INS 4131
DESIGN OF RETAINING STRUCTURES

Retaining Wall Design

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Reference Books

Das, B. M. (2010), ‘‘Principles of Foundation Engineering’’ Seventh Edition, CENGAGE Learning.

Das, B. M. (2010), ‘‘Principles of Geotechnical Engineering’’ Seventh Edition, CENGAGE Learning

Turkish Building and Earthquake Code(2018)

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In this Project class, we will analyze two typical retaining structures to learn their design essentials and determine their stability.

The emphases will be on

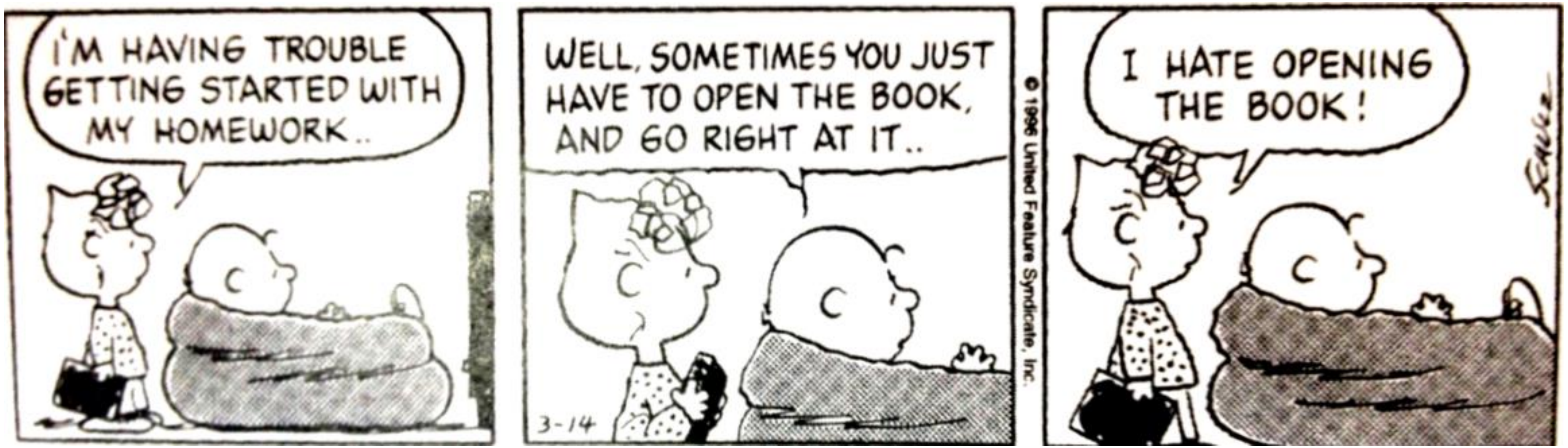
- Gaining an understanding of the forces that provoke failures and methods of analysis of simple earth-retaining structures.

When you complete these two projects, you should be able to:

- Understand and determine lateral earth pressures.
- Understand the forces that lead to instability of retaining structures.
- Determine the stability of retaining structures.
- Design a retaining wall and an anchored wall properly
- Use and apply New releases Turkish Building and Earthquake Code(2018)

How to Be Sucessful In This Class

- Attend classes regularly (Wednesdays: 10.00-12.50)
- Take your own notes during the class (copy center notes are not recommended)
- Study and take a look at the course book or your previous Foundation Engineering class notes
- Ask questions
- Study midterms (not one day before!!!) and review course content



- ✓ Do not copy previous projects!!!
- ✓ Perform the projects by yourself i.e design your own retaining structures

GRADING

Project Assignments :2

Midterm Exam :1

Final Exam: 1

Final Grade= %60 Midterm Exam+ %40 Final Exam

Projects+Midterm Exam

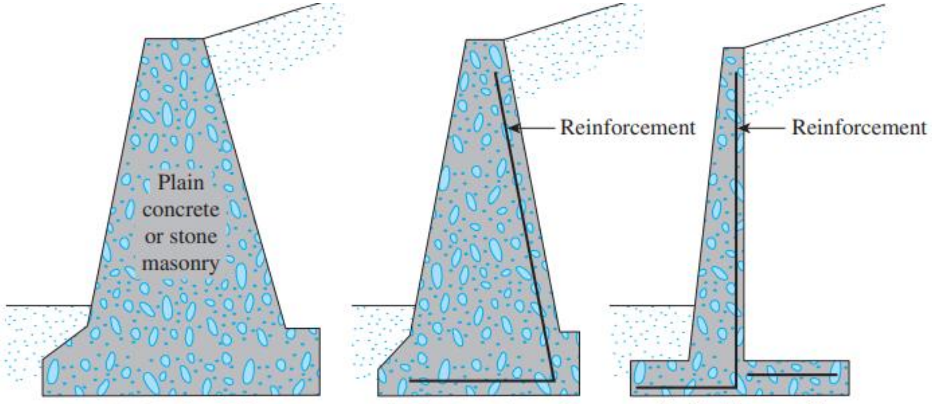
Outline

REVIEW OF EARTH PRESSURE THEORY

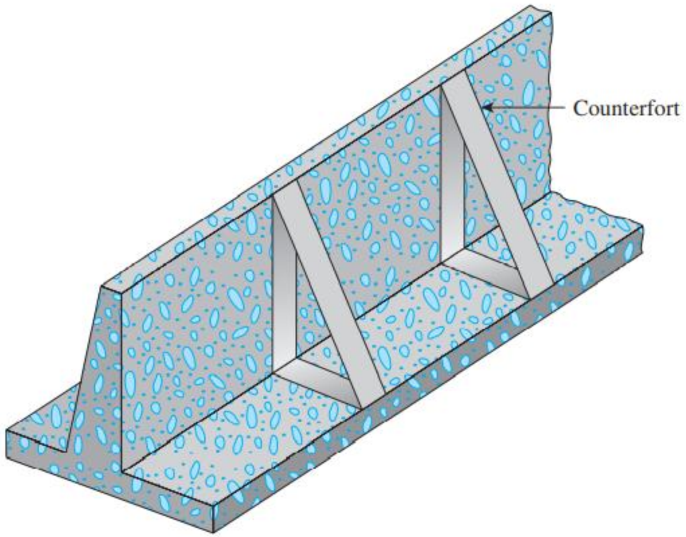
RETAINING STRUCTURES

RETAINING WALL DESIGN

ASSIGNMENT OF 1ST PROJECT



(a) Gravity wall (b) Semigravity wall (c) Cantilever wall



(d) Counterfort wall

QUESTIONS TO GUIDE YOUR 1ST PROJECT

- 1. What is meant by the stability of earth-retaining structures?
- 2. What are the factors that lead to instability?
- 3. What are the main assumptions in the theory of lateral earth pressures?
- 4. When shall I use either Rankine's theory or Coulomb's theory?
- 5. How do I analyze a retaining wall to chec

Types of Rigid Retaining 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

Types of Rigid Retaining Walls

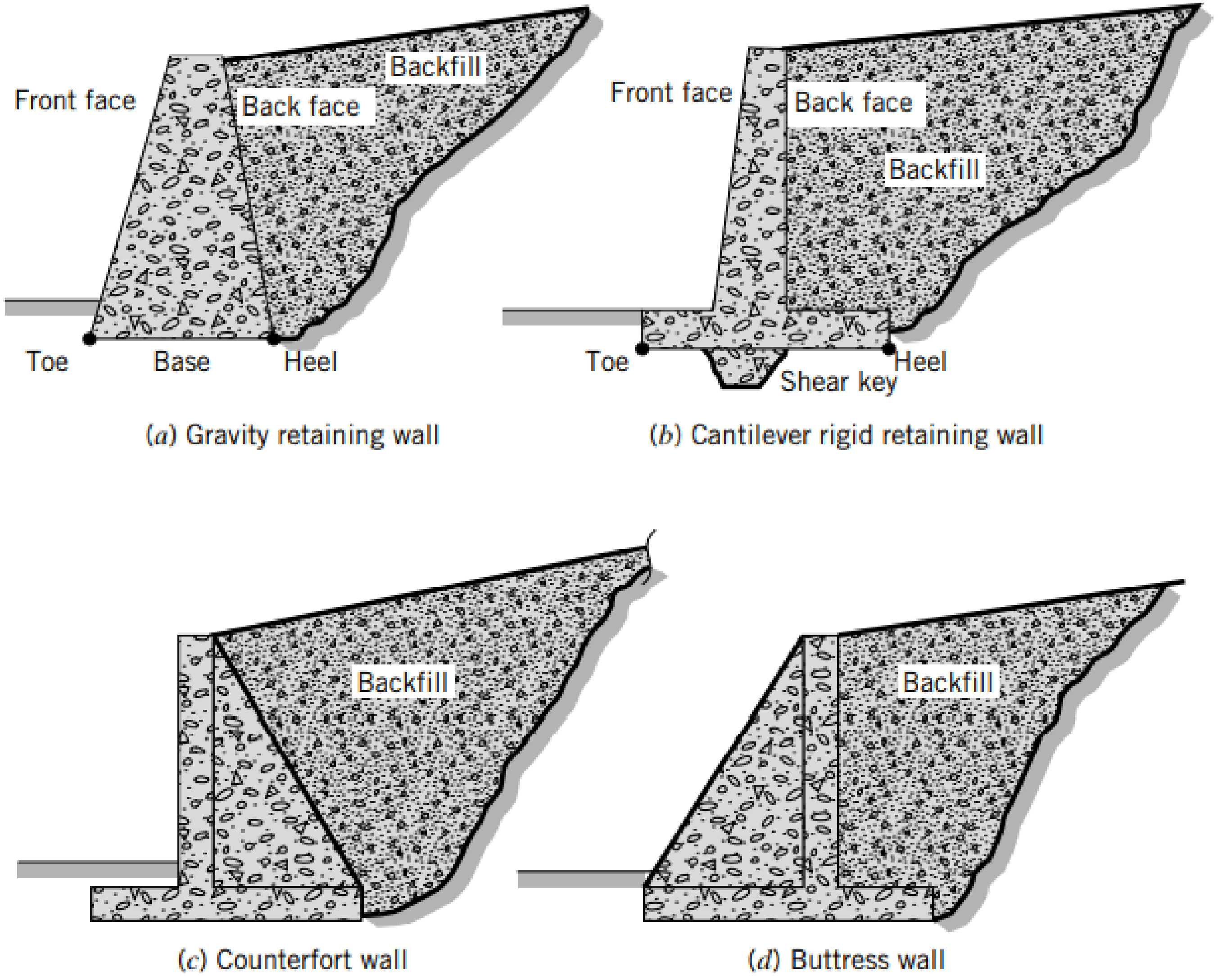


FIGURE 15.13 Types of rigid retaining walls.

Proportioning Gravity and Cantilever Retaining Walls

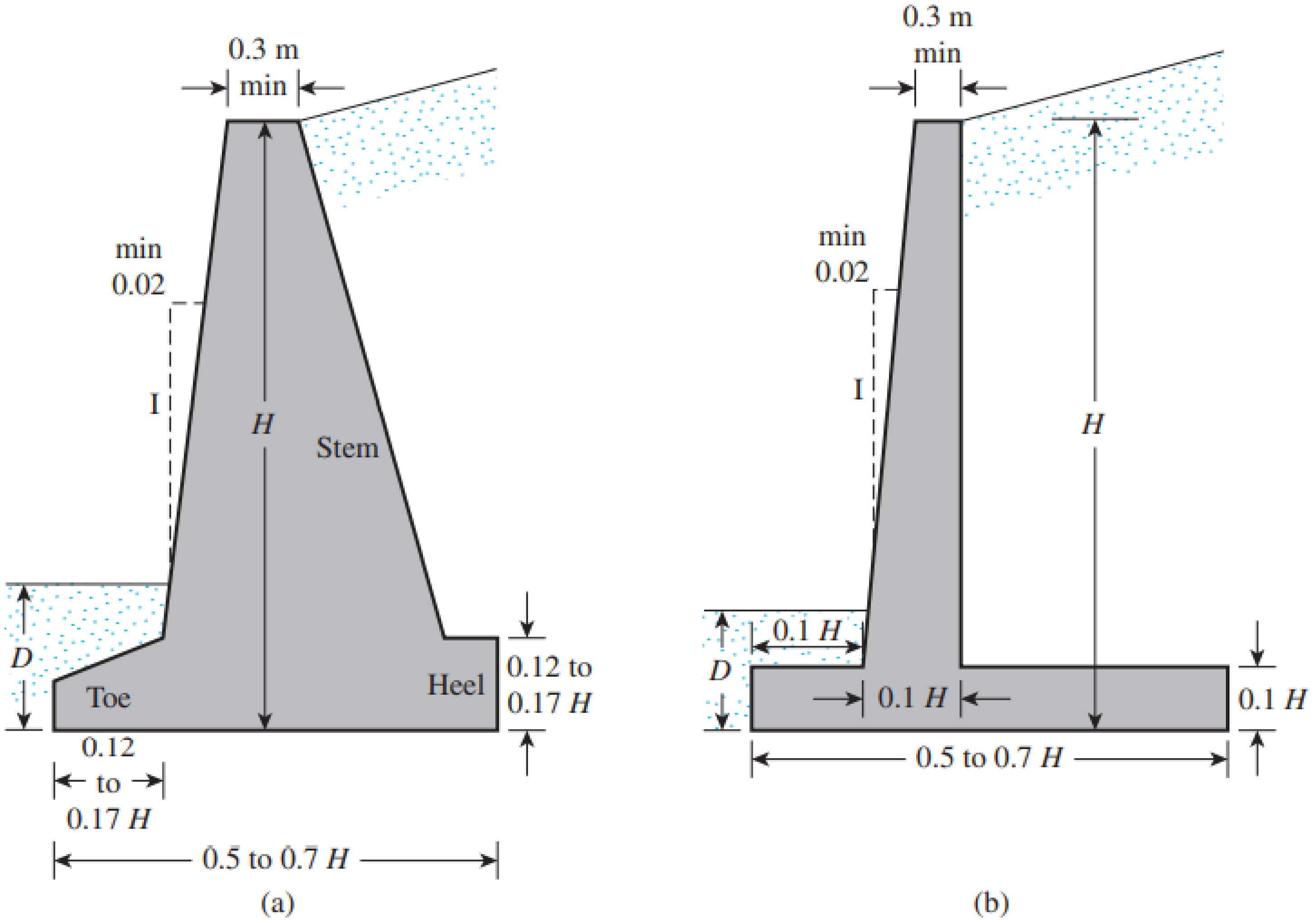
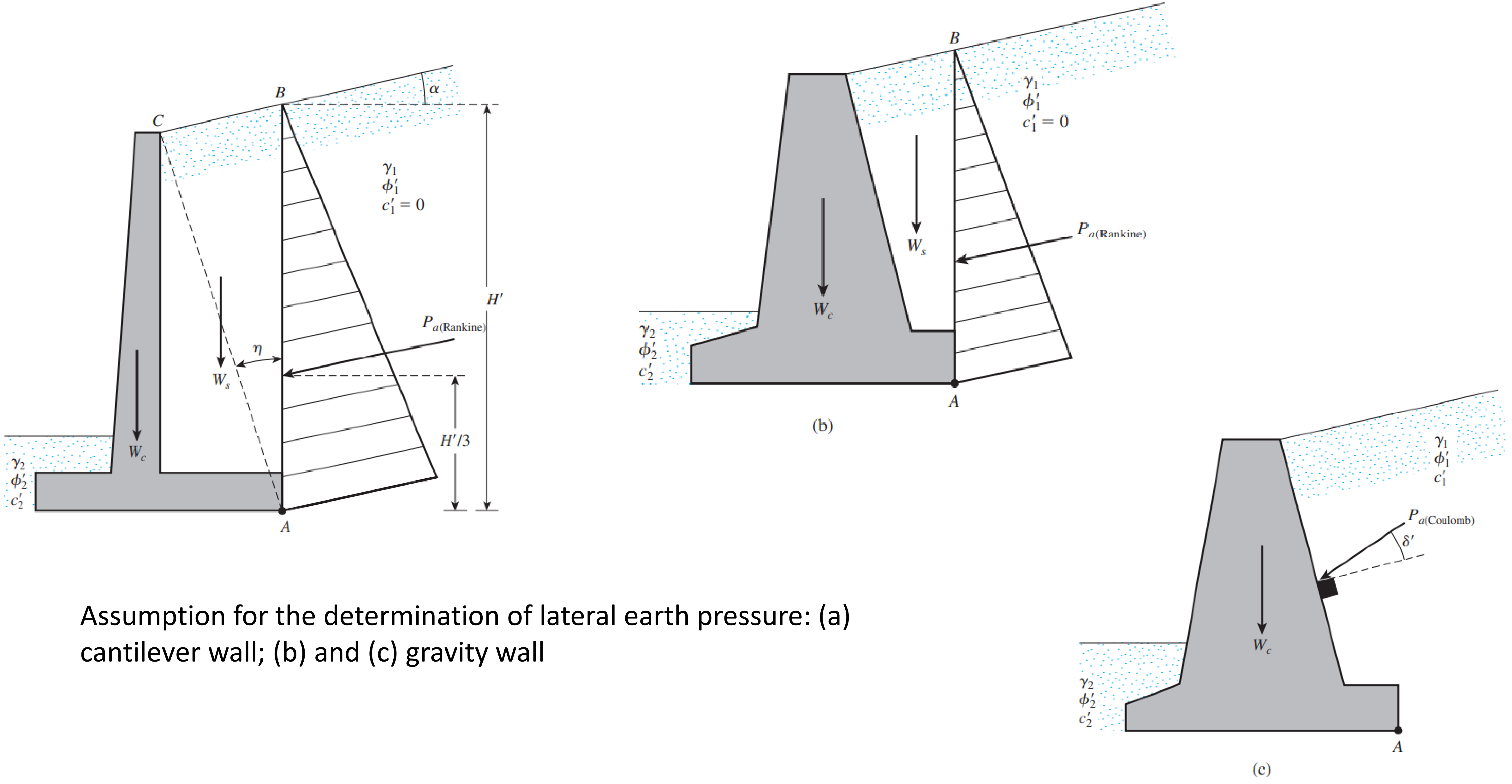


Figure 8.3 Approximate dimensions for various components of retaining wall for initial stability checks: (a) gravity wall; (b) cantilever wall

Application of Lateral Earth Pressure Theories to Design

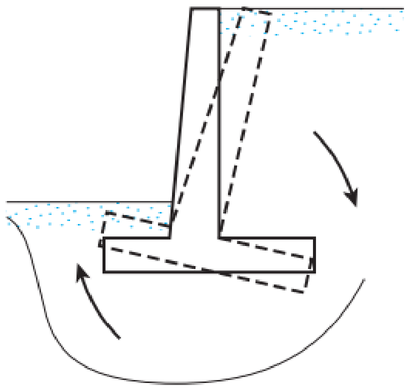
- The fundamental theories for calculating lateral earth pressure were given in **Foundation Engineering Class** in the 3rd Grade.
- **Go back and Review Your Class Notes** and related chapters in the Reference Books!!!



Assumption for the determination of lateral earth pressure: (a) cantilever wall; (b) and (c) gravity wall

Stability of Retaining Walls

- A retaining wall may fail in any of the following ways:
- It may overturn about its toe. (See Figure 15.15b.)
- It may slide along its base. (See Figure 15.15a.)
- It may fail due to the loss of bearing capacity of the soil supporting the base. (See Figure 15.15c.)



- It may undergo deep-seated shear failure. (See Figure 15.15.c) • It may go through excessive settlement.

FAILURE MODES FOR RETAINING WALLS

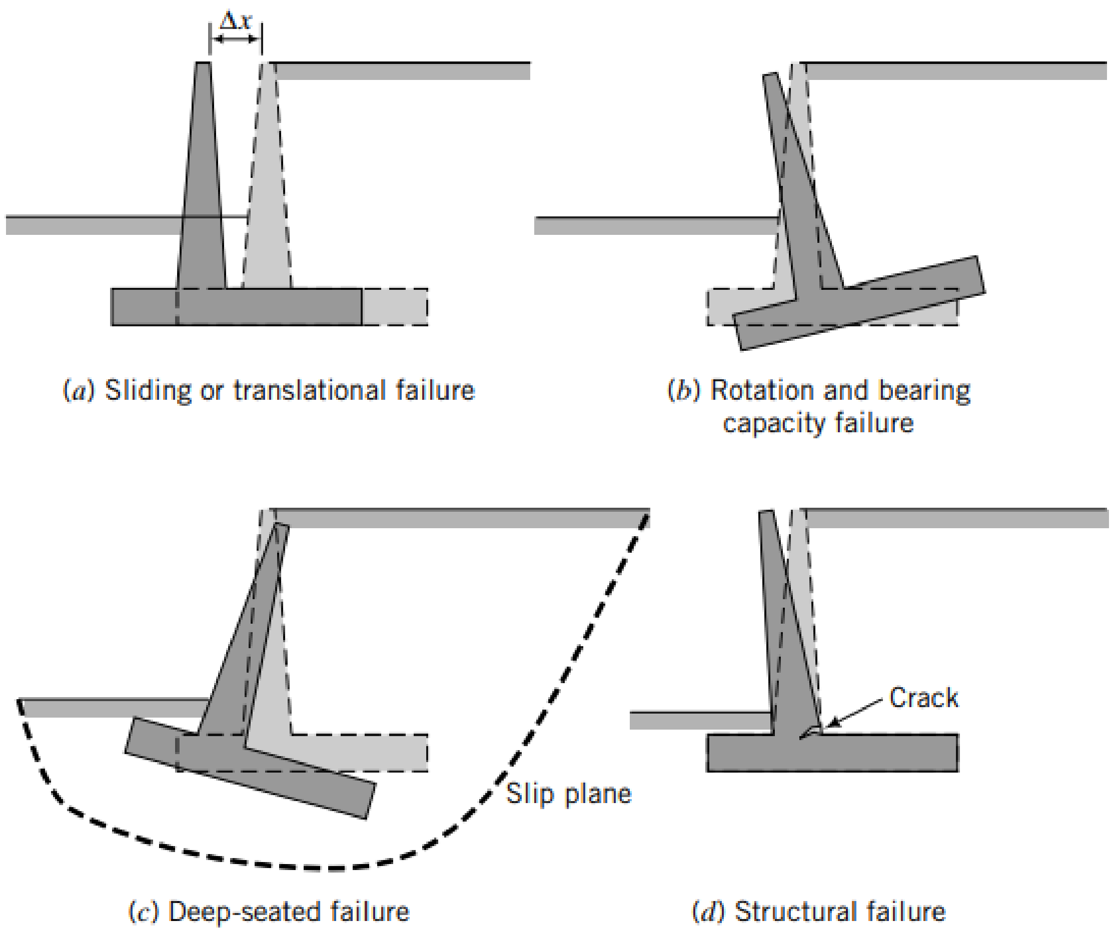


FIGURE 15.15 Failure modes for rigid retaining walls (the dotted lines show the original position of the wall).

Check for Overturning

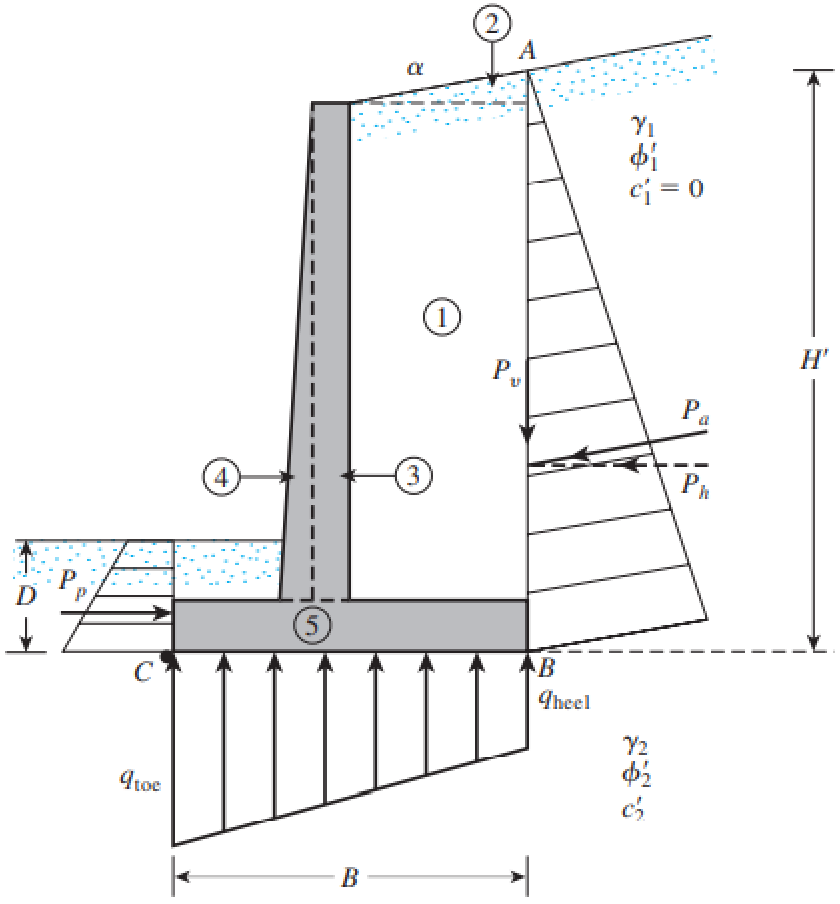
- The factor of safety against overturning about the toe—that is, about point C in the below Figure.

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

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

$$\Sigma M_o = P_h\left(\frac{H'}{3}\right)$$



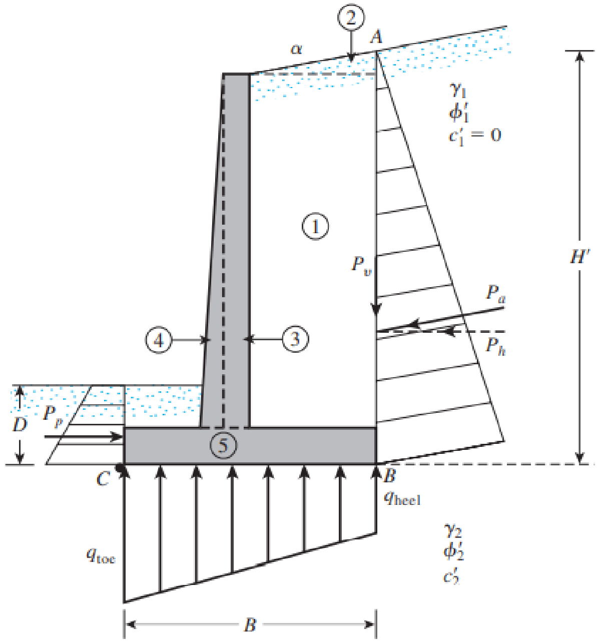


Table 8.1 Procedure for Calculating ΣM_R

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)

Some designers prefer to determine the factor of safety against overturning with the formula

$$\text{FS}_{(\text{overturning})} = \frac{M_1 + M_2 + M_3 + M_4 + M_5 + M_6}{P_a \cos\alpha(H'/3) - M_v} \tag{8.6}$$

Check for Sliding Along The Base

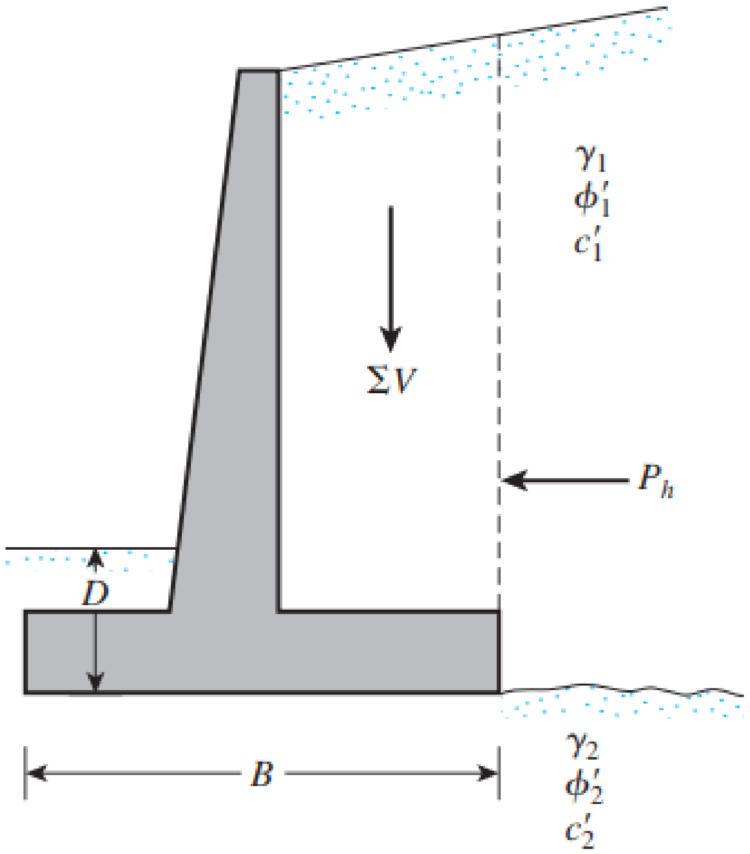
The factor of safety against sliding may be expressed by the equation

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

where

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

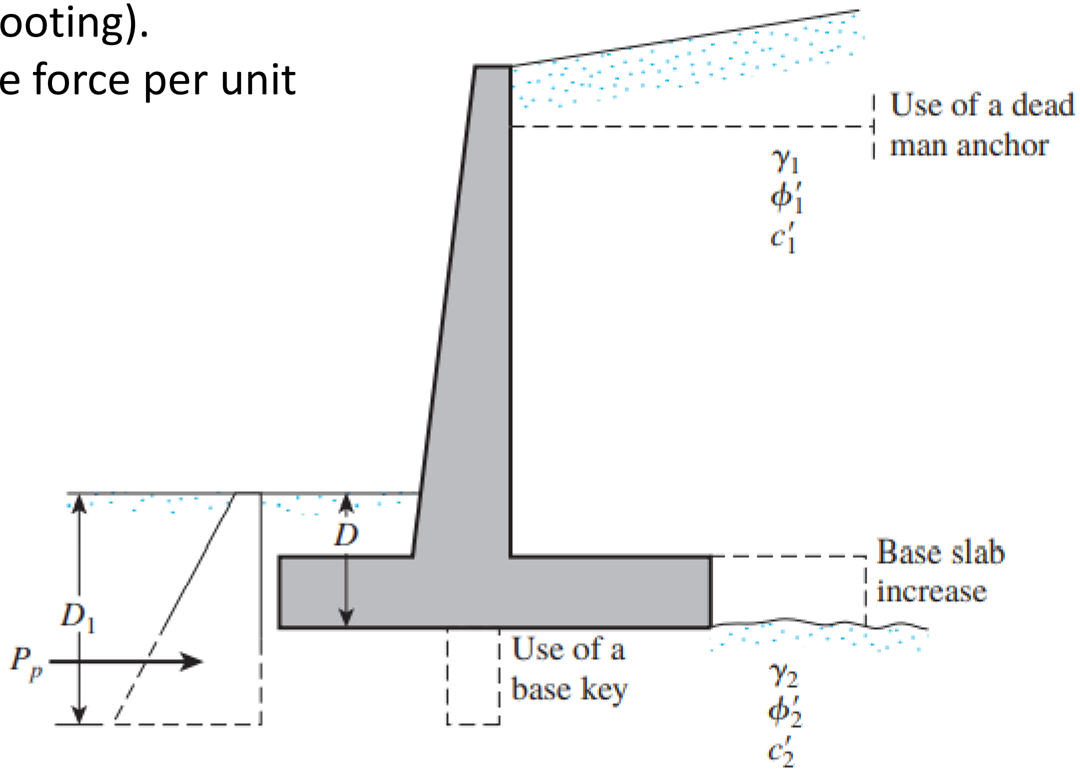
$$FS_{(sliding)} = \frac{(\sum V)\tan(k_1\phi_2') + Bk_2c_2' + P_p}{P_a\cos\alpha}$$



Alternatives for increasing the factor of safety with respect to sliding

If the desired value of is not achieved, several alternatives may be investigated

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



$$P_p = \frac{1}{2}\gamma_2 D_1^2 K_p + 2c'_2 D_1 \sqrt{K_p}$$

where $K_p = \tan^2\left(45 + \frac{\phi'_2}{2}\right)$.

- Use a deadman anchor at the stem of the retaining wall.
- Another possible way to increase the value of FS(sliding) is to consider reducing the value of Pa [see Eq. (8.11)]. One possible way to do so is to use the method developed by Elman and Terry (1988).

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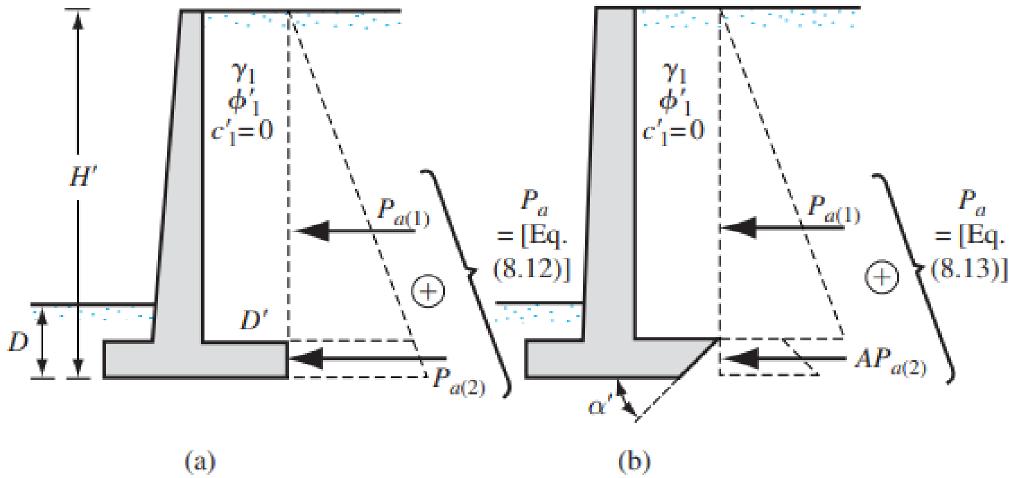


Figure 8.10 Retaining wall with sloped heel

Table 8.2 Variation of A with ϕ_1' (for $\alpha' = 45°$)

Soil friction angle, ϕ_1' (deg)	A
20	0.28
25	0.14
30	0.06
35	0.03
40	0.018

So, for the active pressure diagram shown in Figure 8.10b,

$$P_a = \frac{1}{2}\gamma_1 K_a (H' - D')^2 + \frac{A}{2}\gamma_1 K_a [H'^2 - (H' - D')^2]$$

Check for Bearing Capacity Failure

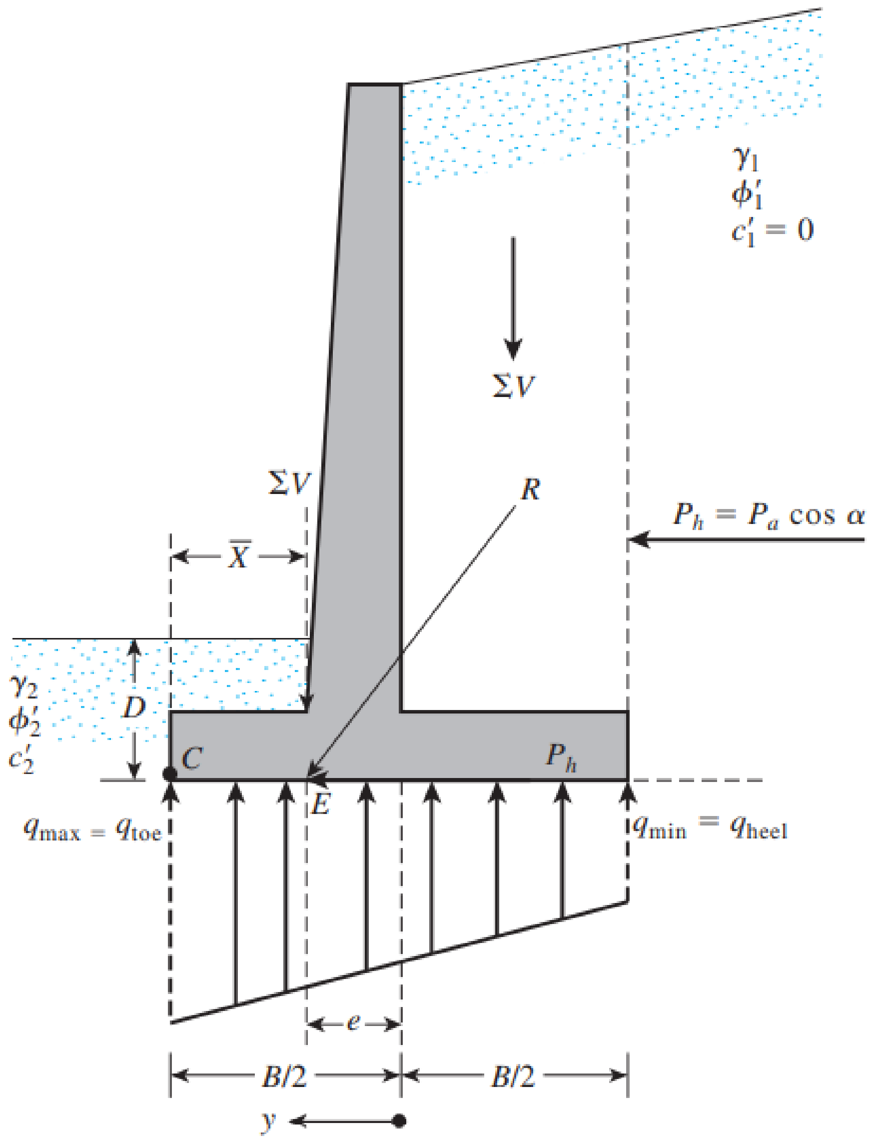
The vertical pressure transmitted to the soil by the base slab of the retaining wall should be checked against the ultimate bearing capacity of the soil.

For maximum and minimum pressures, the value of y in Eq. (8.19) equals $B/2$. Substituting into Eq. (8.19) gives

$$q_{\max} = q_{\text{toe}} = \frac{\Sigma V}{(B)(1)} + \frac{e(\Sigma V)\frac{B}{2}}{\left(\frac{1}{12}\right)(B^3)} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right) \tag{8.20}$$

Similarly,

$$q_{\min} = q_{\text{heel}} = \frac{\Sigma V}{B}\left(1 - \frac{6e}{B}\right) \tag{8.21}$$



If the analysis of a design shows that the design should be reproportioned and calculations redone.

- The ultimate bearing capacity of a shallow foundation is computed with the below computation:

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

where

$$q = \gamma_2 D$$

$$B' = B - 2e$$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan \phi_2'}$$

$$F_{qd} = 1 + 2 \tan \phi_2'(1 - \sin\phi_2')^2 \frac{D}{B'}$$

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

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

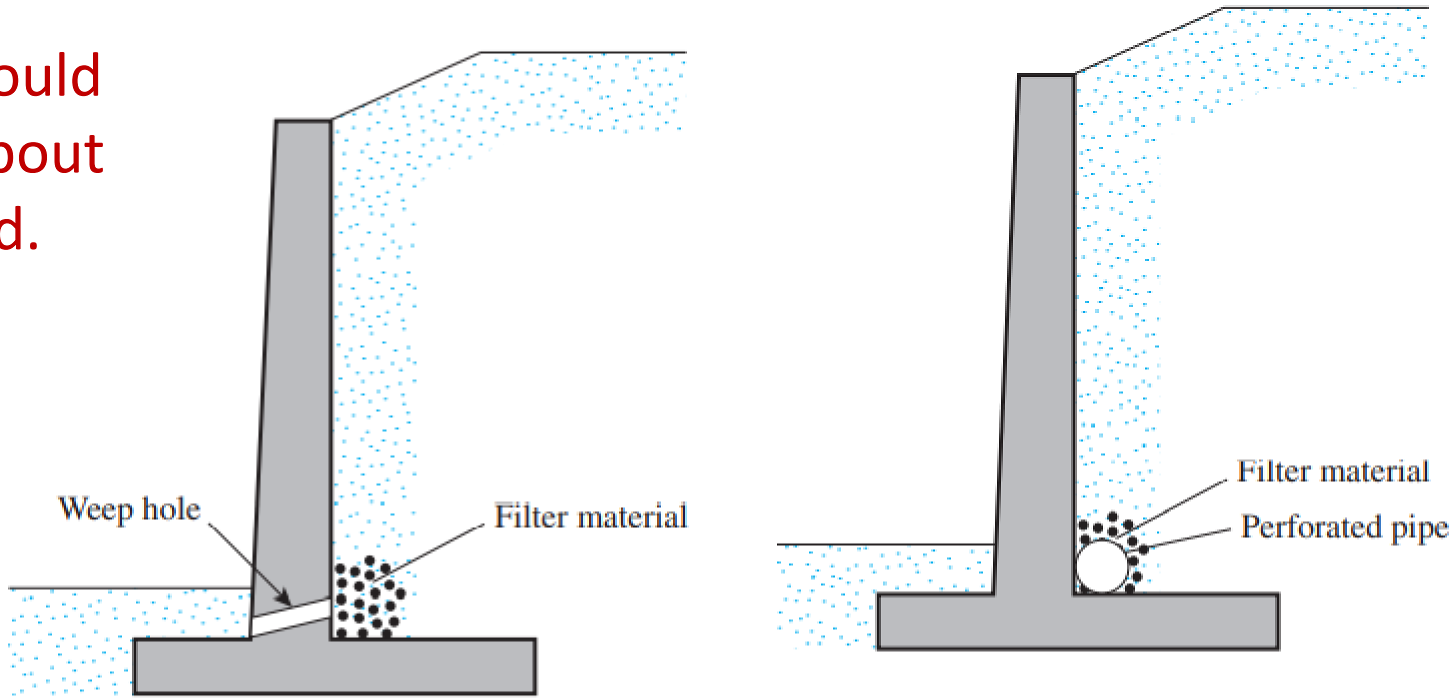
$$F_{\gamma i} = \left(1 - \frac{\psi^\circ}{\phi_2'^\circ}\right)^2$$

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

Drainage from the Backfill

- As the result of rainfall or other wet conditions, the backfill material for a retaining wall may become saturated, thereby increasing the pressure on the wall and perhaps creating an unstable condition.
- For this reason, adequate drainage must be provided by means of weep holes or perforated drainage pipes.

When provided, weep holes should have a minimum diameter of about 0.1 m and be adequately spaced.



(a)

- Note that there is always a possibility that backfill material may be washed into weep holes or drainage pipes and ultimately clog them.
- Therefore, a filter material needs to be placed behind the weep holes or around the drainage pipes, as the case may be; geotextiles now serve that purpose.
- Two main factors influence the choice of filter material:

The grain-size distribution of the materials should be such that

(a) the soil to be protected is not washed into the filter

(b) excessive hydrostatic pressure head is not created in the soil with a lower hydraulic conductivity (in this case, the backfill material).

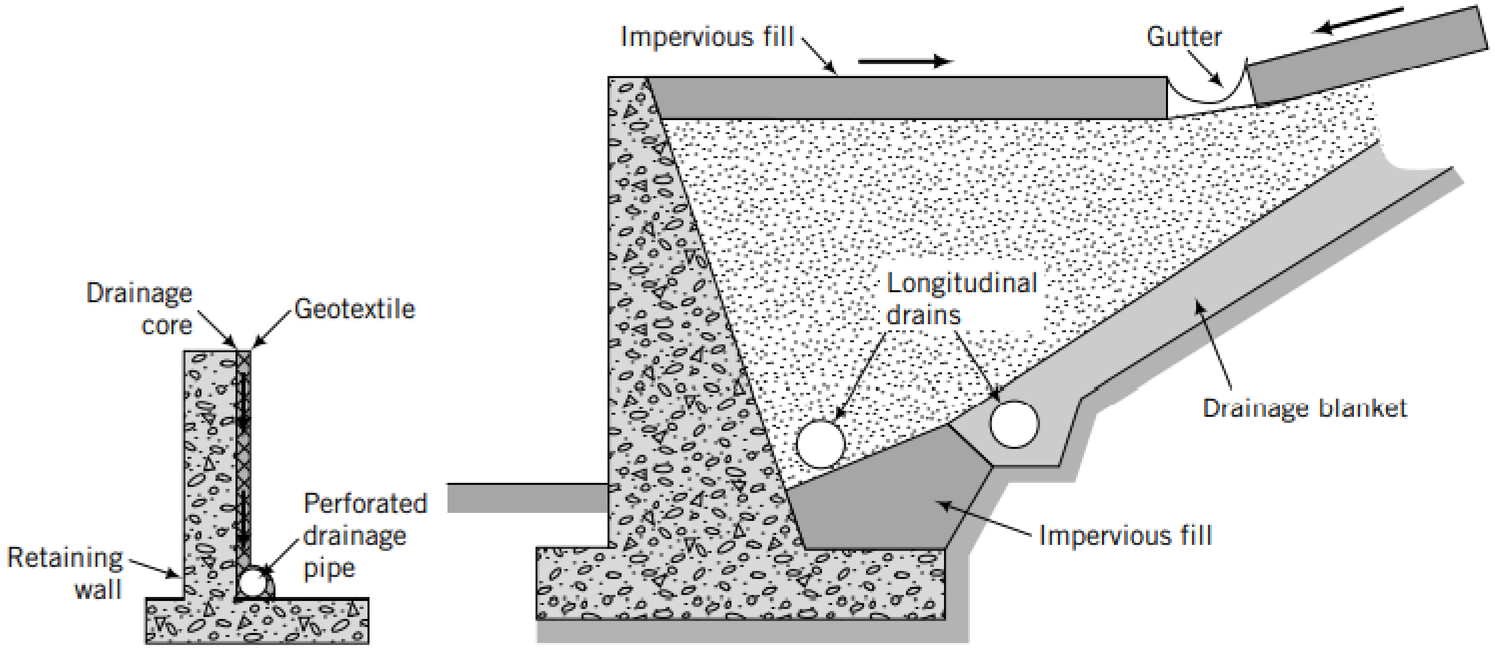
$$\frac{D_{15(F)}}{D_{85(B)}} < 5 \qquad \text{[to satisfy condition (a)]}$$

$$\frac{D_{15(F)}}{D_{15(B)}} > 4 \qquad \text{[to satisfy condition (b)]}$$

In these relations, the subscripts F and B refer to the filter and the backfill soil.

Seepage-induced failure is avoided in rigid retaining walls by providing adequate drainage systems, two of which are depicted in Figure.

Seepage forces are generally present and must be considered in evaluating the stability of these walls.



(*a*) Simple vertical drain

(*b*) Inclined drain (after Sibley, 1967)

FIGURE 15.17 Two types of drainage system behind rigid retaining walls.

THE ESSENTIAL STEPS IN DETERMINING THE STABILITY OF RIGID RETAINING WALLS

- 1. Calculate the active lateral earth force and its components.
- 2. Determine the weight of the wall and soil above the base.
- 3. Perform Stability Checks (overturning, sliding, bearing capacity FAİLİUE)
- 4. Make Overall Stability check
- Check the stability of the Retainig wall under earthquake loading (According to TBDY 2008)