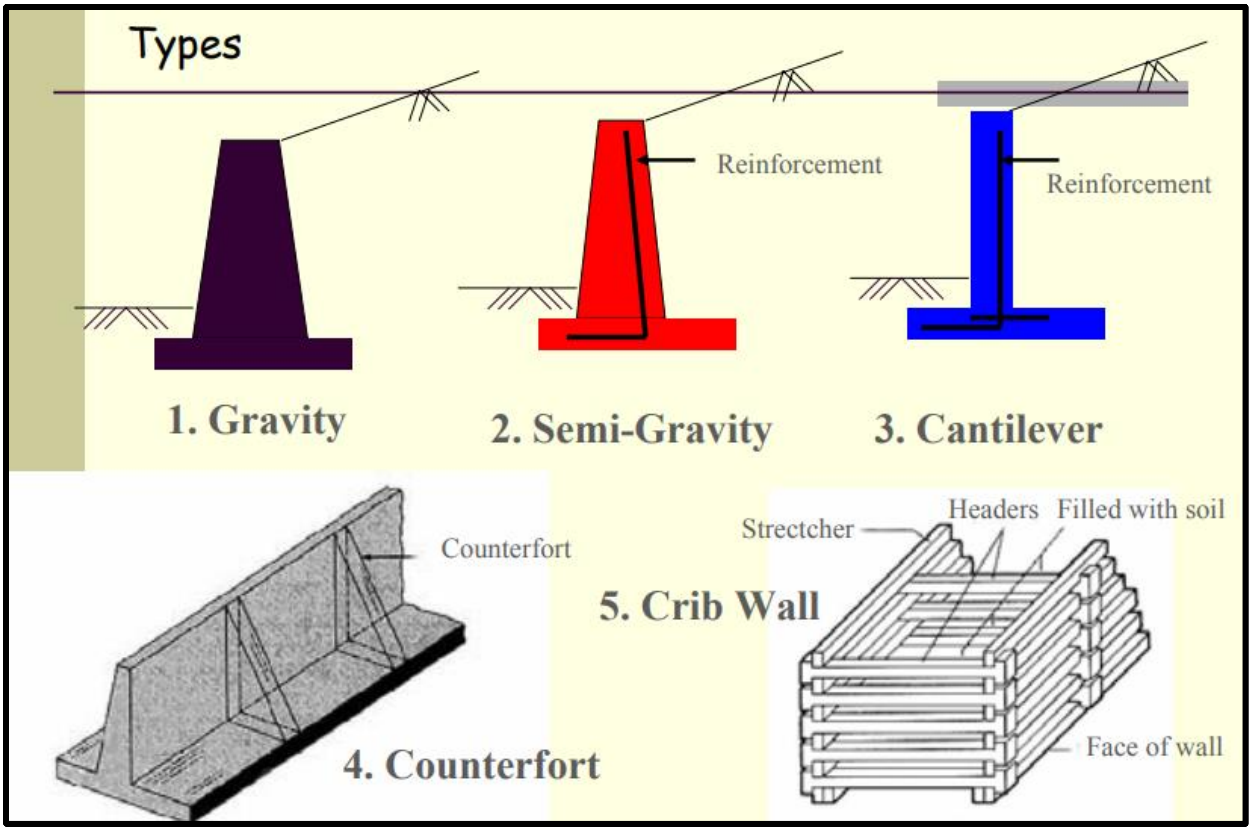
Foundation Engineering Course No. 1.

3.1 RETAINING WALLS

Retaining walls are structures used to provide stability for earth or other materials at their natural slopes. In general, they are used to hold back or support soil banks and water or to maintain difference in the elevation of the ground surface on each of wall sides.

3.2 TYPES OF RETAINING WALLS



3.3 Proportional Retaining Walls

1- In designing retaining walls, an engineer must assume some of their dimensions which is called proportioning, such assumptions allow the engineer to check trial sections of the walls for stability.
2- If the stability checks yield undesirable results, the sections can be changed and rechecked. Figure 3-1 shows the general proportions of various retaining-wall components that can be used for initial checks.
3- Note that the top of the stem of any retaining wall should not be less than about **0.3 m** for proper placement of concrete.
4- The depth, D, to the bottom of the base slab should be a minimum of **0.6 m**.
5- For counterfort retaining walls, the general proportion of the stem and the base slab is the same as for cantilever walls. However, the counterfort slabs may be about 0.3 m thick and spaced at center-to-center distances of **0.3 H** to **0.7 H**.

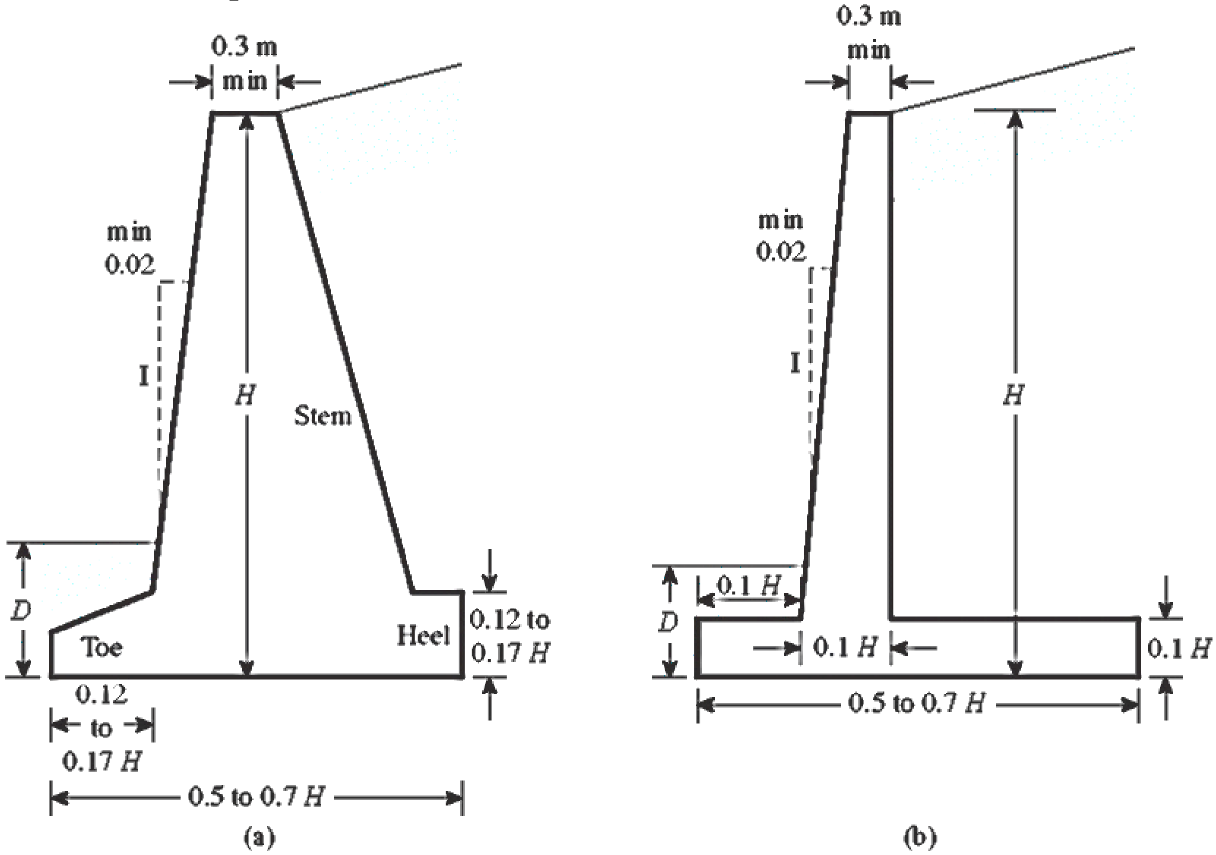


Figure3-1: Approximate dimensions for various components of retaining wall for initial stability checks: (a) gravity wall; (b) cantilever wall.

3.4 Stability of Retaining Walls

1- With the lateral earth pressure known, the structure is checked for stability. The structure is examined for possible ***overturning***, ***sliding***, *and* ***bearing capacity failures***. This check can be regarded as an overall checkup.
2- Each component of the structure is checked for strength, and the steel reinforcement of each component is determined.

A retaining wall may fail in any of the following ways:

1- It may overturn about its toe. (See Figure 3-2a.)
2- It may slide along its base. (See Figure 3.2b.)
3- It may fail due to the loss of bearing capacity of the soil supporting the base. (See Figure 3.2c.)
4- It may undergo deep-seated shear failure and excessive settlement. (Figure 3.2 d.)

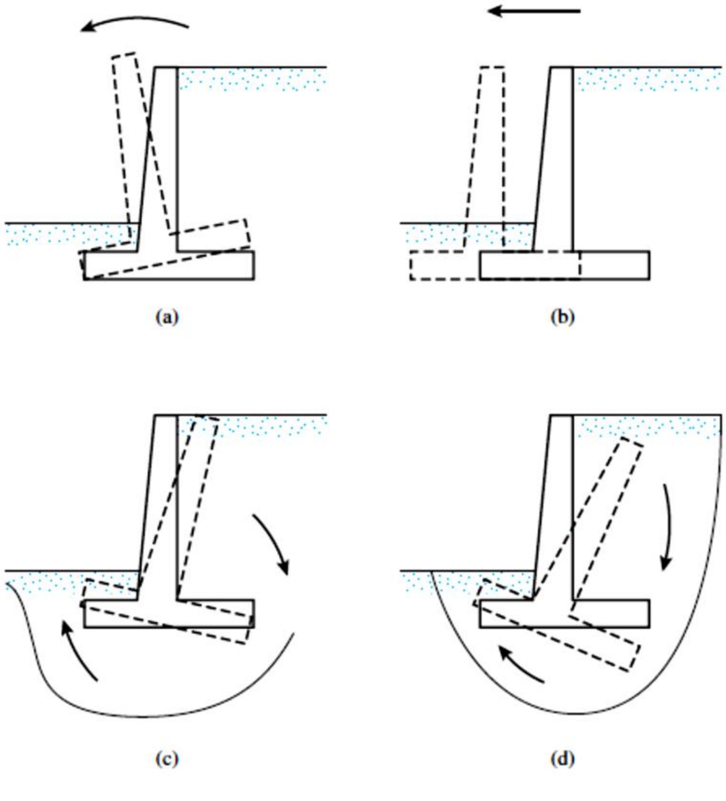


Figure 3-2: Failure of retaining wall :(a) by overturning; (b) by sliding;(c) by bearing capacity failure and (d) by deep-seated shear failure.

3.4.1 Check for Overturning

Figure 3-4 shows the forces acting on a cantilever and a gravity retaining wall, based on the assumption that the Rankine active pressure is acting along a vertical plane AB drawn through the heel of the structure.

$E_a = \frac{1}{2}\, \gamma\, H^2\, K_a - 2\, c\, H\sqrt{K_a}$	**Eq. -1**
$E_p = \frac{1}{2}\, \gamma\, D^2\, K_p + 2\, c\, D\sqrt{K_p}$	**Eq. -2**

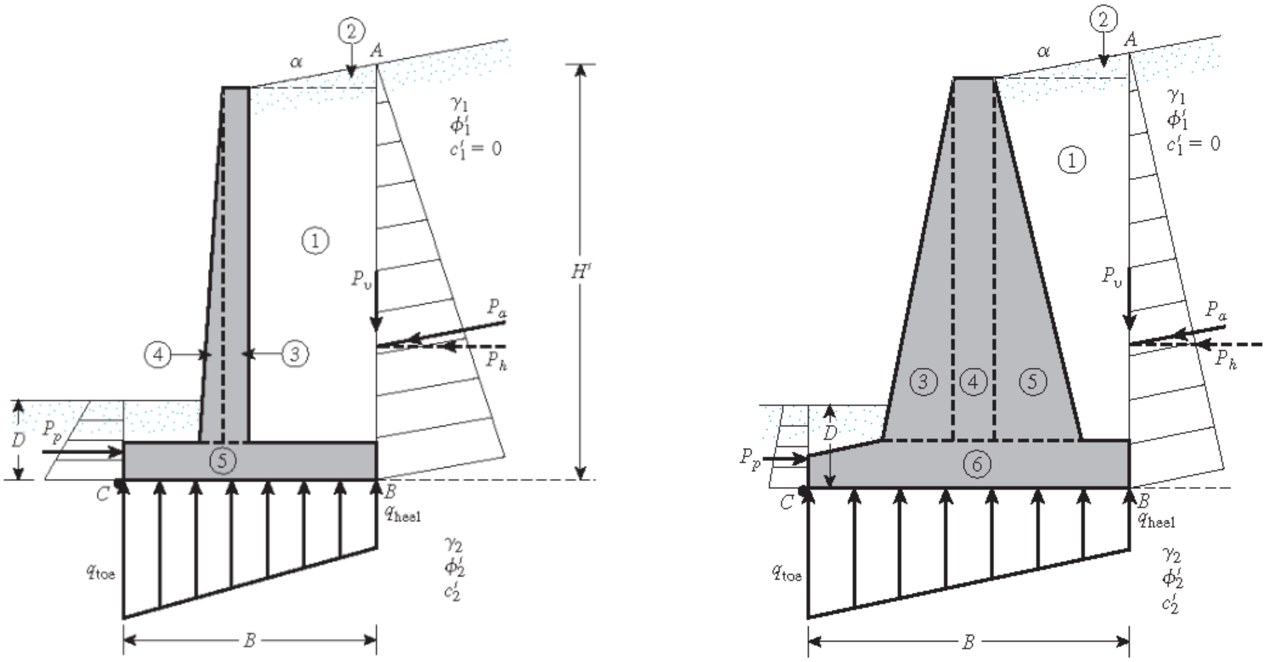


Figure 3-4: Check for overturning, assuming that the Rankine pressure is valid.

The factor of safety against overturning about the toe—that is, about point C in Figure 3-4may be expressed as:

$FS_{overturning} = \frac{Resisting\ Moment}{Overturning\ (Driving)\ Moment} = \frac{\sum M_R}{\sum M_D}$	**Eq. -3**

In Figure 3-4, the driving or overturning moment is:

$\sum M_D = Ea_h\left(\frac{H'}{3}\right) + \text{any other driving external moment (forces} \times \text{arm)}$	Eq-4
$Ea_h = E_a \cos\alpha$	Eq-5

To calculate the resisting moment, $\sum M_R$, (neglecting E_p), a table such as

Table- can be prepared. The weight of the soil above the heel and the weight of the concrete (or masonry) are both forces that contribute to the resisting moment***. It is important to note that the force Ea_v also contributes to the resisting moment and Ea_v is the vertical component of the active force or:***

$Ea_v = E_a \sin\alpha$	Eq. -4

Table-1: Procedure for Calculating $\sum M_R$

Section (1)	Area (2)	Weight/unit length of wall (3)	Moment arm measured from *C* (4)	Moment about *C* (5)
1	A_1	$W_1 = \gamma_1 \times A_1$	X_1	M_1
2	A_2	$W_2 = \gamma_1 \times A_2$	X_2	M_2
3	A_3	$W_3 = \gamma_c \times A_3$	X_3	M_3
4	A_4	$W_4 = \gamma_c \times A_4$	X_4	M_4
5	A_5	$W_5 = \gamma_c \times A_5$	X_5	M_5
6	A_6	$W_6 = \gamma_c \times A_6$	X_6	M_6
		P_v	B	M_v
		ΣV		ΣM_R

(*Note:* γ_l = unit weight of backfill
γ_c = unit weight of concrete)

Once $\sum M_R$ is known, the factor of safety against overturning can be calculated as:

$$FS_{overturning} = \frac{M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_v}{E_a \cos\alpha \left(\frac{H'}{3}\right)} \qquad \text{Eq. -5}$$

The allowable factor of safety is ≥ 1.5. The usual minimum desirable value of the factor of safety with respect to overturning is 1.5-2.0.

3.4.2 Check for the Sliding along the Base

Referring to Figure 3-5, the factor of safety against sliding may be expressed by the equation:

$$FS_{Sliding} = \frac{horizontal\ resisting\ forces}{horizontal\ driving\ forces} = \frac{\sum F_R}{\sum F_d} \qquad \text{Eq. -6}$$

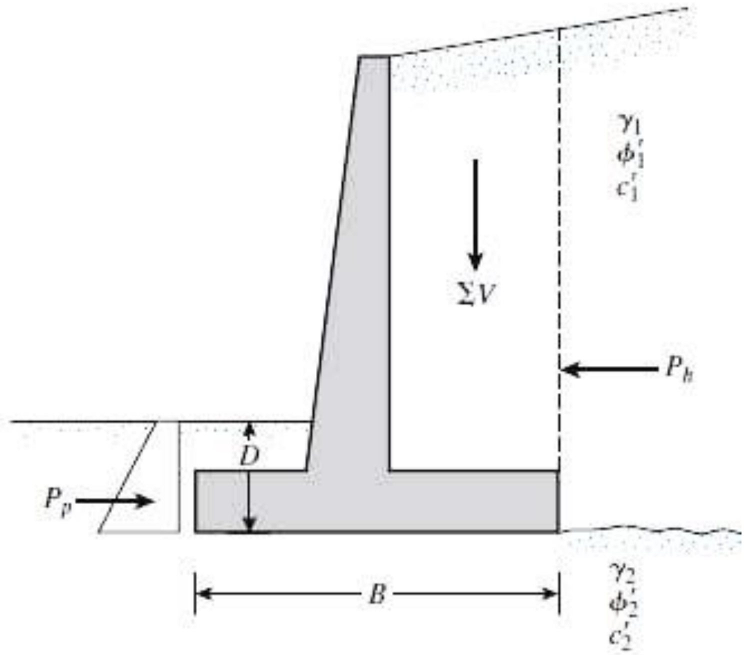


Figure3-5: Checking for Sliding along the Base

The strength of the soil (τ) immediately below the base slab may be represented as:

$$\tau = c_a + \sigma_v \tan\delta \qquad \text{Eq. -7}$$

Where, δ is the friction angle between foundation materials and soil. Some typical values are listed in Table Error! No text of specified style in document.-. Now convert the stresses to forces by multiplying the stress with ($B \times 1.0$) to get:

$S = c_a B + R_v \tan\delta$	Eq. -8
$\therefore FS_{Sliding} = \dfrac{S}{Ea_h} \geq 1.5$	Eq. -9
$or\ FS_{Sliding} = \dfrac{S + E_p}{Ea_h} \geq 2.0$	Eq. -10

Table Error! No text of specified style in document.**-2: Friction angles δ between various foundation materials and soil or rock* (Bowles, 1997)**

Interface materials	Friction angle, δ, degrees†
Mass concrete or masonry on the following:	
Clean sound rock	35°
Clean gravel, gravel-sand mixtures, coarse sand	ϕ
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel	ϕ
Clean fine sand, silty or clayey fine to medium sand	ϕ
Fine sandy silt, nonplastic silt	ϕ
Very stiff and hard residual or preconsolidated clay	ϕ
Medium stiff and stiff clay and silty clay	ϕ
Steel sheet piles against the following:	
Clean gravel, gravel-sand mixture, well-graded rock fill with spalls	22°
Clean sand, silty sand-gravel mixture, single-size hard rock fill	17
Silty sand, gravel, or sand mixed with silt or clay	14
Fine sandy silt, nonplastic silt	11
Formed concrete or concrete sheetpiling against the following:	
Clean gravel, gravel-sand mixtures, well-graded rock fill with spalls	22–26
Clean sand, silty sand-gravel mixture, single-size hard rock fill	17–22
Silty sand, gravel, or sand mixed with silt or clay	17
Fine sandy silt, nonplastic silt	14
Various structural materials	
Masonry on masonry, igneous and metamorphic rocks:	
Dressed soft rock on dressed soft rock	35°
Dressed hard rock on dressed soft rock	33
Dressed hard rock on dressed hard rock	29
Masonry on wood (cross grain)	26
Steel on steel at sheet-pile interlocks	17
Wood on soil	14–16‡

*May be stress-dependent (see text) for sand.

†Single values ±2°. Alternate for concrete poured on soil is $\delta = \phi$.

‡May be higher in dense sand or if sand penetrates wood.

If the factor of safety is not achieved, the following several alternatives may be investigated as shown in Figure 3-6:

1- Increase the width of the base slab (i.e., the heel of the footing).
2- Use a key to the base slab. If a key is included, the passive force per unit length of the wall becomes larger.
3- Use of a dead man anchor

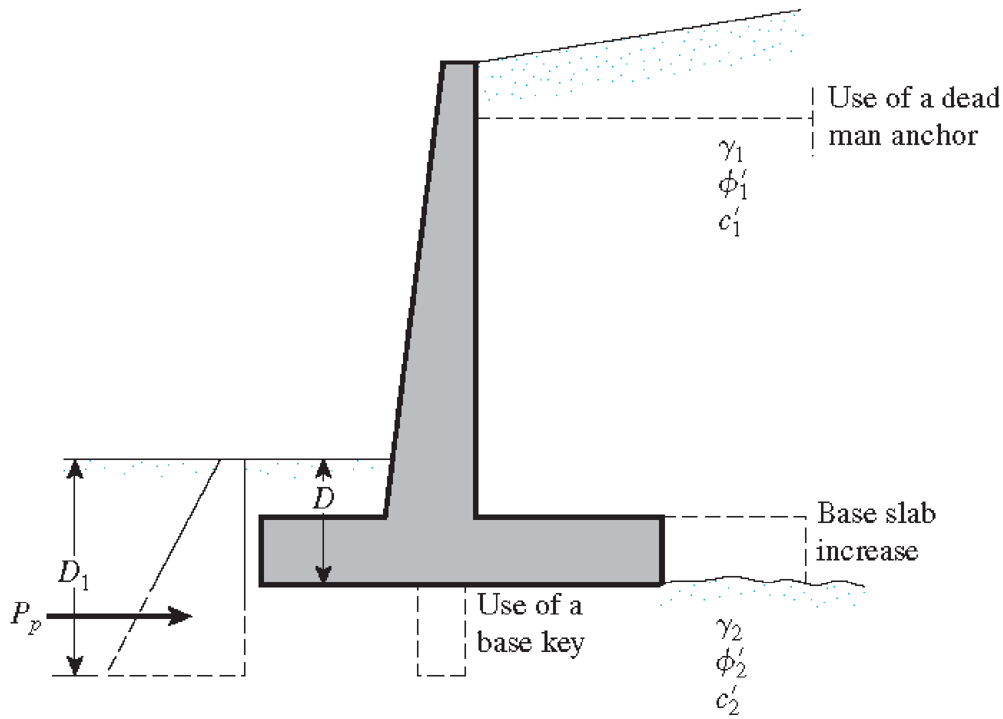


Figure 1: Alternatives for increasing the factor of safety with respect to sliding