Rekayasa Pondasi I

Dosen : Sherly Meiwa ST., MT.

Jurusan Teknik Sipil
Universitas Komputer Indonesia
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Introduction

- **UTS**
  - Shallow Foundation
  - Lateral Earth Pressure
- **UAS**
  - Retaining Wall

Retaining Walls

Introduction

In general, retaining walls can be divided into two major categories: (a) conventional retaining walls and (b) mechanically stabilized earth walls. Conventional retaining walls can generally be classified into four varieties:

1. Gravity retaining walls
2. Semigravity retaining walls
3. Cantilever retaining walls
4. Counterfort retaining walls

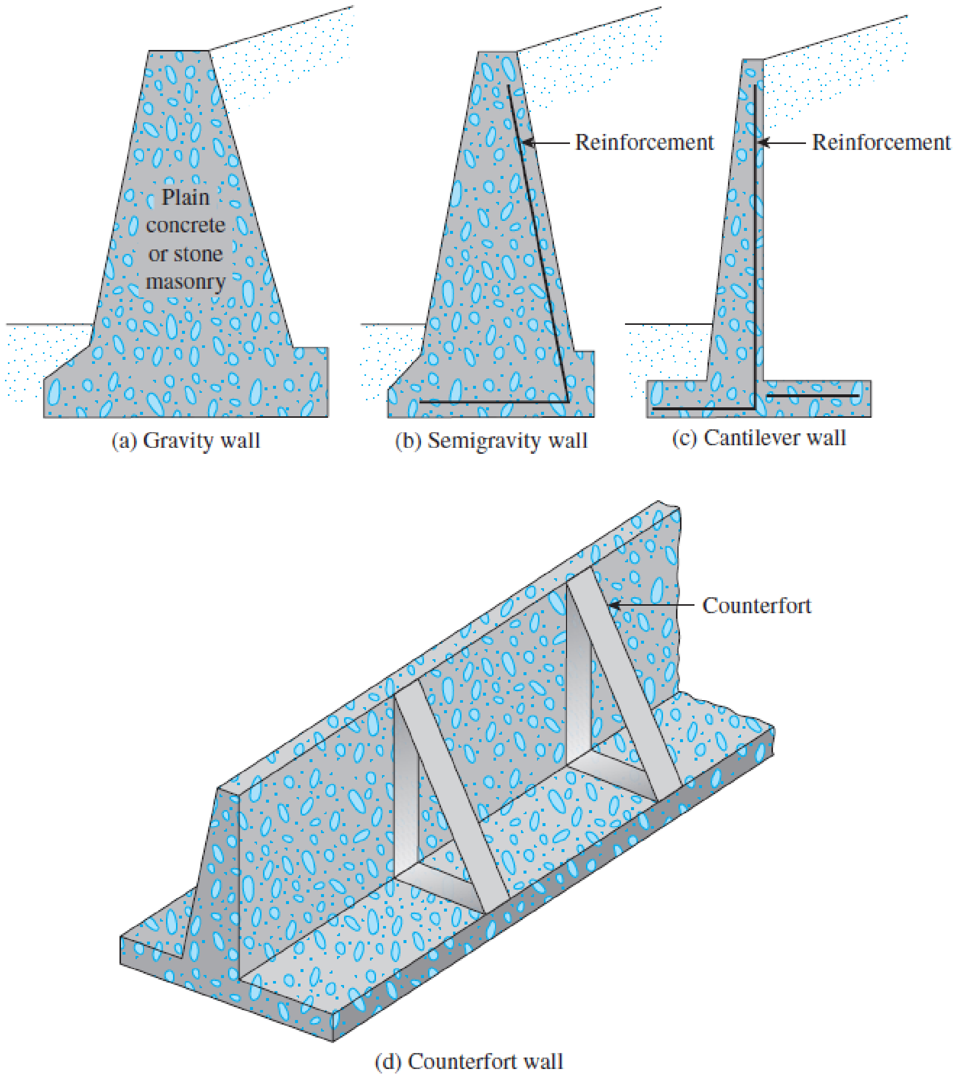
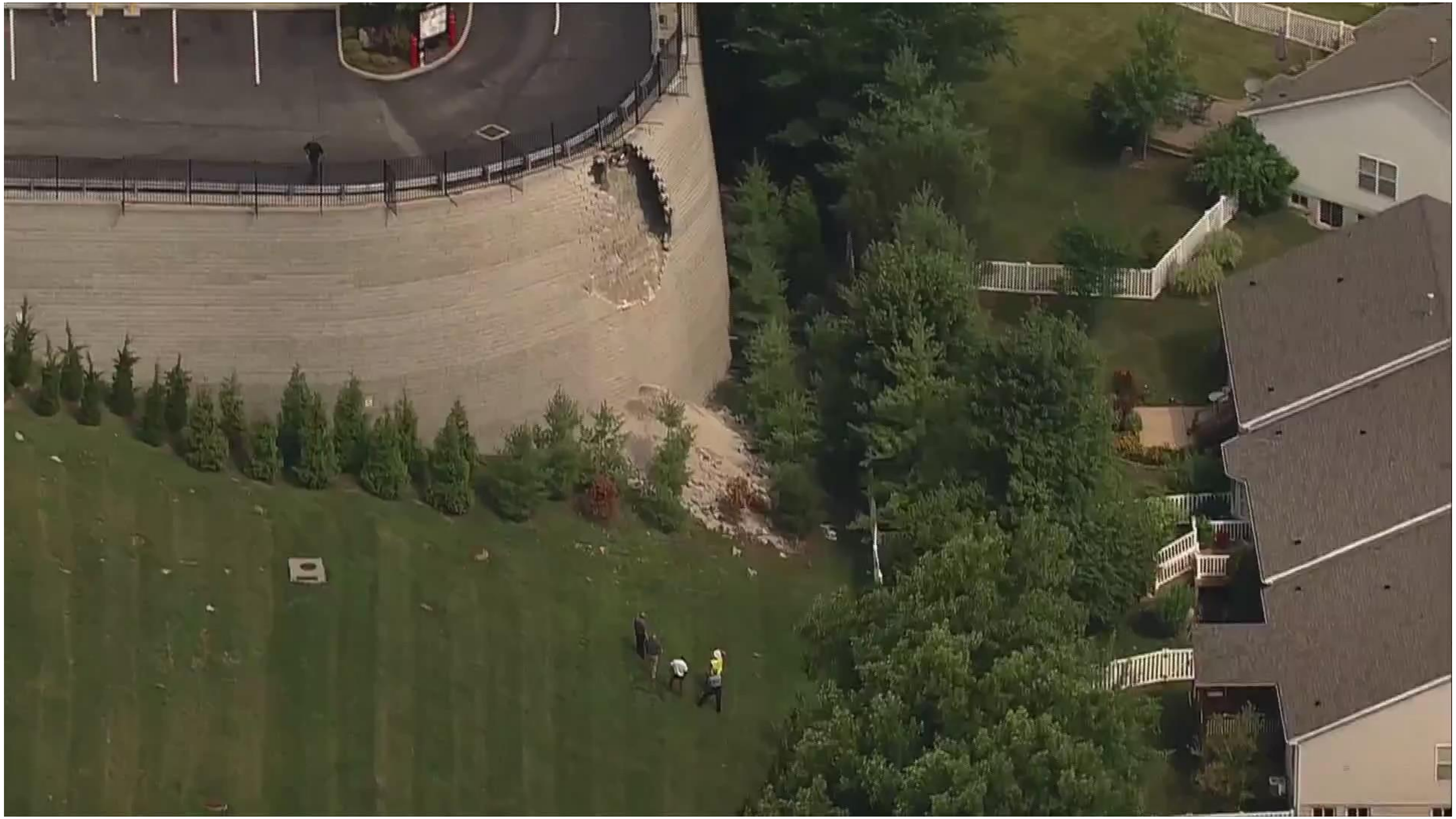


Figure 13.1 Types of retaining wall

Retaining Walls

Retaining Walls



Collapsed retaining wall in Arnold drew concerns over cracking five years ago

Propostioning Retaining Walls

Introduction

In designing retaining walls, an engineer must assume some of their dimensions. Called *proportioning*, such assumptions allow the engineer to check trial sections of the walls for stability. If the stability checks yield undesirable results, the sections can be changed and rechecked.

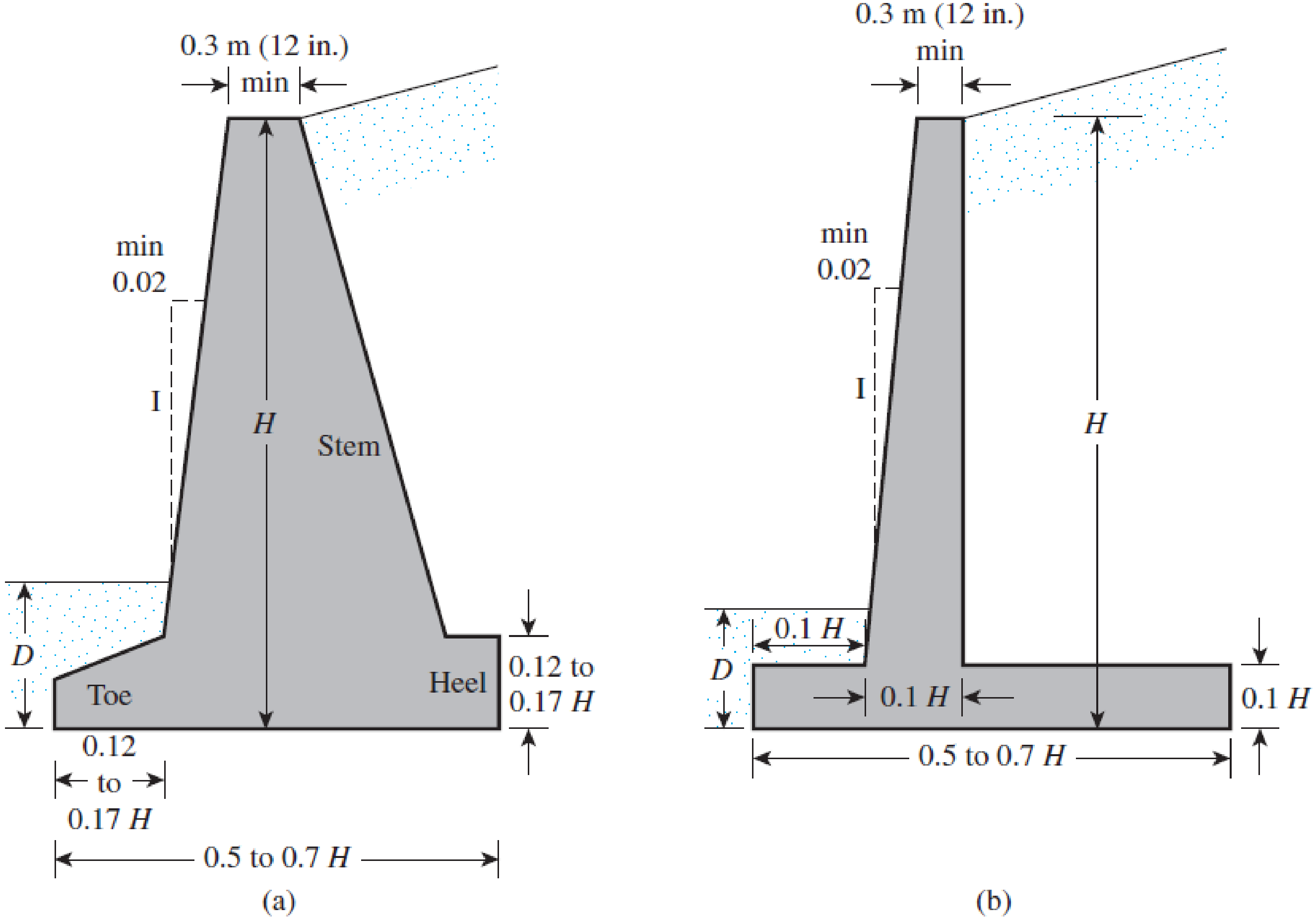
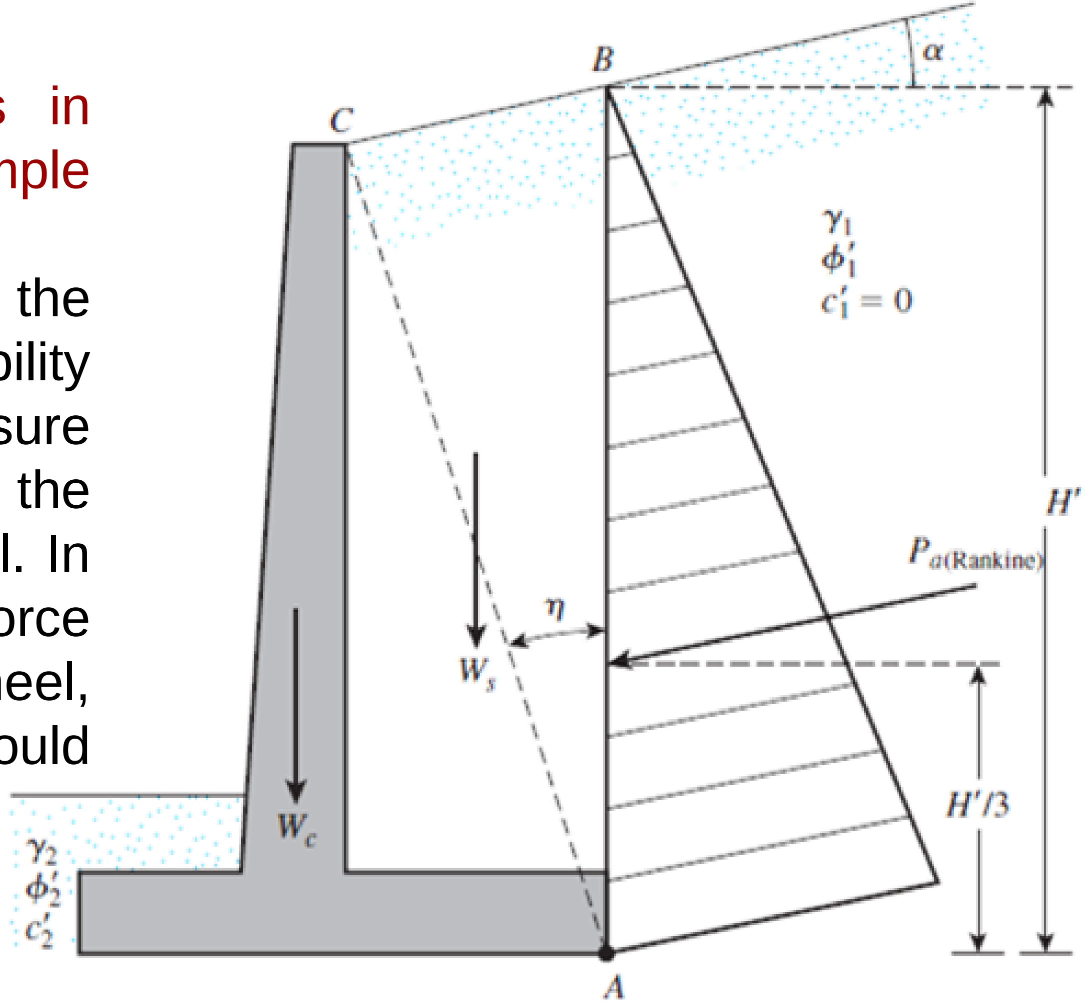


Figure 13.3 Approximate dimensions for various components of retaining wall for initial stability checks: (a) gravity wall; (b) cantilever wall

Application of Lateral Earth Pressure Theories to Design

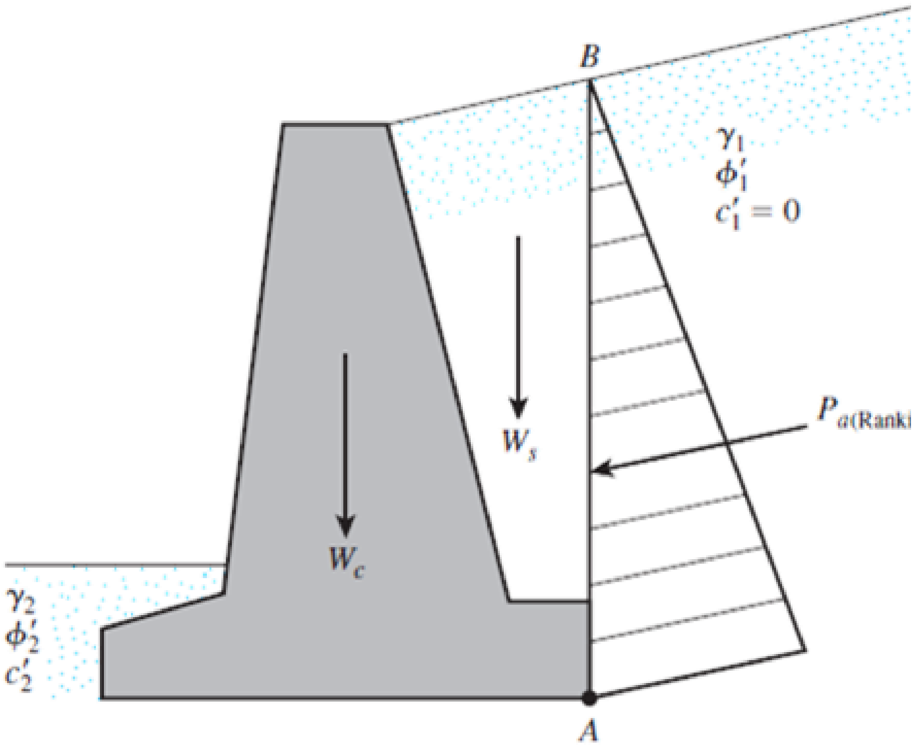
To use lateral earth pressure theories in design, an engineer must make several simple assumptions.

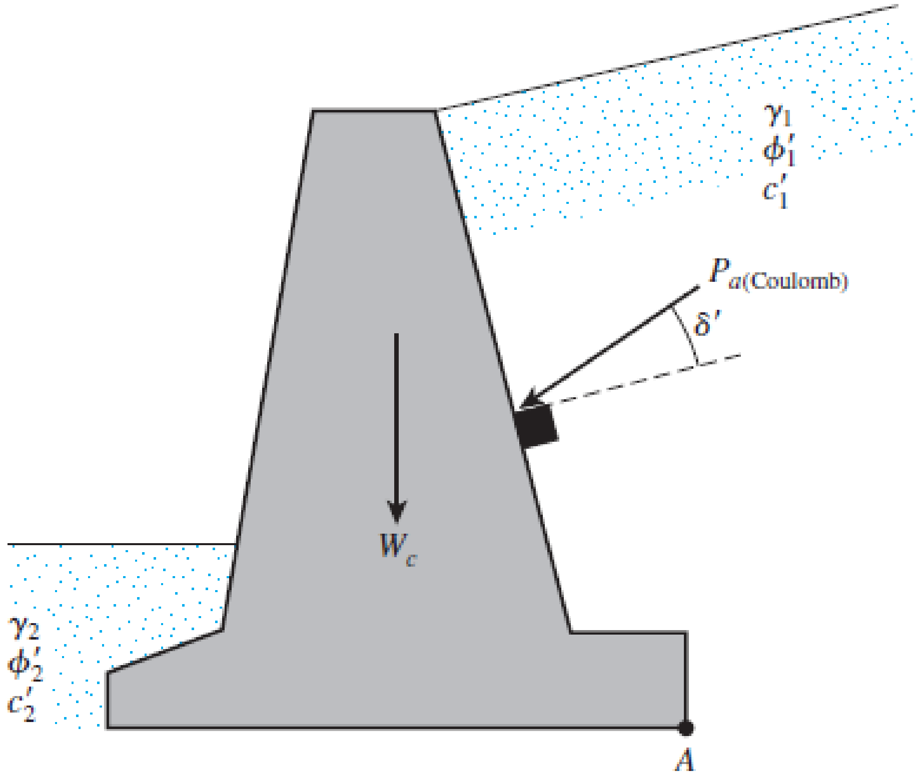
In the case of cantilever walls, the use of the Rankine earth pressure theory for stability checks . Rankine active earth pressure equations may then be used to calculate the lateral pressure on the face *AB* of the wall. In the analysis of the wall's stability, the force $Pa_{(Rankine)}$, the weight of soil above the heel, and the weight *Wc* of the concrete all should be taken into consideration.



Application of Lateral Earth Pressure Theories to Design

A similar type of analysis may be used for gravity walls. However, Coulomb's active earth pressure theory also may be used. If it is used, the only forces to be considered are Pa (Coulomb) and the weight of the wall. Wc.





Application of Lateral Earth Pressure Theories to Design

If Coulomb's theory is used, it will be necessary to know the range of the wall friction angle δ' with various types of backfill material. Following are some ranges of wall friction angle for masonry or mass concrete walls:

Backfill material	Range of δ' (deg)
Gravel	27–30
Coarse sand	20–28
Fine sand	15–25
Stiff clay	15–20
Silty clay	12–16

Stability of Retaining Walls

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

- It may overturn about its toe (a)
- It may slide along its base (b)
- It may fail due to the loss of bearing capacity of the soil supporting the base (c)
- It may undergo deep-seated shear failure (d)
- It may go through excessive settlement.

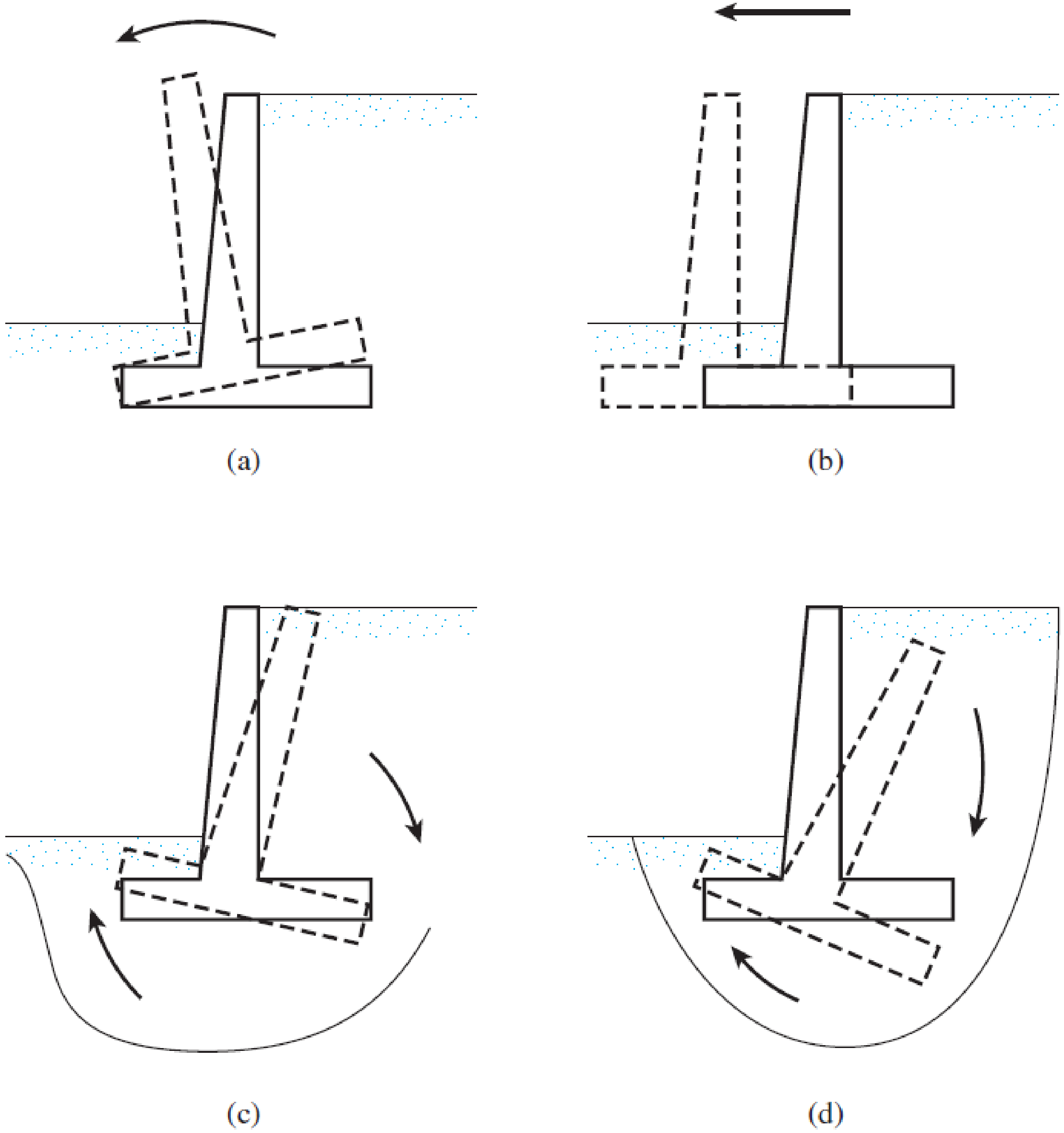
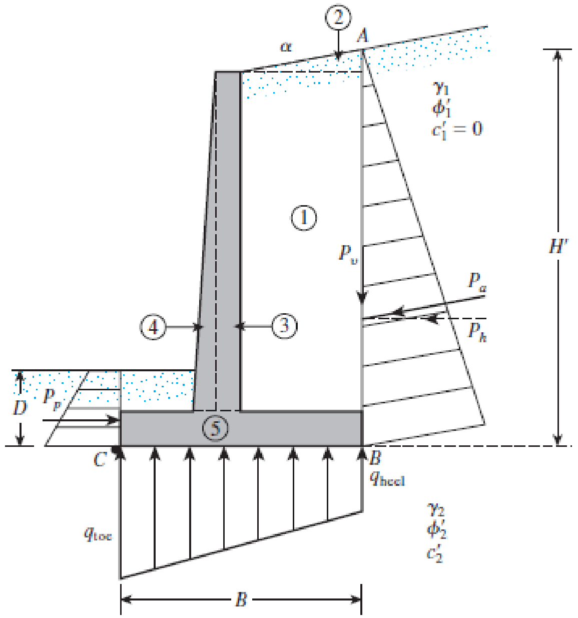
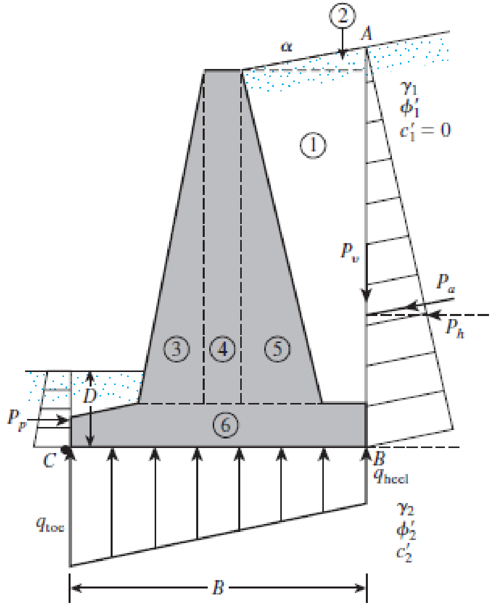


Figure 13.5 Failure of retaining wall:
(a) by overturning; (b) by sliding;
(c) by bearing capacity failure;
(d) by deep-seated shear failure





1. Check for Overturning

Based on the assumption that the Rankine active pressure is acting along a vertical plane AB drawn through the heel of structure. Rankine passive pressure:

$$P_p = \tfrac{1}{2}K_p\gamma_2 D^2 + 2c_2'\sqrt{K_p}D$$

where

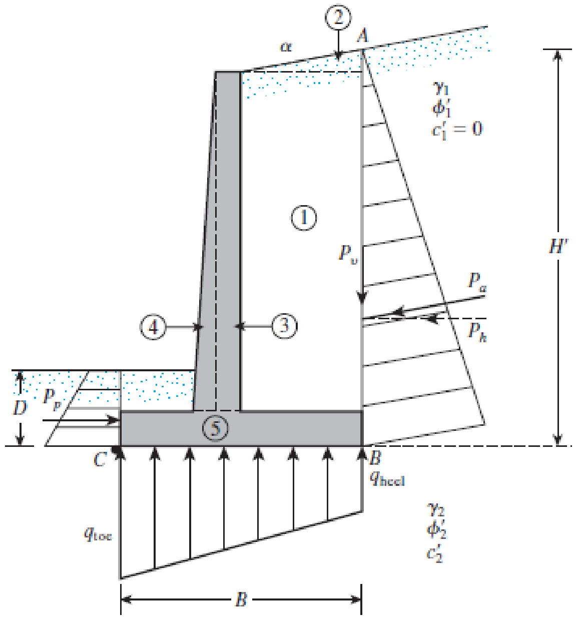
γ_2 = unit weight of soil in front of the heel and under the base slab
K_p = Rankine passive earth pressure coefficient = $\tan^2(45 + \phi_2'/2)$
c_2', ϕ_2' = cohesion and effective soil friction angle, respectively

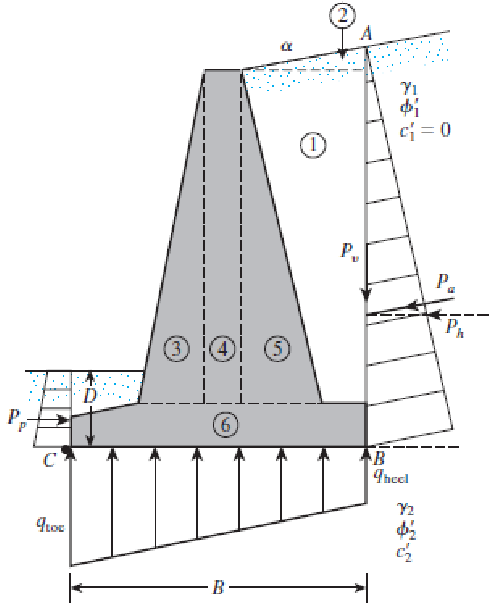
$$\text{FS}_{(\text{overturning})} = \frac{\Sigma M_R}{\Sigma M_o}$$

where

ΣM_o = sum of the moments of forces tending to overturn about point C
ΣM_R = sum of the moments of forces tending to resist overturning about point C

1. Check for Overturning





Based on the assumption that the Rankine active pressure is acting along a vertical plane AB drawn through the heel of structure. Rankine passive pressure:

Rankine active pressure:

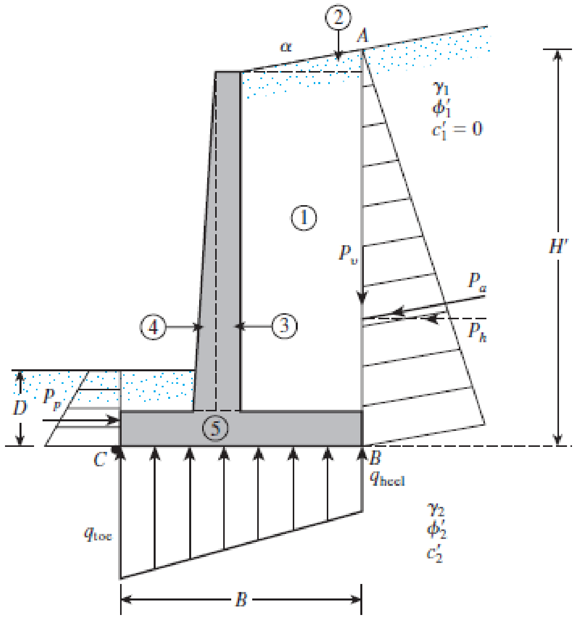
$$P_h = P_a \cos\alpha \qquad P_v = P_a \sin\alpha$$

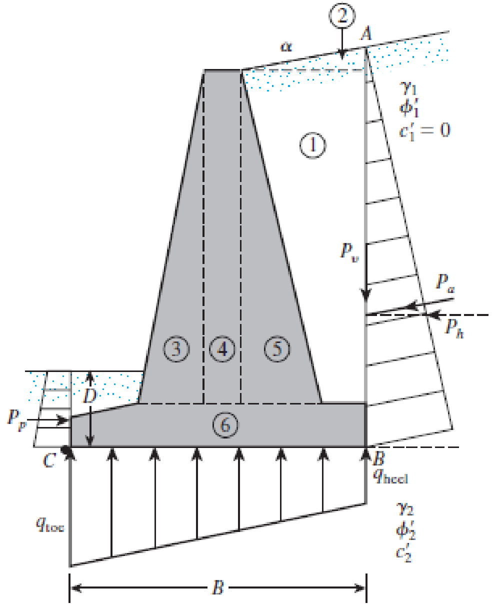
Moment of the force Pv:

$$M_v = P_v B = P_a \sin\alpha B$$

FS againts overturning about the toe:

$$\mathrm{FS}_{(\text{overturning})} = \frac{M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_v}{P_a \cos\alpha (H'/3)}$$





1. Check for Overturning

Calculating ΣMR

$$FS_{(overturning)} = \frac{M_1 + M_2 + M_3 + M_4 + M_5 + M_6}{P_a \cos\alpha(H'/3) - M_v}$$

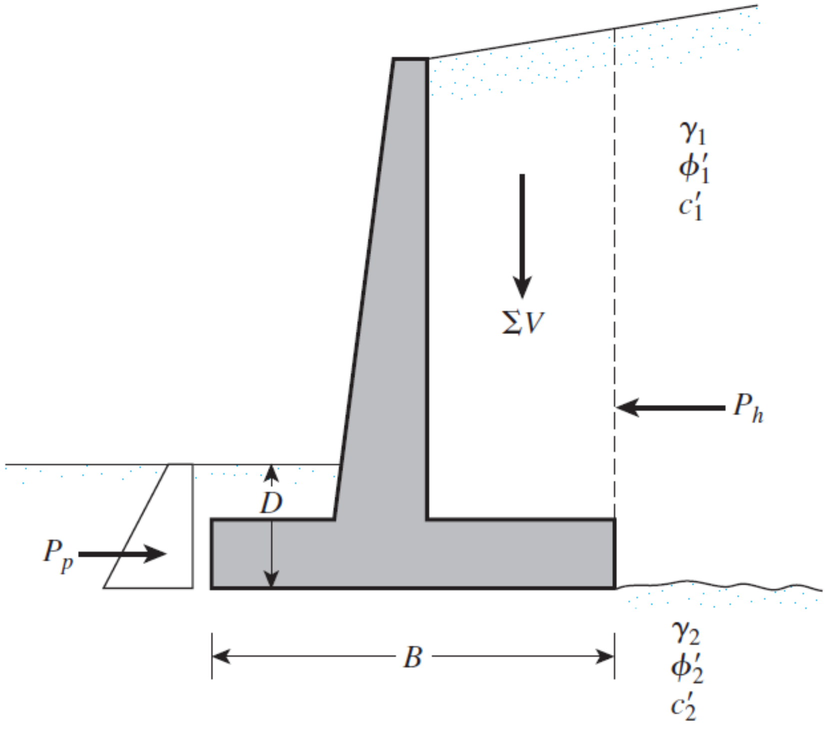
Table 13.1 Procedure for Calculating ΣM_R

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
X_i = horizontal distance between *C* and the centroid of the section)

The usual minimum desirable value of the factor of safety with respect to overturning is 2 to 3.

2. Check for Sliding



The factor of safety against sliding may be expressed by the equation

$$FS_{(sliding)} = \frac{\Sigma F_{R'}}{\Sigma F_d}$$

where

$\Sigma F_{R'}$ = sum of the horizontal resisting forces
ΣF_d = sum of the horizontal driving forces

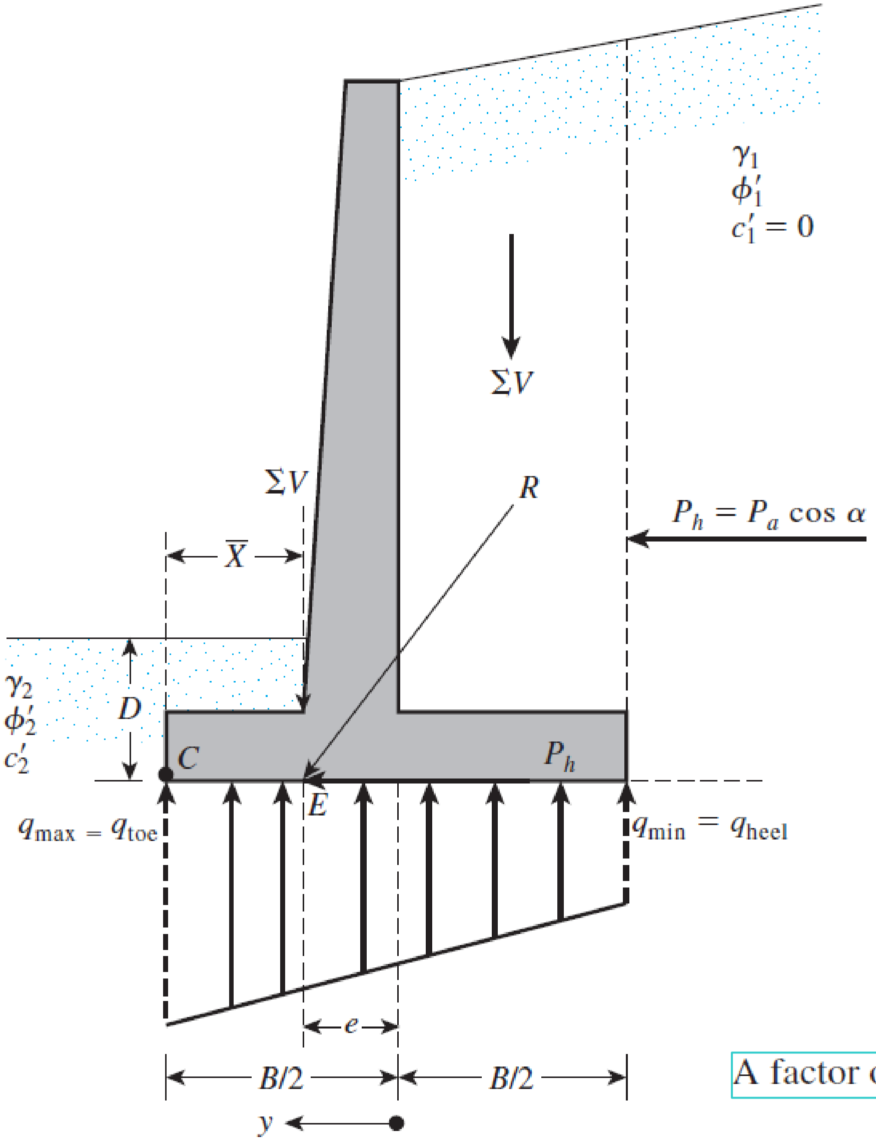
$$FS_{(sliding)} = \frac{(\Sigma V)\tan\delta' + Bc'_a + P_p}{P_a \cos\alpha}$$

A minimum factor of safety of 1.5 against sliding is generally required.

In many cases, the passive force P_p is ignored in calculating the factor of safety with respect to sliding. In general, we can write $\delta' = k_1\phi'_2$ and $c'_a = k_2 c'_2$. In most cases, k_1 and k_2 are in the range from $\frac{1}{2}$ to $\frac{2}{3}$. Thus,

$$FS_{(sliding)} = \frac{(\Sigma V)\tan(k_1\phi'_2) + Bk_2c'_2 + P_p}{P_a \cos\alpha} \qquad (13.11)$$

3. Check for Bearing Capacity Failure



The sum of the vertical force acting on the base slab is ΣV, and the horizontal force P_h is $P_a \cos \alpha$

The resultant force: $\mathbf{R} = \Sigma\,\mathbf{V} + \mathbf{P}_h$

The net moment of these force:

$$M_{net} = \Sigma M_R - \Sigma M_o$$

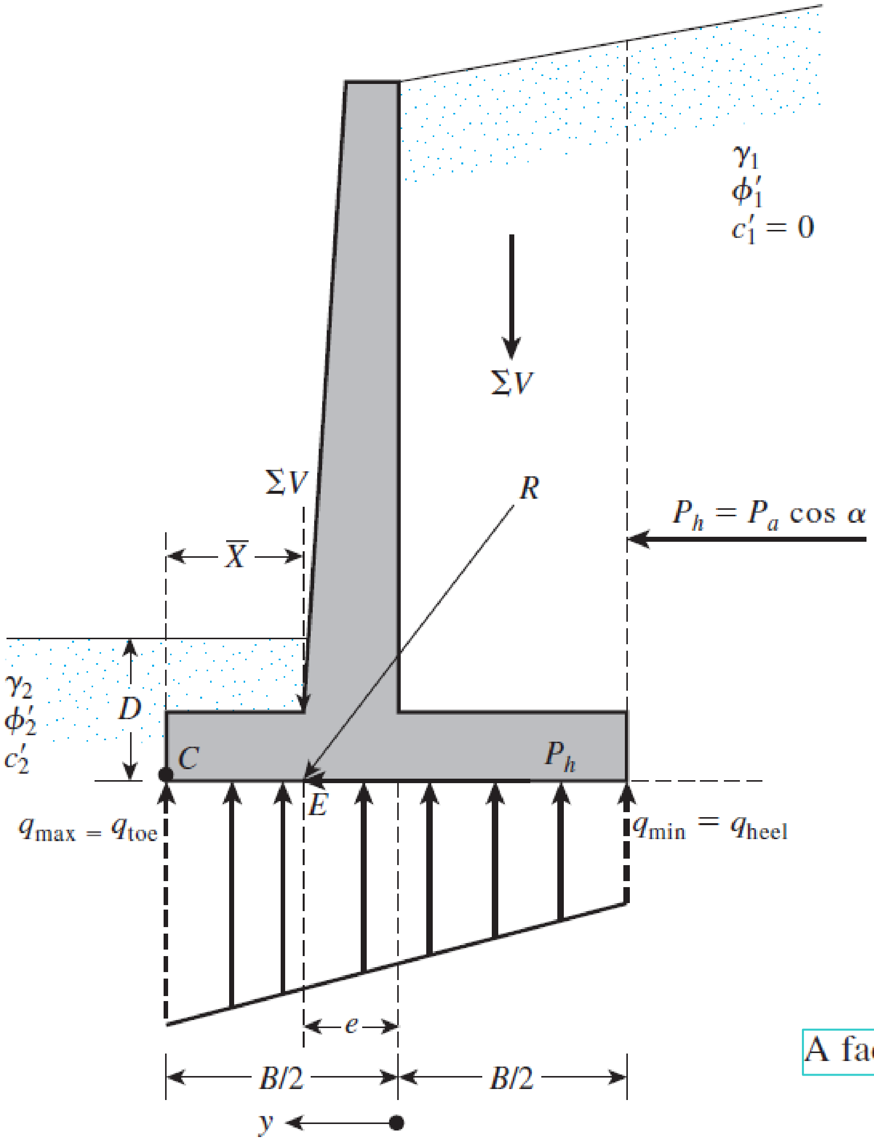
$$q_{max} = q_{toe} = \frac{\Sigma V}{(B)(1)} + \frac{e(\Sigma V)\frac{B}{2}}{\left(\frac{1}{12}\right)(B^3)} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right)$$

$$q_{min} = q_{heel} = \frac{\Sigma V}{B}\left(1 - \frac{6e}{B}\right)$$

$$\boxed{FS_{(bearing\ capacity)} = \frac{q_u}{q_{max}}}$$

A factor of safety of 3 against bearing capacity failure

3. Check for Bearing Capacity Failure



Ultimate bearing capacity of shallow fondation:

$$q_u = c'_2 N_c F_{cd} F_{ci} + q N_q F_{qd} F_{qi} + \tfrac{1}{2}\gamma_2 B' N_\gamma F_{\gamma d} F_{\gamma i}$$

where

$$q = \gamma_2 D$$

$$B' = B - 2e$$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi'_2}$$

$$F_{qd} = 1 + 2\tan\phi'_2(1 - \sin\phi'_2)^2 \frac{D}{B'}$$

$$F_{\gamma d} = 1$$

$$F_{ci} = F_{qi} = \left(1 - \frac{\psi^\circ}{90^\circ}\right)^2$$

$$F_{\gamma i} = \left(1 - \frac{\psi^\circ}{\phi_2'^\circ}\right)^2$$

$$\psi^\circ = \tan^{-1}\left(\frac{P_a \cos\alpha}{\Sigma V}\right)$$

A factor of safety of 3 against bearing capacity failure

EXAMPLE 1

Example 13.1

The cross section of a cantilever retaining wall is shown in Figure 13.12. Calculate the factors of safety with respect to overturning, sliding, and bearing capacity.

Solution

From the figure,

$$H' = H_1 + H_2 + H_3 = 2.6 \tan 10° + 6 + 0.7$$
$$= 0.458 + 6 + 0.7 = 7.158 \text{ m}$$

The Rankine active force per unit length of wall $= P_p = \frac{1}{2}\gamma_1 H'^2 K_a$. For $\phi'_1 = 30°$ and $\alpha = 10°$, K_a is equal to 0.3495. (See Table 12.1.) Thus,

$$P_a = \tfrac{1}{2}(18)(7.158)^2(0.3495) = 161.2 \text{ kN/m}$$

$$P_v = P_a \sin 10° = 161.2\ (\sin 10°) = 28.0 \text{ kN/m}$$

and

$$P_h = P_a \cos 10° = 161.2\ (\cos 10°) = 158.75 \text{ kN/m}$$

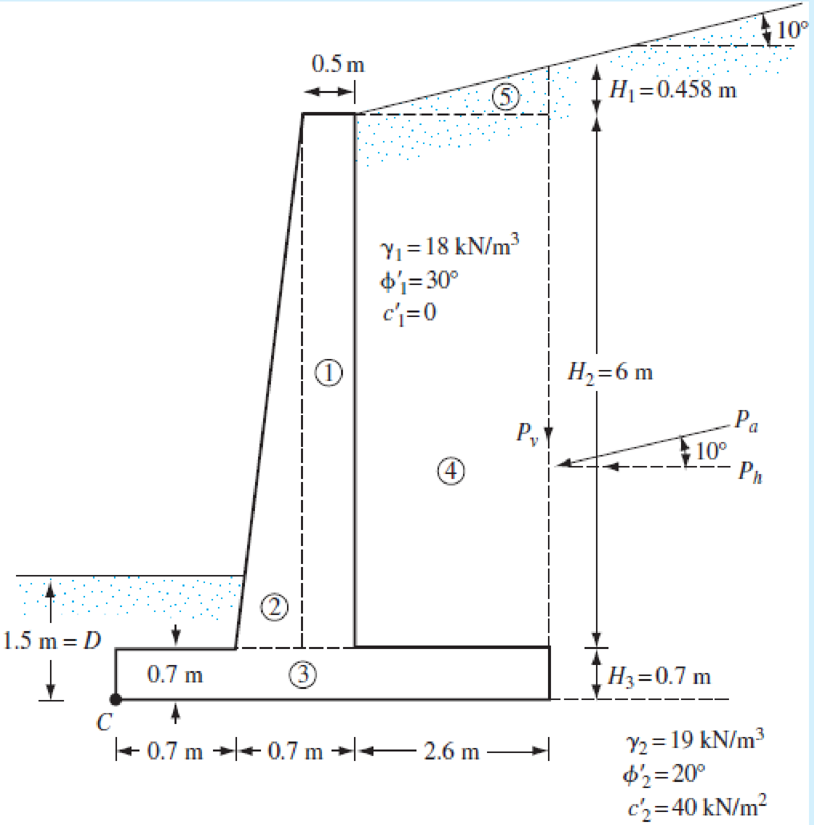


Figure 13.12 Calculation of stability of a retaining wall

EXAMPLE 1

Factor of Safety against Overturning

The following table can now be prepared for determining the resisting moment:

Section no.[a]	Area (m^2)	Weight/unit length (kN/m)	Moment arm from point *C* (m)	Moment (kN-m/m)
1	$6 \times 0.5 = 3$	70.74	1.15	81.35
2	$\frac{1}{2}(0.2)6 = 0.6$	14.15	0.833	11.79
3	$4 \times 0.7 = 2.8$	66.02	2.0	132.04
4	$6 \times 2.6 = 15.6$	280.80	2.7	758.16
5	$\frac{1}{2}(2.6)(0.458) = 0.595$	10.71	3.13	33.52
		$P_v = 28.0$	4.0	112.0
		$\Sigma V = 470.42$		$1128.86 = \Sigma M_R$

[a]For section numbers, refer to Figure 13.12

$\gamma_{concrete} = 23.58\ kN/m^3$

The overturning moment

$$M_o = P_h\left(\frac{H'}{3}\right) = 158.75\left(\frac{7.158}{3}\right) = 378.78\ \text{kN-m/m}$$

and

$$FS_{\text{(overturning)}} = \frac{\Sigma M_R}{M_o} = \frac{1128.86}{378.78} = \mathbf{2.98 > 2,\ OK}$$

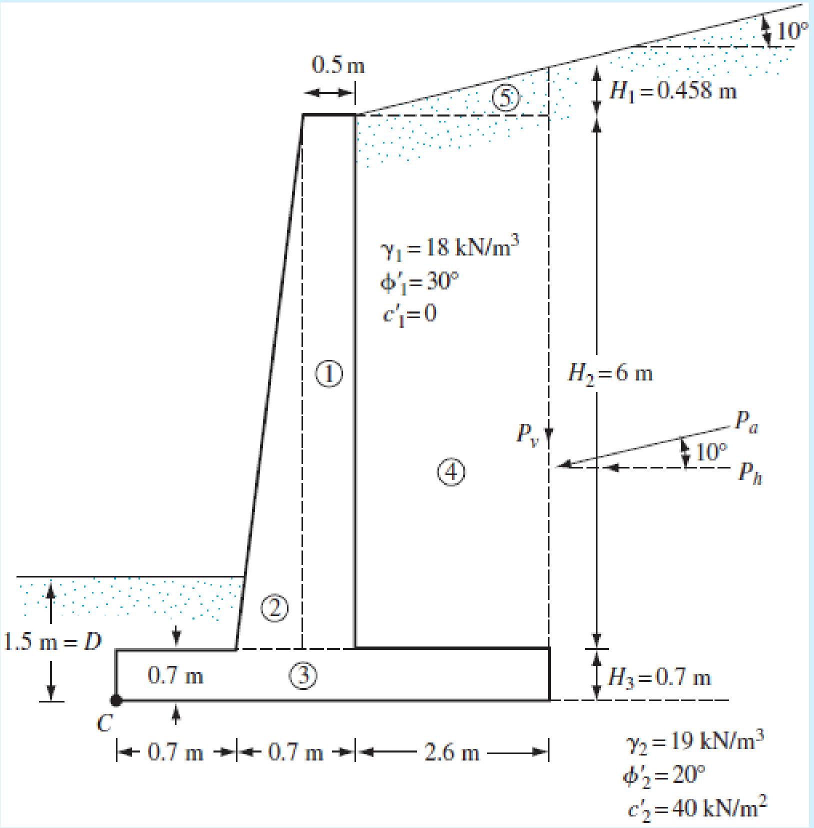


Figure 13.12 Calculation of stability of a retaining wall

γ concrete use : 23.58 kN/m^2

EXAMPLE 1

Factor of Safety against Sliding

From Eq. (12.11),

$$FS_{(\text{sliding})} = \frac{(\Sigma V)\tan(k_1\phi_2') + Bk_2c_2' + P_p}{P_a\cos\alpha}$$

Let $k_1 = k_2 = \frac{2}{3}$. Also,

$$P_p = \tfrac{1}{2}K_p\gamma_2 D^2 + 2c_2'\sqrt{K_p}D$$

$$K_p = \tan^2\left(45 + \frac{\phi_2'}{2}\right) = \tan^2(45 + 10) = 2.04$$

and

$$D = 1.5 \text{ m}$$

So

$$P_p = \tfrac{1}{2}(2.04)(19)(1.5)^2 + 2(40)(\sqrt{2.04})(1.5)$$
$$= 43.61 + 171.39 = 215 \text{ kN/m}$$

Hence,

$$FS_{(\text{sliding})} = \frac{(470.42)\tan\left(\frac{2\times 20}{3}\right) + (4)\left(\frac{2}{3}\right)(40) + 215}{158.75}$$
$$= \frac{111.49 + 106.67 + 215}{158.75} = \mathbf{2.73 > 1.5, OK}$$

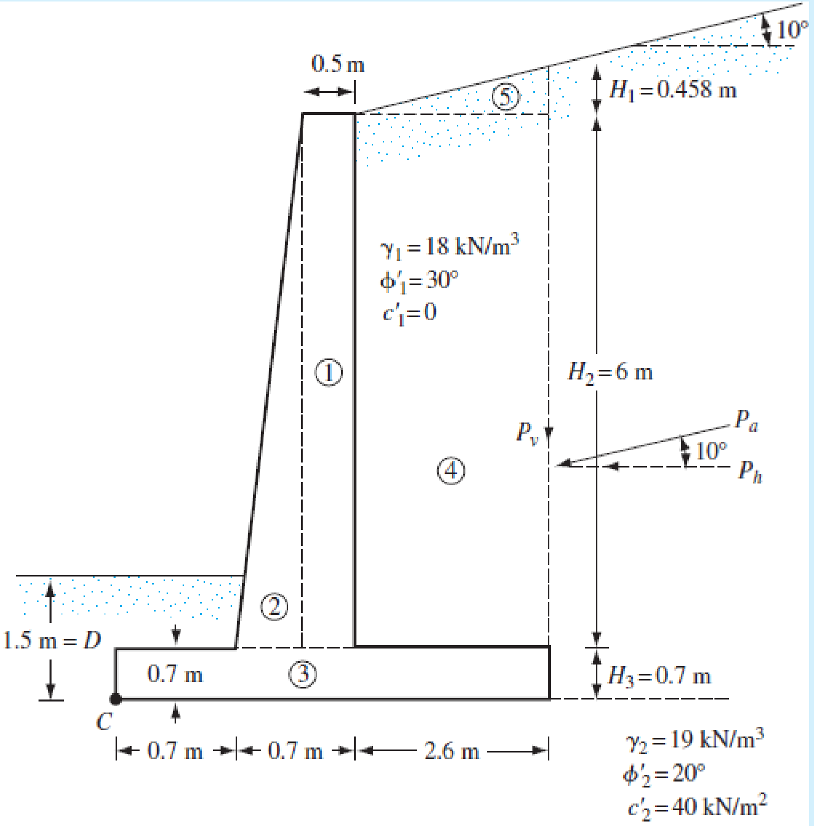


Figure 13.12 Calculation of stability of a retaining wall

Note: For some designs, the depth D in a passive pressure calculation may be taken to be *equal to the thickness of the base slab.*

EXAMPLE 1

Factor of Safety against Bearing Capacity Failure

Combining Eqs. (13.16), (13.17), and (13.18) yields

$$e = \frac{B}{2} - \frac{\Sigma M_R - \Sigma M_o}{\Sigma V} = \frac{4}{2} - \frac{1128.86 - 378.78}{470.42}$$

$$= 0.406 \text{ m} < \frac{B}{6} = \frac{4}{6} = 0.666 \text{ m}$$

Again, from Eqs. (13.20) and (13.21)

$$q_{\substack{\text{toe}\\\text{heel}}} = \frac{\Sigma V}{B}\left(1 \pm \frac{6e}{B}\right) = \frac{470.42}{4}\left(1 \pm \frac{6 \times 0.406}{4}\right) = 189.2 \text{ kN/m}^2 \text{ (toe)}$$

$$= 45.98 \text{ kN/m}^2 \text{ (heel)}$$

The ultimate bearing capacity of the soil can be determined from Eq. (13.22)

$$q_u = c_2' N_c F_{cd} F_{ci} + q N_q F_{qd} F_{qi} + \frac{1}{2}\gamma_2 B' N_\gamma F_{\gamma d} F_{\gamma i}$$

For $\phi_2' = 20°$ (see Table 4.2), $N_c = 14.83$, $N_q = 6.4$, and $N_\gamma = 5.39$. Also,

$$q = \gamma_2 D = (19)(1.5) = 28.5 \text{ kN/m}^2$$

$$B' = B - 2e = 4 - 2(0.406) = 3.188 \text{ m}$$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi_2'} = 1.148 - \frac{1 - 1.148}{(14.83)(\tan 20)} = 1.175$$

$$F_{qd} = 1 + 2\tan\phi_2'(1 - \sin\phi_2')^2\left(\frac{D}{B'}\right) = 1 + 0.315\left(\frac{1.5}{3.188}\right) = 1.148$$

$$F_{\gamma d} = 1$$

$$F_{ci} = F_{qi} = \left(1 - \frac{\psi°}{90°}\right)^2$$

$$\psi = \tan^{-1}\left(\frac{P_a \cos\alpha}{\Sigma V}\right) = \tan^{-1}\left(\frac{158.75}{470.42}\right) = 18.65°$$

$$F_{ci} = F_{qi} = \left(1 - \frac{18.65}{90}\right)^2 = 0.628$$

$$F_{\gamma i} = \left(1 - \frac{\psi}{\phi_2'}\right)^2 = \left(1 - \frac{18.65}{20}\right)^2 \approx 0$$

$$q_u = (40)(14.83)(1.175)(0.628) + (28.5)(6.4)(1.148)(0.628)$$
$$+ \tfrac{1}{2}(19)(5.93)(3.188)(1)(0)$$
$$= 437.72 + 131.5 + 0 = 569.22 \text{ kN/m}^2$$

$$FS_{\text{(bearing capacity)}} = \frac{q_u}{q_{\text{toe}}} = \frac{569.22}{189.2} = \mathbf{3.0\ OK}$$

EXAMPLE 2

Example 13.2

A gravity retaining wall is shown in Figure 13.13. Use $\delta' = 2/3\phi'_1$ and Coulomb's active earth pressure theory. Determine

a. The factor of safety against overturning
b. The factor of safety against sliding
c. The pressure on the soil at the toe and heel

Solution

The height

$$H' = 5 + 1.5 = 6.5 \text{ m}$$

Coulomb's active force is

$$P_a = \tfrac{1}{2}\gamma_1 H'^2 K_a$$

With $\alpha = 0°$, $\beta = 75°$, $\delta' = 2/3\phi'_1$, and $\phi'_1 = 32°$, $K_a = 0.4023$. (See Table 12.6.) So,

$$P_a = \tfrac{1}{2}(18.5)(6.5)^2(0.4023) = 157.22 \text{ kN/m}$$

$$P_h = P_a \cos(15 + \tfrac{2}{3}\phi'_1) = 157.22 \cos 36.33 = 126.65 \text{ kN/m}$$

and

$$P_v = P_a \sin(15 + \tfrac{2}{3}\phi'_1) = 157.22 \sin 36.33 = 93.14 \text{ kN/m}$$

EXAMPLE 2

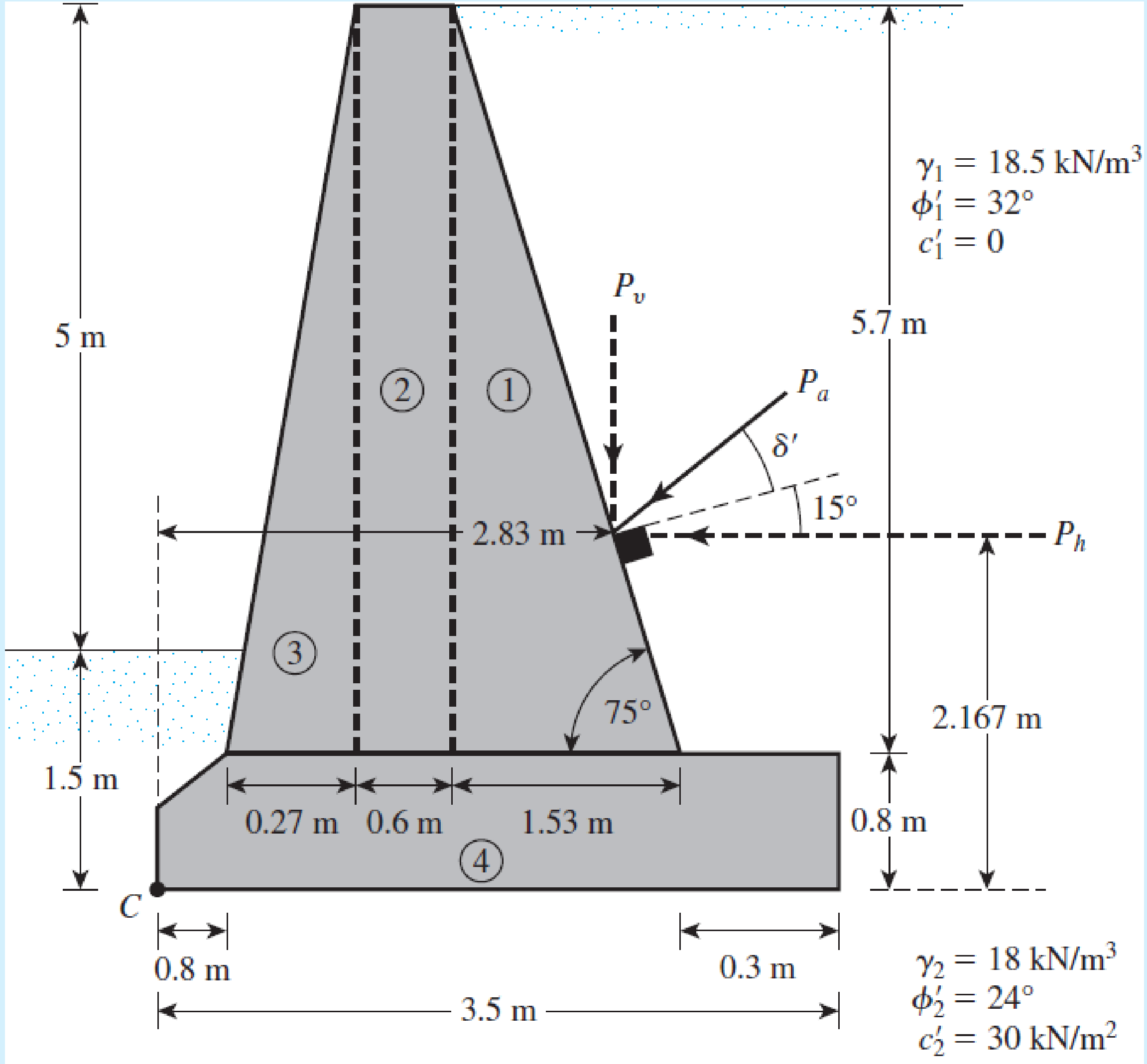


Figure 13.13 Gravity retaining wall (not to scale)

EXAMPLE 2

Part a: Factor of Safety against Overturning

From Figure 13.13, one can prepare the following table:

Area no.	Area (m^2)	Weight* (kN/m)	Moment arm from *C* (m)	Moment (kN-m/m)
1	$\frac{1}{2}(5.7)(1.53) = 4.36$	102.81	2.18	224.13
2	$(0.6)(5.7) = 3.42$	80.64	1.37	110.48
3	$\frac{1}{2}(0.27)(5.7) = 0.77$	18.16	0.98	17.80
4	$\approx (3.5)(0.8) = 2.8$	66.02	1.75	115.54
		$P_v = 93.14$	2.83	263.59
		$\Sigma V = 360.77$ kN/m		$\Sigma M_R = 731.54$ kN-m/m

$^*\gamma_{concrete} = 23.58$ kN/m^3

Note that the weight of the soil above the back face of the wall is not taken into account in the preceding table. We have

$$\text{Overturning moment} = M_o = P_h\left(\frac{H'}{3}\right) = 126.65(2.167) = 274.45 \text{ kN-m/m}$$

Hence,

$$FS_{(overturning)} = \frac{\Sigma M_R}{\Sigma M_o} = \frac{731.54}{274.45} = \mathbf{2.67 > 2, OK}$$

EXAMPLE 2

Part b: Factor of Safety against Sliding

We have

$$FS_{(\text{sliding})} = \frac{(\Sigma V)\tan\left(\frac{2}{3}\phi_2'\right) + \frac{2}{3}c_2'B + P_p}{P_h}$$

$$P_p = \tfrac{1}{2}K_p\gamma_2 D^2 + 2c_2'\sqrt{K_p}D$$

and

$$K_p = \tan^2\left(45 + \frac{24}{2}\right) = 2.37$$

Hence,

$$P_p = \tfrac{1}{2}(2.37)(18)(1.5)^2 + 2(30)(1.54)(1.5) = 186.59 \text{ kN/m}$$

So

$$FS_{(\text{sliding})} = \frac{360.77\tan\left(\frac{2}{3}\times 24\right) + \frac{2}{3}(30)(3.5) + 186.59}{126.65}$$

$$= \frac{103.45 + 70 + 186.59}{126.65} = \mathbf{2.84}$$

EXAMPLE 2

If P_p is ignored, the factor of safety is **1.37**.

Part c: Pressure on Soil at Toe and Heel

From Eqs. (13.16), (13.17), and (13.18),

$$e = \frac{B}{2} - \frac{\Sigma M_R - \Sigma M_o}{\Sigma V} = \frac{3.5}{2} - \frac{731.54 - 274.45}{360.77} = 0.483 < \frac{B}{6} = 0.583$$

$$q_{\text{toe}} = \frac{\Sigma V}{B}\left[1 + \frac{6e}{B}\right] = \frac{360.77}{3.5}\left[1 + \frac{(6)(0.483)}{3.5}\right] = \mathbf{188.43\ kN/m^2}$$

and

$$q_{\text{heel}} = \frac{V}{B}\left[1 - \frac{6e}{B}\right] = \frac{360.77}{3.5}\left[1 - \frac{(6)(0.483)}{3.5}\right] = \mathbf{17.73\ kN/m^2}$$