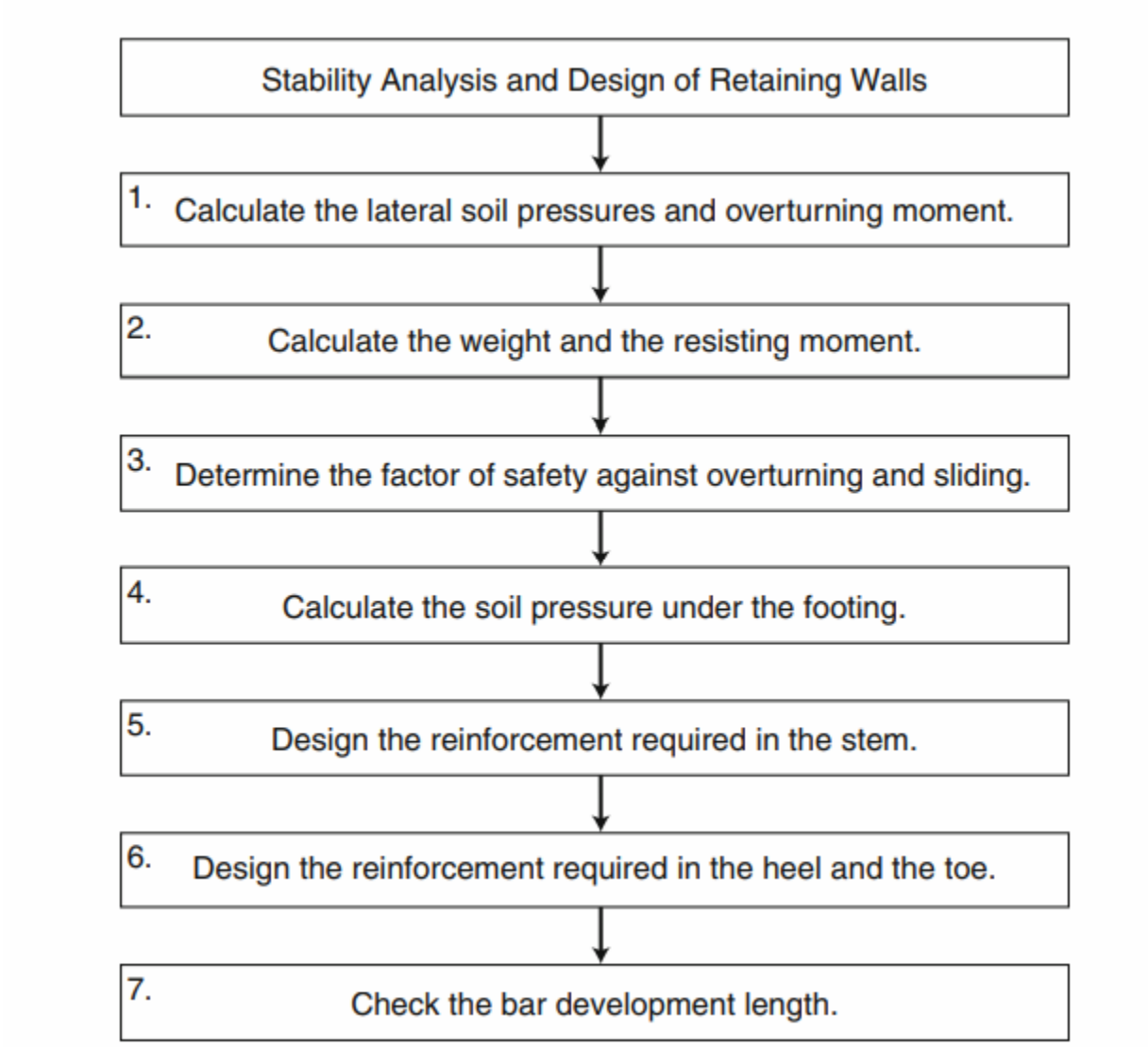
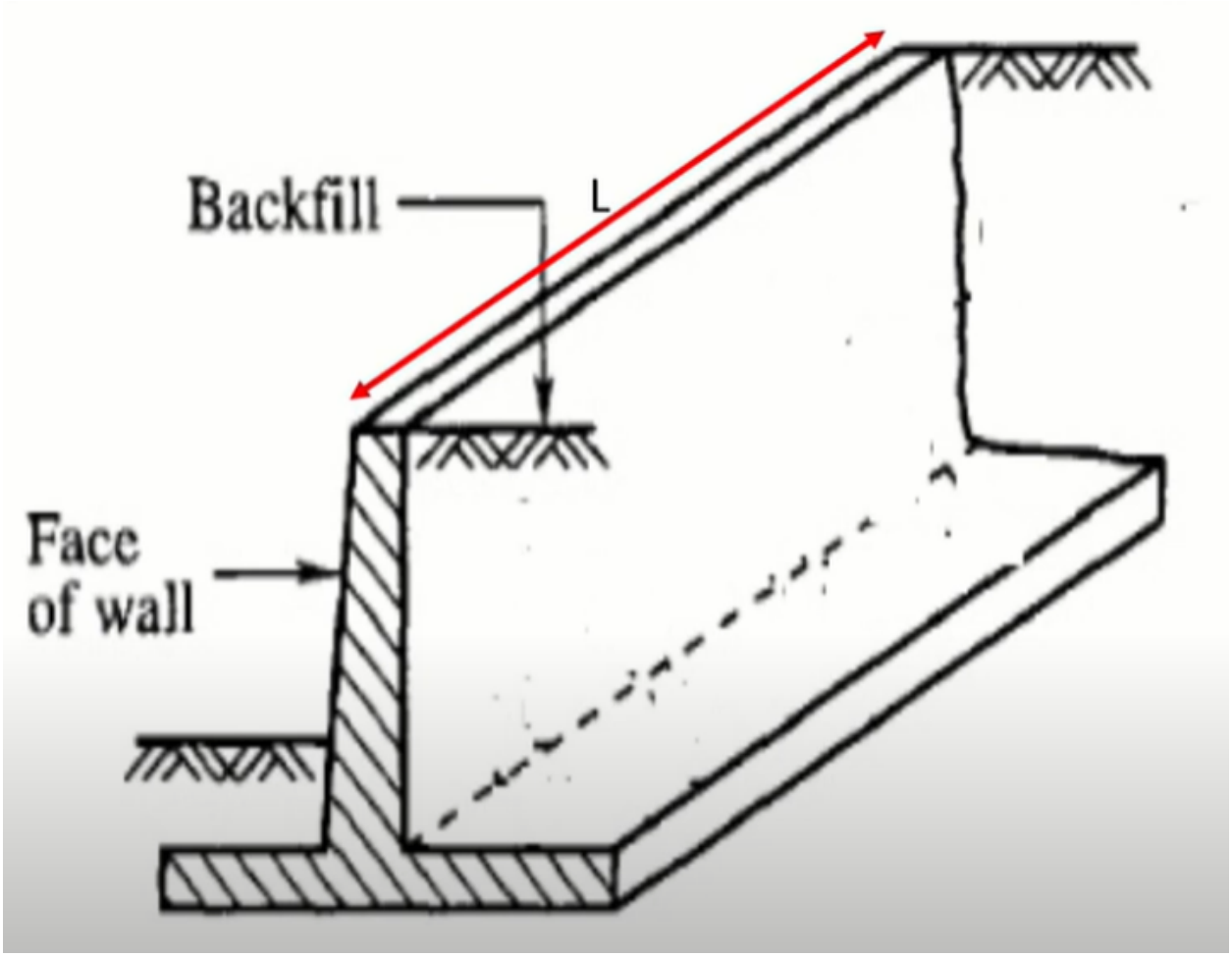
DESIGN OF RETAINING WALL

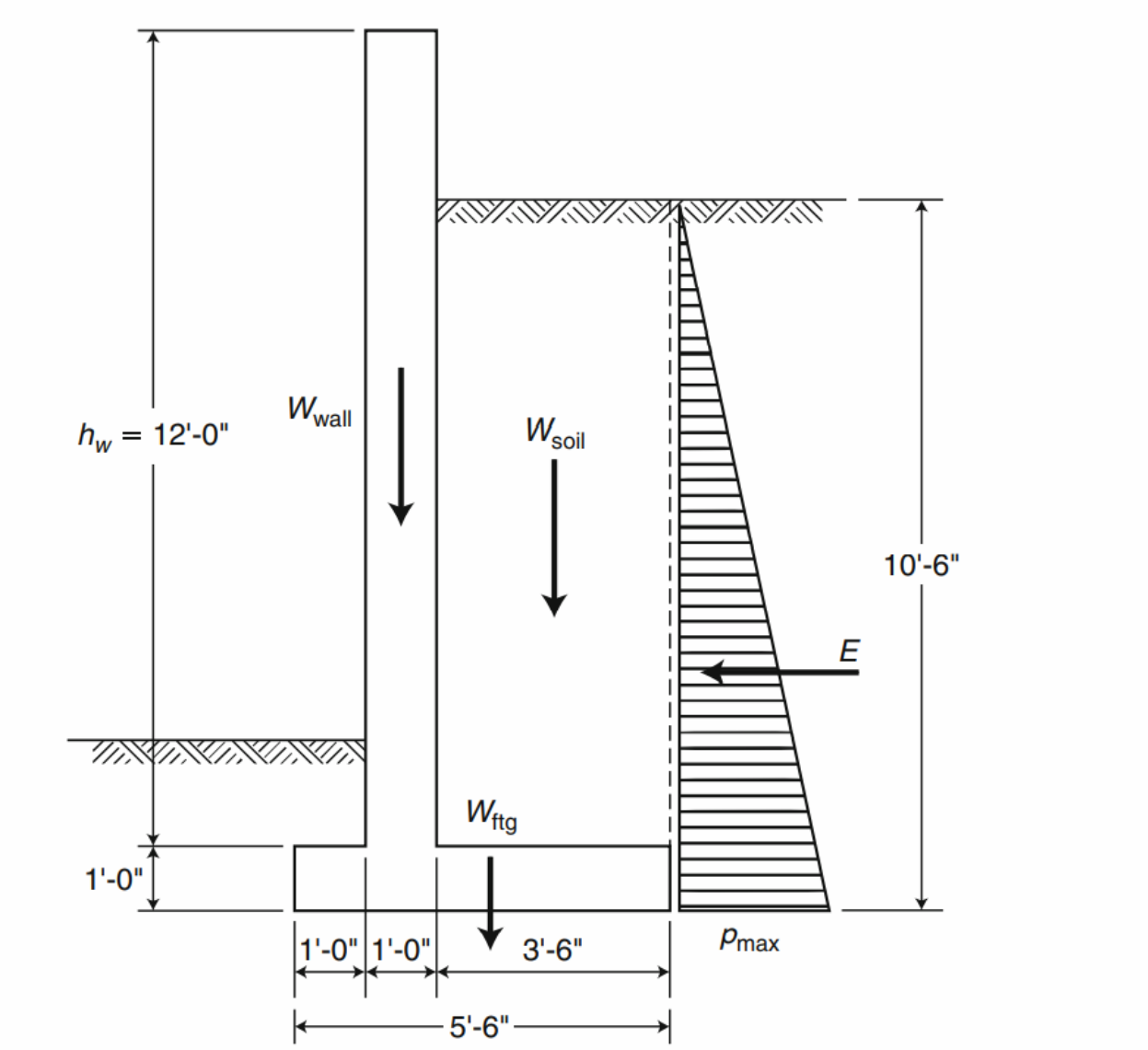
STEPS OF DESIGN OF RETAINING WALL




Backfill
L
Face
of wall

PROBLEM 01

Analyze the **stability** of the reinforced concrete cantilever retaining wall shown in Figure below. Calculate the **reinforcement required** in the wall and the footing. Disregard the passive resistance of the soil in front of the toe. Assume K_a = 0.32, = 115 pcf, and μ = 0.50. Use f_c' = 3,000 psi and f_y = 60,000 psi. Concrete is normal weight.



SOLUTION

Step 1. Calculate the lateral soil pressure and the overturning moment:

$$p_{\max} = K_a \gamma_{\text{soil}} h = 0.32 \times 115 \times 10.5 = 386.4 \text{ psf}$$

$$E = \frac{p_{\max} h}{2} = \frac{386.4 \times 10.5}{2} = 2{,}029 \text{ lb/ft}$$

$$M_{ot} = E\frac{h}{3} = 2{,}029 \times \frac{10.5}{3} = 7{,}102 \text{ ft-lb/ft}$$

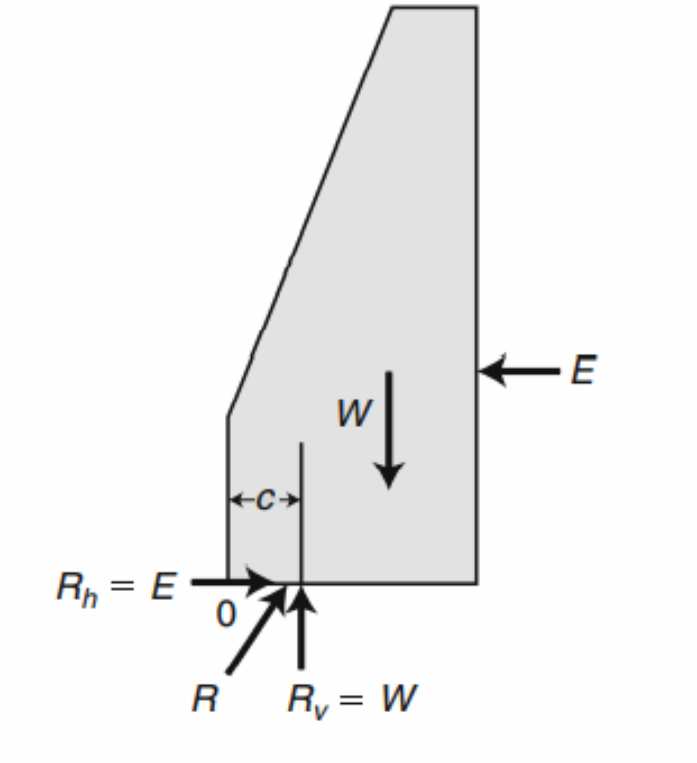
Step 2. Calculate the weight and the resisting moment. Include the weight of the backfill atop the heel of the wall and treat that as an integral part of the retaining wall.

Item	*W*	*x* (From Toe)	*Wx* (Moment to Toe)
Wall	$12 \times 1 \times 150 = 1{,}800$ lb/ft	1.50	2,700 ft-lb/ft
Footing	$5.5 \times 1 \times 150 = 825$ lb/ft	2.75	2,269 ft-lb/ft
Soil	$3.5 \times 9.5 \times 115 = 3{,}824$ lb/ft	3.75	14,340 ft-lb/ft
	$\sum = 6{,}449$ lb/ft		19,309 ft-lb/ft

Step 3. Determine the factors of safety against overturning and sliding:

$$FS_{ot} = \frac{M_r}{M_{ot}} = \frac{19{,}309}{7{,}102} = 2.72 > 1.5 \quad \therefore \text{ ok}$$

$$FS_s = \frac{\mu W}{E} = \frac{0.50 \times 6{,}449}{2{,}029} = 1.59 > 1.5 \quad \therefore \text{ ok}$$



RESULTANT FORCE AND ITS COMPONENTS AT THE BASE

Figure above shows all the forces acting on the wall. Determine the location where the R force (the reaction of

the resultant of W and E) intercepts the base of the wall. The vertical component of the resultant is $R_v = W$, and the horizontal component is $R_h = E$; (W, E, R_h, and R_v are the forces acting on the wall). The moment of a resultant about any point must equal the sum of the moments of the composing forces about the same point. The moments of the composing forces are already known. The moment of W about the toe is the resisting moment (M_r). The moment of E is the overturning moment (M_{ot}). Hence, from the equilibrium of forces acting on the wall:

$$\sum M_o = 0$$

$$-Wc + M_r - M_{ot} = 0$$

$$Wc = M_r - M_{ot}$$

$$c = \frac{M_r - M_{ot}}{W}$$

$$A = b \times 1 = b \text{ ft}^2 \quad \text{and} \quad S_m = \frac{1 \times b^2}{6} \text{ ft}^3$$

The pressures for the individual cases then can be found as:

$$f_{max} = \frac{P}{b} \qquad \begin{vmatrix} f_{max} = \frac{P}{b}\left(1 + \frac{6e}{b}\right) \\ f_{min} = \frac{P}{b}\left(1 - \frac{6e}{b}\right) \end{vmatrix} \qquad f_{max} = \frac{2P}{3c}$$

(Case I) (Case II) (Case III)

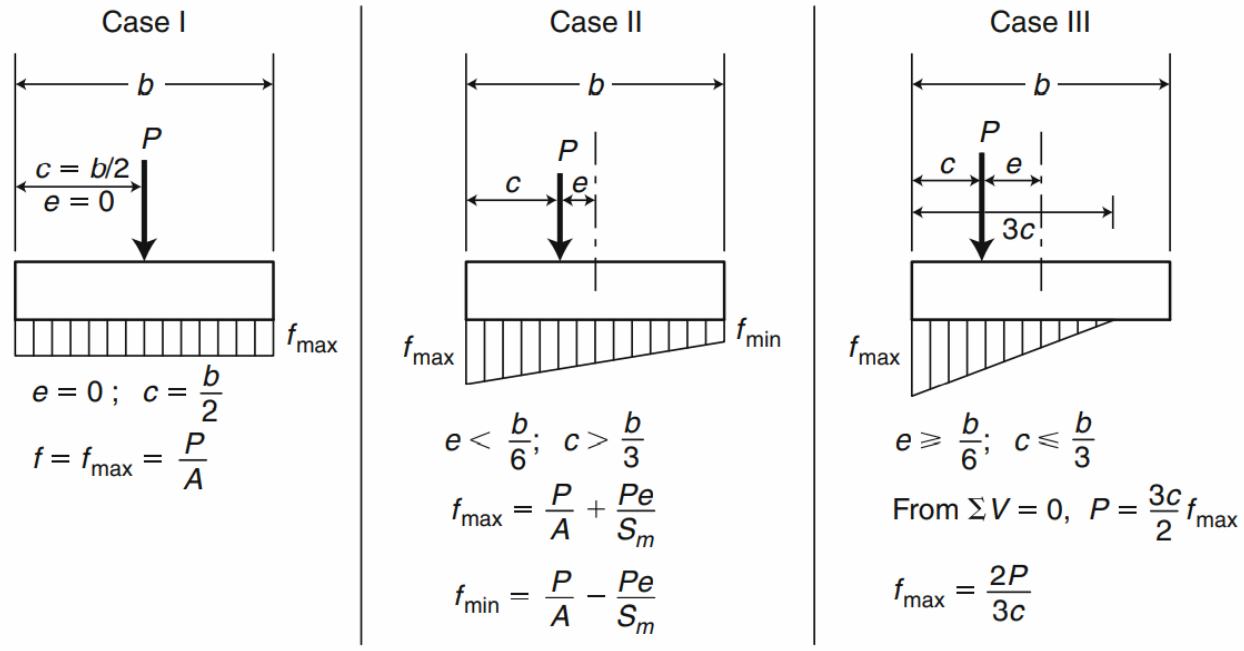


FIGURE 7.71: ECCENTRIC PRESSURES UNDER WALL FOOTINGS

Step 4. Calculate the soil pressure under the footing. Determine the location at which the resultant force intersects the bottom of the footing and calculate the resulting soil pressures.

$$c = \frac{M_r - M_{ot}}{W} = \frac{19{,}309 - 7{,}102}{6{,}449} = 1.89 \text{ ft from the toe}$$

So the eccentricity is

$$e = \frac{b}{2} - c = \frac{5.50}{2} - 1.89 = 0.86 \text{ ft}$$

Because

$$e = 0.86 < \frac{b}{6} = \frac{5.5}{6} = 0.92 \text{ ft}$$

Therefore, Case II (see Figure 7.71) is applicable. The soil pressures under the footing are:

$$f_{\max} = \frac{W}{b}\left(1 + \frac{6e}{b}\right) = \frac{6{,}449}{5.50}\left(1 + \frac{6 \times 0.86}{5.50}\right) = 2{,}273 \text{ psf}$$

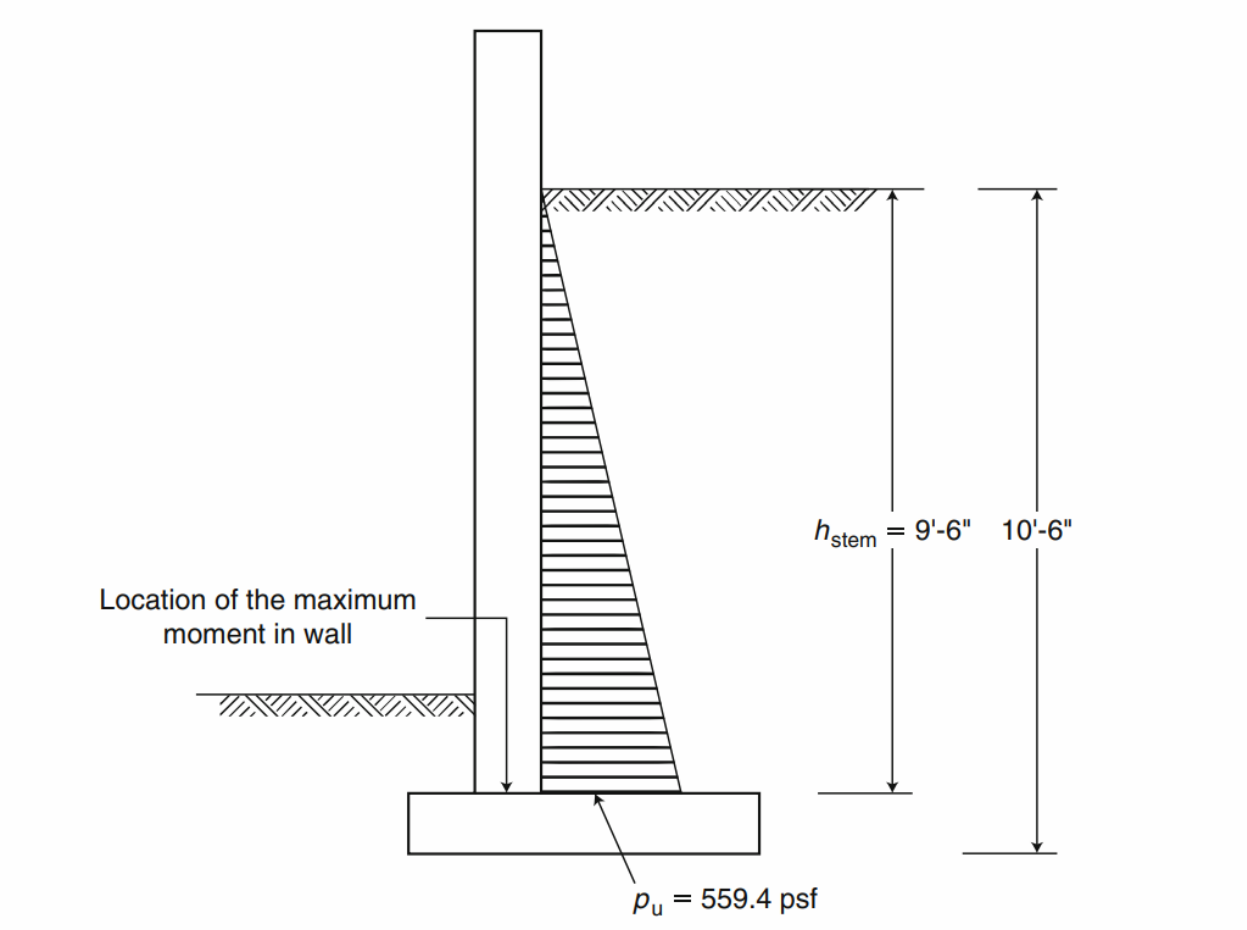
$$f_{\min} = \frac{W}{b}\left(1 - \frac{6e}{b}\right) = \frac{6{,}449}{5.50}\left(1 - \frac{6 \times 0.86}{5.50}\right) = 72 \text{ psf}$$

Step 5. Design the required reinforcement in the stem. Calculate the factored bending moment in the stem, as illustrated in Figure below. The maximum pressure at the base of the stem is:

$$p_a = 0.32 \times 115 \times 9.5 = 349.6 \text{ psf}$$

$$p_u = 1.6 \times 349.6 = 559.4 \text{ psf}$$

The factored design moment at the bottom of the stem is:



$$M_u = \left(\frac{p_u h_{stem}}{2}\right)\left(\frac{h_{stem}}{3}\right) = \frac{559.4 \times 9.5}{2} \times \frac{9.5}{3}$$

$$= 8{,}414 \text{ ft-lb/ft} = 8.41 \text{ ft-kip/ft}$$

The minimum concrete cover required for #6 or larger bars (ACI Code, Section 20.6.1.3.1) is 2 in., as the back of the wall is exposed to the soil. Thus (assuming #6 bars):

$$d = 12 - 2 - (0.75/2) = 9.63 \text{ in.}$$

For a 1-ft length of the wall:

$$R = \frac{12{,}000M_u}{bd^2} = \frac{12{,}000(8.41)}{(12)(9.63)^2} = 91 \text{ psi}$$

Using $f'_c = 3{,}000$ psi concrete and $f_y = 60{,}000$ psi steel from Table A2.6a:

$$\rho_{req} = 0.0018 \quad \text{(conservatively)}$$

From Table A2.4:

$$\rho_{min} = 0.0033 > 0.0018 \qquad \therefore \text{ use } \rho_{min} = 0.0033$$
$$A_{s,req} = 0.0033 \times 12 \times 9.63 = 0.38 \text{ in.}^2/\text{ft}$$

From Table A2.10 select

$$\#5 \text{ @9 in. c/c } \left(A_s = 0.41 \text{ in.}^2/\text{ft}\right)$$

or

$$\#6 \text{ @12 in. c/c } \left(A_s = 0.44 \text{ in.}^2/\text{ft}\right)$$

We place some vertical reinforcements to support the horizontal bars on the exterior face of the wall. Use #4 @ 18 in. for walls with a height, $h_w \leq 14$ ft, and use #5 @ 18 in. where $h_w > 14$ ft. Therefore, here we use #4 @ 18 in. since $h_w = 12$ ft. The horizontal shrinkage and temperature reinforcement required in the stem and footing is:

$$A_{sh} = 0.002bt = 0.002 \times 12 \times 12 = 0.288 \text{ in.}^2/\text{ft}$$

From Table A2.10 select #5 @ 12 in. c/c ($A_s = 0.31$ in.^{2}/ft) for the footing. Use #4 @ 16 in. on each face of the stem, as walls thicker than 10 in. require two layers of reinforcement (total $A_s = 2 \times 0.15 = 0.30$ in.^{2}/ft).

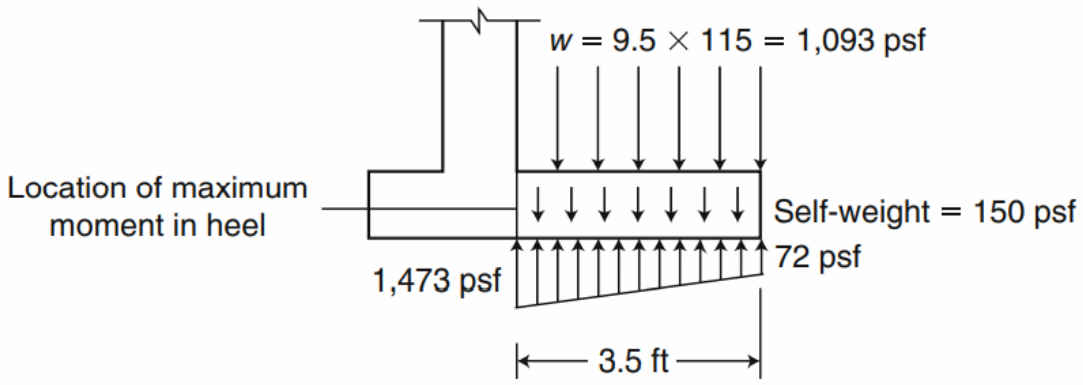
Step 6. Design the reinforcement required in the heel and toe. The heel acts like a cantilever from the back of the stem to the end of the heel, as shown in Figure below. The loads acting on it are the weight of the soil from above, its self-weight, and the upward reaction pressures at its bottom (found in step 4):

$$p_1 = 72 \text{ psf}$$

$$p_2 = 72 + \frac{2{,}273 - 72}{5.5} \quad (3.5)$$

$$p_2 = 1{,}473 \text{ psf}$$

The moment at the intersection of the heel and the stem is:



$$M = [(1,093 + 150) \times 3.5] \times \frac{3.5}{2} - 72 \times 3.5 \times \frac{3.5}{2}$$
$$- (1,473 - 72) \times \frac{3.5}{2} \times \frac{3.5}{3} = 4,312 \text{ ft-lb/ft}$$

The factored moment is:

$$M_u = 1.6 \times 4,312 = 6,900 \text{ ft-lb/ft} = 6.9 \text{ ft-kip/ft}$$

The reinforcement will be placed at the top of the heel. Thus, 2 in. cover (as in the case of stem) is required, therefore, $d = 9.63$ in. For a 1-ft length of the heel:

$$R = \frac{12,000M_u}{bd^2} = \frac{12,000(6.9)}{(12)(9.63)^2} = 74 \text{ psi}$$

From Table A2.6a:

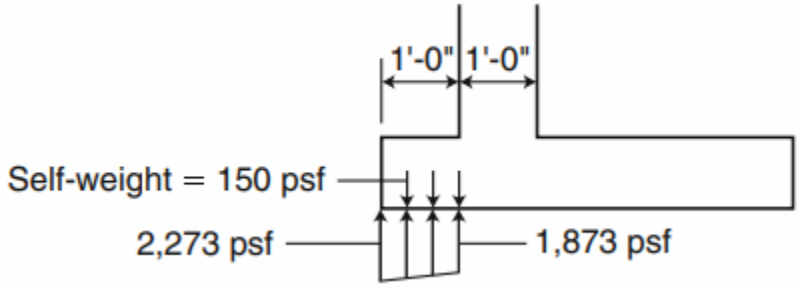
$$\rho_{req} = 0.0014 \rightarrow A_s = 0.0014(12)(9.63) = 0.16 \text{ in.}^2/\text{ft}$$

Per the ACI Code, Sections 13.3.2.1 and 7.6.1.1 the minimum reinforcement is equal to the required shrinkage and temperature reinforcements.

$$A_{s,\min} = 0.0018bt = 0.0018bt = 0.0018 \times 12 \times 12$$
$$= 0.26 \text{ in.}^2/\text{ft} > 0.16 \text{ in.}^2/\text{ft}$$

From Table A2.10 select #5 @ 14 in. c/c ($A_s = 0.27$ in.^{2}/ft).

$s_{max} = \min\{3h, 18\} = \min\{3 \times 12, 18\} = 18 \text{ in.} > 14 \text{ in.} \quad \therefore \text{ ok}$



FORCES ON THE TOE

The toe is only 1′–0″ long, so the reinforcement required will not be significant. For the sake of thoroughness, however, we will also determine the reinforcement in the toe.

$$p_1 = 2{,}273 \text{ psf}$$

$$p_2 = 72 + \frac{2{,}273 - 72}{5.5}(4.5) = 1{,}873 \text{ psf}$$

Neglecting, conservatively, the soil on the toe, the moment at the intersection of the toe and the stem, as shown in Figure above, is

$$M = (1{,}873 - 150)(1.0)\left(\frac{1.0}{2}\right) + (2{,}273 - 1{,}873)\left(\frac{1.0}{2}\right)\left(\frac{2}{3} \times 1.0\right) = 995 \text{ ft-lb/ft}$$

$$M_u = 1.6(995) = 1{,}592 \text{ ft-lb} = 1.6 \text{ ft-kip/ft}$$

$$d = 12 - 3(\text{footing cover}) - \frac{0.75}{2} = 8.63 \text{ in.} (\text{assuming } \#6 \text{ bars})$$

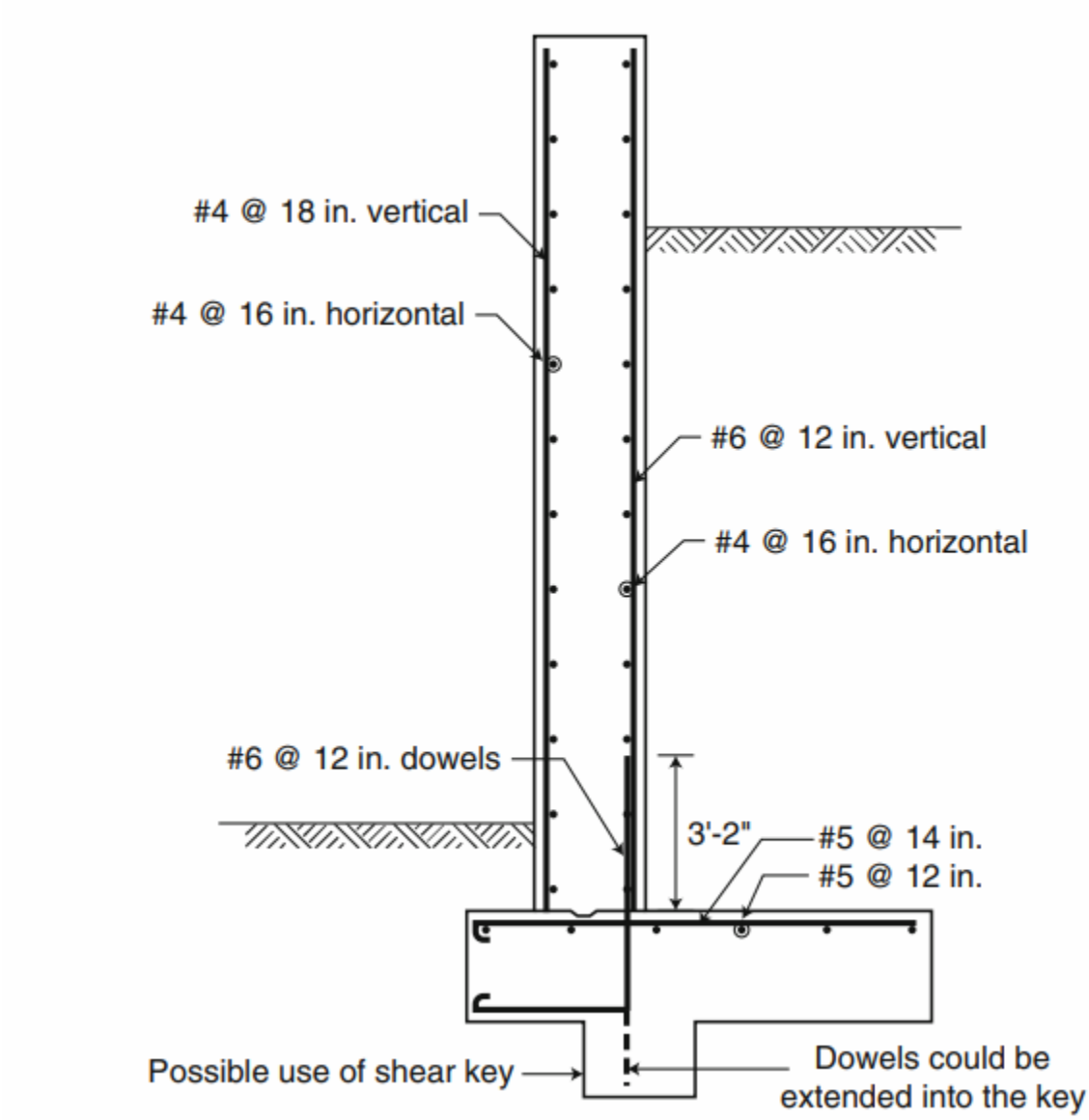
For a 1-ft length of the toe:

$$R = \frac{12{,}000(1.6)}{12(8.63)^2} = 22 \text{ psi} \rightarrow \text{Table A2.6a} \rightarrow \rho_{req} < 0.0010$$

$$\therefore \text{ use minimum steel}$$

$$A_s = 0.0018(12 \times 12) = 0.26 \text{ in.}^2/\text{ft}$$

Table A2.10 → Use 6 @ 12 in. c/c to dowel bars from the footing into the stem ($A_s = 0.44$ in.^{2}/ft). These bars will also serve for reinforcement in the toe.


#4 @ 18 in. vertical
#4 @ 16 in. horizontal
#6 @ 12 in. vertical
#4 @ 16 in. horizontal
#6 @ 12 in. dowels
3'-2"
#5 @ 14 in.
#5 @ 12 in.
Possible use of shear key
Dowels could be
extended into the key