Lecture 06

Design of Reinforced Concrete Retaining Walls

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- RC cantilever retaining wall
- Stability evaluation of retaining wall
- Earth pressure and Soil parameters
- Design of RC cantilever retaining wall
- Example 6.1
- Practical examples
- References

Learning Outcomes

- **At the end of this lecture, students will be able to;**
  - ***Identify*** different types of retaining walls
  - ***Explain*** failure mechanism of retaining walls
  - ***Analyze*** and ***Design*** RC Cantilever Wall

General

❑ Introduction

- A retaining wall is a structure that holds or retains soil masses of earth or other loose material behind it.

- Used in the construction of railways, highways, bridges, canals, basement walls in buildings, walls of underground reservoirs, swimming pools etc.

General

- Introduction

General

- ❑ **Introduction**

General

❑ Introduction

General

❑ Introduction

General

- Introduction

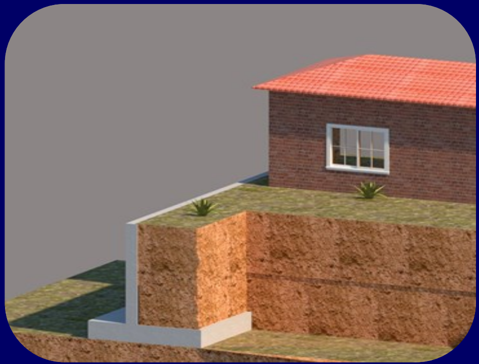
General

Types of Retaining Walls

- Retaining walls are generally classified based on the method of attaining stability against the lateral load imposed by the retained earth.

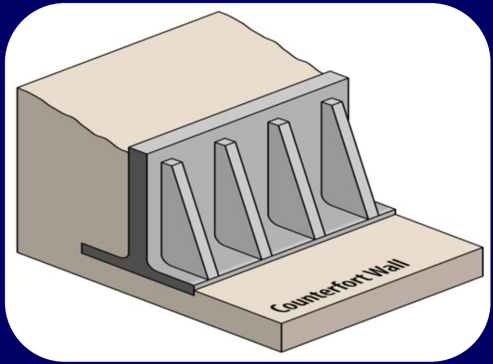
Gravity Wall

Uses its own weight and that of the retained soil for stability and are either lightly reinforced or contain no reinforcement.



Cantilever Wall

Weight of the soil on the heel of the footing provides the primary contribution to overall stability.



Counterfort Wall

Similar to Cantilever wall but the stem is stiffened by buttresses, to achieve more strength

General

❑ Selection of Suitable Type of Retaining Wall

- Gravity walls are economical only for relatively low walls; possibly up to about 10 ft.
- Cantilever Retaining Walls are generally economical up to a height of approximately 20ft.
- For greater heights or for the conditions where the backfill pressure is unusually high, Counterfort or Buttress Retaining Walls are recommended.
- This lecture is only focused on the structural analysis and design of Cantilever retaining wall.

RC Cantilever Retaining Wall

❑ Different Terms Related to Retaining Wall

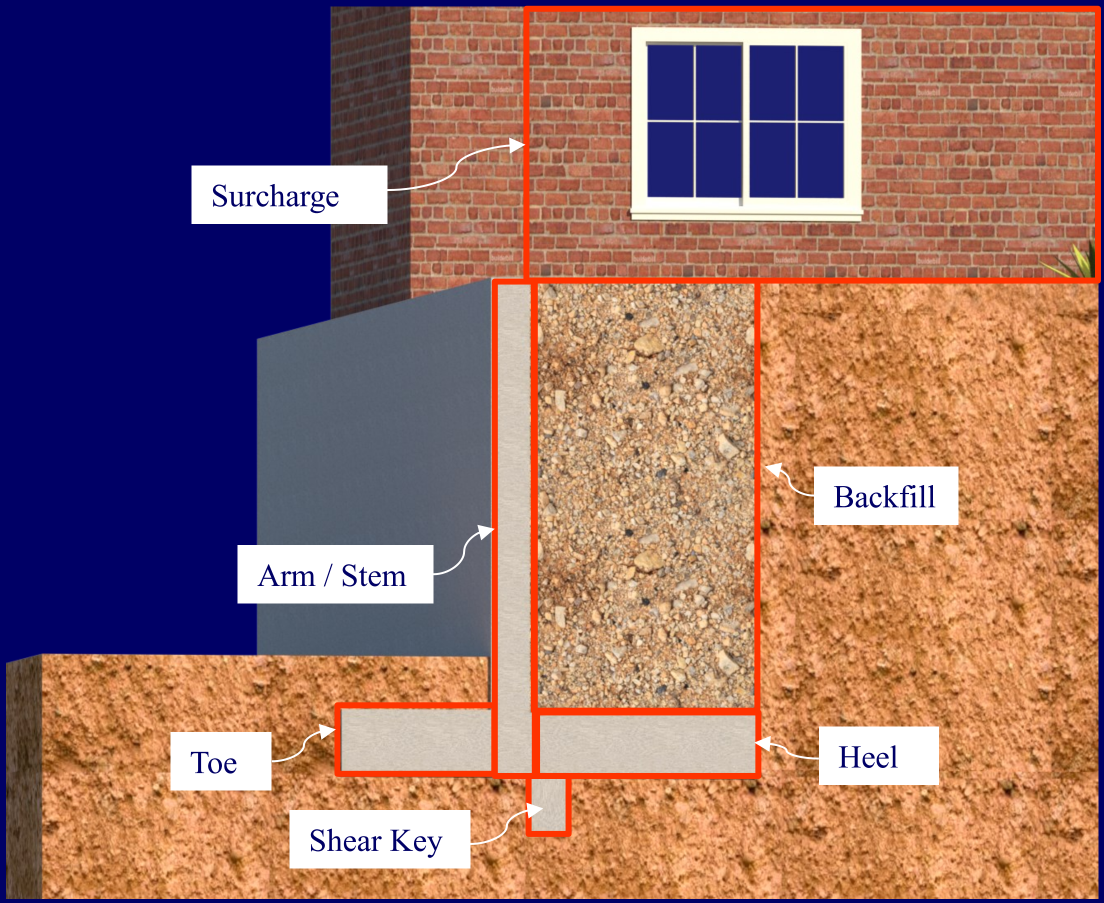
- A typical Cantilever retaining wall is an assembly of the following components

    1. **Stem:** Stem is a Vertical arm that provides horizontal resistance against the overturning force of the soil
    2. **Base:** It is a horizontal footing that is typically divided into two parts, the Toe and the Heel.
    3. **Key:** A key is basically a small vertical element constructed below the footing (base) to increase sliding resistance.

- Illustration of these components have been shown on the next slide.

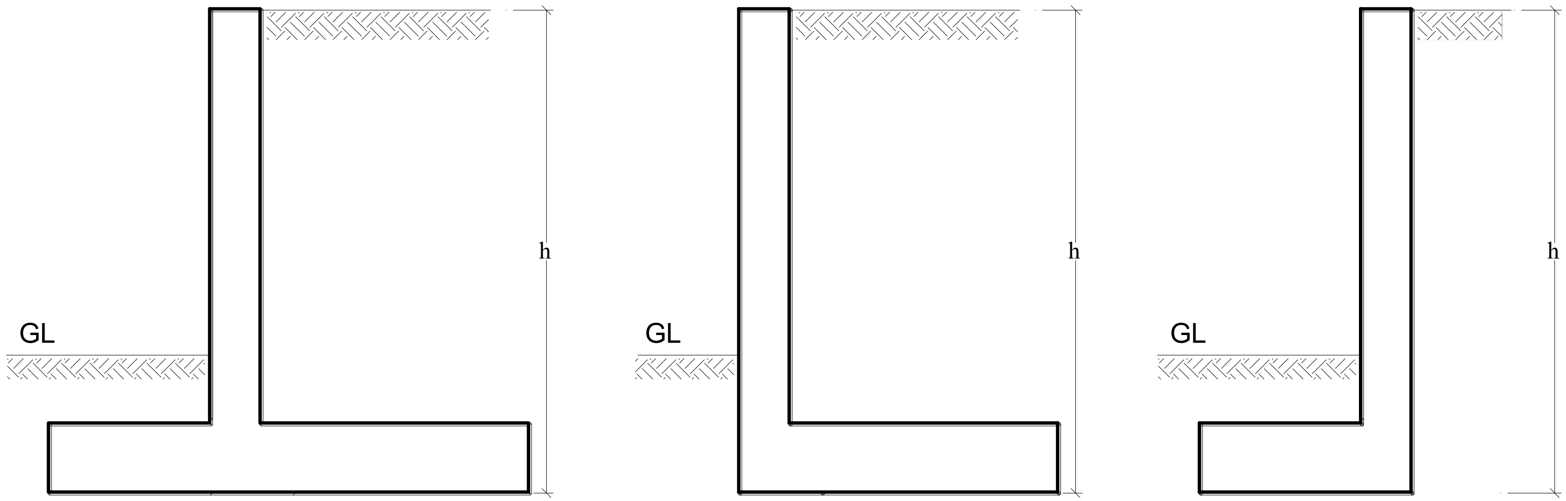
RC Cantilever Retaining Wall

❑ Different Terms Related to Retaining Wall



RC Cantilever Retaining Wall

❑ Types of cantilever Retaining Walls

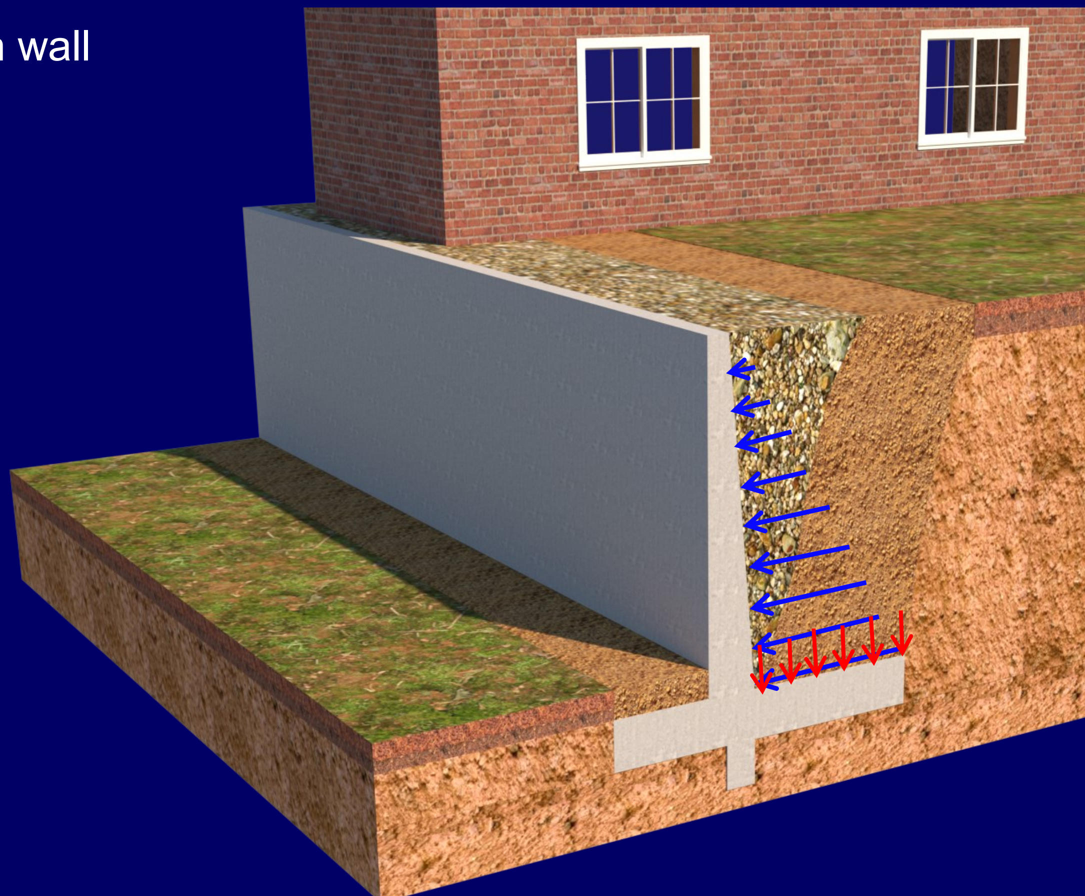


(a) Typical (b) with heel only (c) with toe only

RC Cantilever Retaining Wall

❑ Behavior of Cantilever Retaining Wall

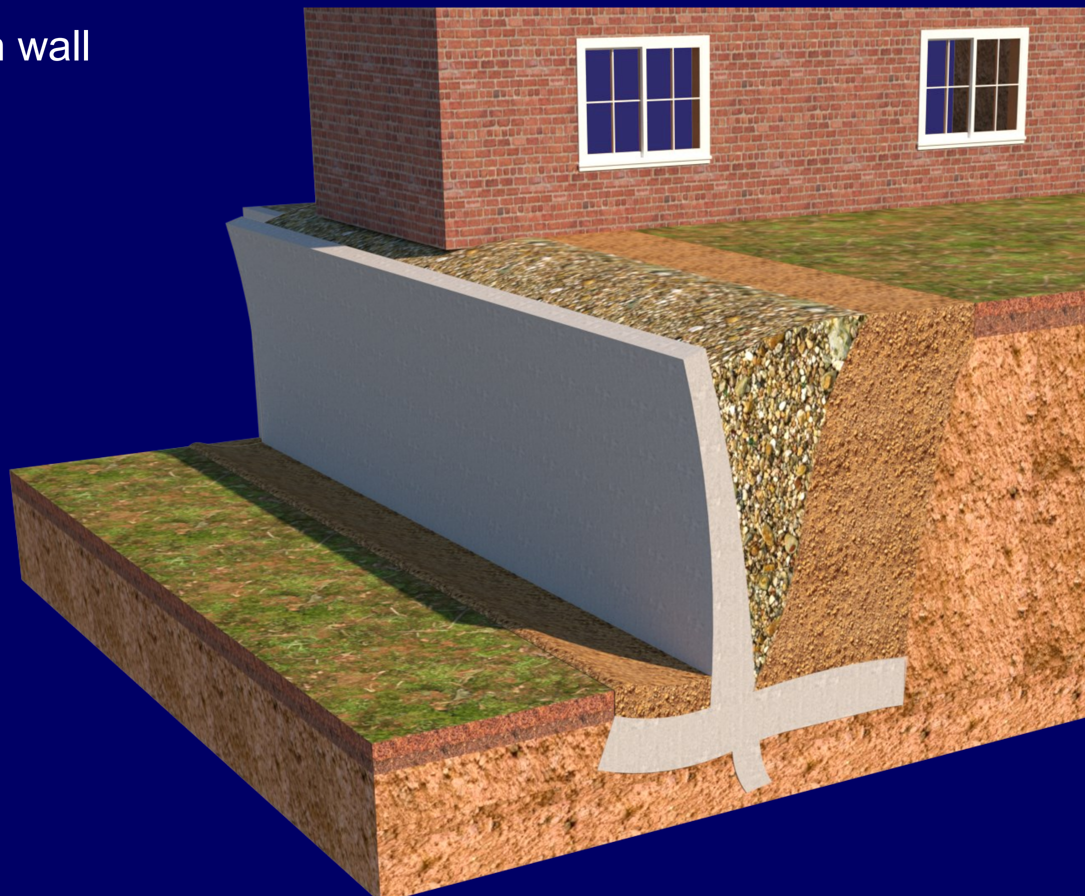
- Applied loading on wall



RC Cantilever Retaining Wall

❑ Behavior of Cantilever Retaining Wall

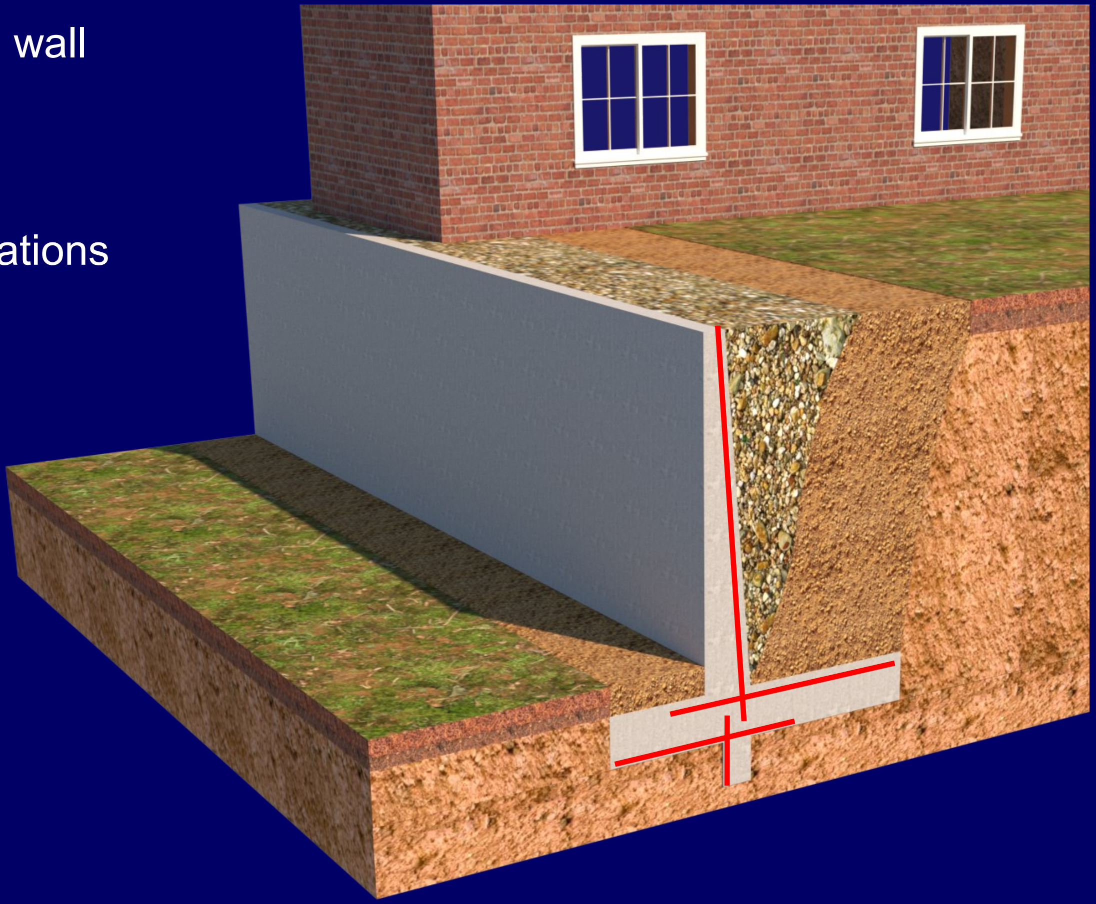
- Applied loading on wall
- Deflected shape



RC Cantilever Retaining Wall

❑ Behavior of Cantilever Retaining Wall

- Applied loading on wall
- Deflected shape
- Reinforcement locations



RC Cantilever Retaining Wall

Various Failure Modes

- RC retaining wall may fail in two different ways:

1. **Stability Failure**

   - The wall as a whole may be bodily displaced by the earth pressure, without breaking up internally. This can be

     I. Overturning

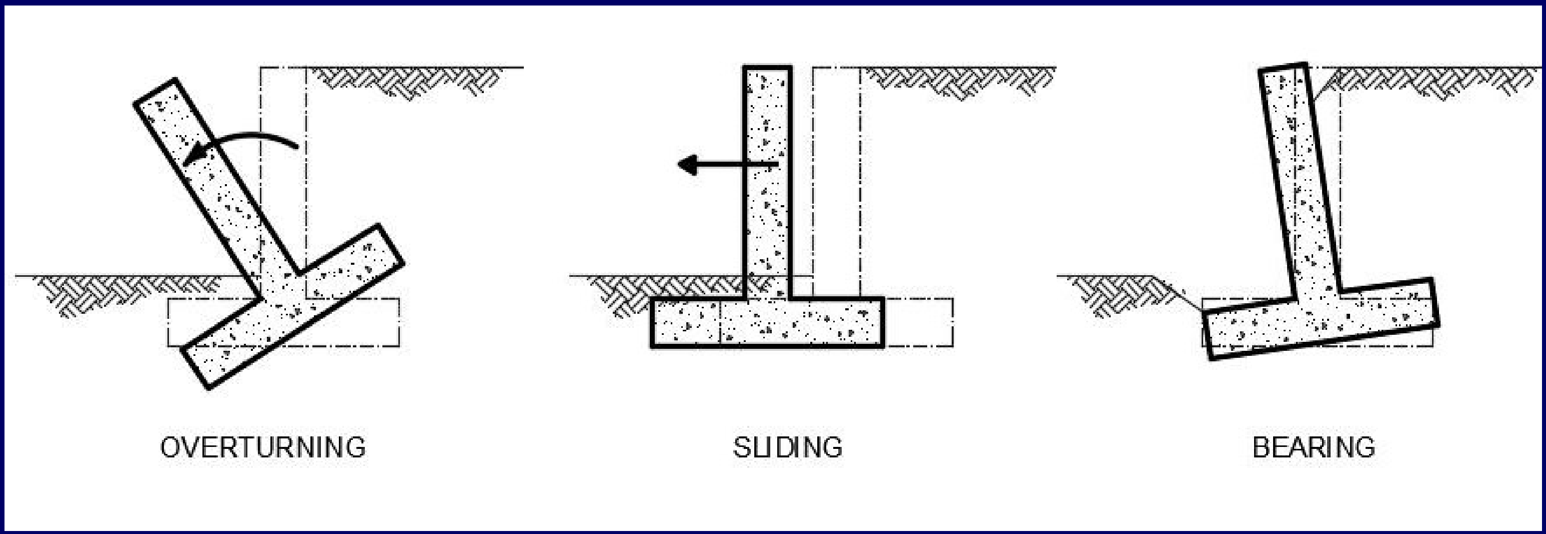
     II. Sliding

     III. Bearing / Settlement

RC Cantilever Retaining Wall

❑ Various Failure Modes

1. **Stability Failure**

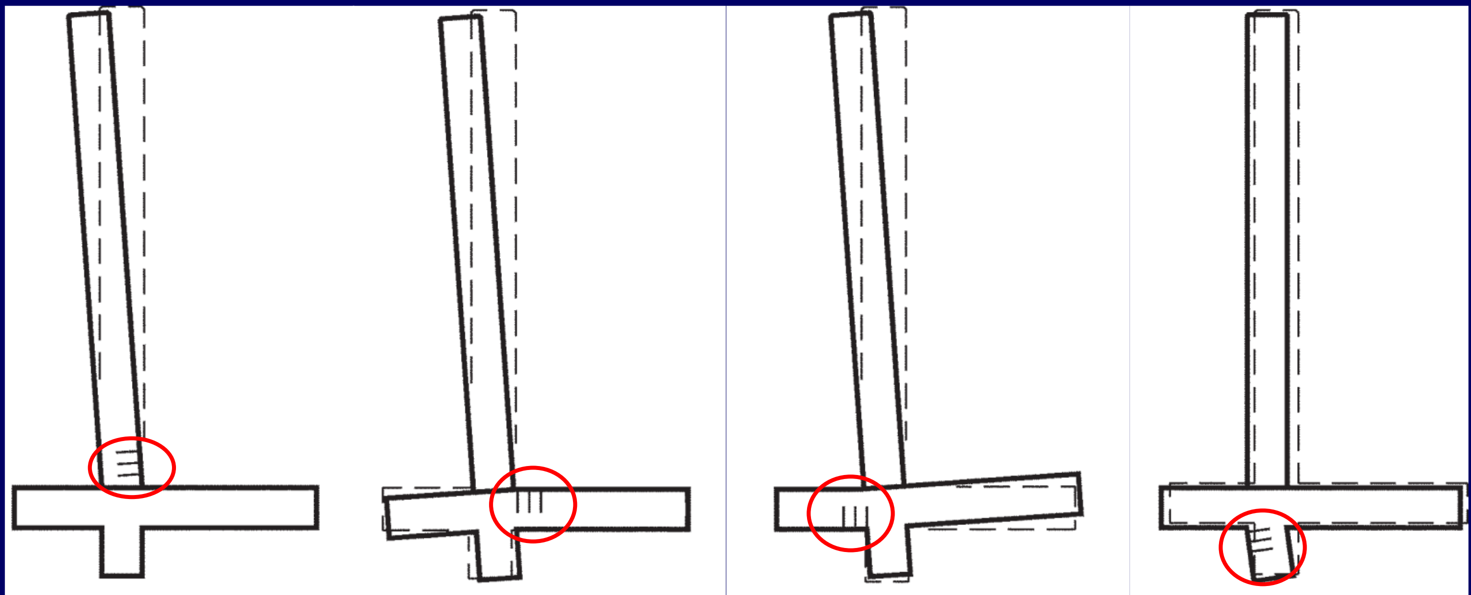


RC Cantilever Retaining Wall

Various Failure Modes

2. Body Failure

- The individual structural parts (stem, toe, heel) of the wall may not be strong enough to resist the acting forces.



(a) Stem failure (b) Heel failure (c) Toe failure (d) Key failure

RC Cantilever Retaining Wall

❑ Various Failure Modes

Animation explaining behavior of Cantilever retaining wall under lateral pressure

Earth Pressure and Soil Parameters

❑ Various Conditions of Loading

1. Horizontal surface of fill at the top

- From Rankine's formula, we have

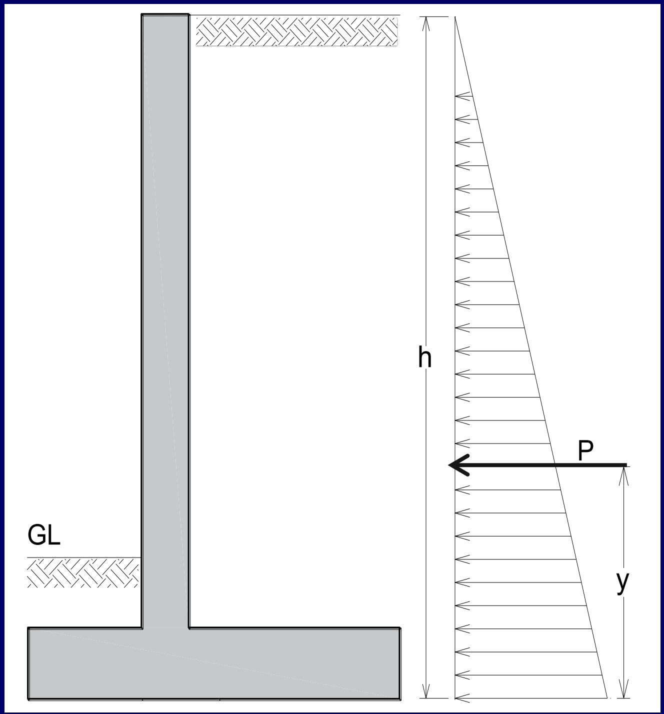
$$p_a = K_a \gamma_s h \quad \text{Where, } K_a = \frac{1 - \sin(\emptyset)}{1 + \sin(\emptyset)}$$

The resultant of this pressure is:

$$P = \frac{1}{2}(p_a)(h) = \frac{1}{2} K_a \gamma_s h^2$$

and the location of "P" from the base is:

$$y = \frac{h}{3}$$



$\emptyset$ = angle of internal friction of soil
γ_s = unit weight of soil

Earth Pressure and Soil Parameters

Various Conditions of Loading

2. Inclined surface of fill at top

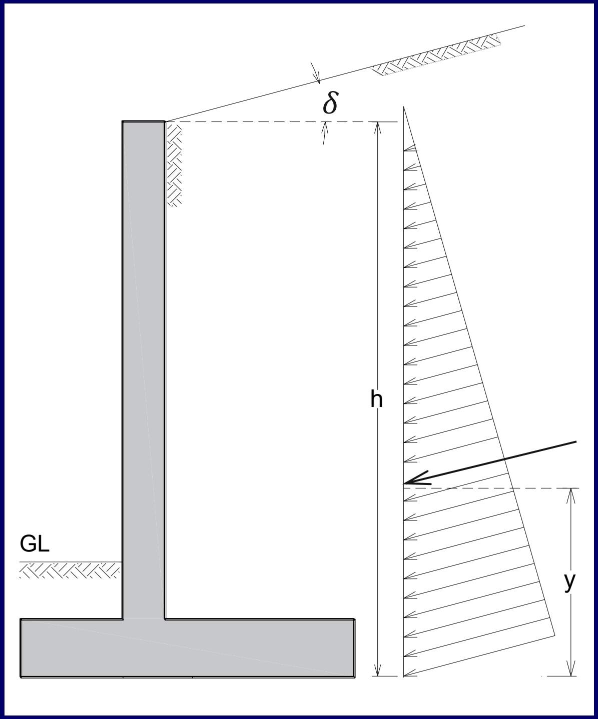
- The resultant of this pressure is

$$P = \frac{1}{2}(p_a)(h) = \frac{1}{2}K_a \gamma_s h^2$$

and the location of "P" is given by

$$y = \frac{h}{3}$$

For $\delta = \emptyset,\ K_a = \cos\emptyset$



Earth Pressure and Soil Parameters

❑ Various Conditions of Loading

3. Horizontal surface of fill carrying UDL surcharge

- The increase in pressure caused by uniform surcharge "S" is computed by converting its load into an equivalent imaginary height of earth h_s above the top of the wall such that,

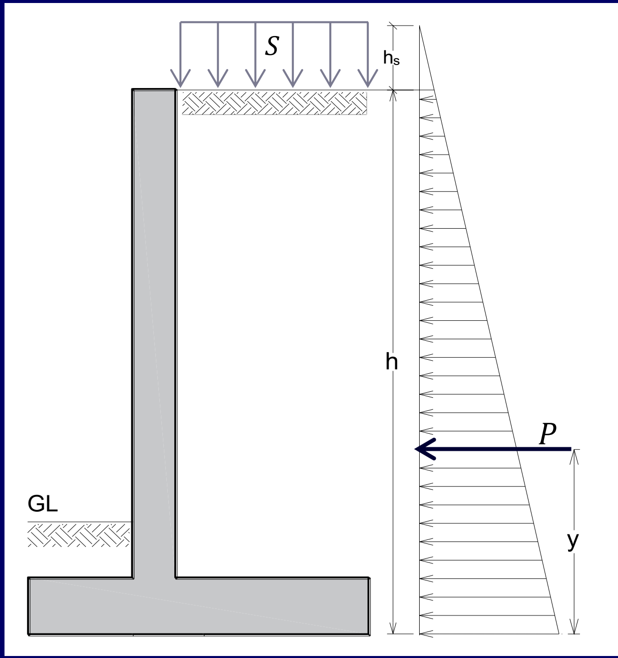
$h_s = S/\gamma$

Then resultant of pressure is

$$P = \frac{1}{2} K_a \gamma_s h(h + 2h_s)$$

and the location of "P" from the base is

$$y = \frac{h^2 + 3hh_s}{3(h + 2h_s)}$$



Earth Pressure and Soil Parameters

Soil Parameters

- The following table gives representative values of typical soil parameters, often used in engineering practice.

Table: Unit weight (γ_s), effective angles of internal friction (φ'), and the coefficient of friction with concrete (μ)

S. No	Type of Soil	Typical parameters			Remarks
		Unit Weight γ_s (pcf)	Internal friction angle φ' (degrees)[1]	Coefficient of friction μ[2]	
1	Sand or gravel without fine particles, highly permeable	110 to 120	30 to 40	0.5 to 0.6	Should be used as backfill for retaining walls wherever possible
2	Sand or gravel with silt mixture, low permeability	120 to 130	25 to 35	0.4 to 0.5	
3	Silty sand, sand and gravel with high clay content	110 to 120	25 to 30	0.3 to 0.4	The value of Φ may be un-conservative under saturated conditions
4	Medium or stiff clay	100 to 120	25 to 35	0.2 to 0.4	
5	Soft clay, silt	90 to 110	20 to 35	0.2 to 0.3	

[1] The φ values do not account for probable additional pressures due to pore water, seepage, frost, etc.

[2] Coefficient of friction between concrete and various soils.

Stability Evaluation of Retaining Wall

Stability checks

- To evaluate the stability of retaining wall against overturning, sliding and bearing pressure, the following three factors of safety must be computed and compared with recommended values suggested in ACI Reinforced Concrete Design Handbook Volume-2_Special Topics, MNL-17(21).

  1. **Factor of safety against overturning** (FS_{OT})
  2. **Factor of safety against sliding** (FS_{SL})
  3. **Factor of safety against bearing** (FS_{BR})

Stability Evaluation of Retaining Wall

❑ Stability Checks

1. Factor of safety against overturning

- The factor of safety against overturing about the tip of toe is given by

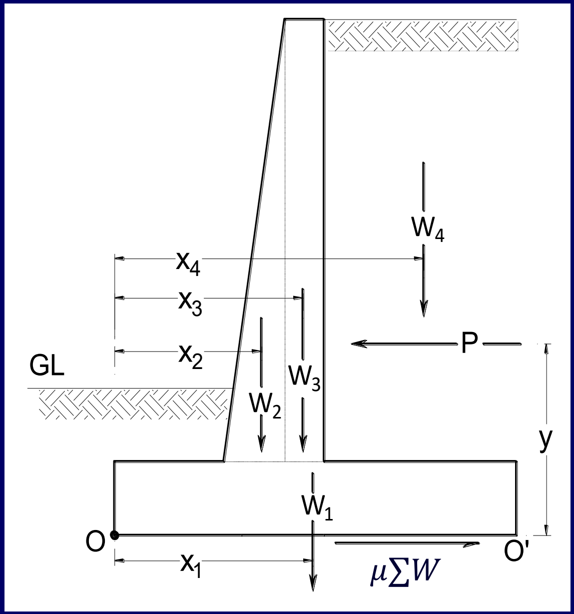
$$FS_{OT} = \frac{Restoring\ Moment}{Overturning\ moment} = \frac{M_R}{M_{OT}}$$

Where;

$$M_R = \sum(Wx) = W_1x_1 + W_2x_2 + W_3x_3 + W_4x_4$$

$$M_{OTM} = P\ y$$

- General recommended value is ≥ 2.0.



Stability Evaluation of Retaining Wall

❑ Stability Checks

2. Factor of safety against sliding

- The factor of safety against sliding at base is given by;

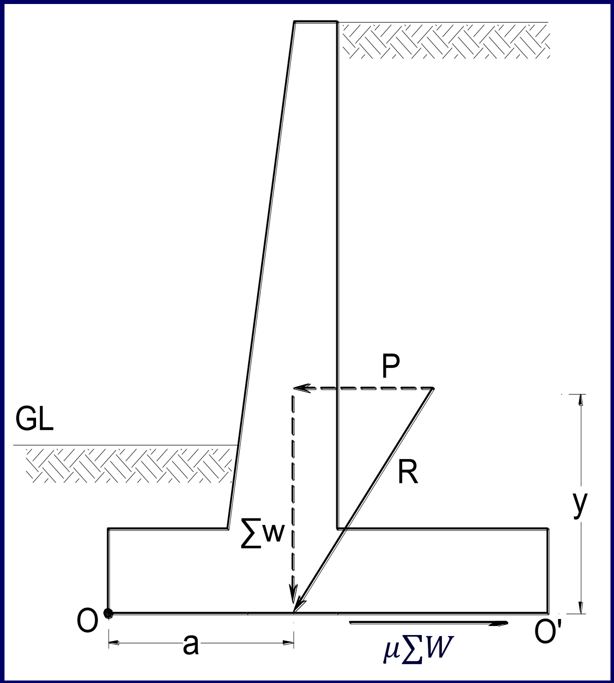
$$FS_{SL} = \frac{\mu \sum W}{P}$$

Where;

μ = Coefficient of friction b/w soil and concrete.

$\sum W$ = Total weight of retaining wall including front fill and backfill.

P = Active soil pressure.



- General recommended value is ≥ 1.5.

Stability Evaluation of Retaining Wall

Stability Checks

3. Factor of safety against bearing

- The factor of safety against bearing can be determined as;

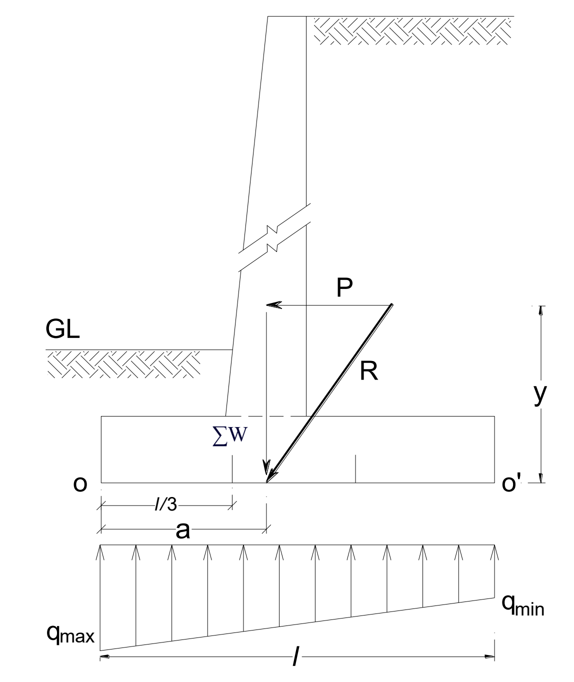
$$FS_{BR} = \frac{q_a}{q_{max}}$$

Where;

q_a = Allowable bearing capacity of soil

q_{max} = Maximum soil bearing pressure

- General recommended value is ≥ 3.



Stability Evaluation of Retaining Wall

Stability Checks

3. Factor of safety against bearing

Calculation of bearing pressure

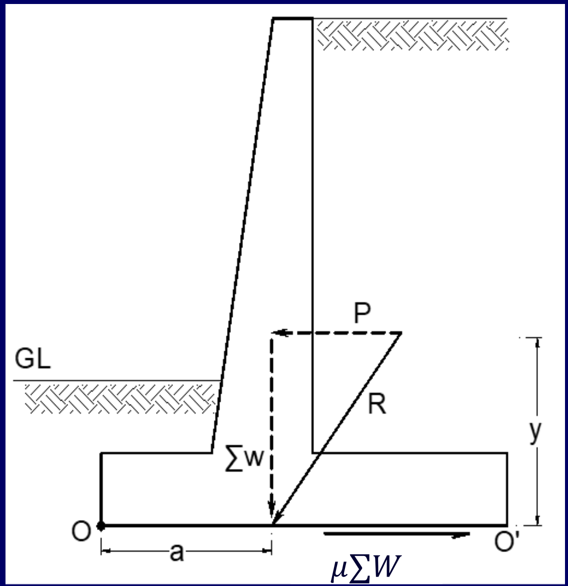
Let "a" be the location of resultant R from the exterior end of toe (point O). Then we have;

$\Delta M = M_R - M_{OT}$

Since, $\Delta M = (\sum W)a$

Therefore, solving for a gives;

$$a = \frac{M_R - M_{OT}}{\sum W}$$



Stability Evaluation of Retaining Wall

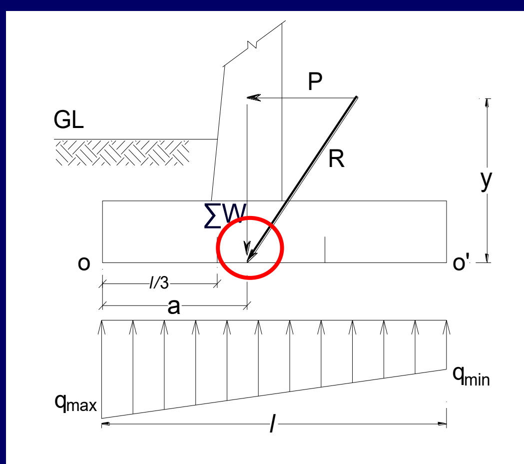
❑ Stability Checks

3. Factor of safety against bearing

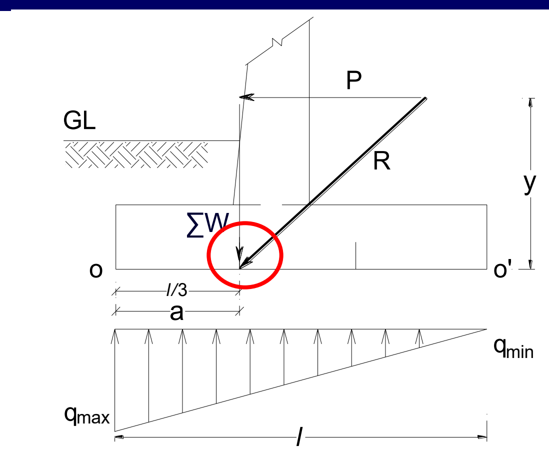
- **Calculation of bearing pressure**

- The bearing pressure diagram of soil below the base, depends on the location of resultant as shown below.

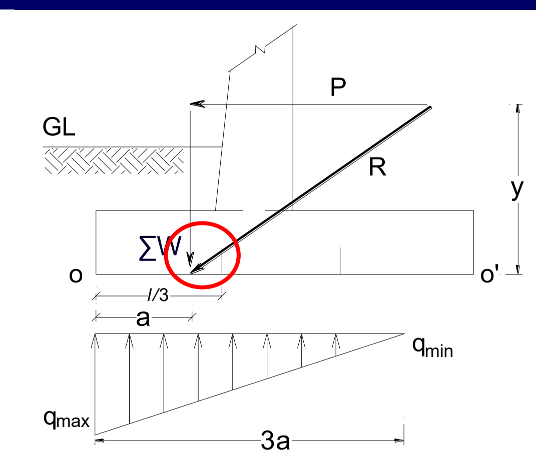
Case 1: a > $l/3$



Case 2: a = $l/3$



Case 3: a < $l/3$



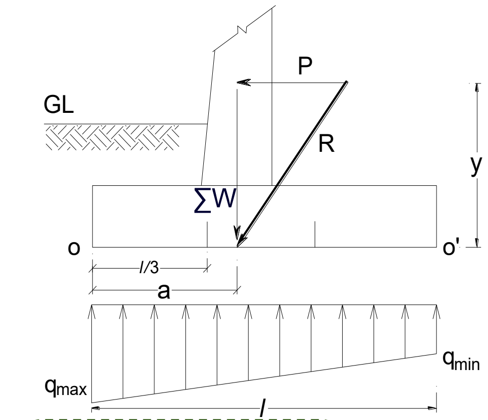
Stability Evaluation of Retaining Wall

❑ Stability Checks

3. Factor of safety against bearing

- ❑ **Calculation of bearing pressure**

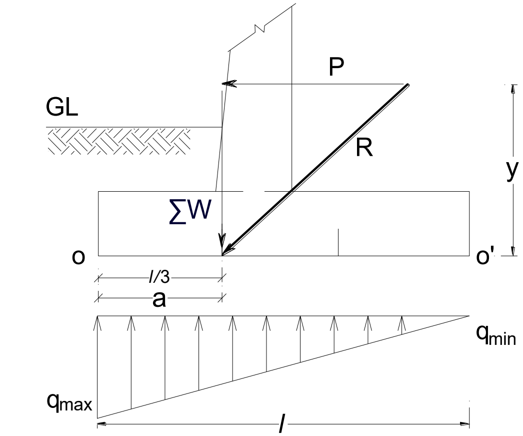
Case 1: a > $l/3$



$$q_{max} = (4l - 6a)\frac{\sum W}{l^2}$$

$$q_{min} = (6a - 2l)\frac{\sum W}{l^2}$$

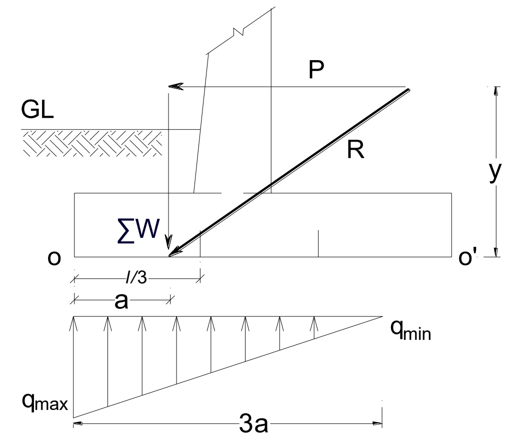
Case 2: a = $l/3$



$$q_{max} = \frac{2\sum W}{l}$$

$$q_{min} = 0$$

Case 3: a < $l/3$



$$q_{max} = \frac{2\sum W}{3a}$$

$$q_{min} < 0$$

Design of RC Cantilever Retaining Wall

Design Criteria

- The stem of a cantilever retaining wall shall be designed as a one–way slab in accordance with the applicable provisions of Chapter 7 (one - way slabs). (ACI 318 -19, section 13.3.6.1)
- The base is designed as one–way shallow foundation using applicable provisions of Chapter 7 (one - way slabs) and Chapter 9 (Beams). (ACI 318 -19, section 13.3.2.1)

Design of RC Cantilever Retaining Wall

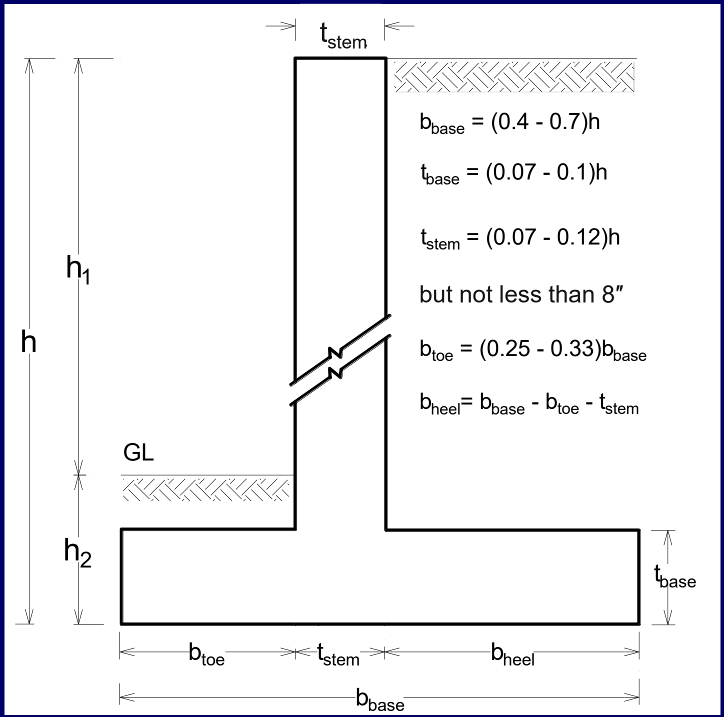
Load Combinations

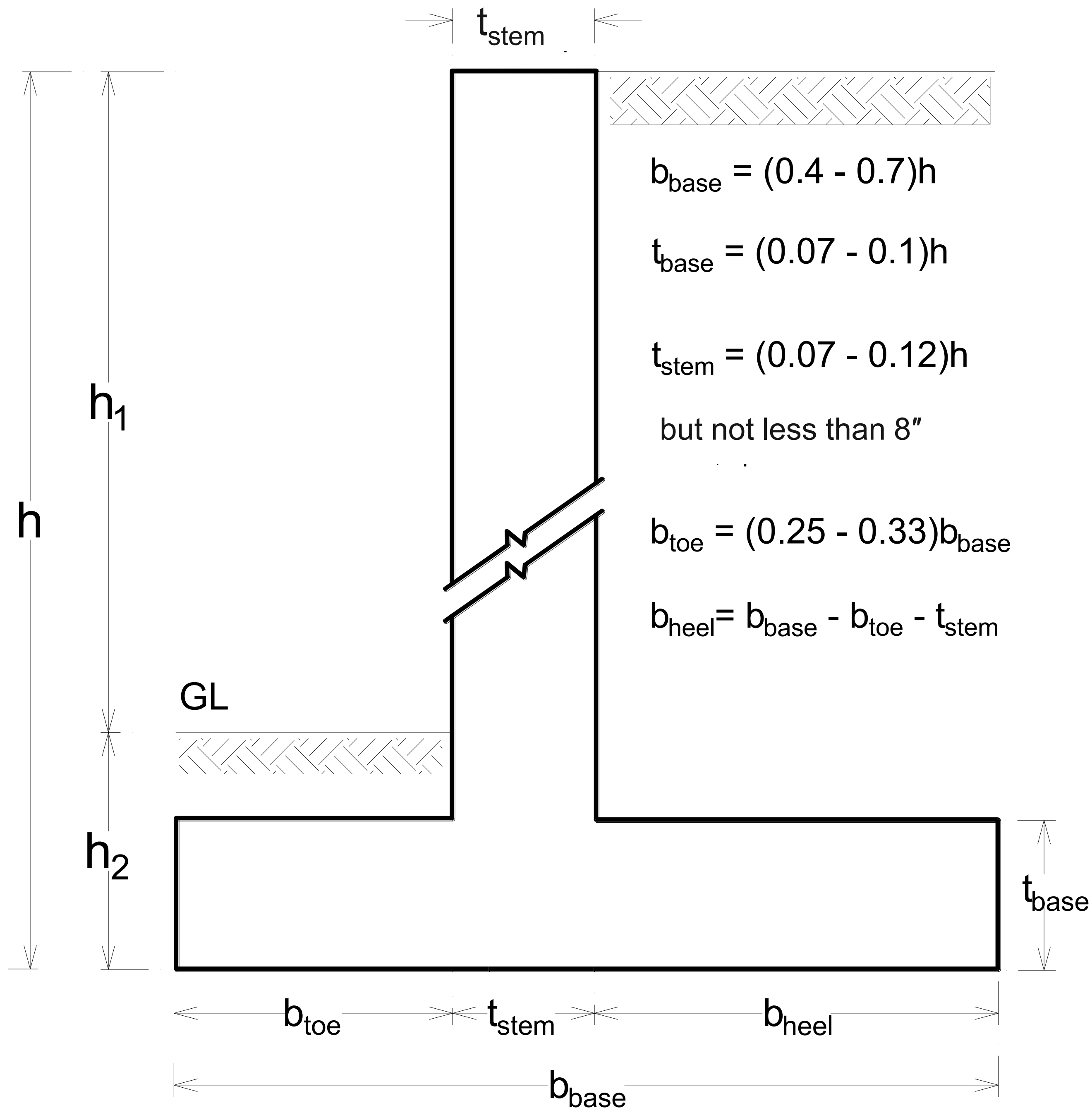
- Load combination relating to structural design of retaining walls shall be in accordance with ACI 318 -19, section 5.3.1.
  - U = 1.2D + 1.6L + 1.6H

Design of RC Cantilever Retaining Wall

❑ Preliminary Sizes

- ACI recommends the dimensions from the guidelines presented by "Bowels" in the fifth edition of "*Foundations Analysis and Design*", for preliminary calculations.





$b_{base} = (0.4 - 0.7)h$

$t_{base} = (0.07 - 0.1)h$

$t_{stem} = (0.07 - 0.12)h$

but not less than 8″

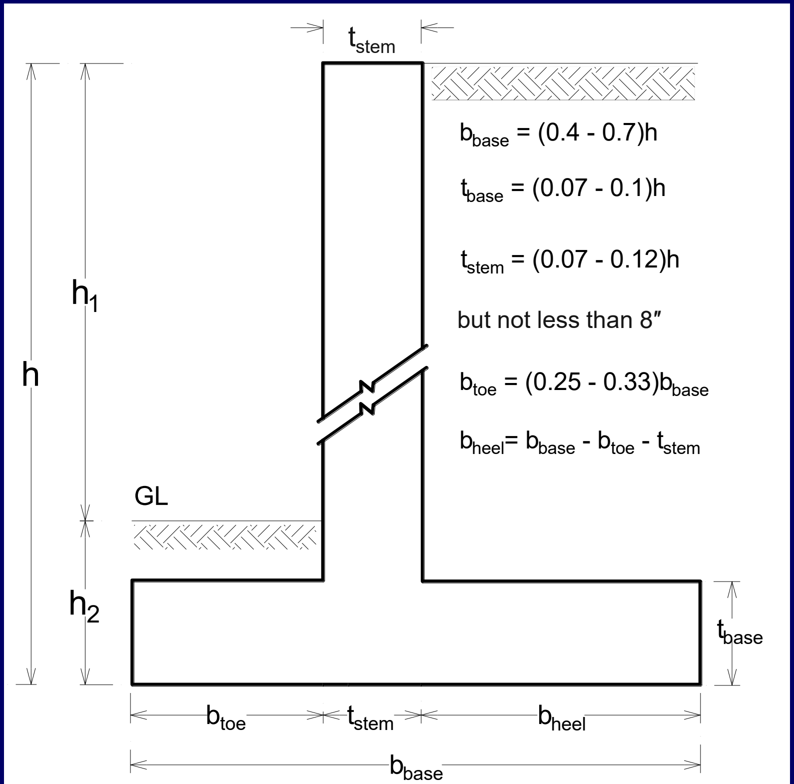
$b_{toe} = (0.25 - 0.33)b_{base}$

$b_{heel} = b_{base} - b_{toe} - t_{stem}$

Design of RC Cantilever Retaining Wall

❑ Preliminary Sizes

- In case of surcharge, "h" is replaced by $h_{eq} = h + h_s$ where ;h_s = height of surcharge



Design of RC Cantilever Retaining Wall

❑ Preliminary Sizes

- The estimated sizes must be checked with the minimum thickness requirements for one-way cantilever slabs provided in ACI 318-19 Table 7.3.1.1

Table 7.3.1.1— Minimum thickness of solid nonprestressed one-way slabs

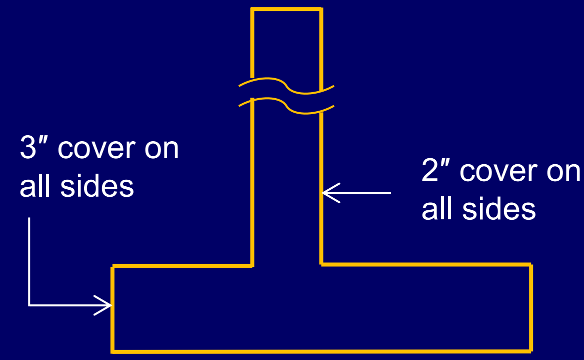
Support condition	Minimum h [1]
Simply supported	$l/20$
One end continuous	$l/24$
Both ends continuous	$l/28$
Cantilever	$l/10$

- l = Span length (Center to center length for interior spans, clear projection for cantilevers) (Section 2.2)
- [1] For f_y other than 60,000 psi, the expressions in the table shall be multiplied by (0.4 + f_y /100,000)

Design of RC Cantilever Retaining Wall

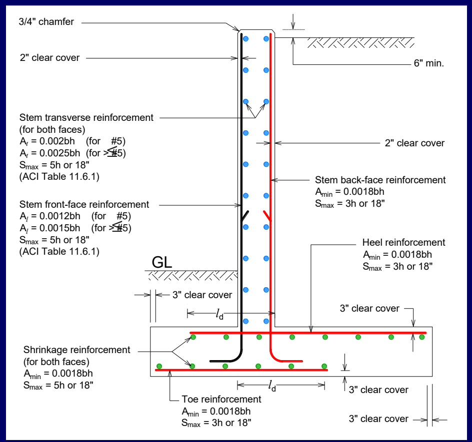
❑ Concrete Clear Cover

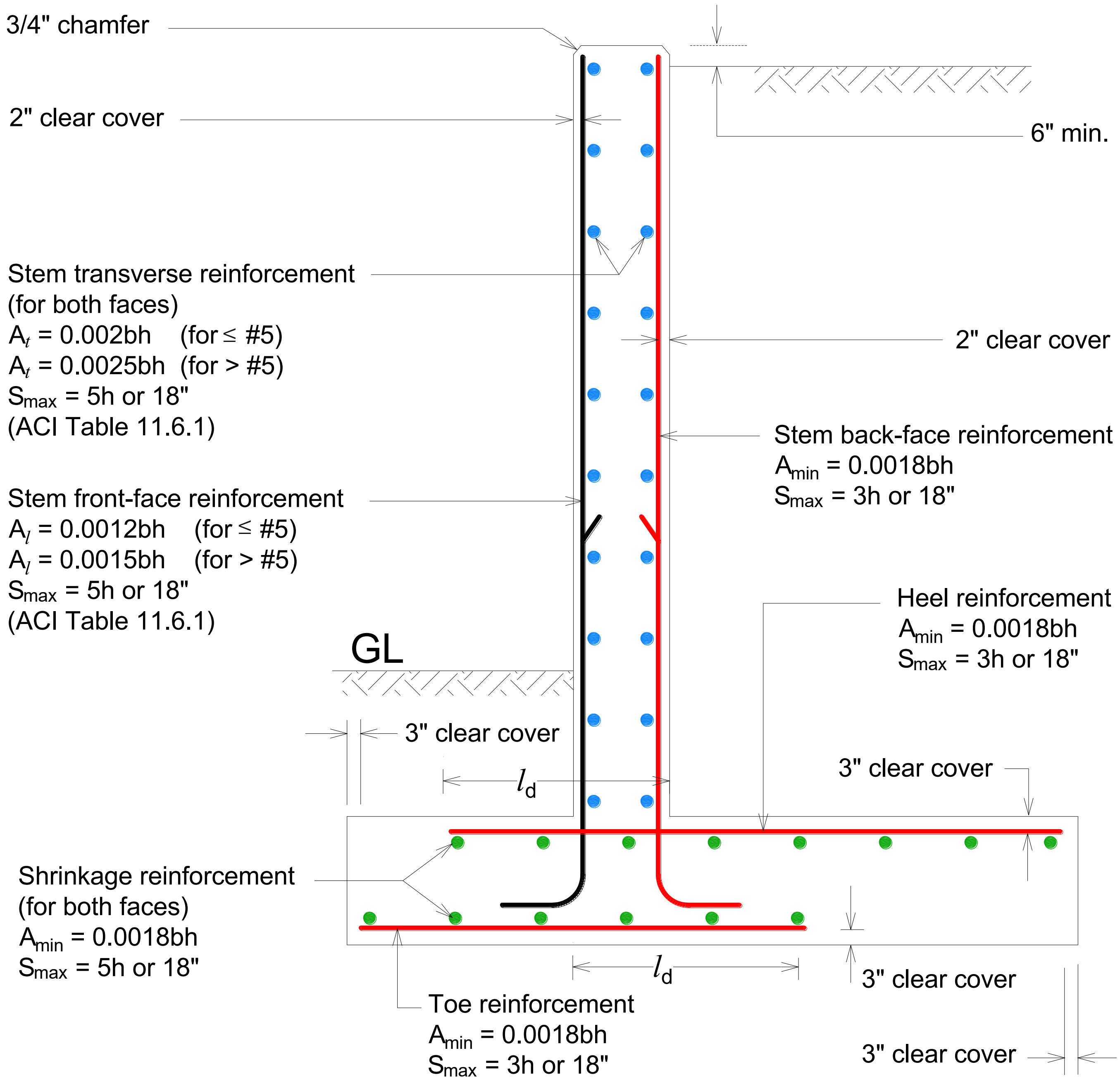
- The minimum specified clear cover is 3 inches for horizontal concrete members cast permanently in contact with the ground, and 2 inches for vertical members (ACI Table 20.5.1.3.1).



❑ Reinforcement Limits

- Overall reinforcement requirement of retaining wall is shown in figure.

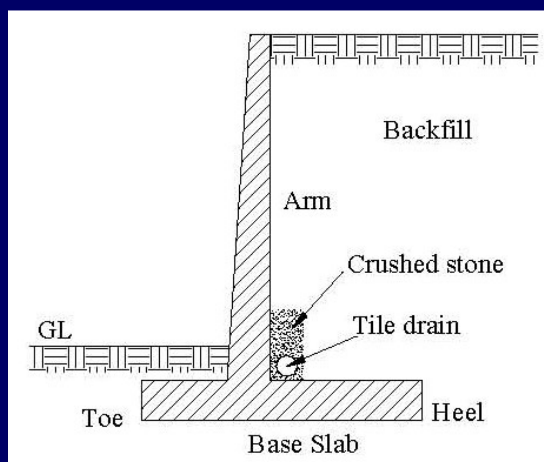



3/4" chamfer
2" clear cover
6" min.
Stem transverse reinforcement
(for both faces)
A_t = 0.002bh (for ≤ #5)
A_t = 0.0025bh (for > #5)
S_{max} = 5h or 18"
(ACI Table 11.6.1)
2" clear cover
Stem back-face reinforcement
A_{min} = 0.0018bh
S_{max} = 3h or 18"
Stem front-face reinforcement
A_l = 0.0012bh (for ≤ #5)
A_l = 0.0015bh (for > #5)
S_{max} = 5h or 18"
(ACI Table 11.6.1)
Heel reinforcement
A_{min} = 0.0018bh
S_{max} = 3h or 18"
GL
3" clear cover
l_d
3" clear cover
Shrinkage reinforcement
(for both faces)
A_{min} = 0.0018bh
S_{max} = 5h or 18"
l_d
3" clear cover
Toe reinforcement
A_{min} = 0.0018bh
S_{max} = 3h or 18"
3" clear cover

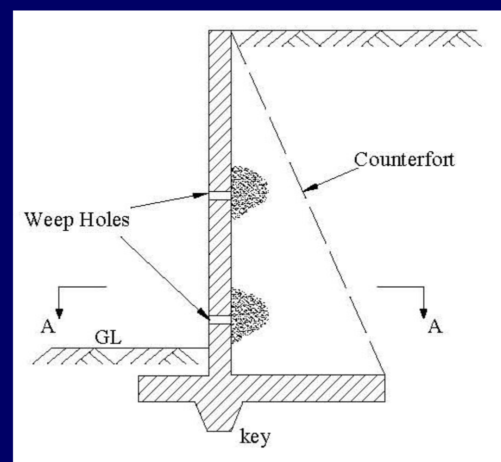
Design of RC Cantilever Retaining Wall

❑ Drainage and Other Details

- A proper drainage system must be provided to retaining wall for collecting and redirecting rainwater away from the wall, otherwise the retaining wall may fail. Drainage can be provided in various ways, but two common ways are:



Longitudinal Drains
To prevent outflow to seep into the soil underneath the wall



Weep Holes
usually spaced horizontally at an interval of 5 to 10 ft.

Design of RC Cantilever Retaining Wall

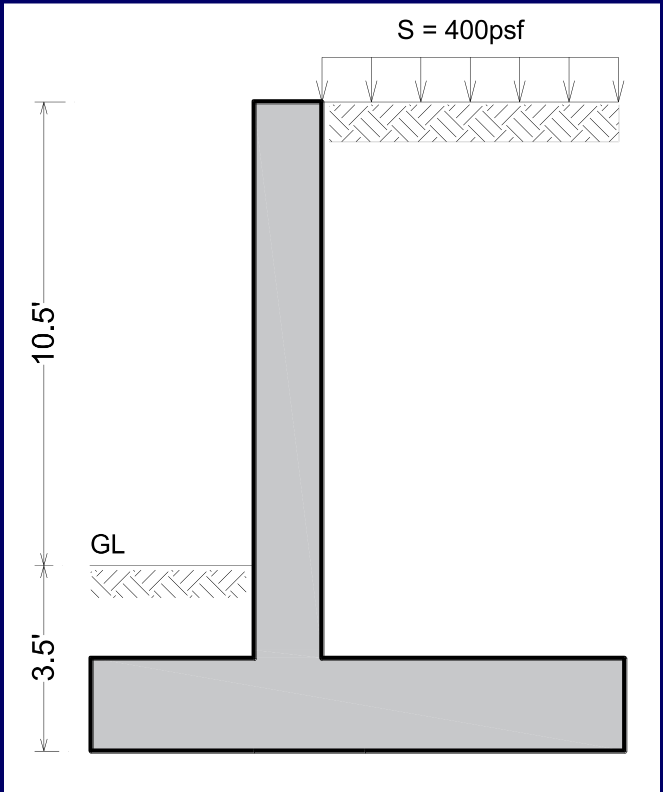
❑ Summary of Design Steps

1. Choose Preliminary Dimensions and verify with ACI minimum thickness requirements
2. Calculate Horizontal load and Overturning Moment
3. Calculate Vertical load and Restoring Moment
4. Calculate Soil Bearing Pressure
5. Apply Stability Checks
6. Analyze and Design Stem
7. Analyze and Design Heel
8. Analyze and Design Toe
9. Design Key (if required)
10. Detail reinforcement as per ACI requirements
11. Provide drainage system

Example 6.1

❑ Problem Statement

- ***Design*** the cantilever retaining wall for the following data:
  - Height of stem from GL, h_1 = 10.5'
  - Depth of base from GL, h_2 = 3.5'
  - Surcharge, S = 400 psf
  - Allowable bearing capacity, $q_a = 8$ ksf
  - Base friction coefficient, $\mu = 0.6$
  - Internal friction angle , $\emptyset = 30^{o}$
  - Unit weight of Soil, $\gamma_s = 120$ pcf
  - $f_c' = 4.5\ ksi\ \ and\ \ f_y = 60\ ksi$



Example 6.1

Solution

Step 1: Preliminary dimensions

Equivalent depth of surcharge is calculated as

$$h_s = \frac{S}{\gamma} = \frac{400}{120} = 3.33'$$

$$h_{eq} = h + h_s = 14 + 3.33 = 17.33'$$

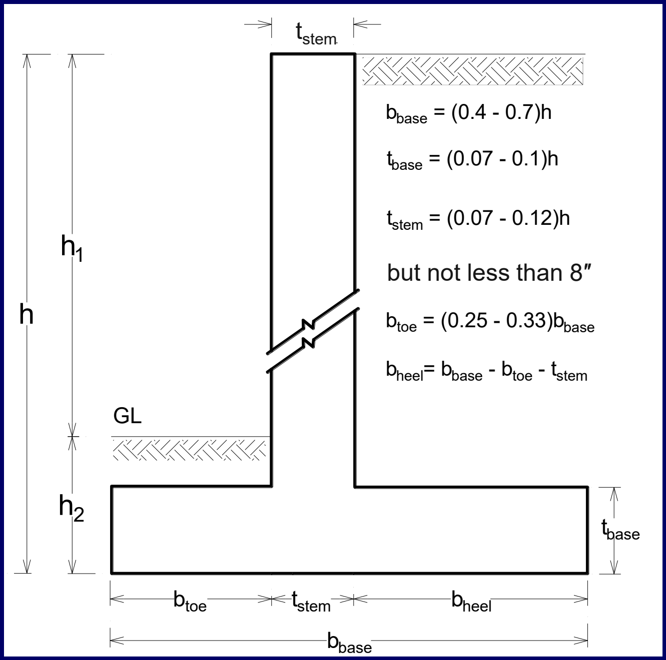
Let $b = 0.58h_{eq} = 0.58(17.33) = 10'$

$$b_{toe} = 0.3b = 0.3(10) = 3'$$

$$b_{heel} = 10 - 3 - 1.25 = 5.75'$$

$$t_{base} = 0.1(17.33) \times 12 = 21''$$

$$t_{stem}(top \,\&\, bot) = 0.07(17.33) \times 12 = 15''$$



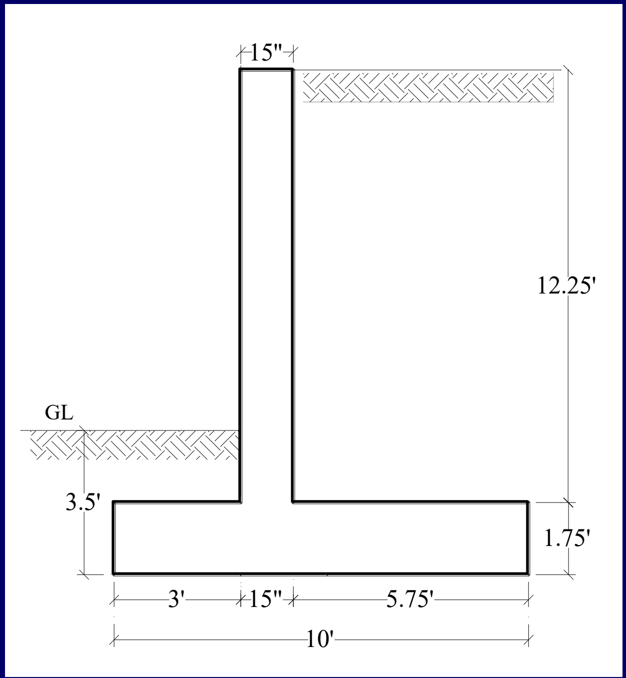
Example 6.1

❑ Solution

➢ Step 1: Preliminary dimensions

Check the dimensions against the minimum thickness requirements provided in Table 7.3.1.1.

Minimum thickness requirements			
Component	**Assumed depth**	**Minimum h = l/10**	**Remarks**
Stem/Arm	15"	$\frac{12.25 \times 12}{10} = 14.7"$	OK
Heel	21"	$\frac{5.75 \times 12}{10} = 6.9"$	OK
Toe	21"	$\frac{3 \times 12}{10} = 3.6"$	OK



Example 6.1

❑ Solution

➢ Step 2: Calculation of Horizontal load and Overturning Moment

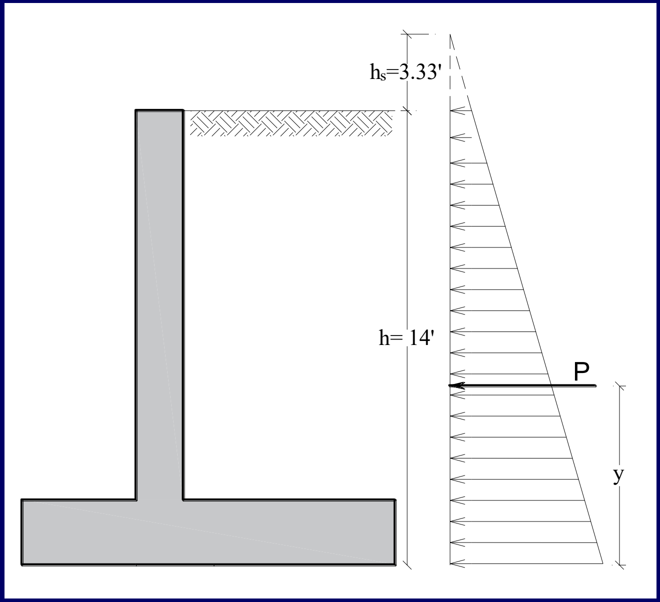
$$K_a = \frac{1 - \sin(\emptyset)}{1 + \sin(\emptyset)} = \frac{1 - \sin(30)}{1 + \sin(30)} = 0.33$$

$$P = \frac{1}{2}[K_a \gamma_s h(h + 2h_s)]$$

$$P = \frac{1}{2}[0.33 \times 0.120 \times 14\ (14 + 2 \times 3.33)]$$

on solving, we get

$$P = 5.73\ kips$$



Example 6.1

Solution

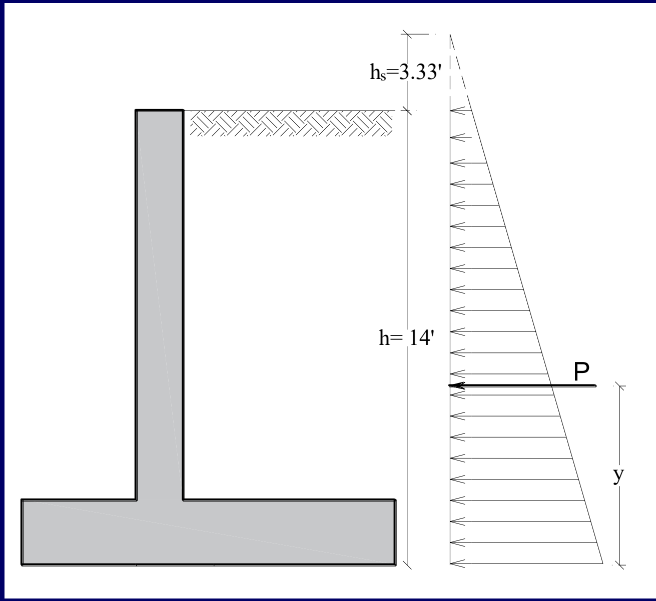
Step 2: Calculation of Horizontal load and Overturning Moment

$$y = \frac{h^2 + 3hh_s}{3(h + 2h_s)}$$

$$y = \frac{14^2 + 3 \times 14 \times 3.33}{3(14 + 2 \times 3.33)} = 5.42'$$

So, overturning moment about the tip of toe can be determined as,

$$M_{OT} = P \times y = 5.73 \times 5.42 = 31.06\ ft.kip$$



Example 6.1

❑ Solution

➢ Step 3: Calculation of Vertical load and Restoring Moment

- Vertical load and restoring or stabilizing moment due to the weight of retaining wall and the soil is calculated as follows:

  - **Self weight of Retaining wall**

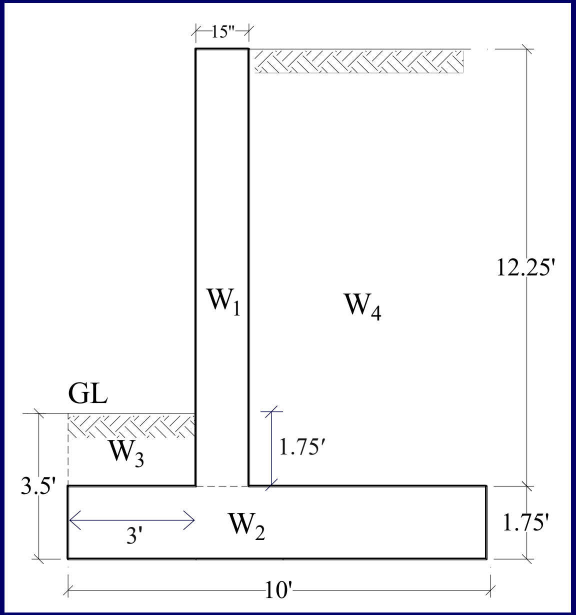
$$W_1 = A_1\gamma_c = (1.25 \times 12.25)\ 0.150 = 2.30\ k/ft$$

$$W_2 = A_2\gamma_c = (1.75 \times 10)0.150 = 2.63\ k/ft$$

  - **Self weight of Soil**

$$W_3 = A_3\gamma_s = (1.75 \times 3)0.120 = 0.63\ k/ft$$

$$W_4 = A_4\gamma_s = (5.75 \times 12.25)0.120 = 8.45\ k/ft$$



Example 6.1

❑ Solution

➢ Step 3: Calculation of Vertical load and Restoring Moment

- Vertical load and restoring or stabilizing moment due to the weight of retaining wall and the soil is calculated and shown below

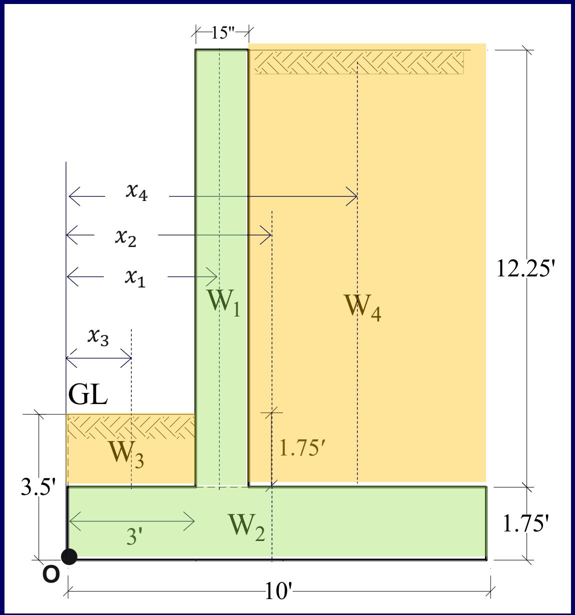
  - **Moment arms about Point O**

$$x_1 = 3 + \frac{1.25}{2} = 3.63\ ft$$

$$x_2 = \frac{10}{2} = 5.0 ft$$

$$x_3 = \frac{3}{2} = 1.5\ ft$$

$$x_4 = 10 - \frac{5.75}{2} = 7.13 ft$$



Example 6.1

❑ Solution

➢ Step 3: Calculation of Vertical load and Restoring Moment

S. No.	W (kip/ft)	x (ft)	Wx (kip.ft/ft)
1	2.30	2.63	8.35
2	2.63	5.0	13.15
3	0.63	1.5	0.95
4	8.45	7.13	60.25
Sum	**14.01**		**82.69**

Hence, we get;

Vertical Load, = $\sum \mathrm{W} = 14.01\mathrm{kips/ft}$

Restoring Moment, $M_R = \sum \mathrm{Wx} = 82.69\mathrm{kip.ft/ft}$

Example 6.1

❑ Solution

➢ Step 4: Calculation of Bearing pressure

To find the point of action "a" , we have

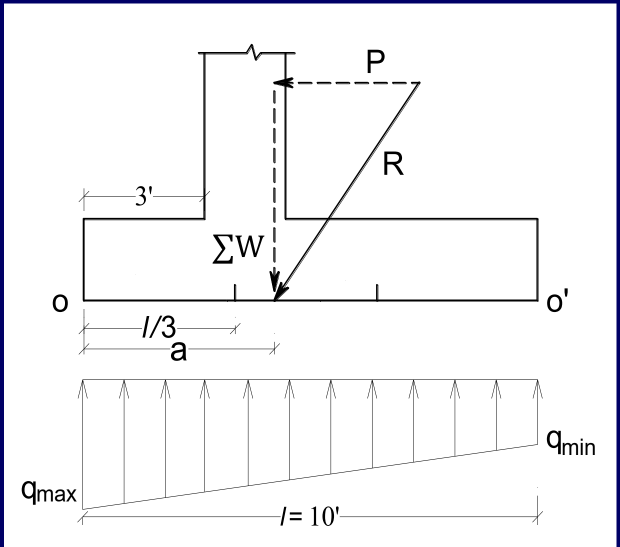
$$a = \frac{M_R - M_{OT}}{\sum W}$$

$$a = \frac{82.69 - 31.06}{14.01} = 3.68'$$

Now,

$$\frac{l}{3} = \frac{10}{3} = 3.33' < 3.68'$$

Hence, the resultant lies within the middle third of the base.



Example 6.1

Solution

Step 4: Calculation of Bearing pressure

$$q_{max} = (4l - 6a)\frac{\Sigma W}{l^2}$$

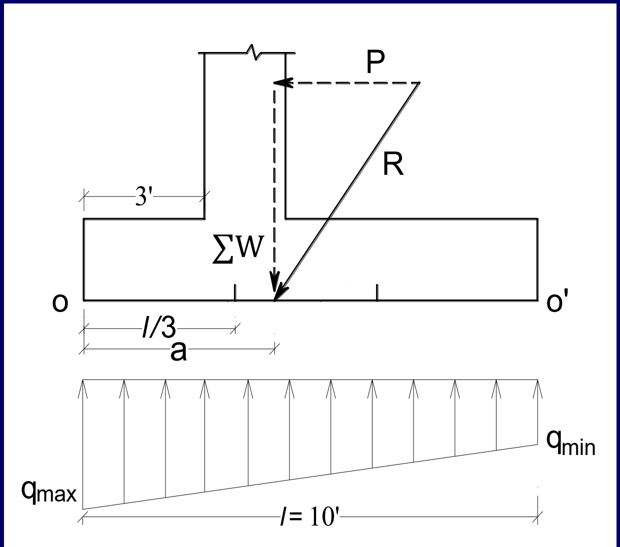
By substituting values;

$$q_{max} = (4 \times 10 - 6 \times 3.68)\frac{14.01}{10^2} = 2.51 ksf$$

Similarly,

$$q_{min} = (6a - 2l)\frac{\Sigma W}{l^2}$$

$$q_{min} = (6 \times 3.68 - 2 \times 10)\frac{14.01}{10^2} = 0.29\ ksf$$



Example 6.1

❑ Solution

➢ Step 5: Applying stability checks

1. F.O.S against Overturning

$$FS_{OT} = \frac{M_R}{M_{OT}} = \frac{82.69}{31.06} = 2.67 > 2 \Rightarrow OK!$$

2. F.O.S against Sliding

$$FS_{SL} = \frac{\mu \sum W}{P} = \frac{0.6(14.01)}{5.73} = 1.47 \approx 1.5 \Rightarrow OK!$$

3. FOS against Bearing

$$FS_{BP} = \frac{q_a}{q_{max}} = \frac{8}{2.51} = 3.19 > 3 \Rightarrow OK!$$

Example 6.1

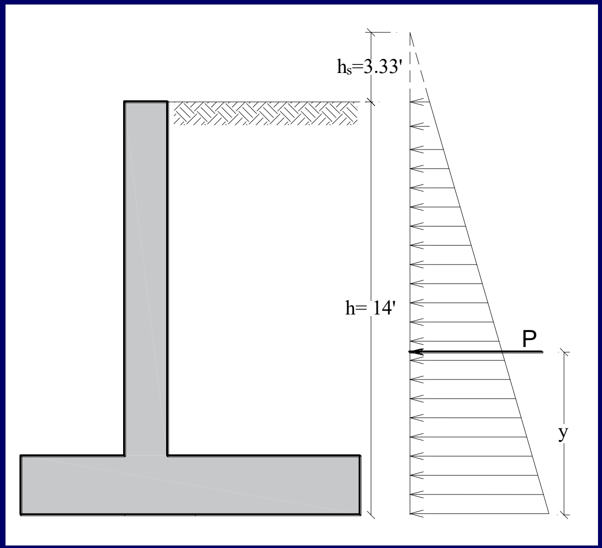
- **Solution**
  - **Step 5: Applying stability checks**
  - **Concluding remarks**
    - The retaining wall preliminary dimensions are adequate to resist overturning, sliding and prevent bearing failure of soil.
    - In the subsequent steps, each component of retaining wall is designed for strength.
    - If any of the determined dimensions are not satisfactory, then all the previous steps must be revised.

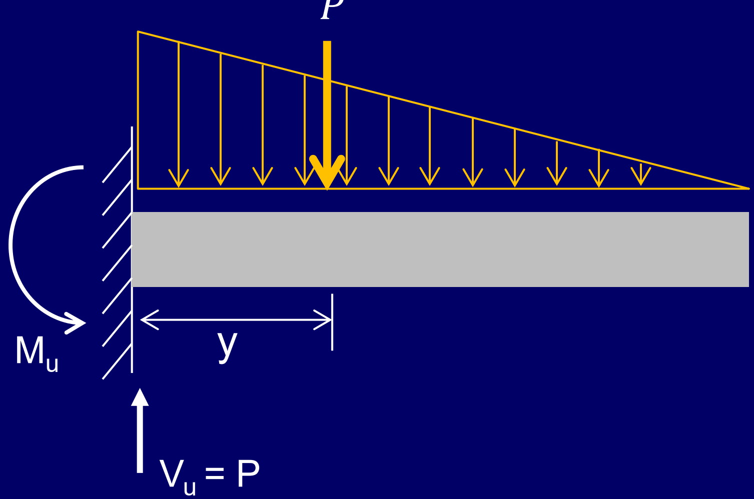
Example 6.1

Solution

Step 6: Analysis and Design of Stem

- Analysis of stem of the cantilever wall is just like the analysis of a cantilever beam subjected to uniformly varying (triangular) load as shown below.





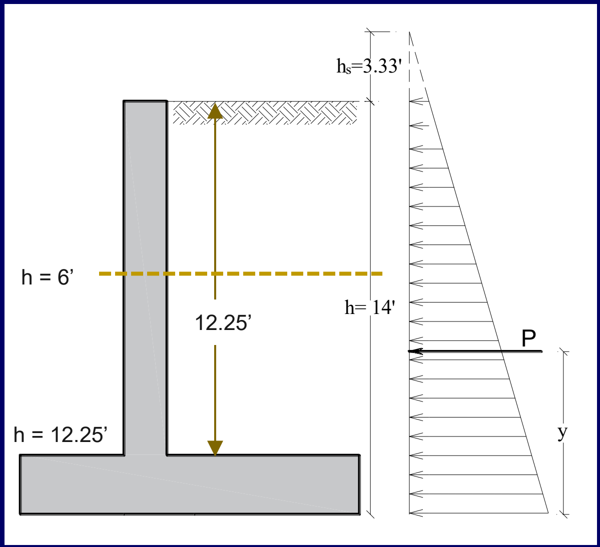
Example 6.1

Solution

Step 6: Analysis and Design of Stem

- A better design approach is to divide the stem height into appropriate intervals and then to calculate shear force and bending moment values at those intervals.

- In the current case, we will divide the stem height into two intervals.



Example 6.1

❑ Solution

➢ Step 6: Analysis and Design of Stem

For shear demand

$$P = \frac{1}{2}[K_a \gamma_s h(h + 2h_s)]$$

Setting h = 12.25' and 6 ft , we have

$$P_{@12.25} = \frac{1}{2}[0.33 \times 0.120 \times 12.25(12.25 + 2 \times 3.33)]$$

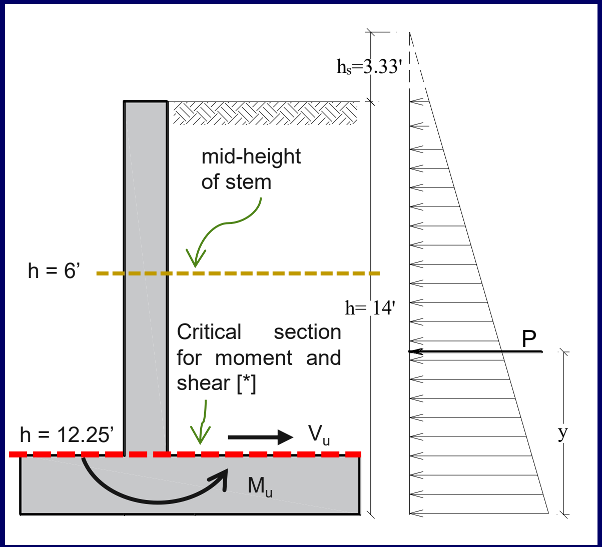
$$P_{@12.25} = 1/2(9.17) = 4.59\ kip$$

$$P_{@6} = 1.51\ kip$$

Now,

$$V_{u@12.25} = load\ factor \times P = 1.6 \times 4.59 = 7.34\ kip$$

$$V_{u@6} = 1.6 \times 1.51 = 2.42\ kip$$



[*] ACI 318-19, section 13.3.6.3

Example 6.1

❑ Solution

➢ Step 6: Analysis and Design of Stem

For bending moment

$$M_u = V_u \times y = V_u \times \frac{h^2 + 3hh_s}{3(h + 2h_s)}$$

At h = 12.25'

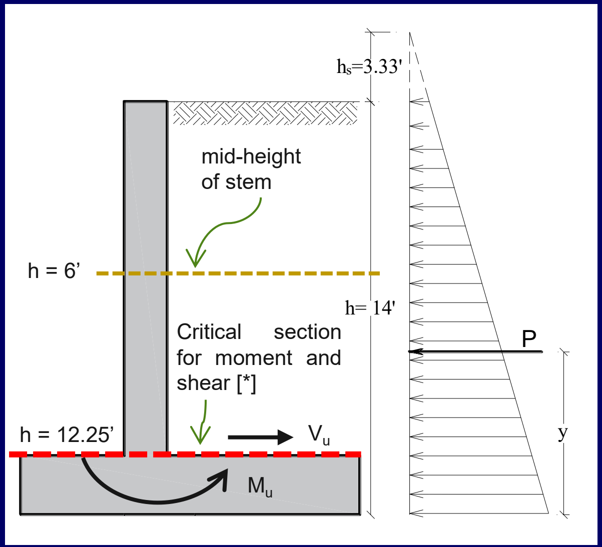
$$M_{u@12.25} = V_{u@12.25} \times \frac{12.25^2 + 3(12.25) \times 3.33}{3(12.25 + 2 \times 3.33)}$$

$$M_{u@12.25} = 7.34 \times 4.8 = 35.2\ ft.kip$$

Similarly, for h = 6ft, we have

$$M_{u@6} = V_{u@6} \times \frac{6^2 + 3(6) \times 3.33}{3(6 + 2 \times 3.33)}$$

$$M_{u@6} = 2.42 \times 2.53 = 6.1\ ft.kip$$



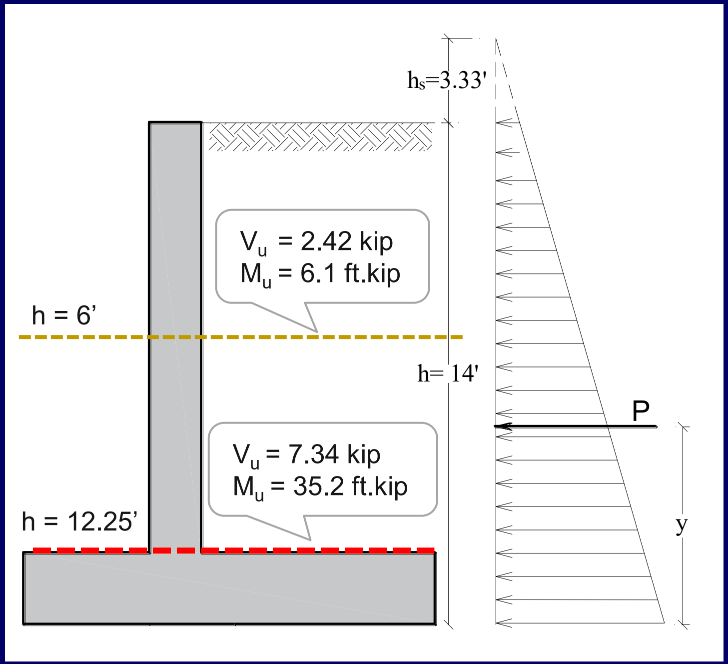
[*] ACI 318-19, section 13.3.6.3

Example 6.1

Solution

- **Step 6: Analysis and Design of Stem**

Analysis Summary



Example 6.1

Solution

Step 6: Analysis and Design of Stem

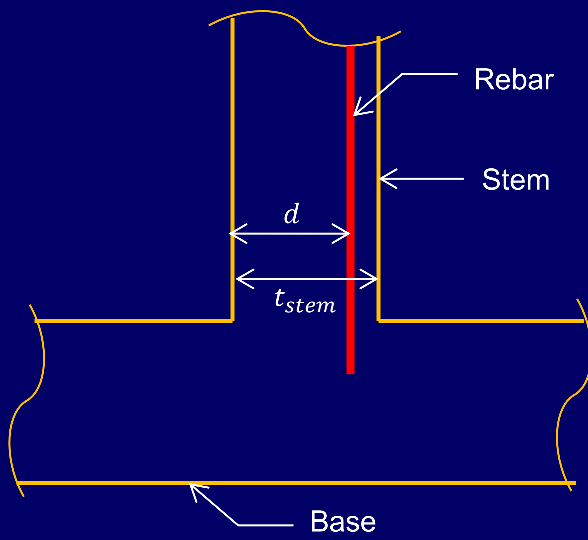
Design for Shear

V_u = 7.34 kips

$$d = t_{stem} - Cc - \frac{d_b}{2}$$

Using 2" clear cover, and assuming #6 bar,

$$d = 15 - 2 - 6/16 = 12.63''$$



$$\emptyset V_c = \emptyset 2\sqrt{f_c{}'}bd$$

$$= (0.75)2\sqrt{4500} \times 12 \times 12.63 = 15.24 kips$$

$$\emptyset V_c > V_u \Rightarrow OK!$$

Example 6.1

❑ Solution

➢ Step 6: Analysis and Design of Stem

❑ Design for Flexure (Vertical reinforcement at the back face)

For h = 12.25′; M_u = 35.2 ft-kip/ft = 422.4 in-kip/ft

$$a = d - \sqrt{d^2 - \frac{2.614 M_u}{f_c' b}} = 12.63 - \sqrt{12.63^2 - \frac{2.614 \times 422.4}{4.5 \times 12}} = 0.85''$$

$$A_s = \frac{M_u}{0.9 f_y \left(d - \frac{a}{2}\right)} = \frac{422.4}{0.9 \times 60 \left(12.63 - \frac{0.85}{2}\right)} = 0.65\ in^2$$

$$A_{s,min} = 0.0018bh = 0.0018(12 \times 15) = 0.324 in^2 < A_s \rightarrow OK$$

Using #6 bar, spacing = $12A_b/A_s$ = 12(0.44)/0.65 = 8.1″c/c

S_{max} = min (3h = 3 x 15 = 45″, 18″) => OK! , Hence, finally provide #6 @ 8″ c/c

Example 6.1

Solution

Step 6: Analysis and Design of Stem

Design for Flexure (Vertical reinforcement at the back face)

For h = 6′; M_u = 6.1 ft-kip/ft = 73.2 in-kip/ft

$$a = d - \sqrt{d^2 - \frac{2.614M_u}{f_c'b}} = 12.63 - \sqrt{12.63^2 - \frac{2.614 \times 73.2}{4.5 \times 12}} = 0.14''$$

$$A_s = \frac{M_u}{0.9f_y\left(d - \frac{a}{2}\right)} = \frac{73.2}{0.9 \times 60\left(12.63 - \frac{0.14}{2}\right)} = 0.11\ in^2$$

$A_{s,min} = 0.324in^2 > A_s \rightarrow A_{s,min}\ \ governs$

Using #6 bar, spacing = $12A_b/A_s$ = 12(0.44)/0.324 = 16.3″c/c

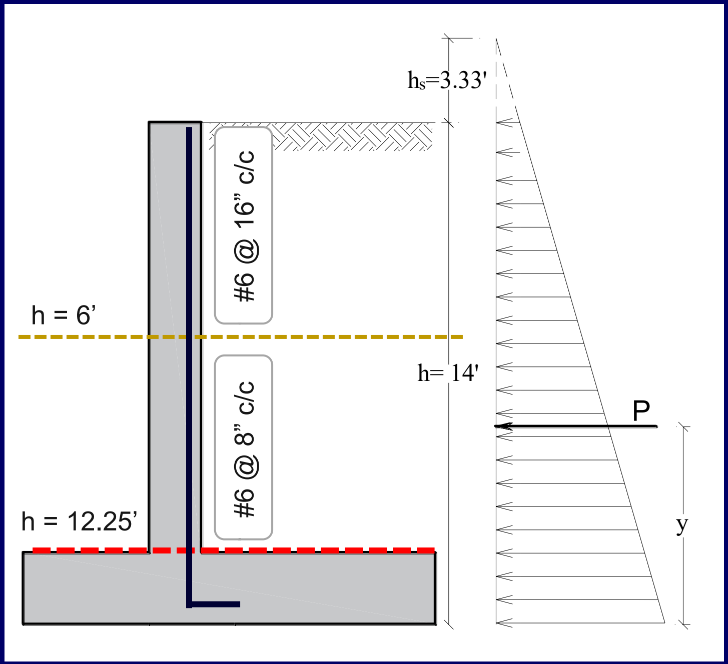
S_{max} = min (3h = 3 x 15 = 45″, 18″) => OK! , Hence, finally provide #6 @ 16″ c/c

Example 6.1

❑ Solution

➢ Step 6: Analysis and Design of Stem

❑ Design for Flexure (Vertical reinforcement at the back face)



Example 6.1

❑ Solution

➢ **Step 6: Analysis and Design of Stem**

❑ **Vertical reinforcement at the front face**

$A_s = 0.0012 \times 12 \times 15 = 0.216$ in^2 (From slide No. 31)

Using #4 bar with area $A_b = 0.20$ in^2

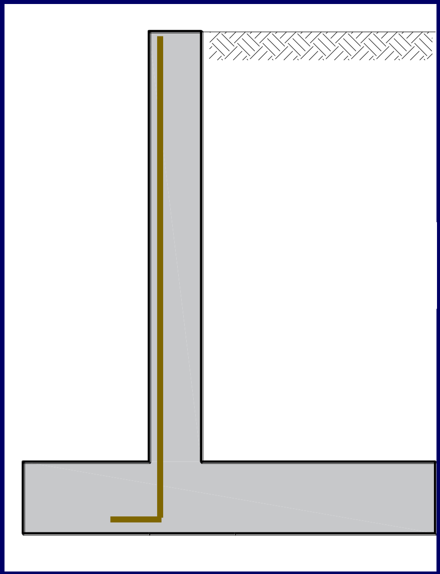
Spacing = Area of one bar A_b/A_{st}

$= (0.20 / 0.216) \times 12 = 11.1''$

Maximum spacing should not exceed;

- $5h = 5 \times 15 = 75''$ or $18''$

Provided spacing is OK!. Finally provide #4 @ 10″



Example 6.1

Solution

Step 6: Analysis and Design of Stem

Horizontal /Transverse reinforcement

$A_{st} = 0.0020bh$ (From slide No. 31)

$A_{st} = 0.0020 \times 12 \times 15 = 0.36$ in^2/ft

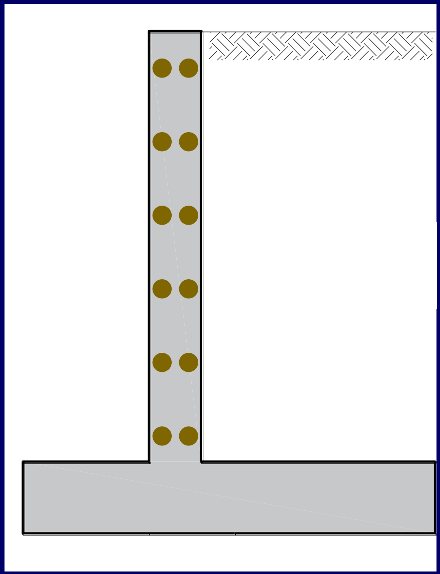
This is the total required area of horizontal reinforcement, i-e for both faces.

So, for each face, $A_{st} = 0.36/2 = 0.18$in^2/ft

Using #4 bar with $A_b = 0.20$in^2

Spacing = (0.20/0.18) x 12 = 13.3″ < 18″ => OK!

Finally, Use #4 @ 10″ c/c



Example 6.1

❑ Solution

➢ Step 6: Analysis and Design of Stem

❑ Calculation of development length

As per ACI 318, section 25.4.3.1, development length l_{dh} for deformed bar, is largest of :

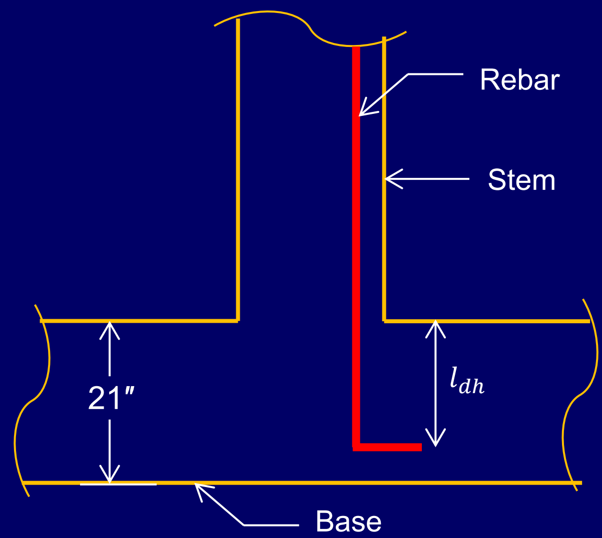
1. $\dfrac{9f_y}{550\sqrt{f_c{}'}}d_b = \dfrac{9(60000)}{550\sqrt{4500}}(0.75) = 11"$

2. $8d_b = 8(0.75) = 6"$

3. $6"$

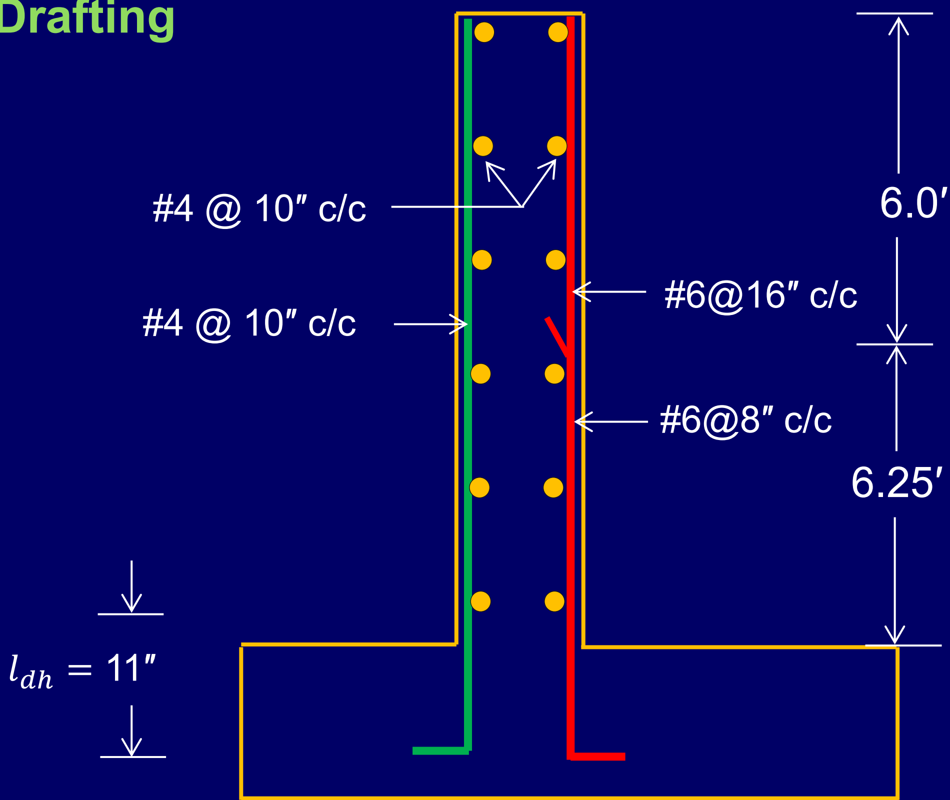
Therefore, $l_{dh} = 11"$

Since, $l_{dh} = 11" < depth\ of\ base \Rightarrow OK!$



Example 6.1

- **Solution**
  - **Step 6: Analysis and Design of Stem**
  - **Drafting**



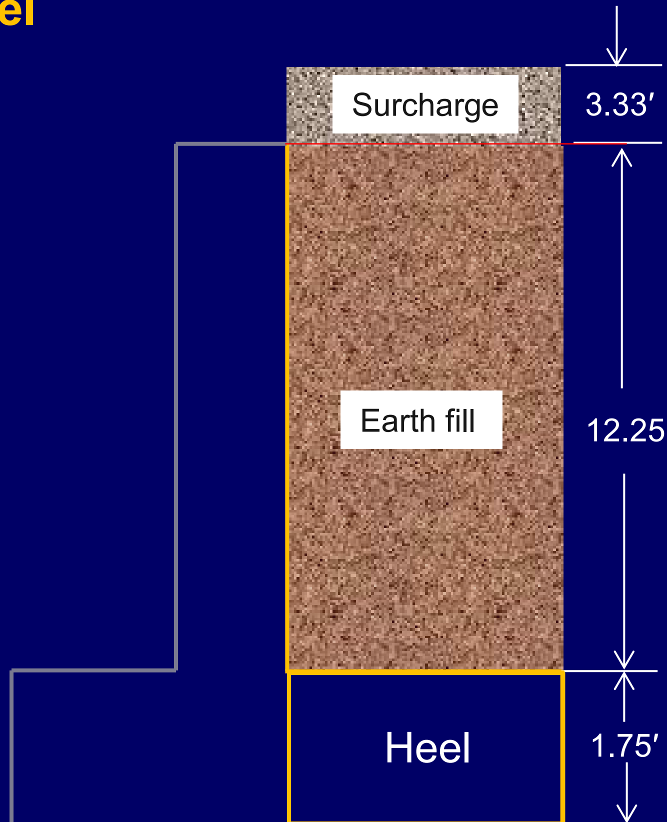
Example 6.1

❑ Solution

➢ Step 7: Analysis and Design of Heel

❑ Loads

Component	Factored Load (k/ft)
Self weight of heel	$1.2\gamma h_b = 1.2(0.15)(1.75 \times 1) = 0.32$
Earth fill load	$1.6\gamma hb = 1.6(0.12)(12.25 \times 1) = 2.35$
Surcharge Load	$1.6\gamma h_s b = 1.6(0.12)(3.33 \times 1) = 0.64$
Total:	W_u = 0.32 +2.35+0.64 = 3.31 k/ft



Example 6.1

Solution

Step 7: Analysis and Design of Heel

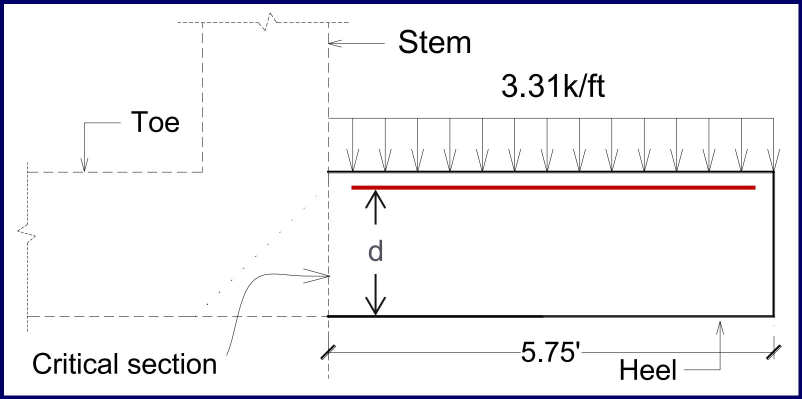
Analysis for Shear

Taking 3" clear cover, and assuming #6 bar,

$d = 21 - 3 - 6/16 = 17.63''$

Shear force at critical location is,

$V_u = 3.31 \times (5.75) = 19.0 kips$



Analysis for Flexure

$$M_u = 3.31 \times 5.75 \times \left(\frac{5.75}{2}\right)$$

$$M_u = 54.71\ ft.kip\ or\ 656.62\ in.kip/ft$$

Example 6.1

Solution

Step 7: Analysis and Design of Heel

Design for Shear

V_u = 19.0 kips

Design shear capacity of concrete is given as:

$$\emptyset V_c = \emptyset 2\sqrt{f_c'}bd$$

$$\emptyset V_c = (0.75)2\sqrt{4500} \times 12 \times 17.63 = 21.29kips$$

$$\emptyset V_c > V_u \Rightarrow OK!$$

Example 6.1

Solution

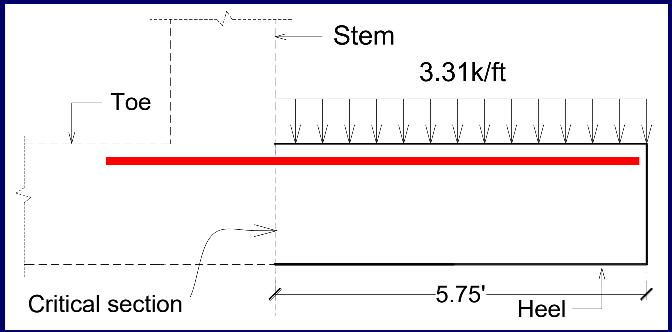
Step 7: Analysis and Design of Heel

Design for Flexure (Longitudinal reinforcement)

M_u = 656.62 in-kip/ft

$$a = 17.63 - \sqrt{17.63^2 - \frac{2.614 \times 656.62}{4.5 \times 12}} = 0.93"$$

$$A_s = \frac{656.62}{0.9 \times 60\left(17.63 - \frac{0.93}{2}\right)} = 0.71\ in^2$$



Example 6.1

Solution

Step 7: Analysis and Design of Heel

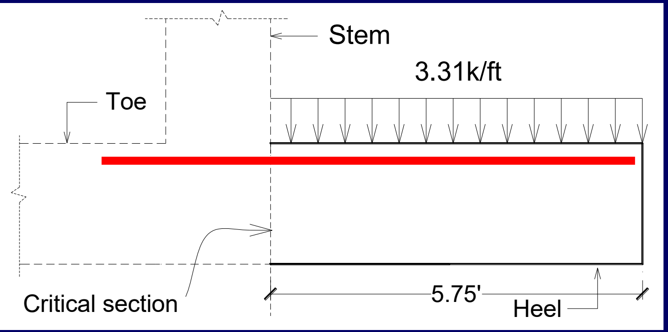
Design for Flexure (Longitudinal reinforcement)

$$A_{min} = 0.0018bh = 0.0018(12 \times 21) = 0.454in^2$$

Using #6 bar, spacing = $12A_b/A_s$ = 12(0.44)/0.71 = 7.4″c/c

S_{max} = min (3h = 3 x 21 = 63″, 18″) => OK!

Hence, finally provide #6 @ 7″ c/c



Example 6.1

Solution

Step 7: Analysis and Design of Heel

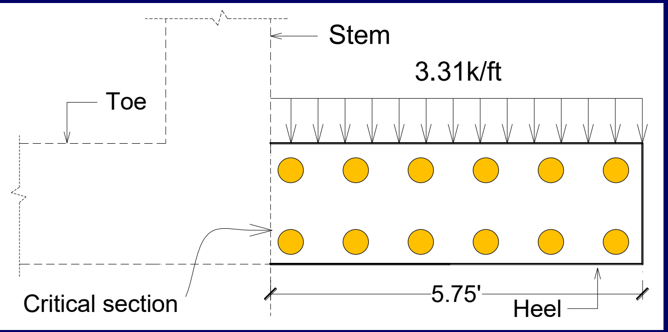
Transverse reinforcement

Minimum shrinkage reinforcement is given by

$$A_{shrinkage} = 0.0018bh = 0.0018(12 \times 21) = 0.454in^2/ft$$

Divide this equally between two faces,

$$A_{shrinkage} = \frac{0.454}{2} = 0.227in^2/ft$$



Example 6.1

Solution

Step 7: Analysis and Design of Heel

Transverse reinforcement

Using #4 bar with A_b = 0.20 in^2

Spacing = (0.20/0.227) x 12 = 10.57″c/c

Maximum spacing for shrinkage should be least of

- 5h = 5 x 21 = 105″ or 18″

Provided spacing is OK!.

Finally provide #4@10″ c/c on top and bottom face of heel

Example 6.1

Solution

Step 7: Analysis and Design of Heel

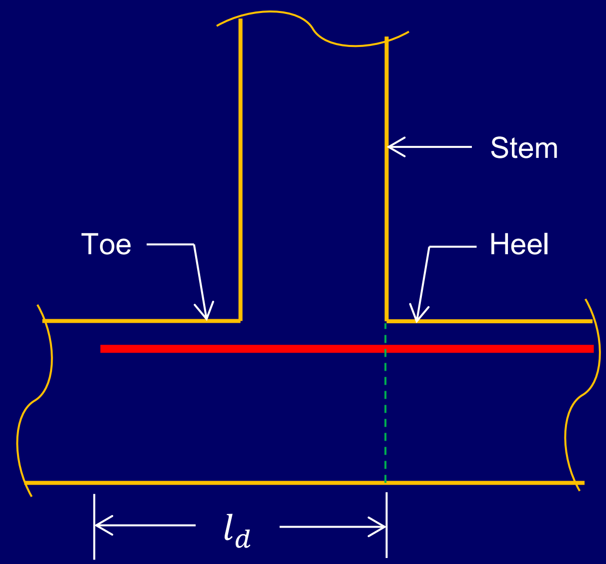
Calculation of development length

Development length of Heel reinforcement into Toe as per ACI 318-19, section 25.4.2.4 is given by

$$l_d = \frac{f_y}{25\sqrt{f_c{}'}} d_b$$

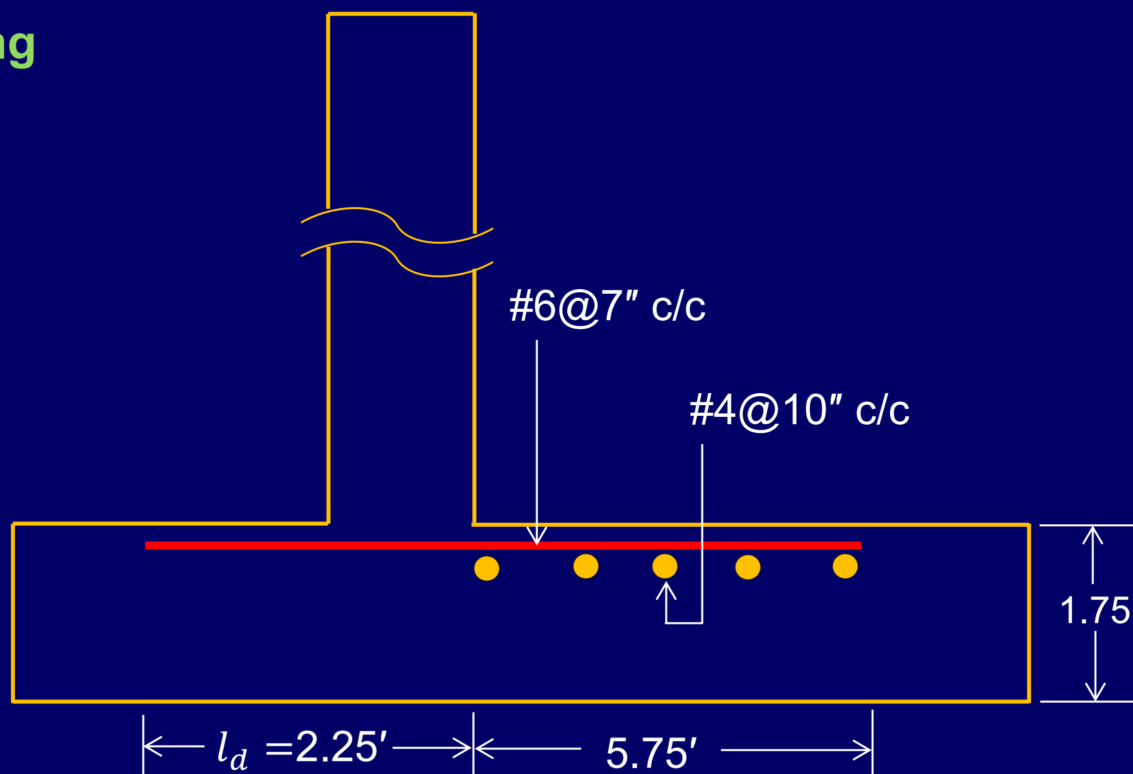
$$l_d = \frac{60000}{25\sqrt{4500}}(0.75) = 26.8" \approx 27"$$

Therefore, $l_d = 2.25'$



Example 6.1

- **Solution**
  - **Step 7: Analysis and Design of Heel**
  - **Drafting**



Example 6.1

Solution

Step 8: Analysis and Design of Toe

Loads

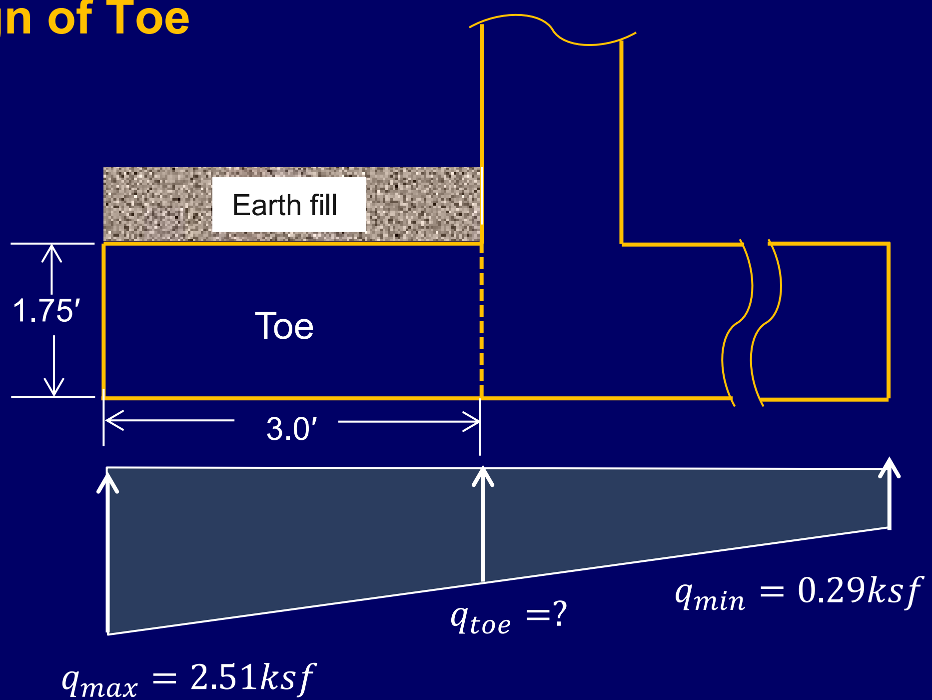
Weight of Earth fill = Ignored

Self weight of Toe = Ignored

Factored q_{max} = 1.6 x 2.51 = 4.01

Factored q_{min} = 1.6 x 0.29 = 0.46

Now, the factored soil pressure at interior end of toe slab can be determined using similarity of triangles as shown on next slide.

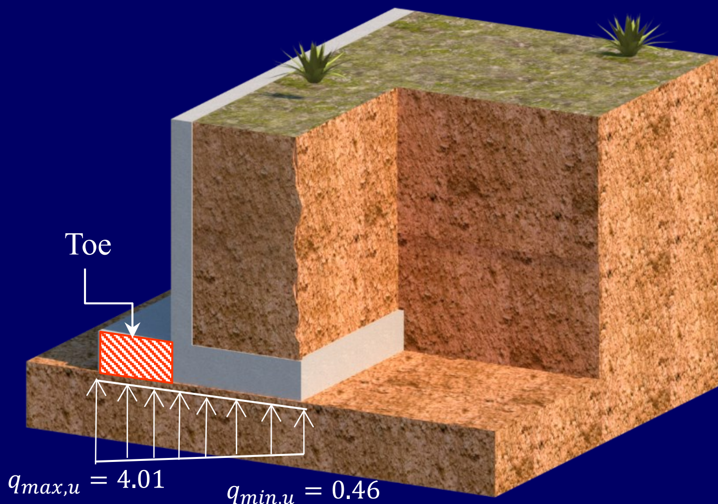


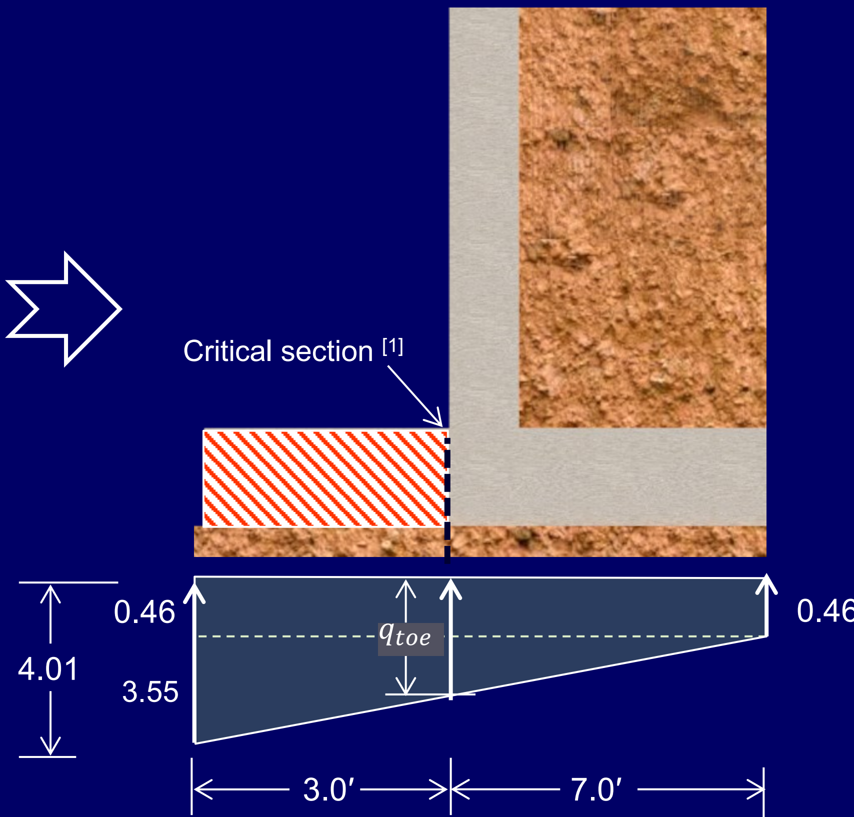
Example 6.1

❑ Solution

➢ Step 8: Analysis and Design of Toe

❑ Loads





Note:
[1] Although the ACI Code recommends taking the critical section of the toe at a distance of d from the face of support, here we chose to take the critical section at the interface to make the case simple.

Example 6.1

❑ Solution

➢ Step 8: Analysis and Design of Toe

❑ Loads

From $\Delta ACD \Leftrightarrow \Delta BDC$

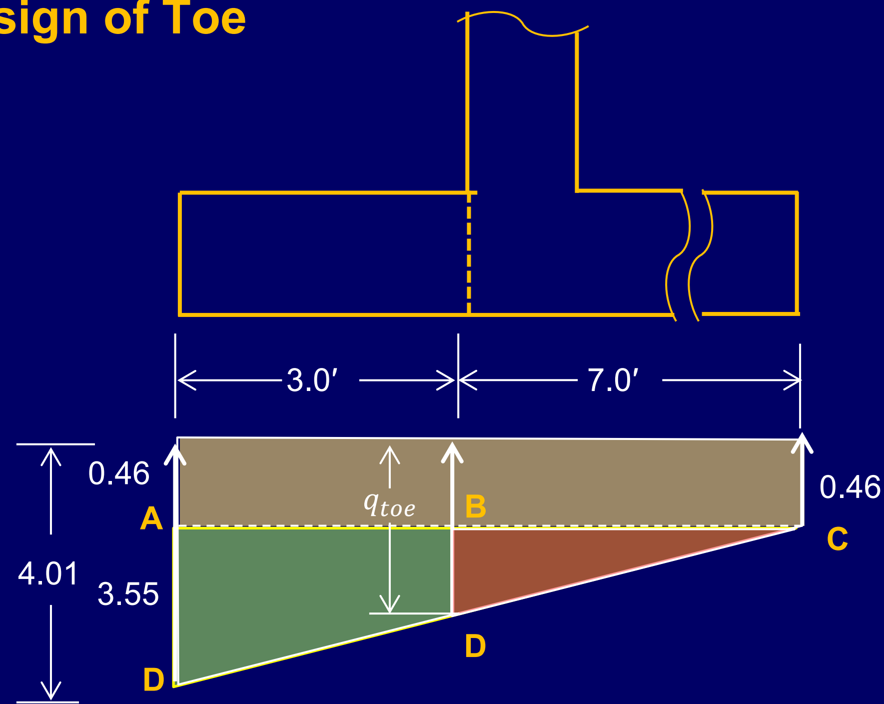
$$\frac{BD}{AD} = \frac{BC}{AC}$$

$$\frac{BD}{3.55} = \frac{7}{10}$$

$$BD = 2.48\ ksf$$

Now,

$$q_{toe} = 0.46 + 2.48 = 2.94\ ksf$$



General formula:

$$q_{toe} = q_{min} + \frac{l_{base} - l_{toe}}{l_{base}}(q_{max} - q_{min})$$

Example 6.1

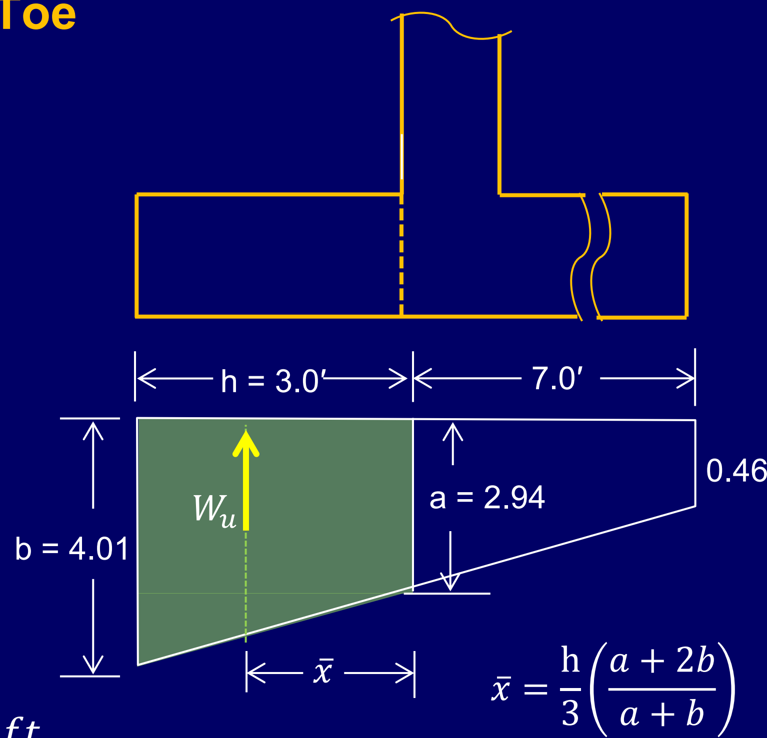
❑ Solution

➢ Step 8: Analysis and Design of Toe

❑ Analysis for Shear

$$V_u = W_u = Area\ of\ shaded\ region$$

$$V_u = \frac{4.01 + 2.94}{2} \times 3 = 10.42\ kips$$



❑ Analysis for flexure

$$M_u = W_u \times \bar{x} = 10.42\bar{x}$$

From figure, $\bar{x} = 1.58'$

So, $M_u = 10.42 \times 1.58 = 16.46\ ft.kip/ft$

Example 6.1

❑ Solution

➢ Step 8: Analysis and Design of Toe

❑ Design for Shear

V_u = 10.42 kips

Design shear capacity of concrete is given as:

$$\emptyset V_c = \emptyset 2\sqrt{f_c'}bd = 0.75 \times 2\sqrt{4500} \times 12 \times 17.63 = 21.29\ kips$$

$$\emptyset V_c > V_u \Rightarrow OK!$$

Example 6.1

❑ Solution

➢ Step 8: Analysis and Design of Toe

❑ Design for Flexure

M_u = 16.46x 12 = 197.52 in-k/ft

$$a = d - \sqrt{d^2 - \frac{2.614 M_u}{f_c' b}} = 12.63 - \sqrt{12.63^2 - \frac{2.614 \times 197.52}{4.5 \times 12}} = 0.27"$$

$$A_s = \frac{M_u}{0.9 f_y \left(d - \frac{a}{2}\right)} = \frac{197.52}{0.9 \times 60 \left(17.63 - \frac{0.27}{2}\right)} = 0.21\ in^2$$

$$A_{s,min} = 0.454\ in^2 > A_s \rightarrow A_{s,min}\ \ governs$$

Using #6 bar, spacing = $12A_b/A_s$ = 12(0.44)/0.454 = 11.63″c/c

S_{max} = min (3h = 3 x 21 = 63″, 18″) => OK! , Hence, finally provide #6 @ 10″ c/c

Example 6.1

❑ Solution

➢ Step 8: Analysis and Design of Toe

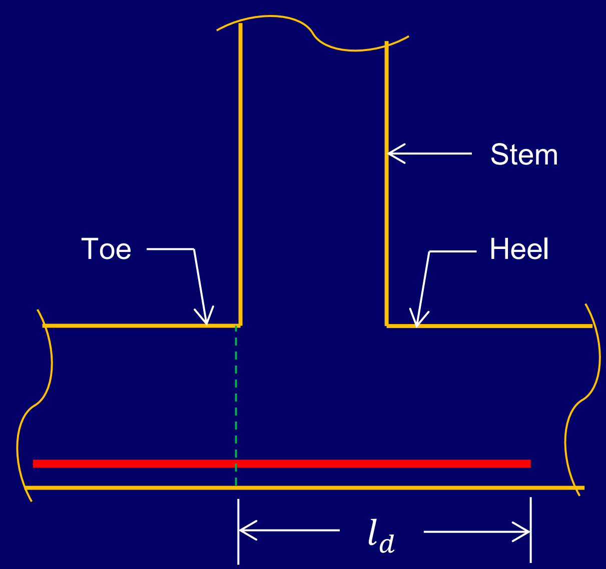
❑ Calculation of development length

Development length of Toe reinforcement into heel as per ACI 318-19, section 25.4.2.4 is given by

$$l_d = \frac{f_y}{25\sqrt{f_c'}} d_b$$

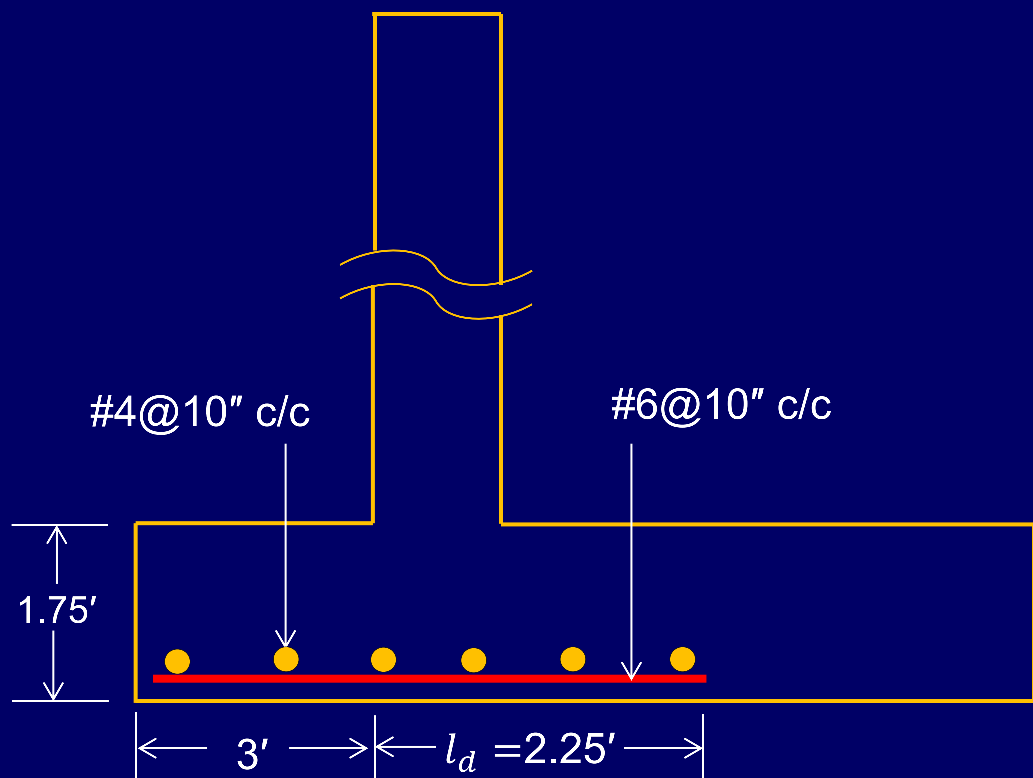
$$l_d = \frac{60000}{25\sqrt{4500}}(0.75) = 26.8" \approx 27"$$

Therefore, $l_d = 2.25'$

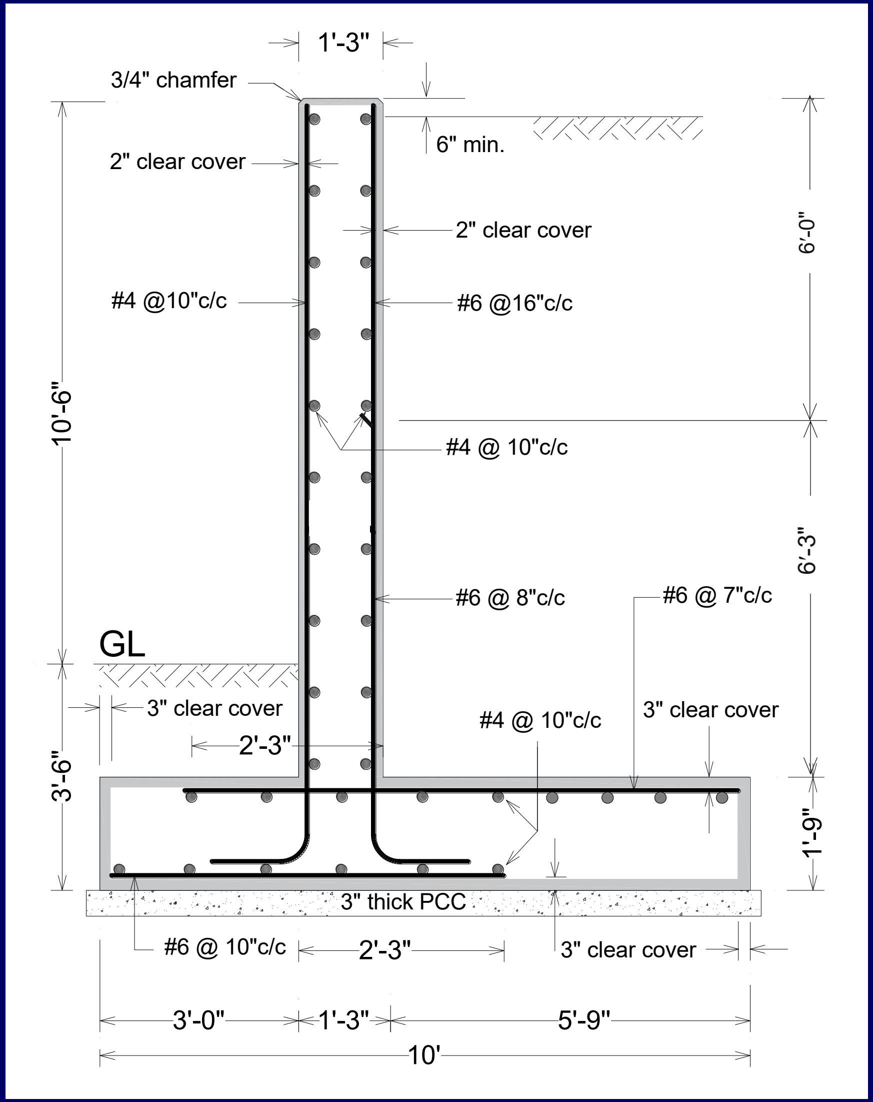


Example 6.1

- **Solution**
  - **Step 8: Analysis and Design of Toe**
  - **Drafting**



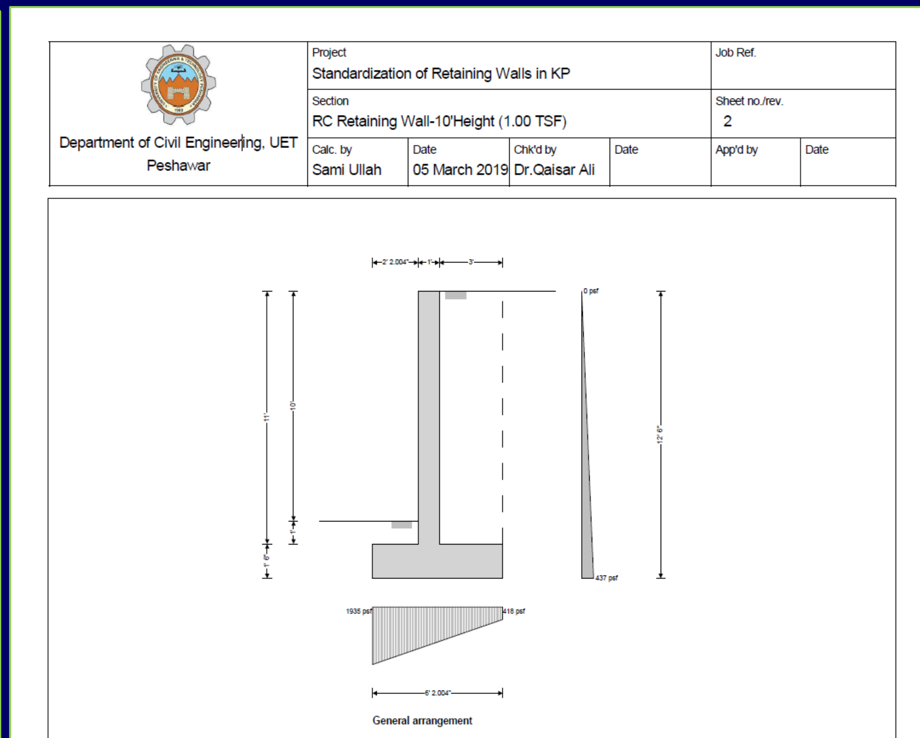
Example 6.1



1'-3"
3/4" chamfer
6" min.
2" clear cover
2" clear cover
#4 @10"c/c
#6 @16"c/c
10'-6"
6'-0"
#4 @ 10"c/c
#6 @ 8"c/c
#6 @ 7"c/c
6'-3"
GL
3" clear cover
3" clear cover
2'-3"
#4 @ 10"c/c
3'-6"
1'-9"
3" thick PCC
#6 @ 10"c/c
2'-3"
3" clear cover
3'-0"
1'-3"
5'-9"
10'

Practical Examples

- Tekla Tedds for Analysis and Design of RC Cantilever Retaining Wall



Department of Civil Engineering, UET Peshawar	Project				Job Ref.	
	Standardization of Retaining Walls in KP					
	Section				Sheet no./rev.	
	RC Retaining Wall-10'Height (1.00 TSF)				2	
	Calc. by	Date	Chk'd by	Date	App'd by	Date
	Sami Ullah	05 March 2019	Dr.Qaisar Ali			

Various failures of Retaining wall at Nathia Gali

Practical Examples

- Retaining Wall Construction

Practical Examples

- Retaining Wall Construction

Practical Examples

- Retaining Wall Construction

Practical Examples

- Retaining Wall Construction

Practical Examples

- Retaining Wall Construction

Practical Examples

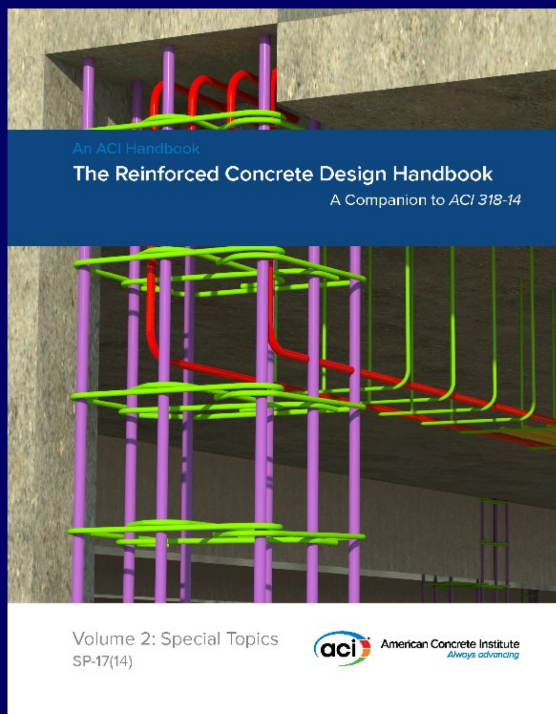
- Retaining Wall Construction

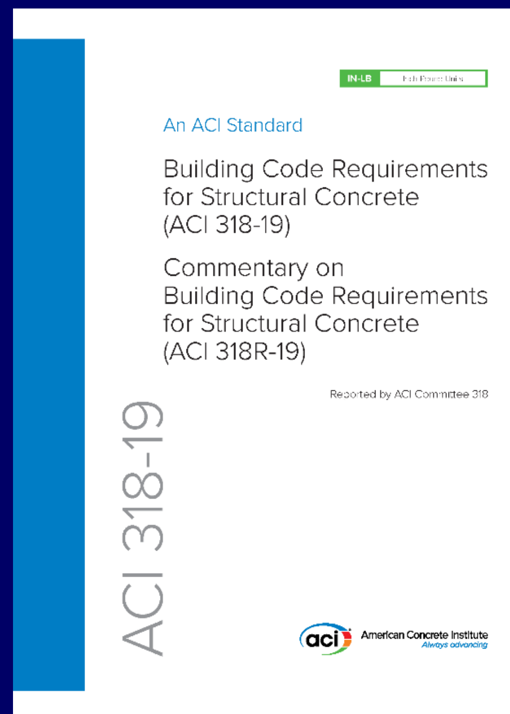
Practical Examples

- Retaining Wall Construction

References

- ACI Reinforced Concrete Design Handbook (Volume: 2)_Special Topics, MNL - 17(21)
- Building Code Requirements for Structural Concrete (ACI 318-19)





Appendix

❑ Derivation of Equations for Case 1

Considering the figure shown, let ***a*** be the distance from the front edge **O** to the intersection of the resultant **R** with the base. From axial plus bending formula, we have:

$$q_{\substack{max \\ min}} = \frac{N}{A} \pm \frac{Mc}{I}$$

Where;

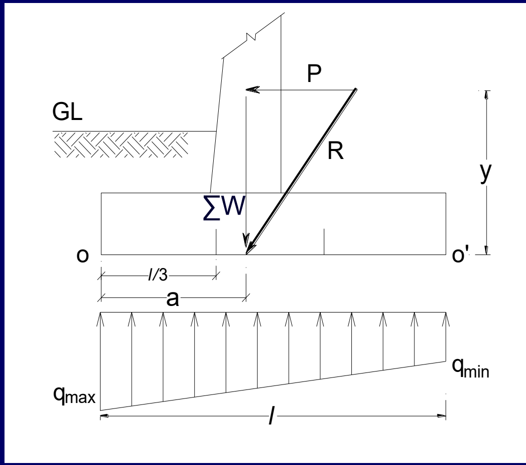
N = normal/axial force acting on the base

M = bending moment about centroid

c = distance of farthest edge from centroid

I = moment of inertia of base

Case 1: a > *l*/3



Appendix

❑ Derivation of Equations for Case 1

For the current case,

$$N = \sum W\ , \qquad M = \sum W\left(\frac{l}{2} - a\right), \qquad A = b \times l \ \ c = \frac{l}{2} \quad and \quad I = \frac{bl^3}{12}$$

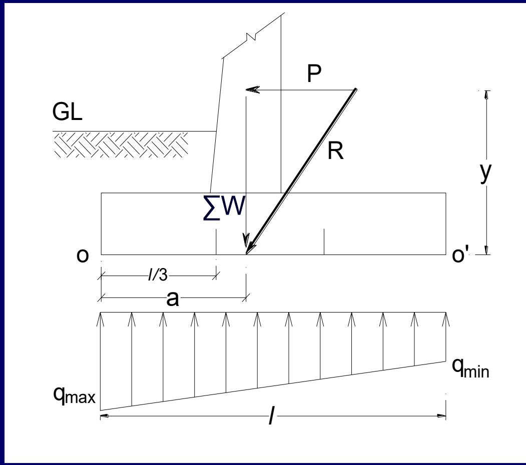
Considering unit width strip (b = 1ft) and

substituting values in the equation

$$q_{\substack{max \\ min}} = \frac{N}{A} \pm \frac{Mc}{I} = \frac{\sum W}{1 \times l} \pm \frac{\sum W\left(\frac{l}{2} - a\right) \times l/2}{1 \times l^3/12}$$

$$q_{\substack{max \\ min}} = \frac{\sum W}{l} \pm \frac{6\sum W\left(\frac{l}{2} - a\right)}{l^2}$$

Case 1: a > *l*/3



Appendix

❑ Derivation of Equations for Case 1

$$q_{\substack{max \\ min}} = \frac{\sum W}{l} \pm \frac{6\sum W\left(\frac{l}{2} - a\right)}{l^2}$$

$$q_{\substack{max \\ min}} = \frac{\sum W}{l^2}[l \pm (3l - 6a)]$$

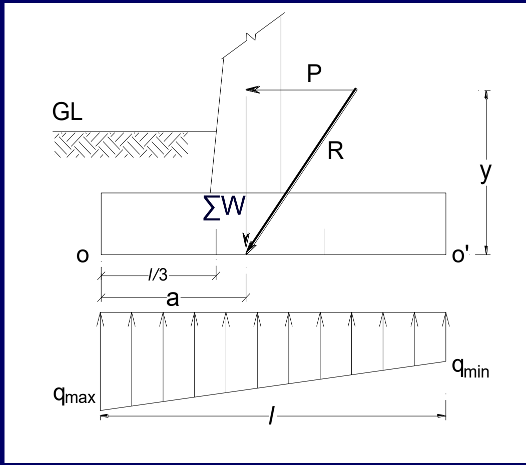
Now

$$q_{max} = \frac{\sum W}{l^2}(l + 3l - 6a) = \frac{\sum W}{l^2}(4l - 6a)$$

and

$$q_{min} = \frac{\sum W}{l^2}(l - 3l + 6a) = \frac{\sum W}{l^2}(6a - 2l)$$

Case 1: a > *l*/3



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