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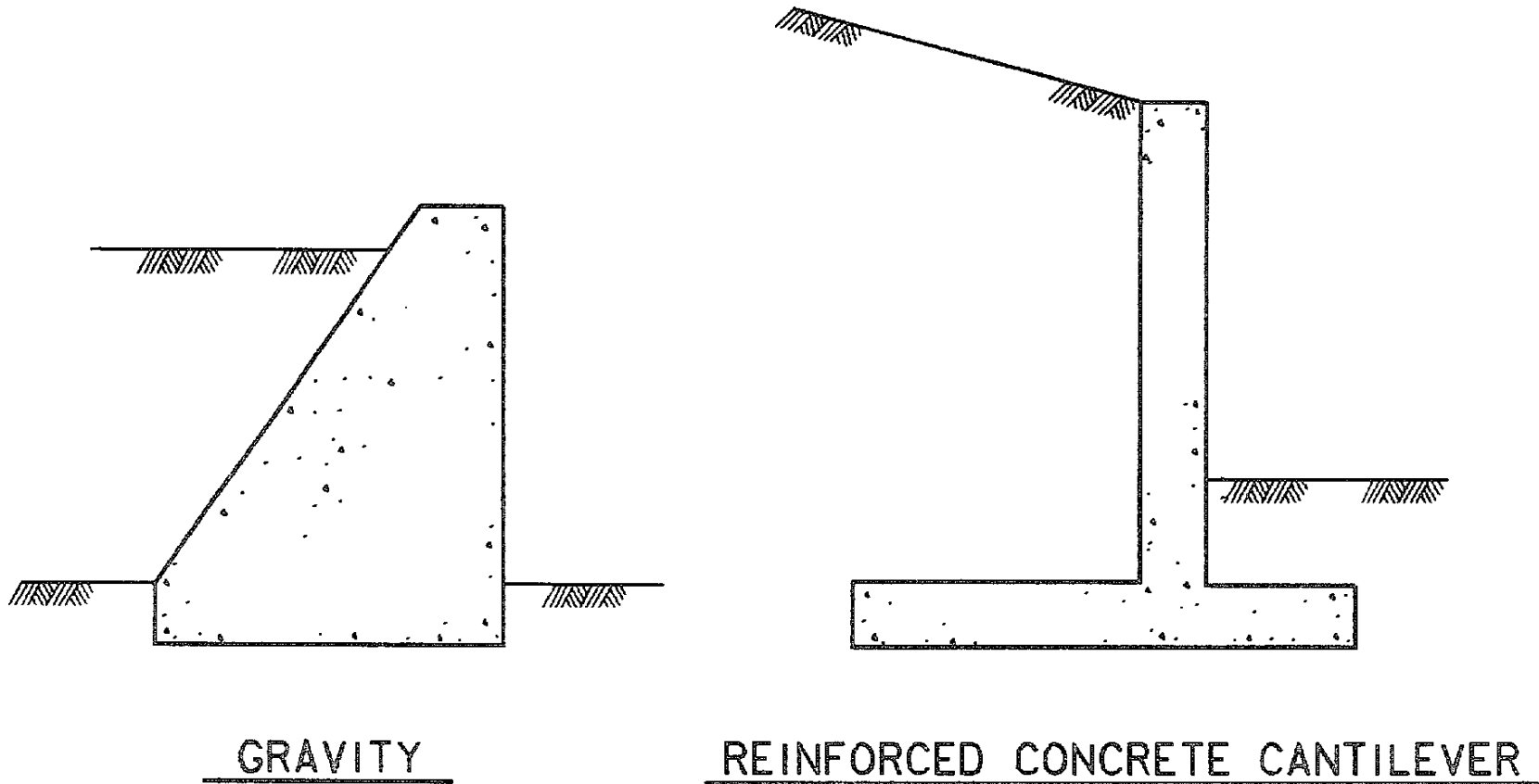
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# ENCE 461

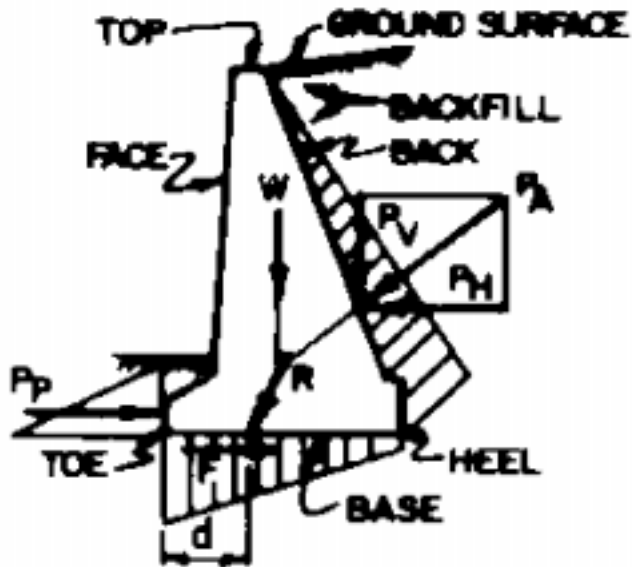
## Foundation Analysis and Design



Cantilever Retaining Walls  
Geotechnical Design

# Rigid Walls

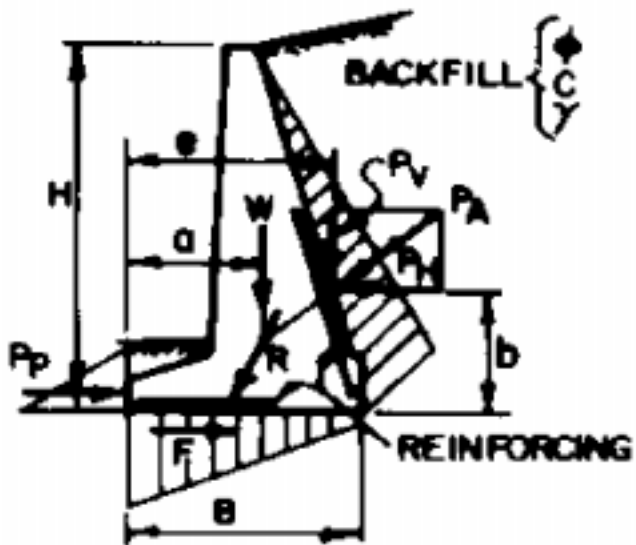
GRAVITY



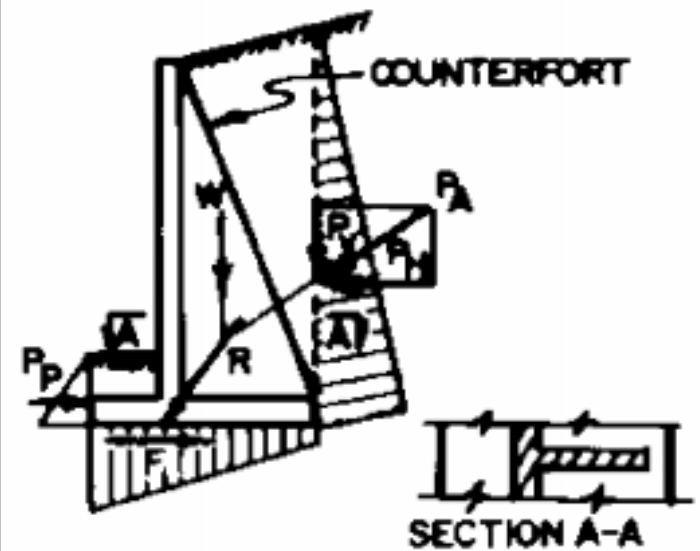
CANTILEVER



SEMIGRAVITY

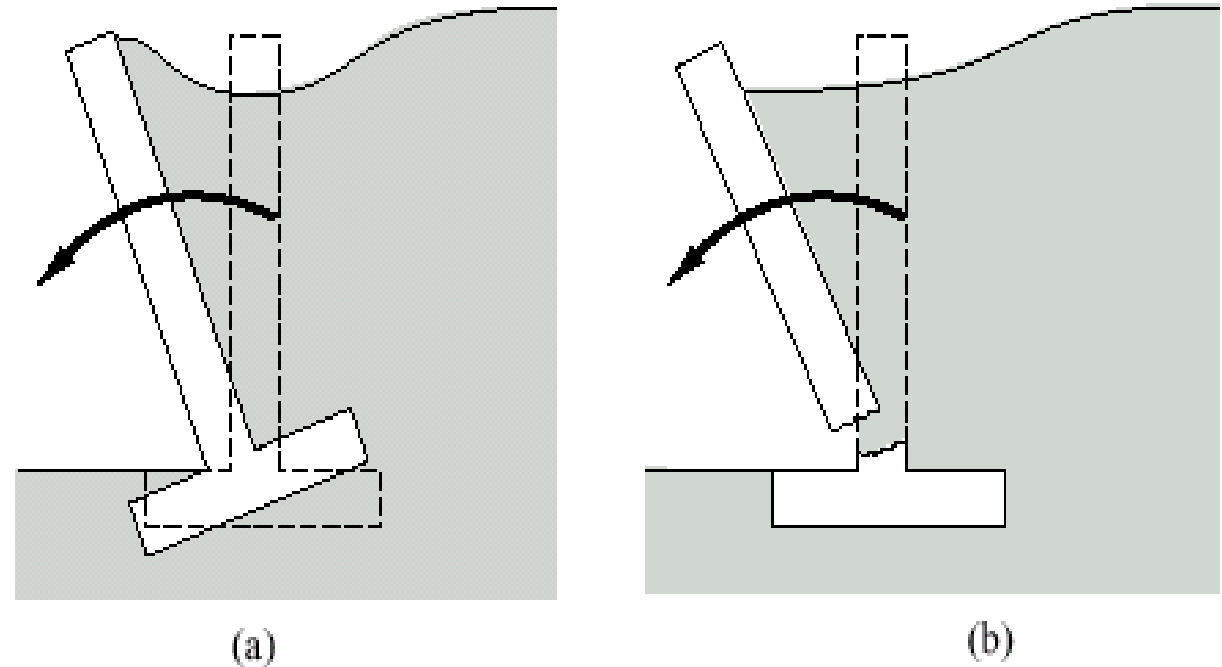


COUNTERFORT

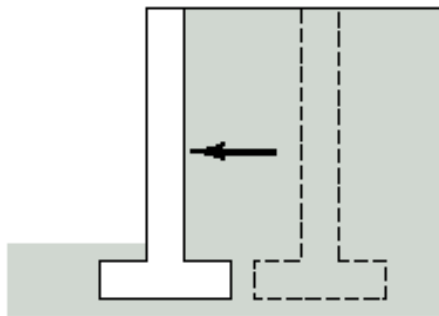


# External vs. Internal Stability

**Figure 24.1** (a) A wall that lacks sufficient external stability moves away from its desired location because the soil fails; (b) A wall with inadequate internal stability (structural integrity) is unable to carry the necessary internal stresses and experiences a structural failure.

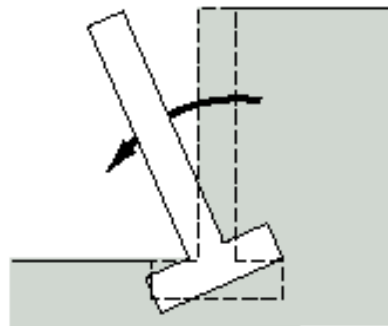


# External Stability Problems



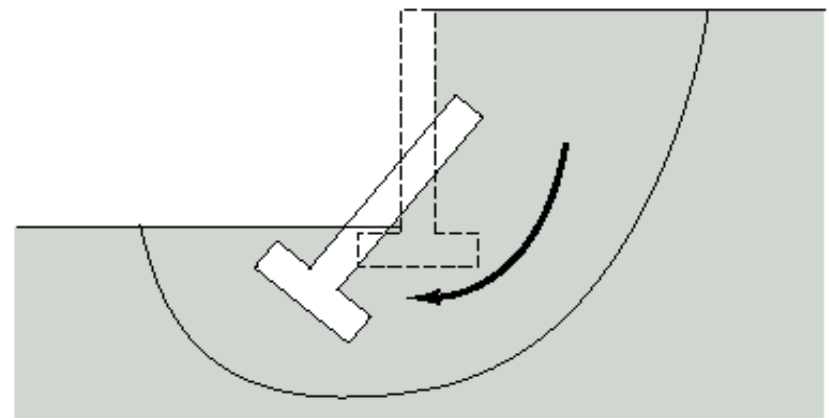
(a)

Sliding Failure



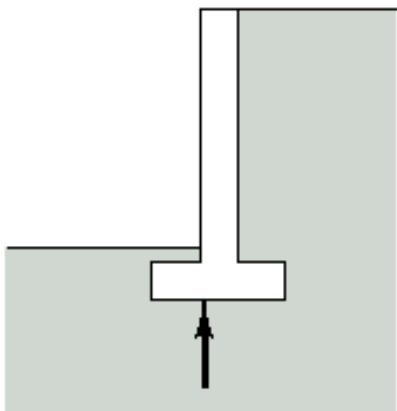
(b)

Overturning Failure



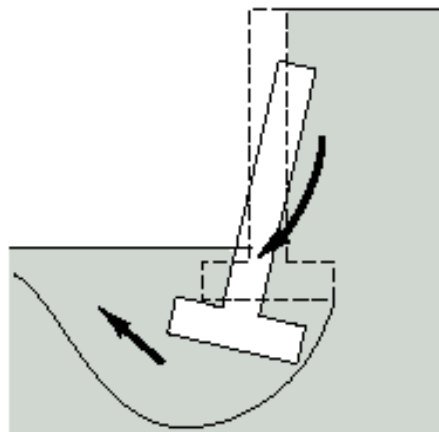
(e)

Deep Seated Shear Failure



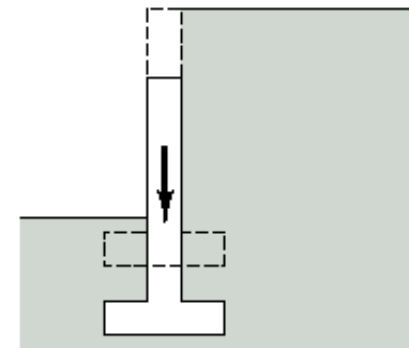
(c)

Normal Force on Footing



(d)

Bearing Capacity

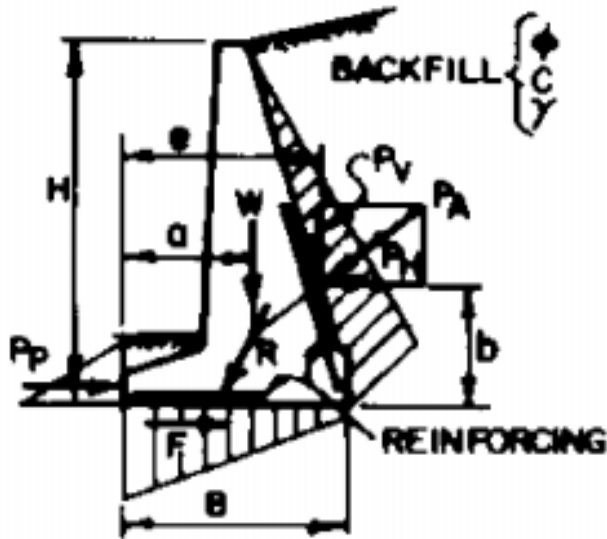


(f)

Excessive Settlement

# Design Parameters for Rigid Walls

SEMIGRAVITY



## LOCATION OF RESULTANT

MOMENTS ABOUT TOE:

$$d = \frac{W_0 + P_v e - P_H b}{W + P_v}$$

ASSUMING  $P_p = 0$

OVERTURNING ←

MOMENTS ABOUT TOE:

$$F_s = \frac{W_0}{P_H b - P_v e} \geq 1.5$$

IGNORE OVERTURNING IF R IS WITHIN MIDDLE THIRD (SOIL), MIDDLE HALF (ROCK).

CHECK R AT DIFFERENT HORIZONTAL PLANES FOR GRAVITY WALLS.

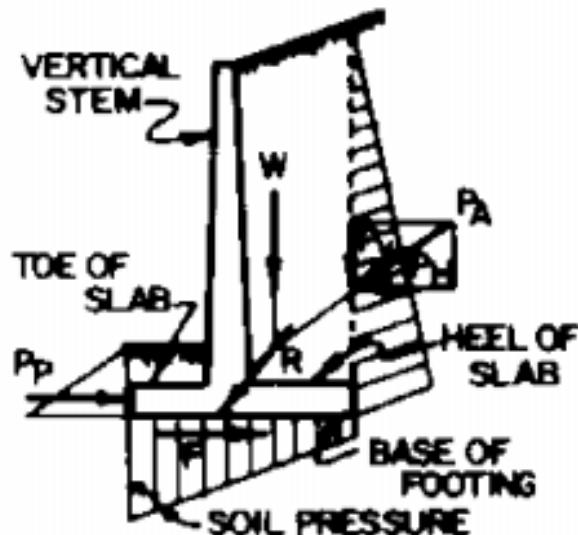
RESISTANCE AGAINST SLIDING ←

$$F_s = \frac{(W + P_v) \tan \delta + C_a B}{P_H} \geq 1.5$$

$$F_s = \frac{(W + P_v) \tan \delta + C_a B + P_p}{P_H} \geq 2.0$$

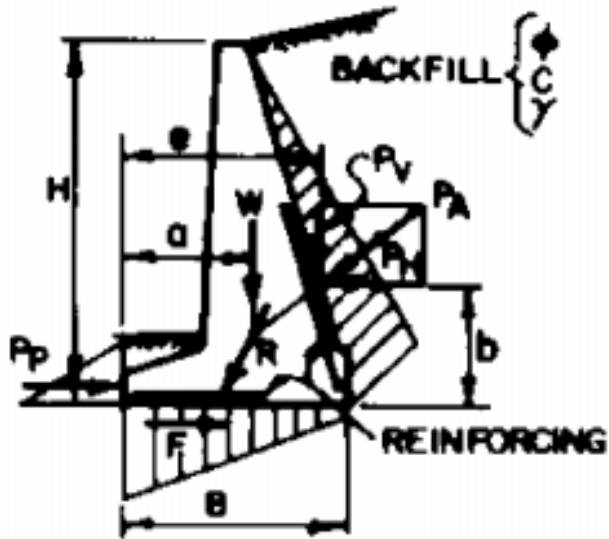
$$F = (W + P_v) \tan \delta + C_a B$$

CANTILEVER



# Design Parameters for Rigid Walls

SEMIGRAVITY



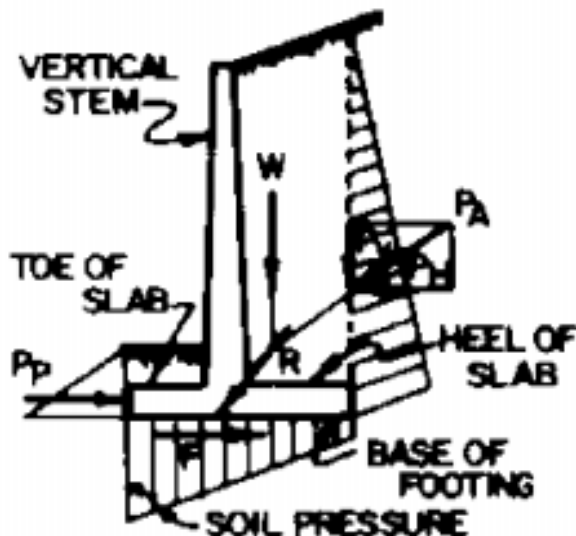
$C_0$  = ADHESION BETWEEN SOIL AND BASE

$\tan \delta$  = FRICTION FACTOR BETWEEN SOIL AND BASE

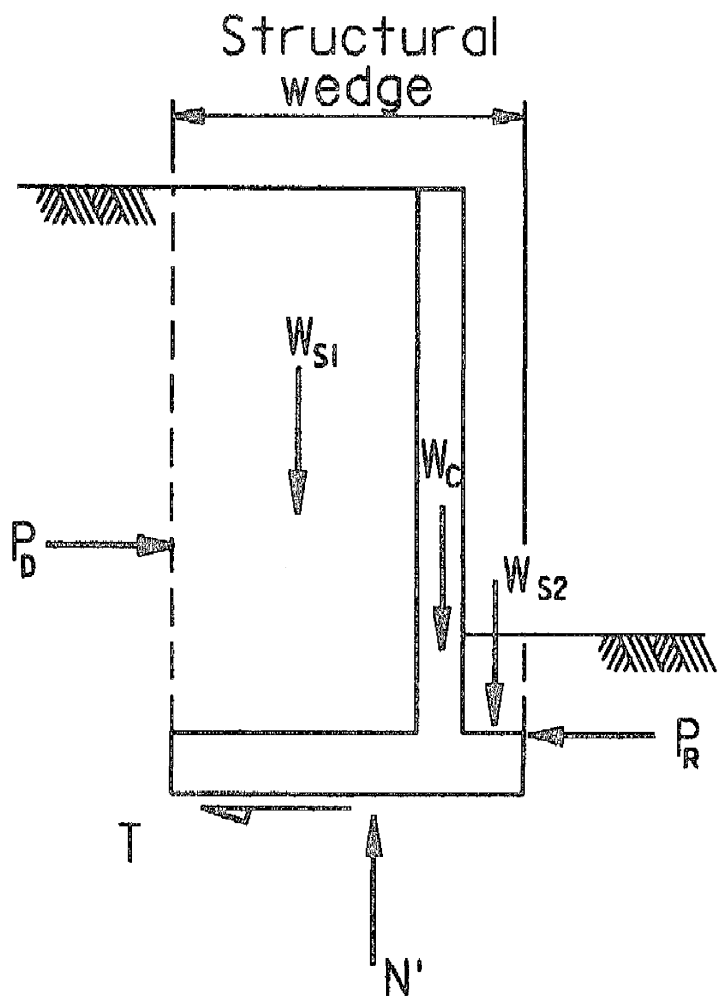
W = INCLUDES WEIGHT OF WALL AND SOIL IN FRONT FOR GRAVITY AND SEMIGRAVITY WALLS.

INCLUDES WEIGHT OF WALL AND SOIL ABOVE FOOTING, FOR CANTILEVER AND COUNTERFORT WALLS.

CANTILEVER



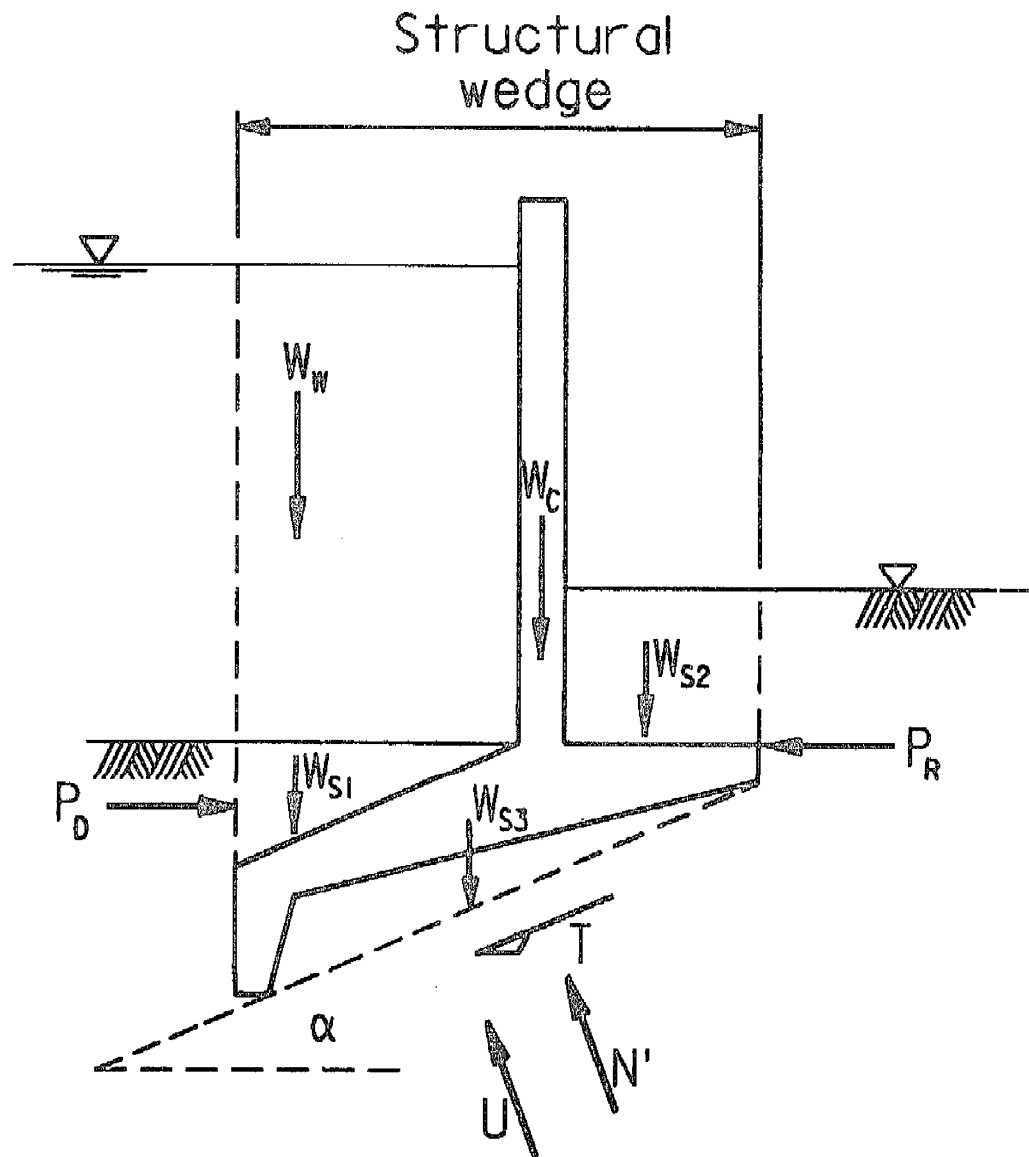
CONTACT PRESSURE ON FOUNDATION ←



$$N' = \sum W$$

$$T = P_D - P_R$$

a. Simple retaining wall



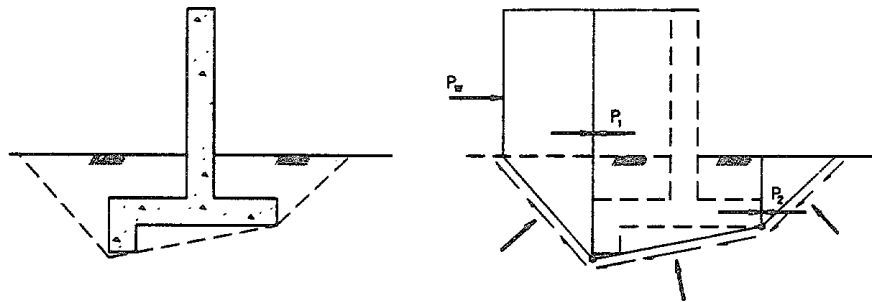
$$T = \sum H \cos \alpha - \sum V \sin \alpha$$

$$N' = \sum V \cos \alpha + \sum H \sin \alpha$$

$\sum H$  and  $\sum V$  are summation of all forces not including  $T$  and  $N'$

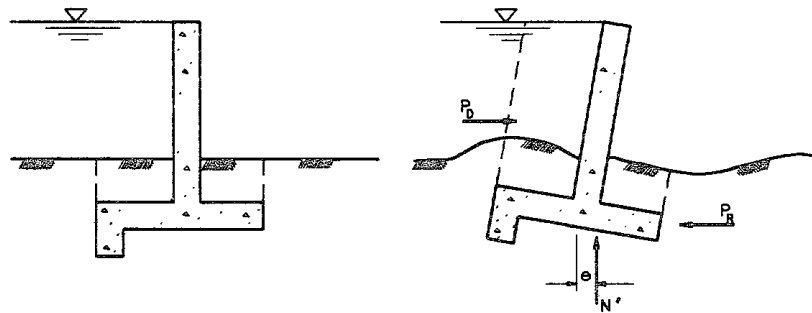
b. Flood wall with sloping base and key

Figure 3-4. Forces on base of wall



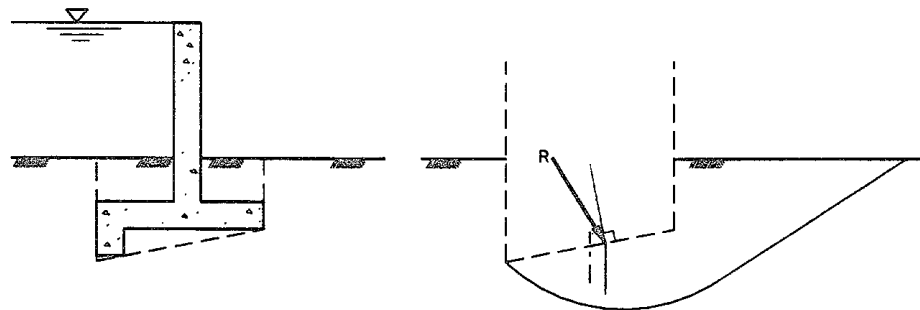
$$\text{Factor of safety} = \frac{\text{Available shear resistance}}{\text{Shear required for equilibrium}}$$

a. Sliding



Safety assessed by checking base resultant location

b. Overturning



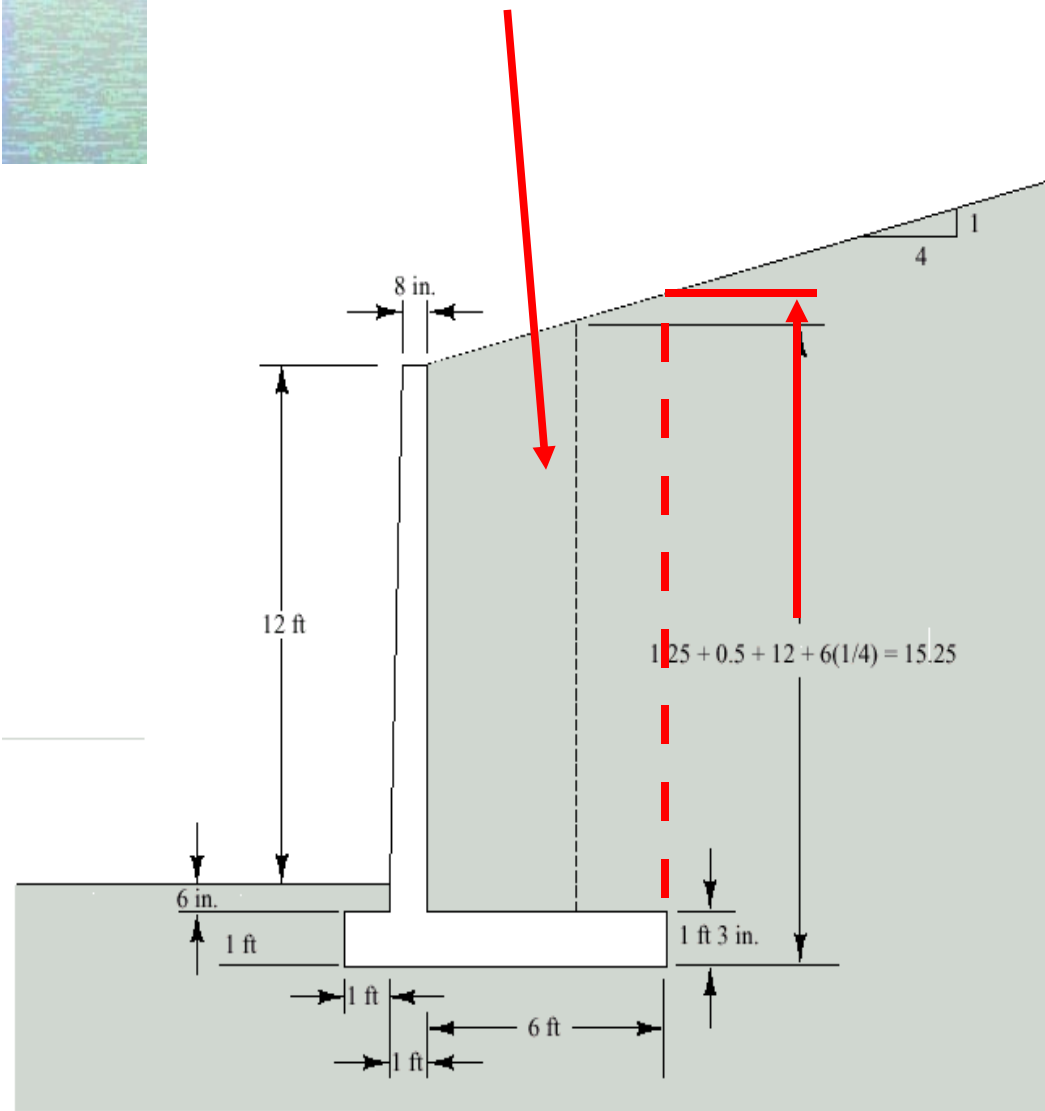
Use bearing theory for inclined, eccentric load, sloping base

c. Bearing

# Cantilever Wall Design Example

Include this soil with wall weight

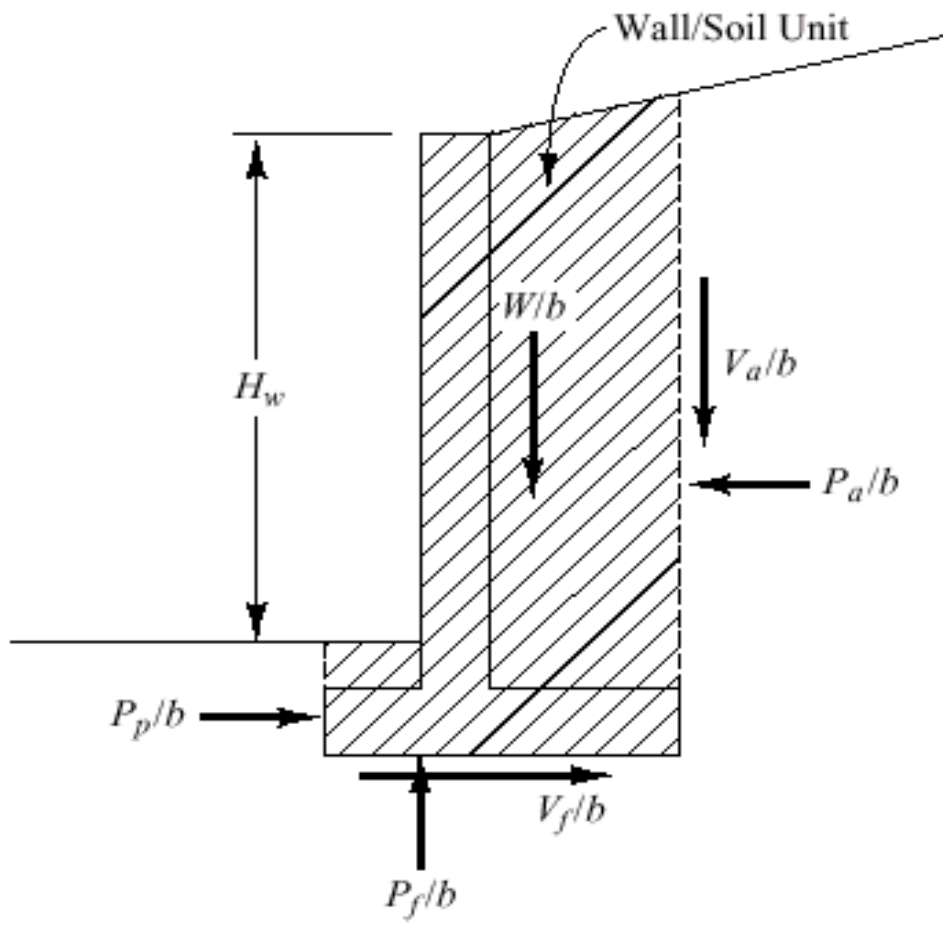
- Wall as shown
- Soil
  - Behind the Wall: Fine to Medium Sand,  $\phi' = 35^\circ$ ,  $\gamma = 122$  pcf
  - Below the Wall: Fine to Medium Sand,  $\phi' = 38^\circ$ ,  $\gamma = 125$  pcf
  - Allowable bearing pressure under foot: 5 ksf
- Find External Stability Criteria



# Cantilever Wall Design Example

- Assumptions
  - Coulomb model of lateral earth pressure
    - Backfill slope  $\beta = \arctan (1/4) = 14^\circ$
    - Coefficient of sliding friction  $\mu = 0.5$  (Table 8.3)
    - Angle of wall friction  $\phi_w$  or  $\delta = \arctan \mu = 26.6^\circ$
    - $K_a = 0.292$
    - $K_p = 47.85$
  - Factors of Safety
    - Against sliding: 1.5
    - Against overturning: 1.5
    - Compare bearing pressure directly

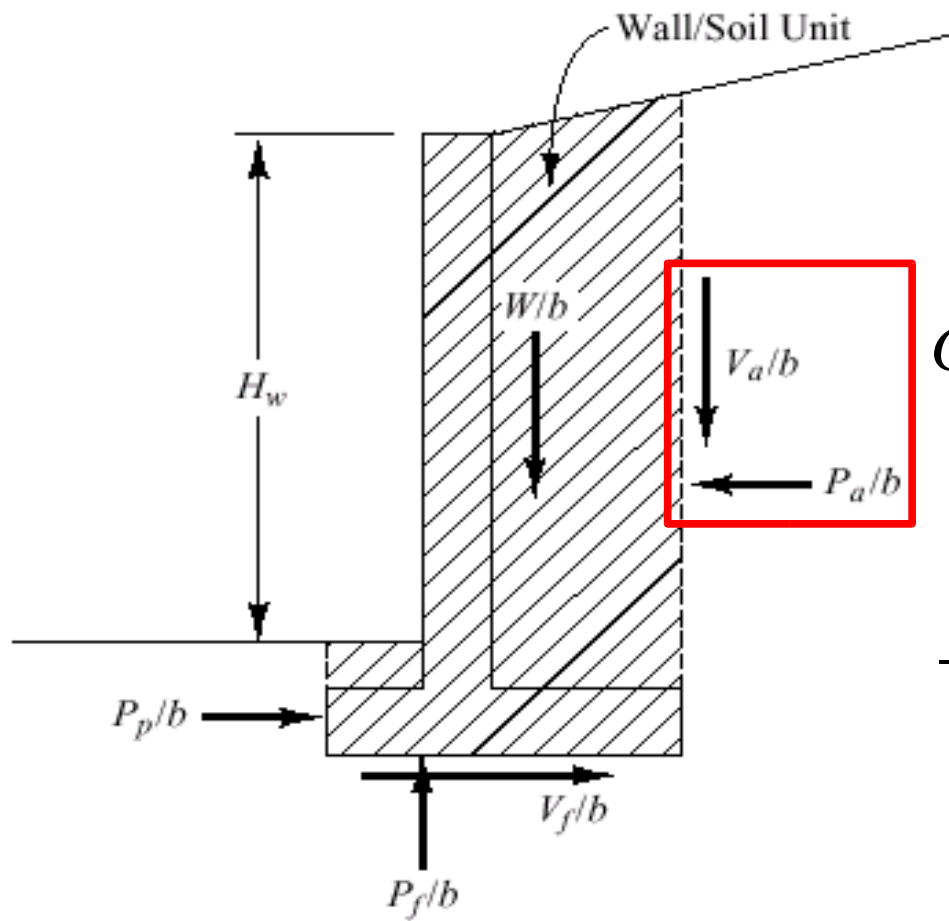
# Cantilever Example



- Objectives
  - Compute resistance against sliding
  - Compute resistance against overturning
  - Compute bearing pressure
- First requirement: compute the forces shown

# Cantilever Example

- Active Earth Pressures



$$G_h = \gamma K_a \cos \phi_w$$

$$G_h = (122)(0.292)(\cos 26.6^\circ) = 31.8 \text{ pcf}$$

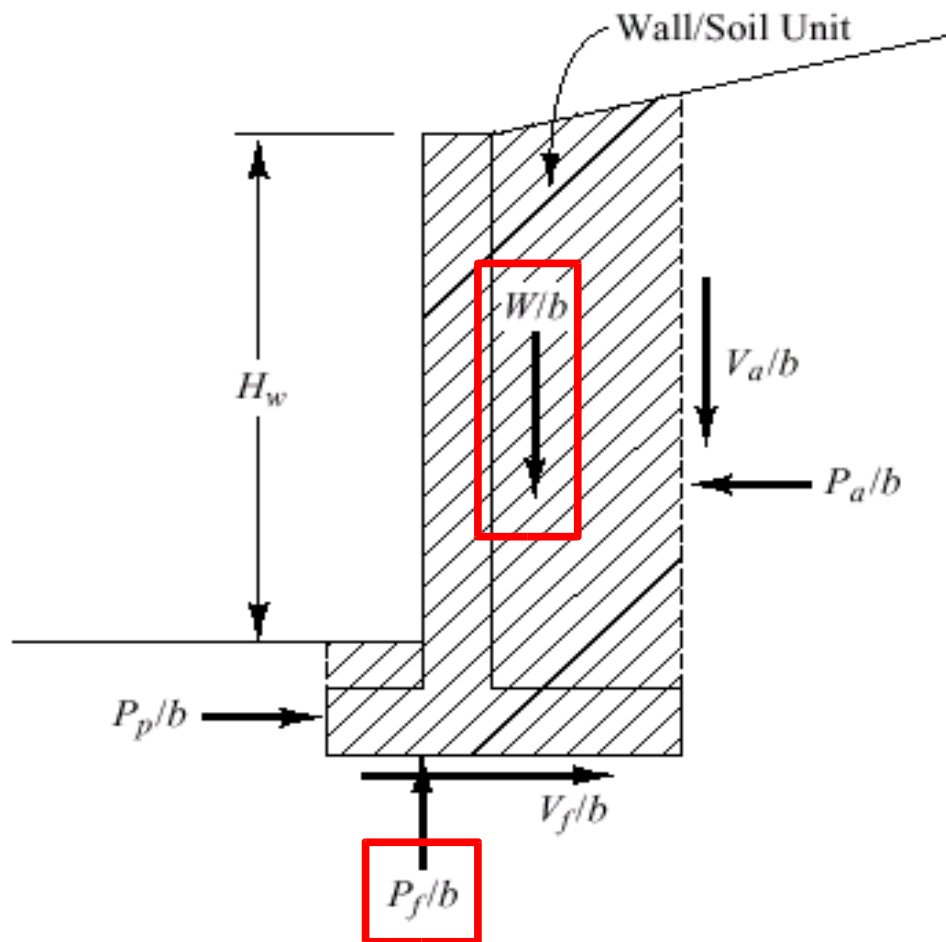
$$G_v = \gamma K_a \sin \phi_w$$

$$G_v = (122)(0.292)(\sin 26.6^\circ) = 16 \text{ pcf}$$

$$\frac{P_a}{b} = \frac{G_h H^2}{2} = \frac{31.8 \times 15.25^2}{2} = 3698 \text{ lb/ft}$$

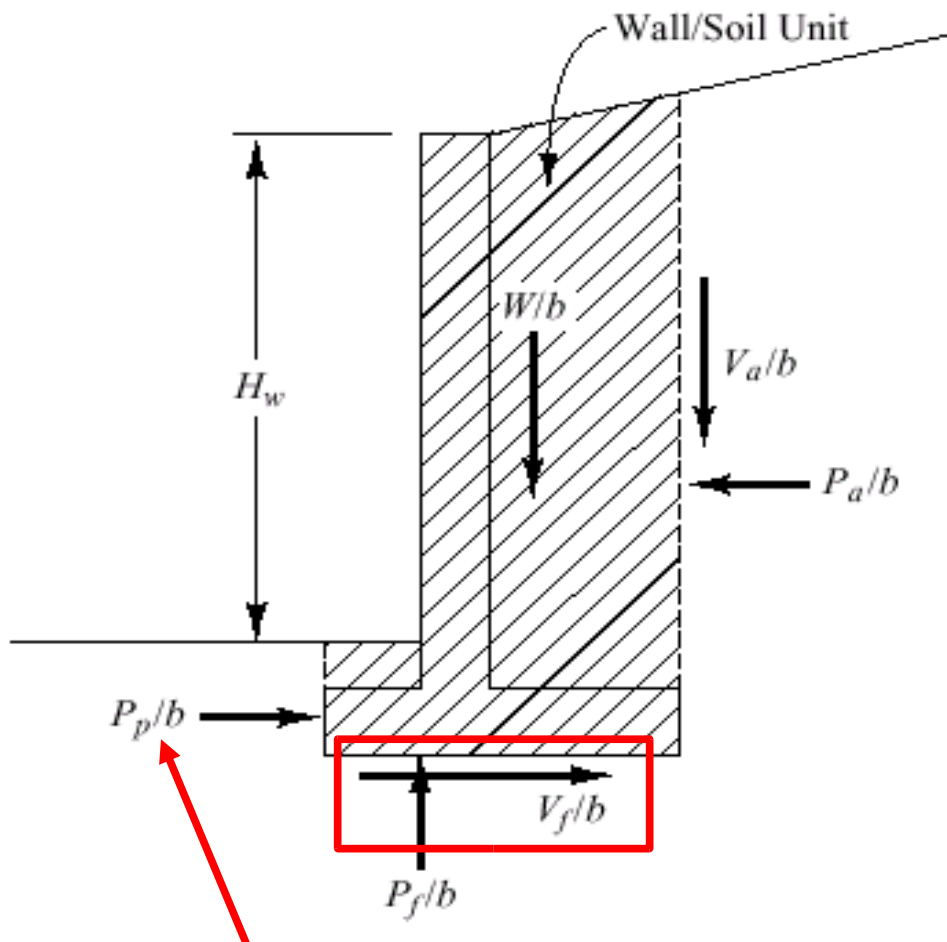
$$\frac{V_a}{b} = \frac{G_v H^2}{2} = \frac{16 \times 15.25^2}{2} = 1861 \text{ lb/ft}$$

# Cantilever Example



- Weight of wall and included soil
- Per calculation in book (p. 794),  $W/b = 12,761$  lb/ft
- Reaction of base of wall
- $P_f/b = W/b + V_a/b = 12,761 + 1861 = 14,622$  lb/ft

# Cantilever Example



Neglect

- Friction of base
  - $V_f/b = \mu P_f/b =$   
 $(0.5)(14622) = 7311$   
lb/ft
- Compute actual sliding factor of safety

$$F_s = \frac{V_f/b}{P_a/b}$$

$$F_s = \frac{7311}{3698} = 1.98 > 1.5$$

# Overturning Moments

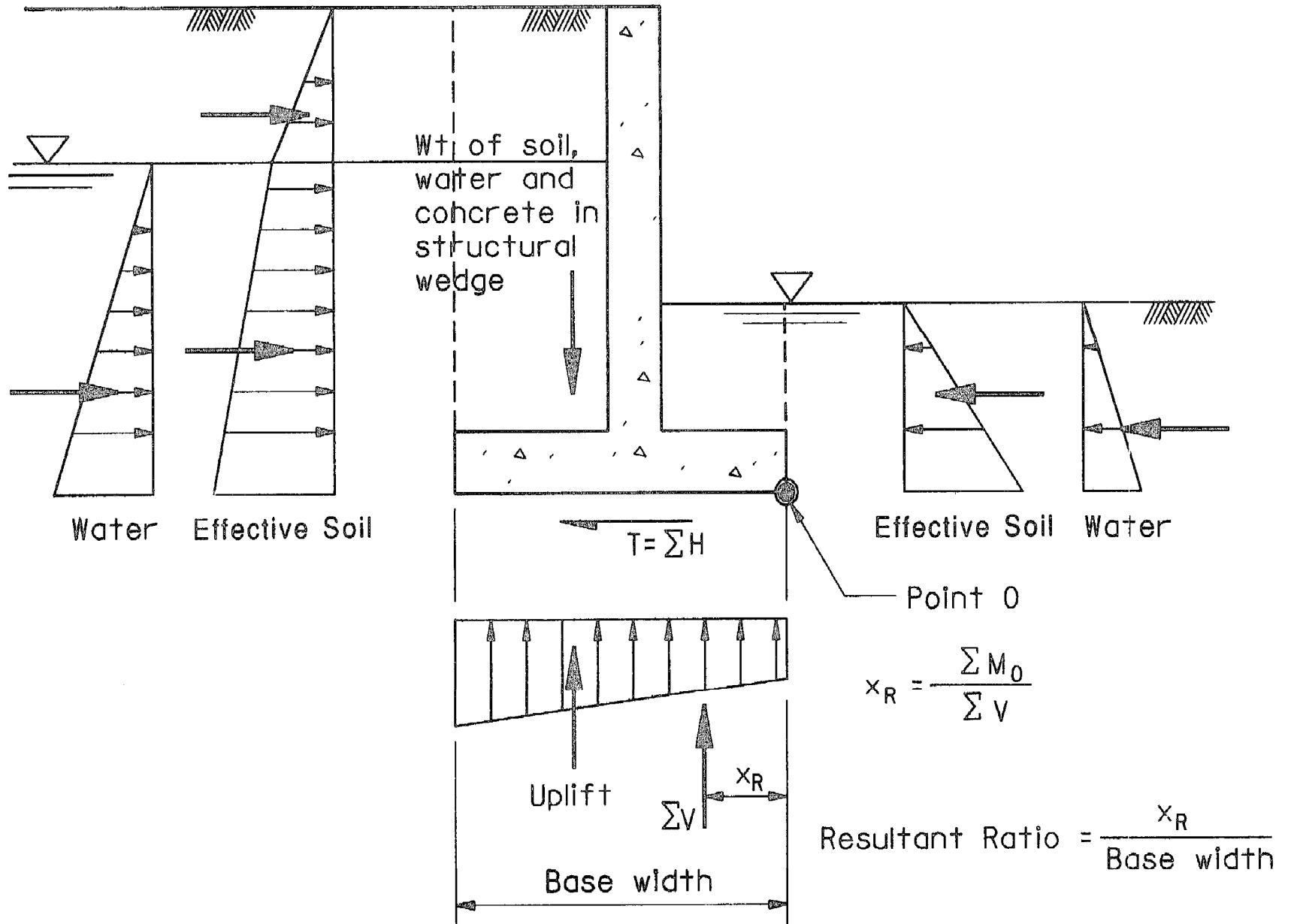
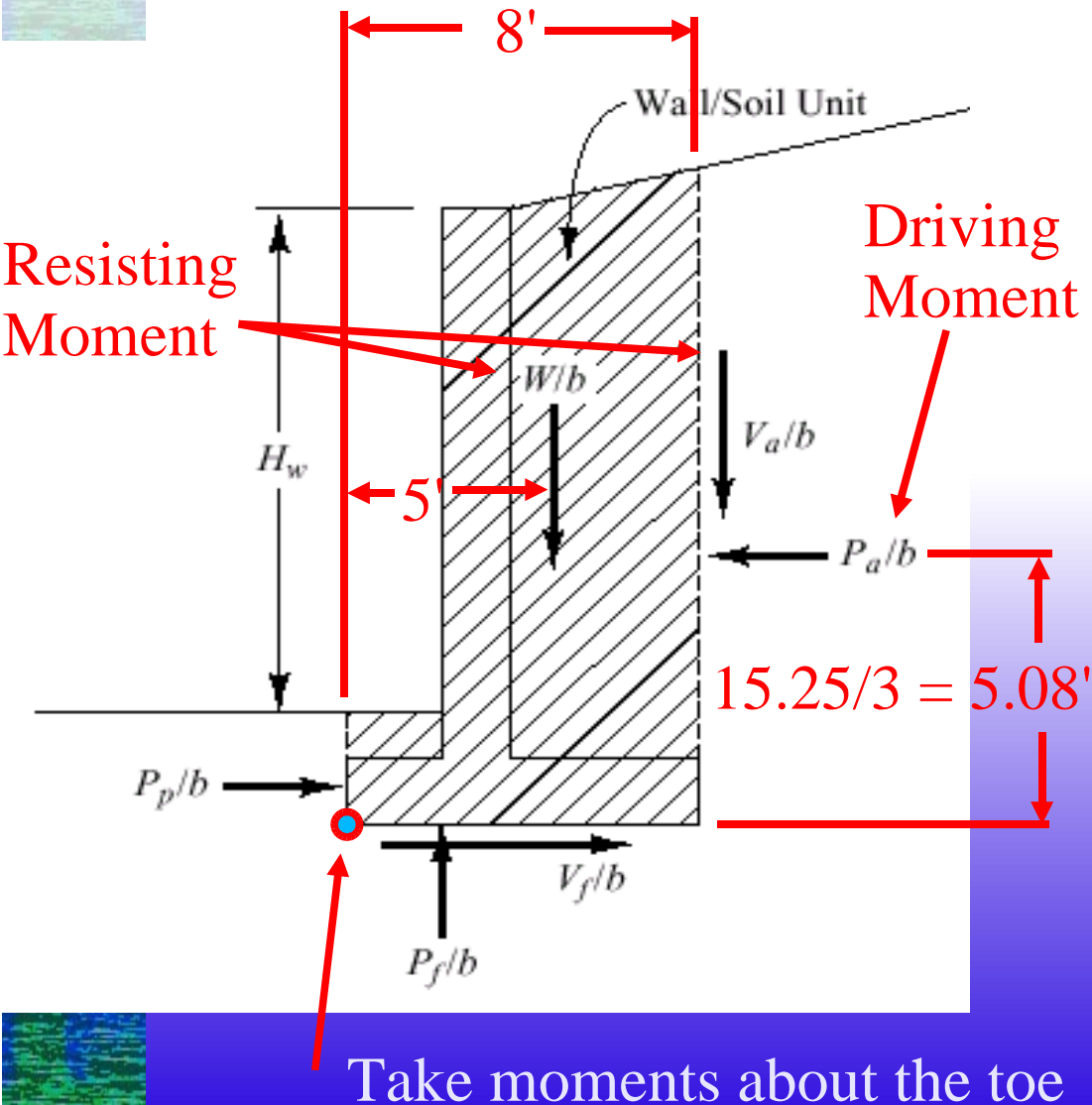


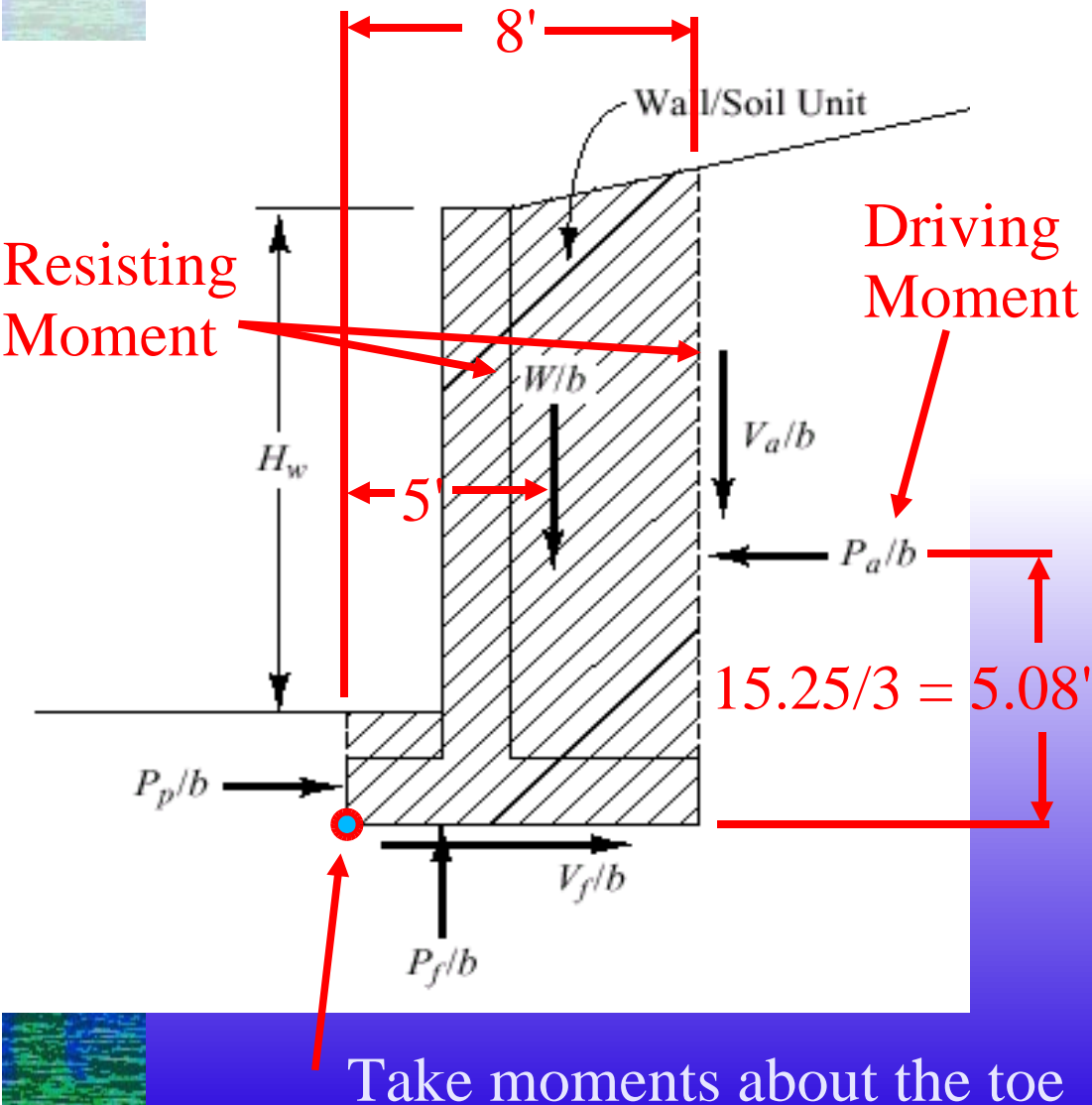
Figure 4-2. Forces for overturning analysis for wall with horizontal base

# Cantilever Example



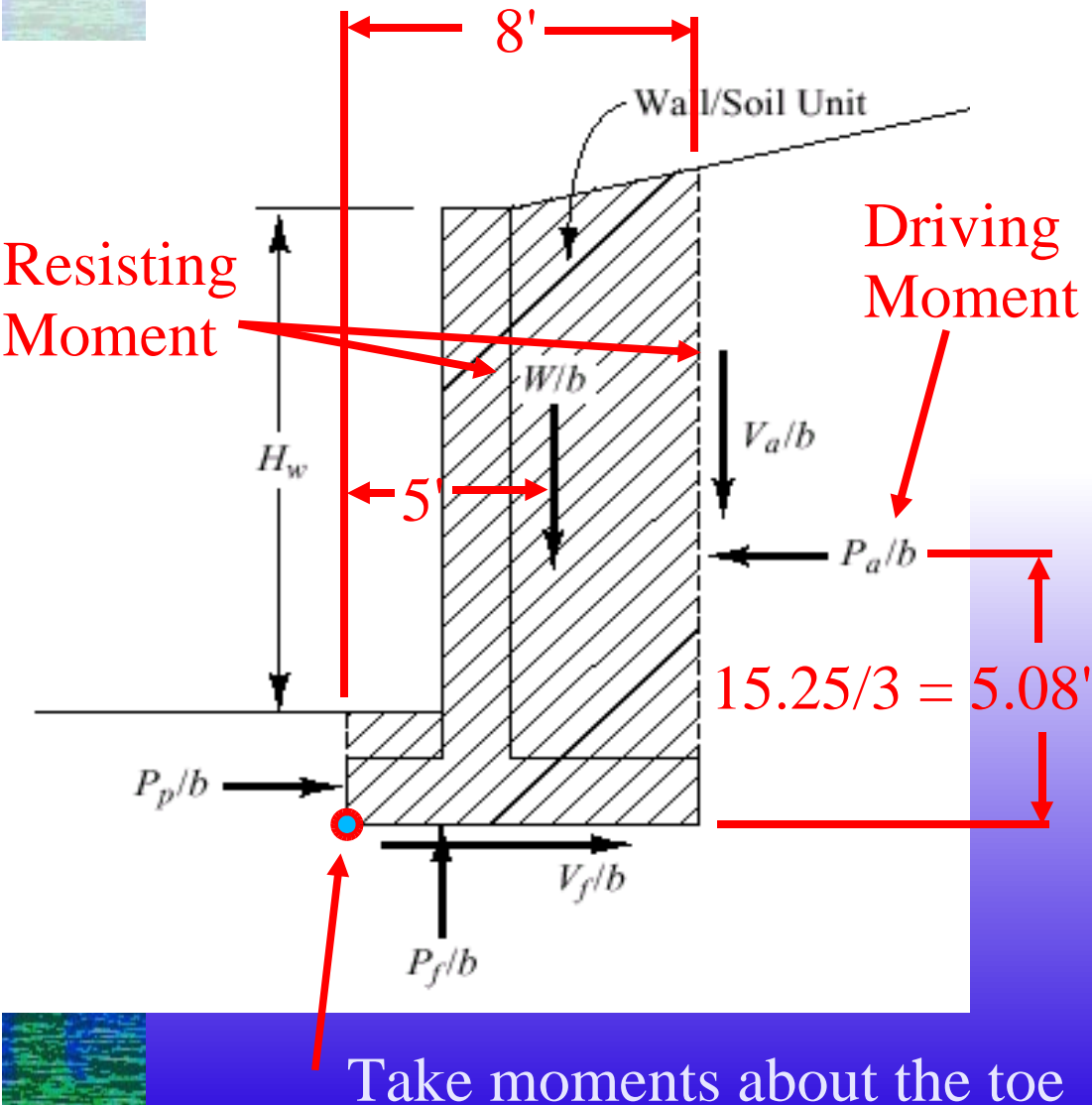
- Compute factor of safety against overturning
- Determine moment arms about the toe
- Driving Moment
  - $M_{P_a/b} = (3698)(5.08) = 18,786 \text{ lb/ft}$

# Cantilever Example



- Determine moment arms about the toe
- Resisting Moment
  - $M_{V_a/b} = (1861)(8) = 14,894 \text{ ft-lb/ft}$
  - $M_{W/b} = (12761)(5) = 63805 \text{ ft-lb/ft}$

# Cantilever Example



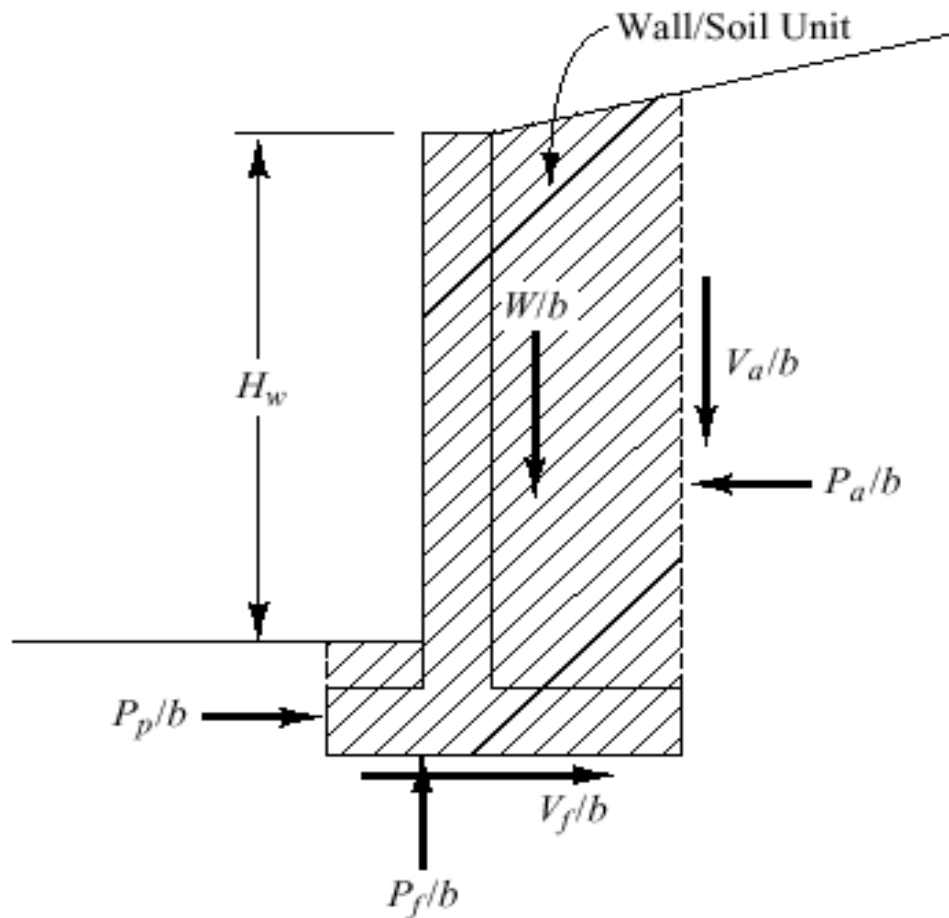
- Compute Factor of Safety

$$F_M = \frac{\text{Resisting Moments}}{\text{Driving Moments}}$$

$$F_M = \frac{14,894 + 63,805}{18786}$$

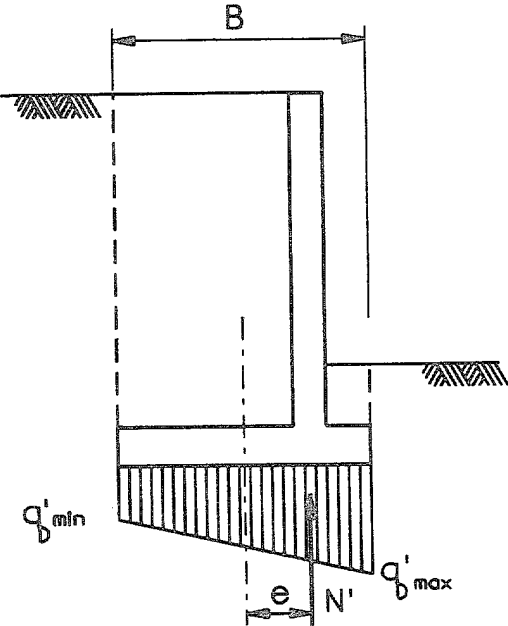
$$F_M = 4.2 > 1.5$$

# Cantilever Example



- Compute Bearing Pressure
- Compute maximum and minimum bearing pressures
- Insure that base reaction  $P_f/b$  is within the kern

# Bearing Pressure

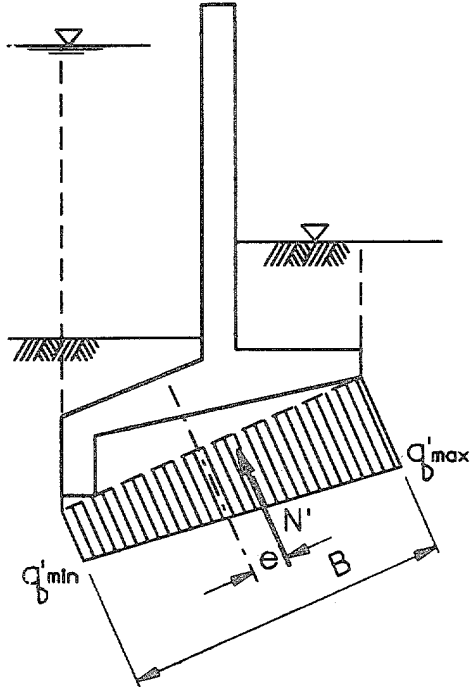


$$q'_b = \frac{N'}{A} \pm \frac{Mc}{I}$$

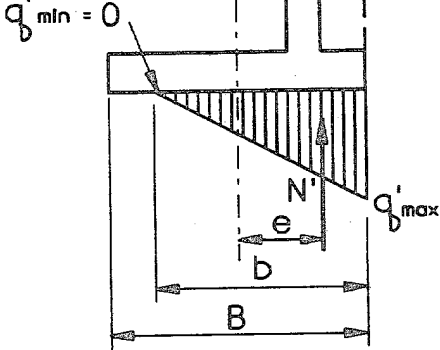
$$q'_{b\max} = \left(\frac{N'}{B}\right)\left(1 + \frac{6e}{B}\right)$$

$$q'_{b\min} = \left(\frac{N'}{B}\right)\left(1 - \frac{6e}{B}\right)$$

a. Simple wall, resultant in middle one-third of base



b. Flood wall with sloping base



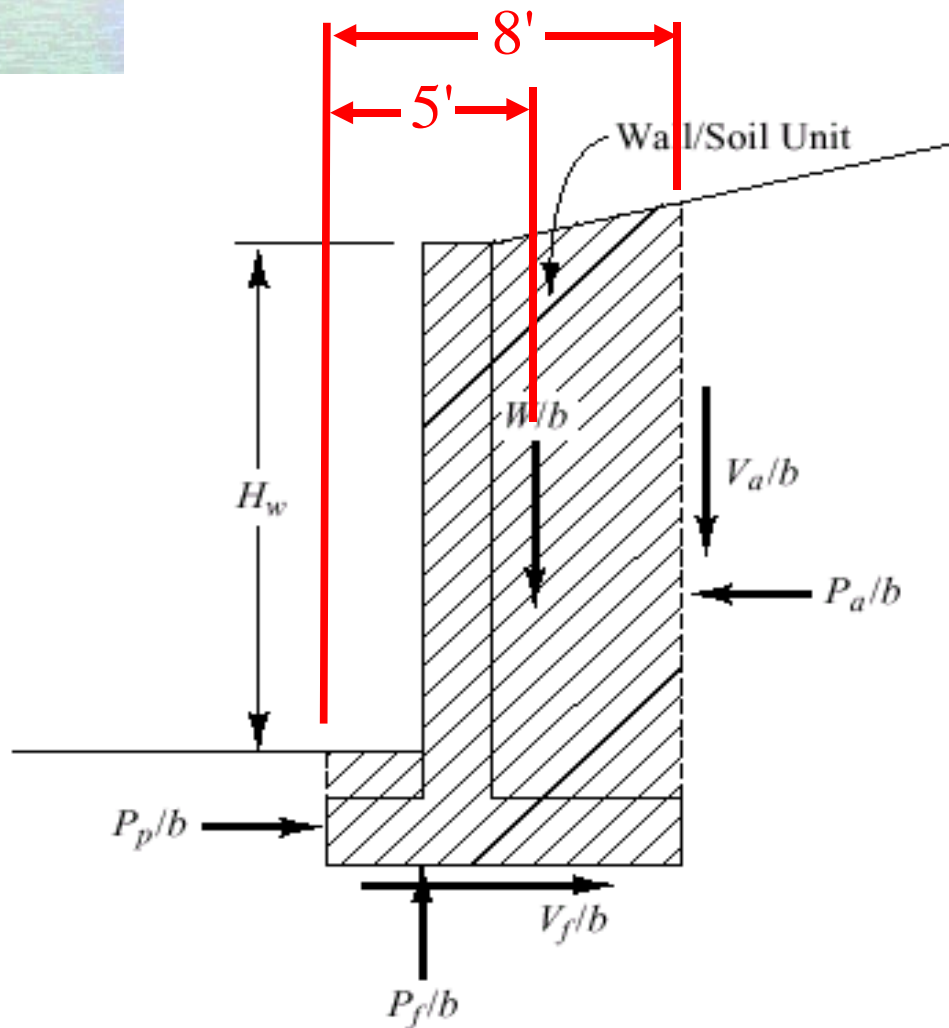
$$q'_{b\min} = 0$$

$$q'_{b\max} = \left(\frac{4}{3}\right)\left(\frac{N'}{B - 2e}\right)$$

$$b = \left(\frac{3}{2}\right)(B - 2e)$$

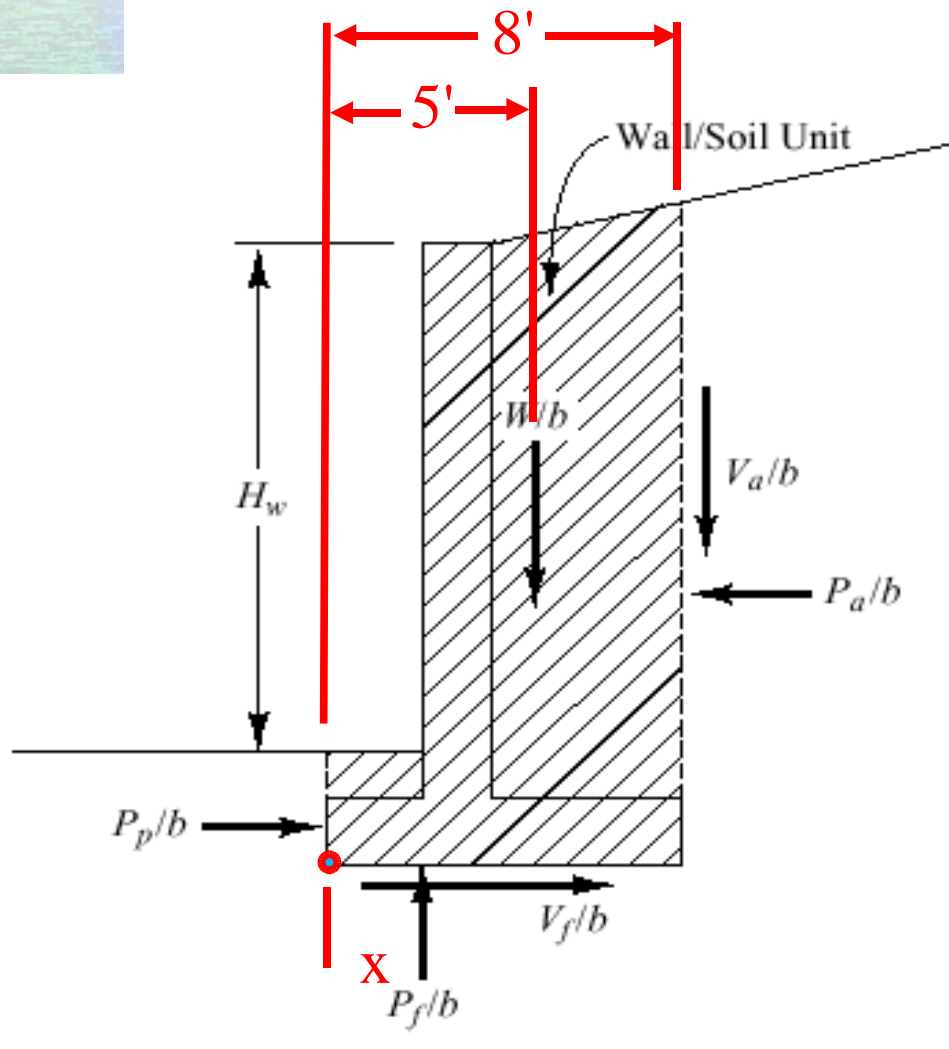
c. Pressure for resultant outside middle one-third

# Cantilever Example



- Compute Bearing Pressure
- Compute maximum and minimum bearing pressures
- Insure that base reaction  $P_f/b$  is within the kern

# Cantilever Example



- Insure that base reaction  $P_f/b$  is within the kern
- Compute location of  $P_f/b$ 
  - $M_{V_a/b} = (1861)(8) = 14,894 \text{ ft-lb/ft}$
  - $M_{W/b} = (12761)(5) = 63805 \text{ ft-lb/ft}$
  - $x = (14894 + 63805)/(1861 + 12761) = 5.33'$



# RETWALL

## Stability of Cantilever Retaining Walls

Date April 10, 2002

Identification Example 24.1

### Input Data

#### Units of Measurement

E E or SI

#### Wall

Stem height	12 ft
Footing thickness	1.25 ft
Footing embedment	1.75 ft
Stem thickness - top	0.67 ft
Stem thickness - bottom	1 ft
Toe extension	1 ft
Heel extension	6 ft
Backfill angle	14 deg

#### Backfill Soil

Gh	31.8 lb/ft <sup>3</sup>
Gv	16 lb/ft <sup>3</sup>
Unit weight	122 lb/ft <sup>3</sup>

#### Foundation soil

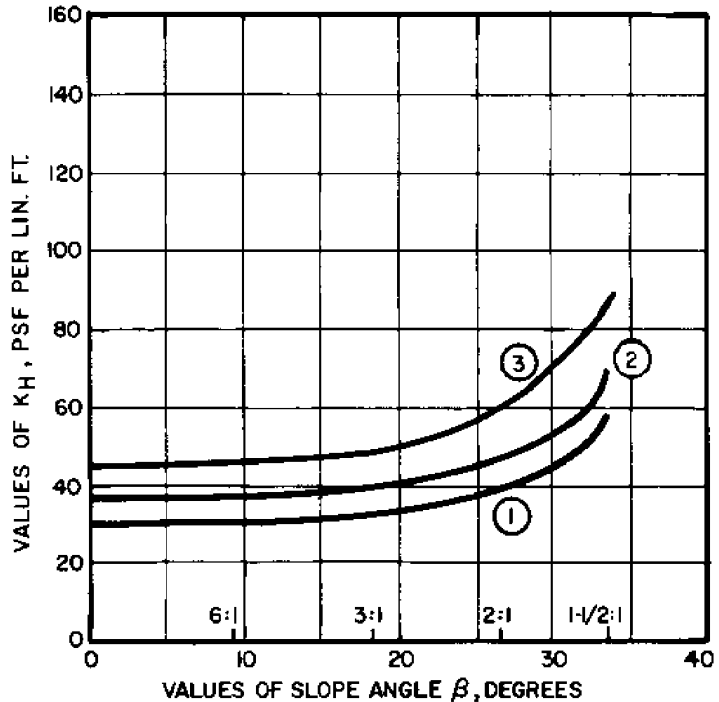
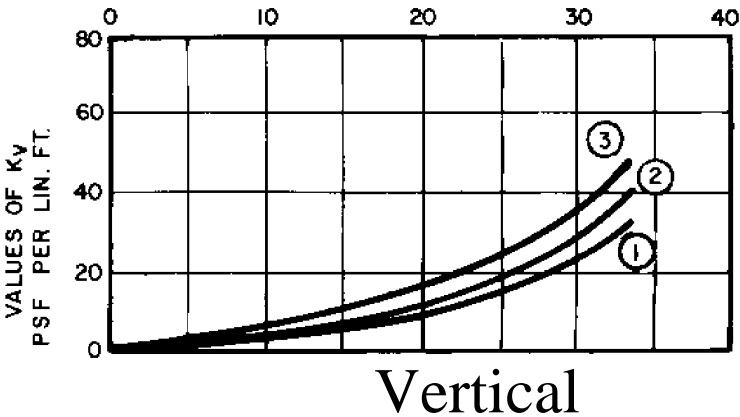
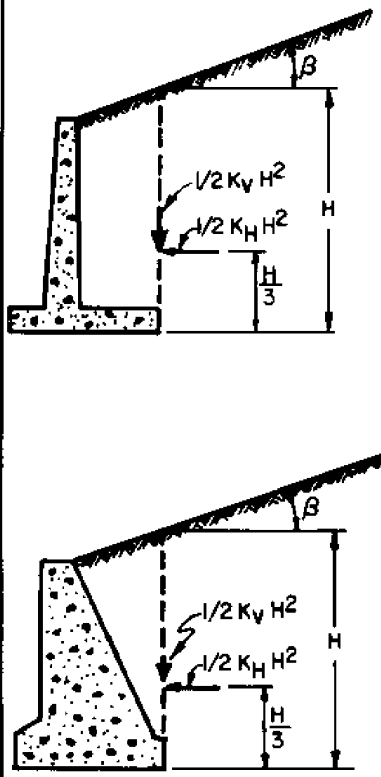
Allowable bearing pressure	5000 lb/ft <sup>2</sup>
Allowable passive pressure	250 lb/ft <sup>3</sup>
Allowable coefficient of friction	0.5

### Results

Sliding	F =	2.15
Overturning	F =	4.05
Resultant in mid third?		Yes
Max q	=	2176 lb/ft <sup>2</sup>
Min q	=	924 lb/ft <sup>2</sup>
Equiv q	=	1910 lb/ft <sup>2</sup>
Bearing pressure OK?		Yes

# Terzaghi & Peck Methods for Low Walls

Equivalent Fluid Density



CIRCLED NUMBERS INDICATE THE FOLLOWING SOIL TYPES:

① CLEAN SAND AND GRAVEL: GW, GP, SW, SP.

② DIRTY SAND AND GRAVEL OF RESTRICTED PERMEABILITY: GM, GM-GP, SM-SP, SM.

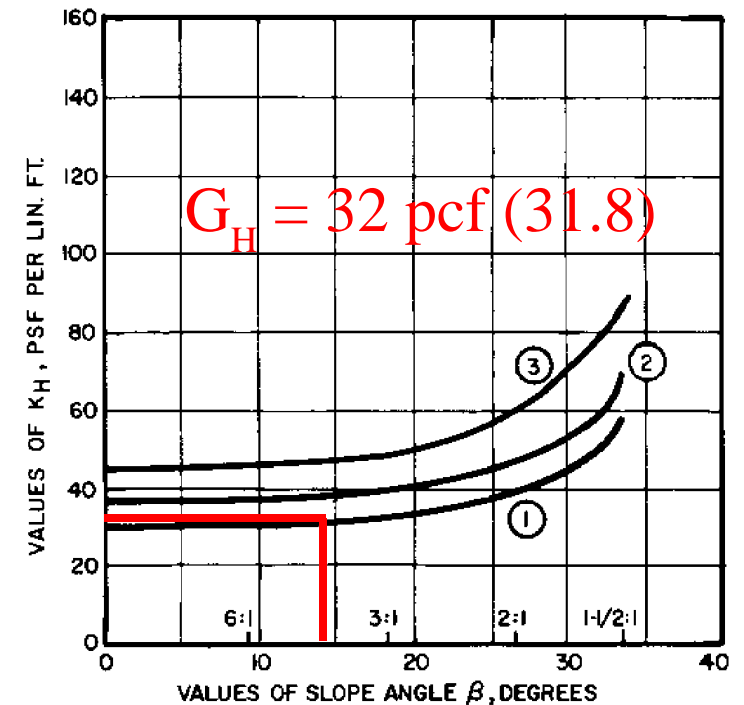
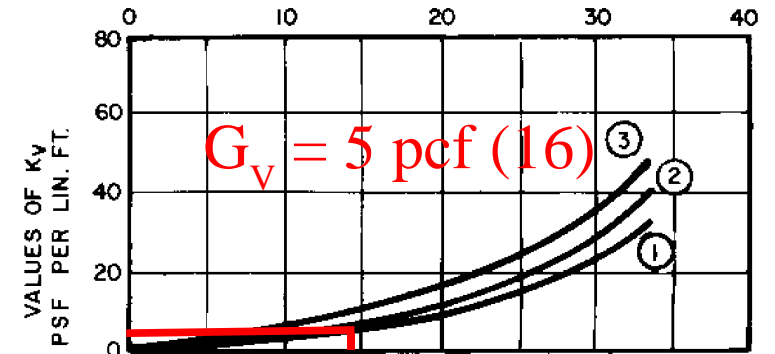
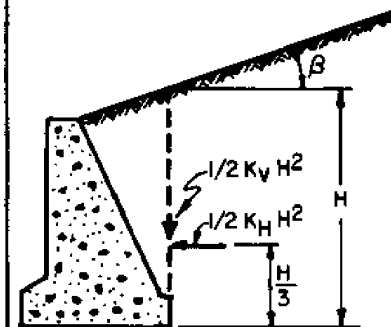
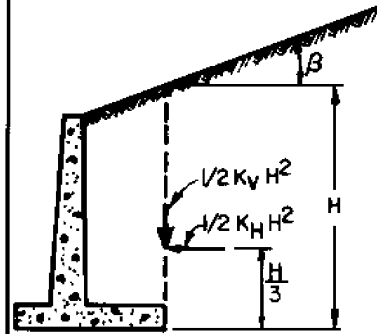
③ STIFF RESIDUAL SILTS AND CLAYS, SILTY FINE SANDS, CLAYEY SANDS AND GRAVELS: CL, ML, CH, MH, SM, SC, GC.

- Useful for walls under 12' – 20' in height
- Charts shown are for a straight slope backfill

FIGURE 16  
Design Loads for Low Retaining Walls (Straight Slope Backfill)

# Example with Terzaghi & Peck Charts

- Use Previous Example
- Soil Type (1) (clean sand)
- $H = 15.25'$
- $\beta = 14^\circ$
- Once these values are known, wall is analysed in the usual way



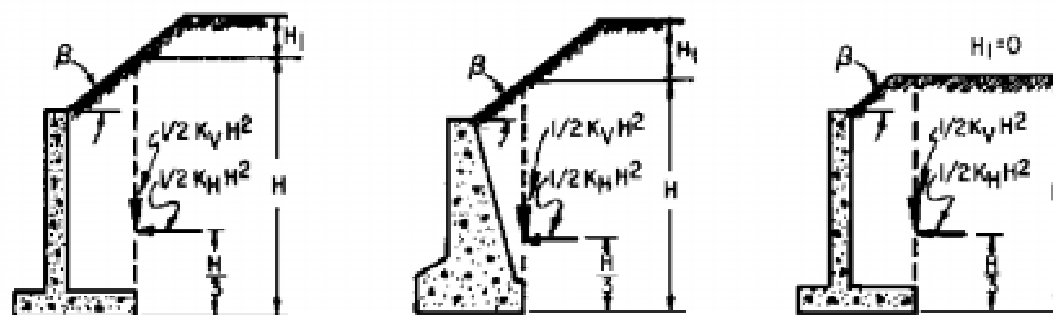
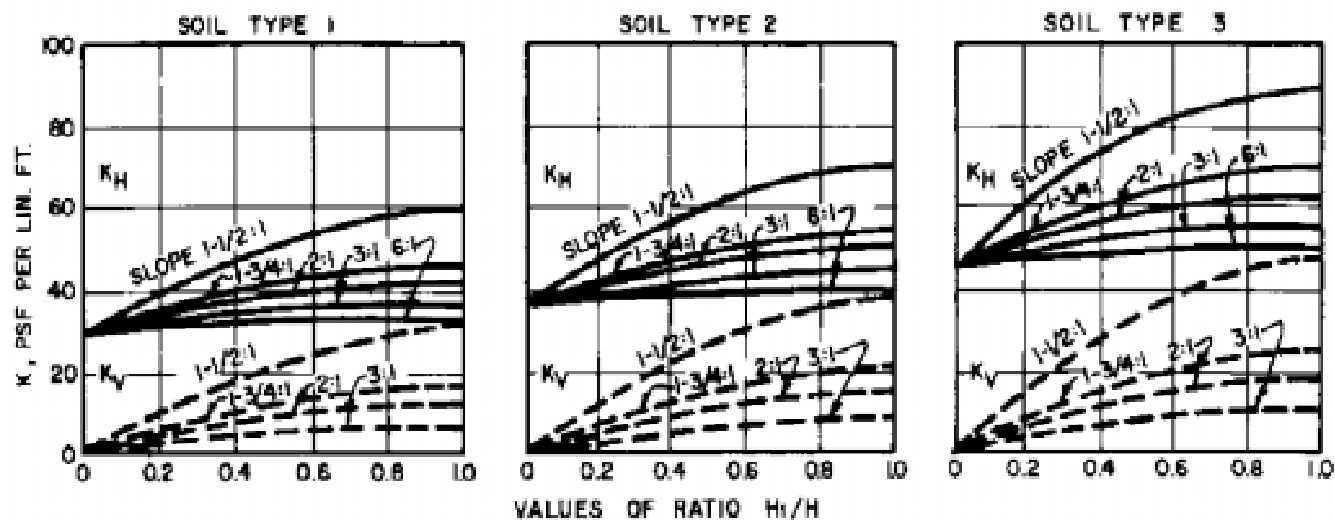
CIRCLED NUMBERS INDICATE THE FOLLOWING SOIL TYPES:

- ① CLEAN SAND AND GRAVEL: GW, GP, SW, SP.
- ② DIRTY SAND AND GRAVEL OF RESTRICTED PERMEABILITY: GM, GM-GP, SM-SP, SM.
- ③ STIFF RESIDUAL SILTS AND CLAYS, SILTY FINE SANDS, CLAYEY SANDS AND GRAVELS: CL, ML, CH, MH, SM, SC, GC.

FIGURE 16

Design Loads for Low Retaining Walls (Straight Slope Backfill)

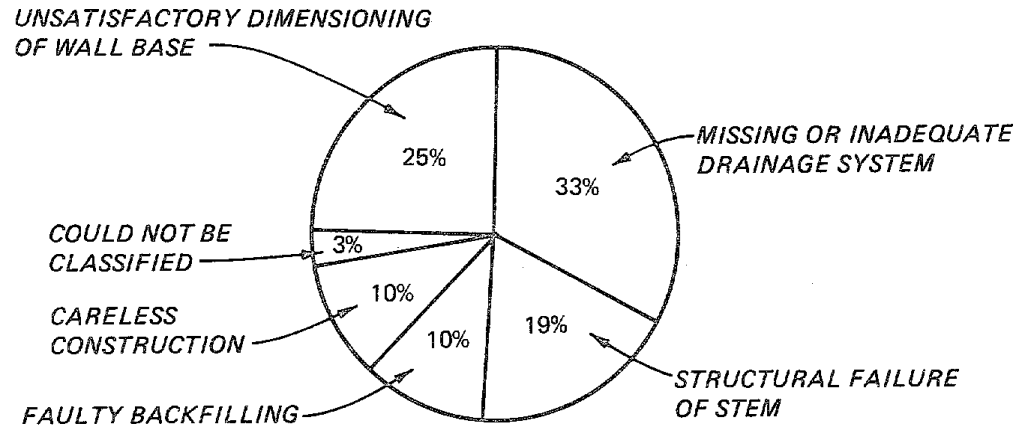
# Broken Slope Backfills



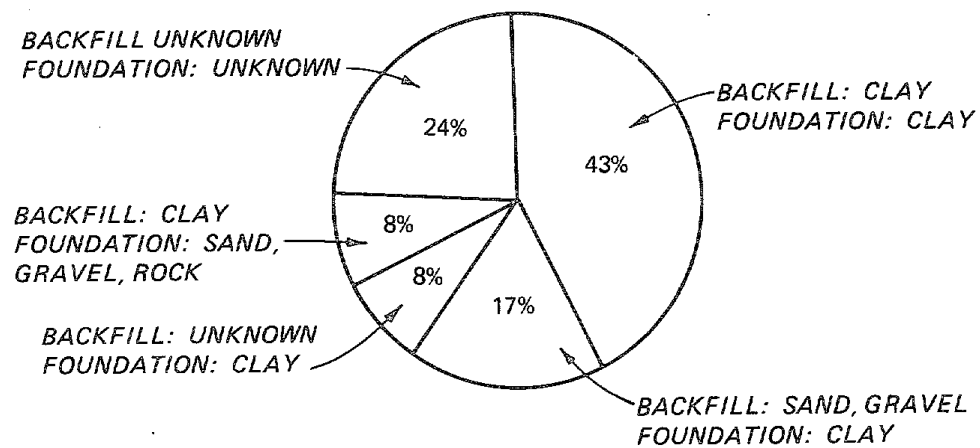
FOR DESCRIPTION OF SOIL TYPE SEE FIGURE 16

FIGURE 17  
Design Loads for Low Retaining Walls (Broken Slope Backfill)

# Failure Causes for Retaining Walls

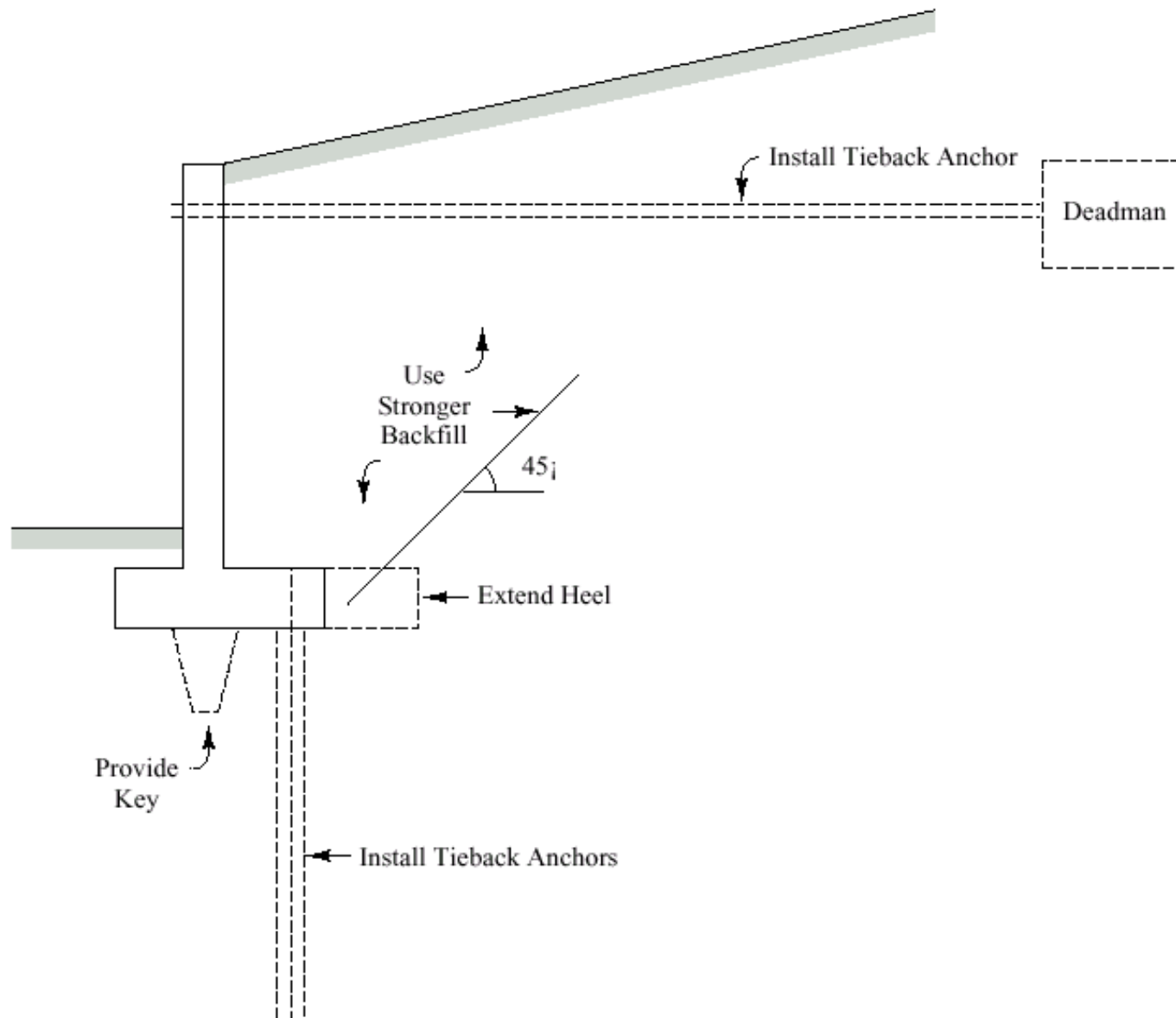


- a. Causes of failure of rigid concrete retaining walls (Techeng and Iseux 1972)

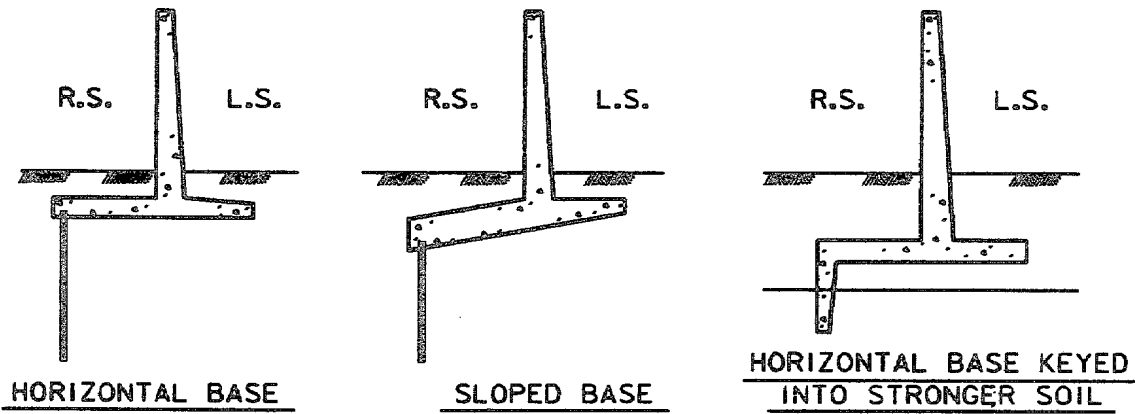


- b. Foundation and backfill material of unsatisfactory retaining walls (Ireland 1964)

# Methods of Improving Stability



# Cantilever Flood Walls

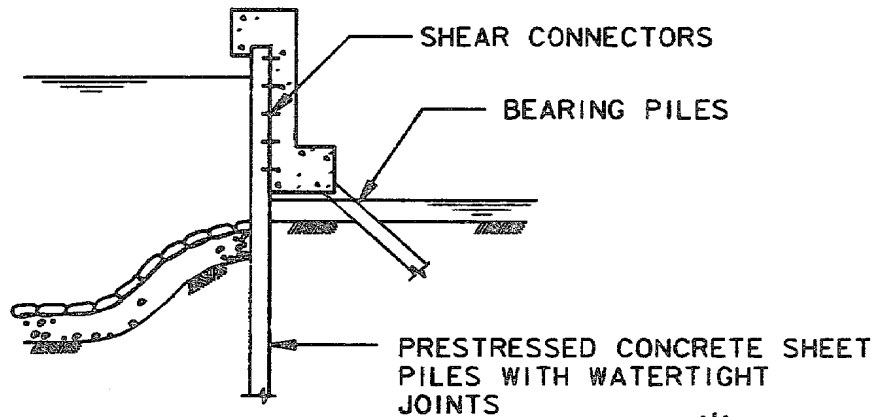


NOTE: R.S.= RIVER SIDE (OR SEAWARD, UNPROTECTED SIDE)  
L.S.= LAND SIDE (OR PROTECTED SIDE)

## INVERTED T-TYPE CANTILEVER WALLS

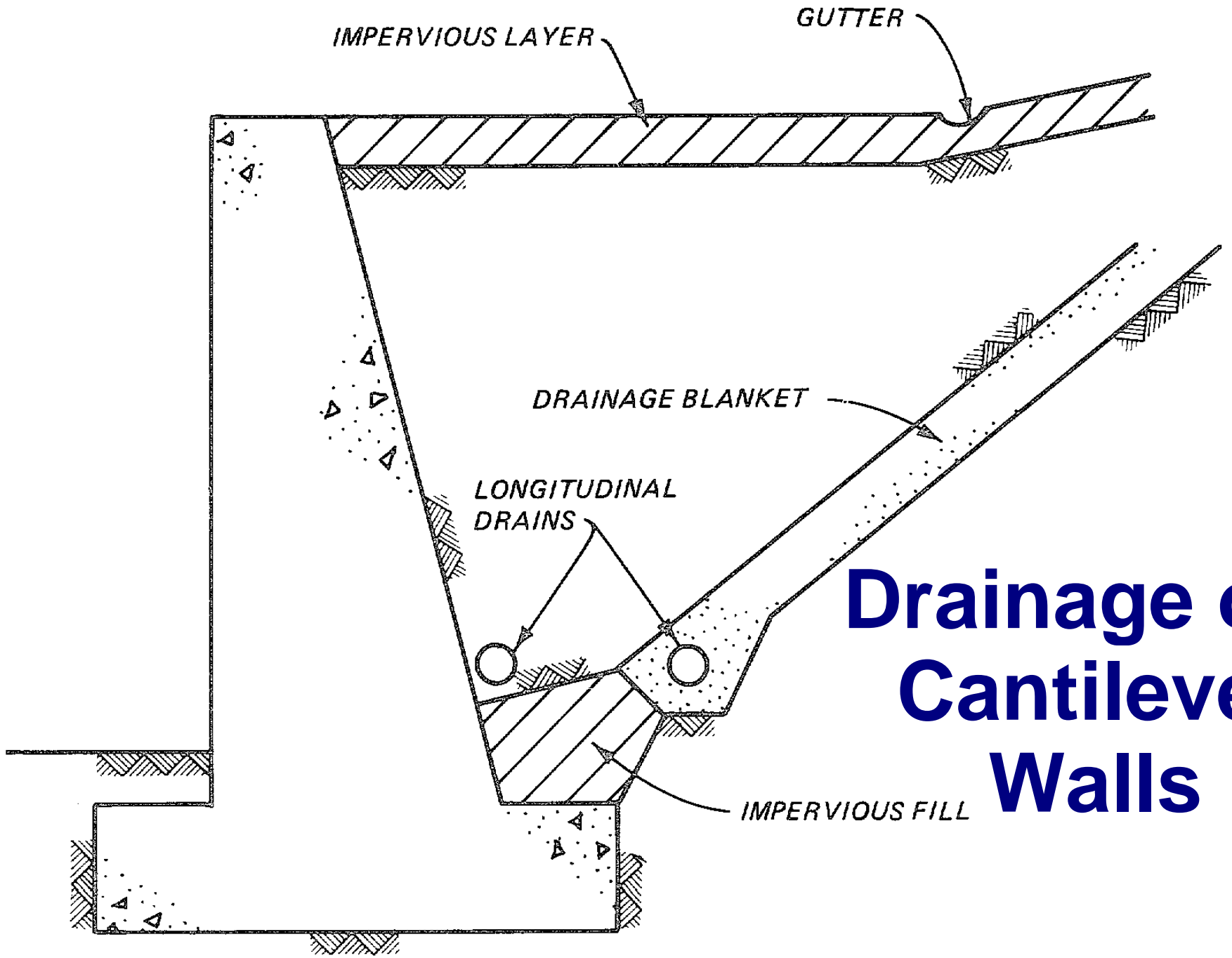


## CANTILEVER I-TYPE SHEET PILE WALLS \*



## BRACED SHEET PILE COASTAL FLOOD WALL \*

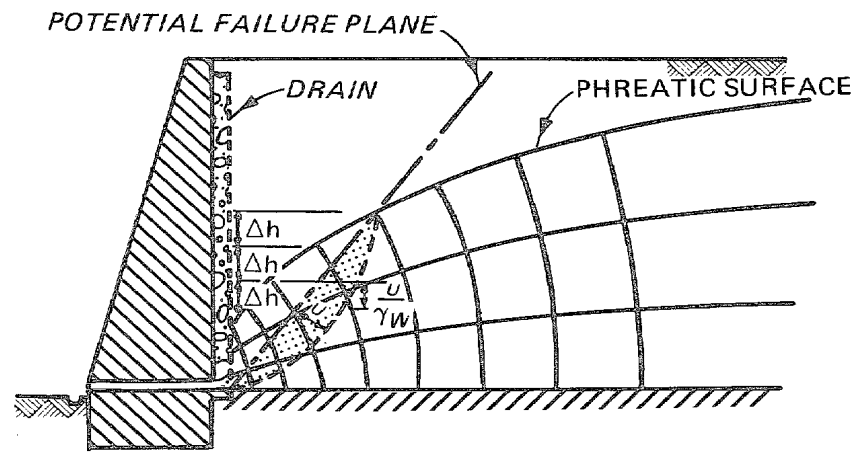
\* Analysis of this type of walls beyond the scope of this manual.



# Drainage of Cantilever Walls

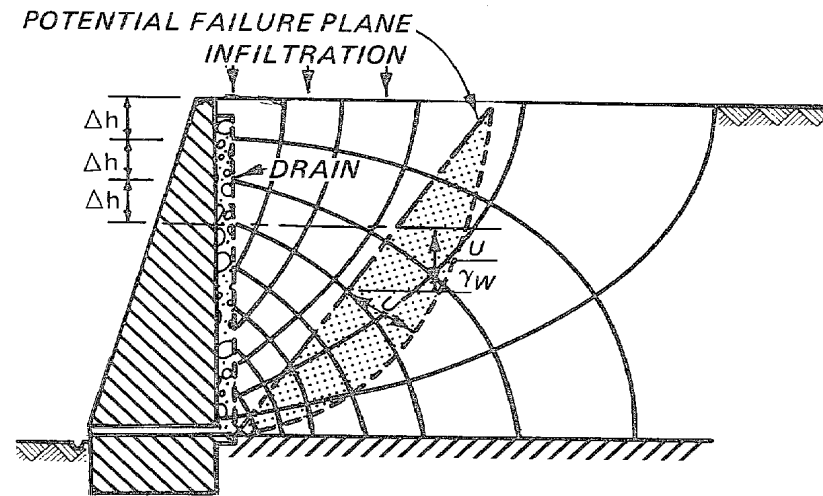
NOT TO SCALE

# Drainage of Cantilever Walls



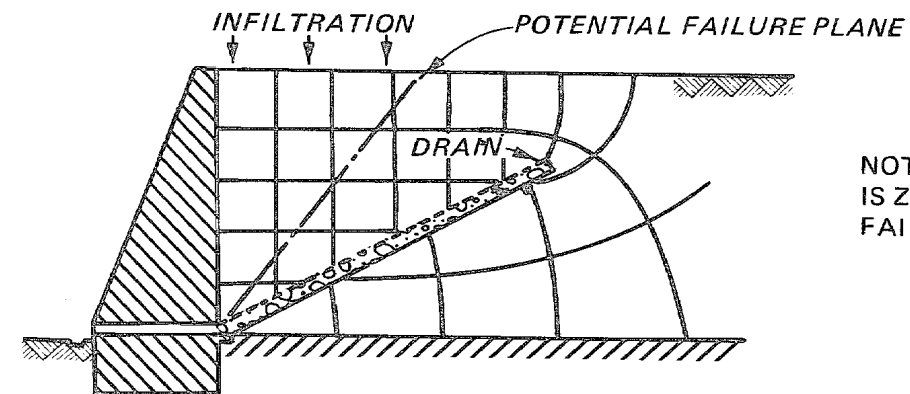
WATER PRESSURE DISTRIBUTION ON POTENTIAL FAILURE PLANE DUE TO STEADY SEEPAGE.

(a) NORMAL STEADY STATE SEEPAGE CONDITION (VERTICAL DRAIN)



NOTE INCREASE IN WATER PRESSURE ON POTENTIAL FAILURE PLANE DUE TO SURFACE INFILTRATION.

(b) SURFACE INFILTRATION (VERTICAL DRAIN)



NOTE WATER PRESSURE IS ZERO ON POTENTIAL FAILURE PLANE.

(c) SURFACE INFILTRATION (INCLINED DRAIN)

# Questions



# Quiz 4



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- Find the total active lateral earth force along the surface AB. Use Rankine theory. Also compute the location of the resultant of this force.

