Appendix A10 Cantilever Retaining Wall #3 Calculations

In this example we have a non-sloping back-filled retaining wall with a load surcharge and a water table present. Here we will calculate all soil pressures, design all aspects of the retaining wall and check for overturning and sliding.

Input Parameters

The retaining wall is cantilevered and the base is not restrained against sliding. The wall and footing are not poured monolithically. Footing dowels occur at both faces of the wall and are of the same size and spacing as the wall reinforcement.

In this example we will use a load combination of 1.0*DL+ 1.0*LL + 1.0*HL for the service LC and a load combination of 1.2*DL + 1.6*LL + 1.6*HL for the strength LC.

$DL_{Factor} := 1.2$ $\quad LL_{Factor} := 1.6$ $\quad HL_{Factor} := 1.6$

Geometry

$H_{wall} := 16 \cdot ft$ Hwall = Hsoil $\quad L_{toe} := 3.5 \cdot ft$ $\quad W_{key} := 18 \cdot in$

$H_{water} := 6 \cdot ft$ $\quad L_{heel} := 5.5 \cdot ft$ $\quad D_{key} := 18 \cdot in$

$t_{wall} := 18 \cdot in$ $\quad t_{foot} := 18 \cdot in$ $\quad L_{key} := 4.5 \cdot ft$

$L_{wall} := 10 \cdot ft$ Total length of wall

$L_{foot} := L_{toe} + L_{heel} + t_{foot} = 10.5\ ft$ Overall length of the footing

$Offset_{key} := L_{key} + W_{key} - L_{toe} - t_{wall} = 1\ ft$ The key offset from the interior face of wall and the interior face of key.

Materials

$\gamma_{conc} := .15 \cdot \dfrac{kip}{ft^3}$ $\quad f_c := 4 \cdot ksi$ $\quad f_y := 60 \cdot ksi$

Soil

$\mu := 0.5$ Coef of friction w/soil $\beta := 0$ backfill angle $H_{toesoil} := 2 \cdot ft$

$Soil_{allow} := 5 \cdot ksf$ $q := 500 \cdot psf$ surcharge

$\gamma_w := 62.4 \cdot pcf$

$\gamma_m := 115 \cdot pcf$

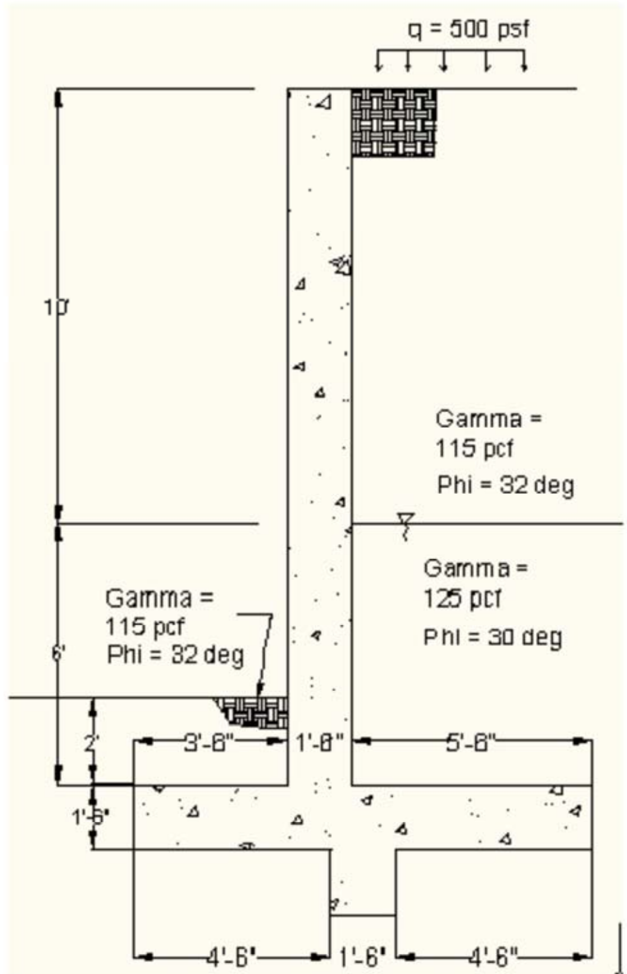
$\phi_m := 32 \cdot deg$

$\gamma_s := 125 \cdot pcf$

$\phi_s := 30 \cdot deg$

$SF := 1.5$ This is the safety factor required for both sliding and overturning.

Note: The moist soil properties are also used for the toe soil.



Wall Reinforcing Properties

$d_{binside} := 0.75 \cdot in$

$d_{bhoriz} := 0.5 \cdot in$

$d_{boutside} := 0.5\ in$

$s := 8 \cdot in$ spacing of vertical bars

$s_{wallhoriz} := 10 \cdot in$ spacing of horizontal bars

$Num_{faces} := 2$ Two faces of reinforcement

$$A_{sinside} := \frac{\pi \cdot d_{binside}^{\ 2}}{4} = 0.442\ in^2$$ #6 bars interior.

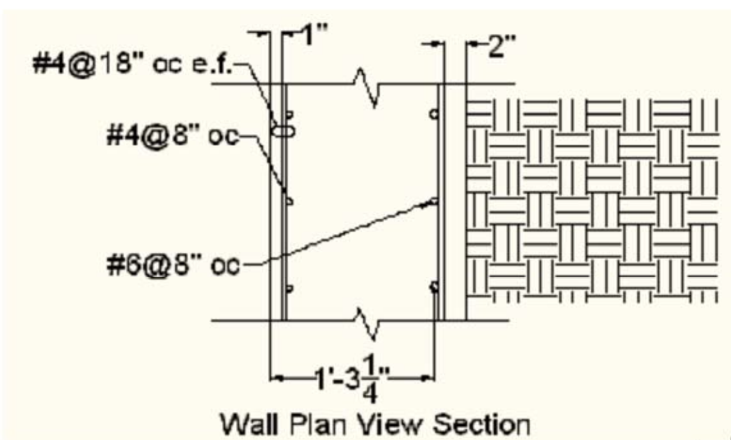
$$A_{soutside} := \frac{\pi \cdot d_{boutside}^{\ 2}}{4} = 0.196\ in^2$$ #4 bars exterior

$$A_{shoriz} := \frac{2 \cdot \pi \cdot d_{bhoriz}^{\ 2}}{4} = 0.393\ in^2$$ #4 bars horizontal each face

$cover_{inside} := 2 \cdot in$

$cover_{outside} := 1 \cdot in$

The outer bars are in the horizontal direction.



Footing Reinforcing Properties

$d_{btop} := 0.75 \cdot in$

$d_{bbot} := 0.75 \cdot in$

$d_{blong} := 0.5\ in$

$s_{top} := 8\ in$

$s_{bot} := 8\ in$

$s_{long} := 16\ in$

$$A_{stop} := \frac{\pi \cdot d_{btop}^{\ 2}}{4} = 0.442\ in^2$$

#6 bars at 8" spacing top

$$A_{sbot} := \frac{\pi \cdot d_{bbot}^{\ 2}}{4} = 0.442\ in^2$$

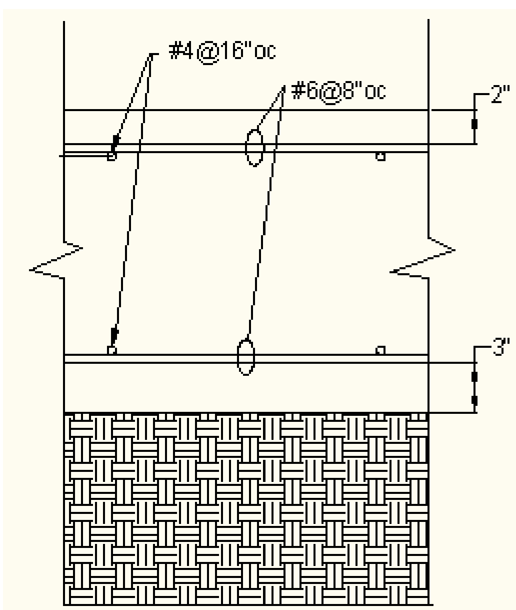
#6 bars at 8" spacing bot

$$A_{slong} := \frac{2 \cdot \pi \cdot d_{blong}^{\ 2}}{4} = 0.393\ in^2$$

#4 bars at 16" spacing longitudinal each face

$cover_{top} := 2\ in$

$cover_{bot} := 3\ in$



Calculations

This section breaks down all of the calculations that occur within RISAFoundation for retaining wall design.

Force Calculations For Overturning, Sliding and Wall Design

Lateral Earth Pressure Coefficients

$$\beta = 0 \qquad \phi_m = 32\ deg \qquad \phi_s = 30\ deg$$

$$K_{am} := \cos(\beta) \cdot \left(\frac{\cos(\beta) - \sqrt{(\cos(\beta))^2 - (\cos(\phi_m))^2}}{\cos(\beta) + \sqrt{(\cos(\beta))^2 - (\cos(\phi_m))^2}} \right) = 0.307$$

$$K_{pm} := \cos(\beta) \cdot \left(\frac{\cos(\beta) + \sqrt{(\cos(\beta))^2 - (\cos(\phi_m))^2}}{\cos(\beta) - \sqrt{(\cos(\beta))^2 - (\cos(\phi_m))^2}} \right) = 3.255$$

$$K_{as} := \cos(\beta) \cdot \left(\frac{\cos(\beta) - \sqrt{(\cos(\beta))^2 - (\cos(\phi_s))^2}}{\cos(\beta) + \sqrt{(\cos(\beta))^2 - (\cos(\phi_s))^2}} \right) = 0.333$$

Lateral Pressure Calculations (Service)

$$P_1 := K_{am} \cdot q = 153.629\ psf$$

$$P_2 := K_{am} \cdot (q + (H_{wall} - H_{water}) \cdot \gamma_m) = 506.977\ psf$$

$$P_3 := K_{as} \cdot (q + (H_{wall} - H_{water}) \cdot \gamma_m) = 550\ psf$$

$$P_4 := P_3 + K_{as} \cdot H_{water} \cdot (\gamma_s - \gamma_w) + H_{water} \cdot \gamma_w = (1.05 \cdot 10^3)\ psf$$

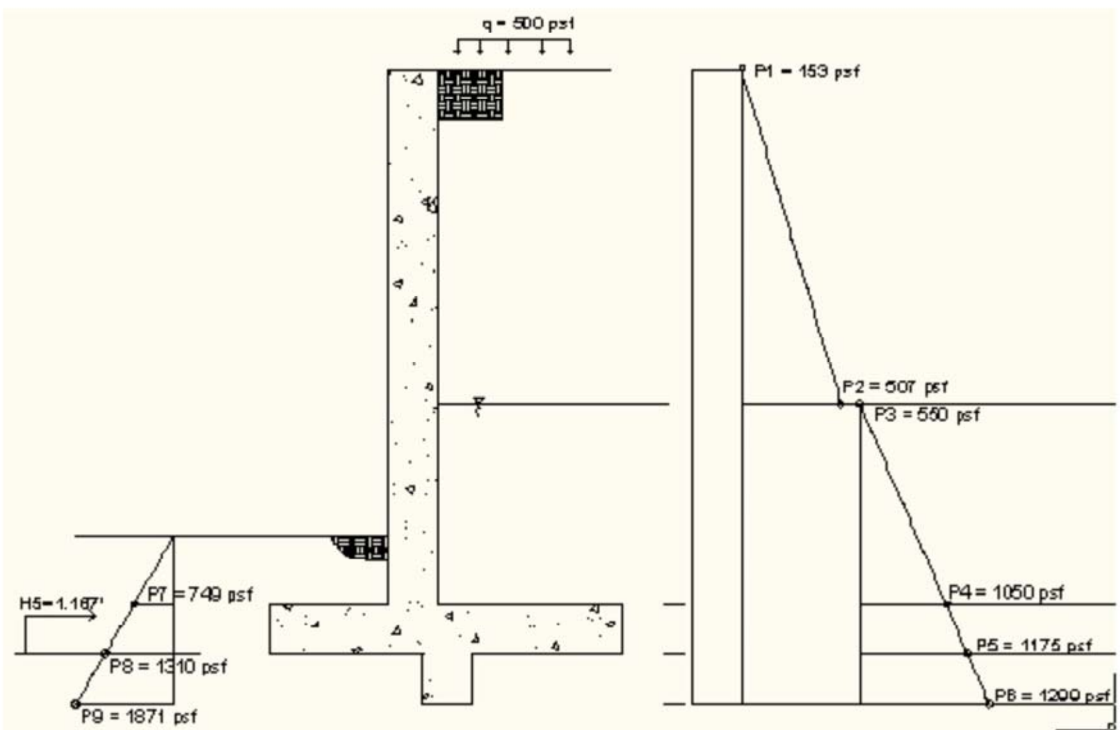
$$P_5 := P_4 + K_{as} \cdot t_{foot} \cdot (\gamma_s - \gamma_w) + t_{foot} \cdot \gamma_w = (1.175 \cdot 10^3)\ psf$$

$$P_6 := P_5 + K_{as} \cdot D_{key} \cdot (\gamma_s - \gamma_w) + D_{key} \cdot \gamma_w = (1.299 \cdot 10^3)\ psf$$

$$P_7 := H_{toesoil} \cdot \gamma_m \cdot K_{pm} = 748.555 \ psf$$

$$P_8 := \left(H_{toesoil} + t_{foot}\right) \cdot \gamma_m \cdot K_{pm} = \left(1.31 \cdot 10^3\right) \ psf$$

$$P_9 := \left(H_{toesoil} + t_{foot} + D_{key}\right) \cdot \gamma_m \cdot K_{pm} = \left(1.871 \cdot 10^3\right) \ psf$$



Lateral Resultant Force Locations for Overturning

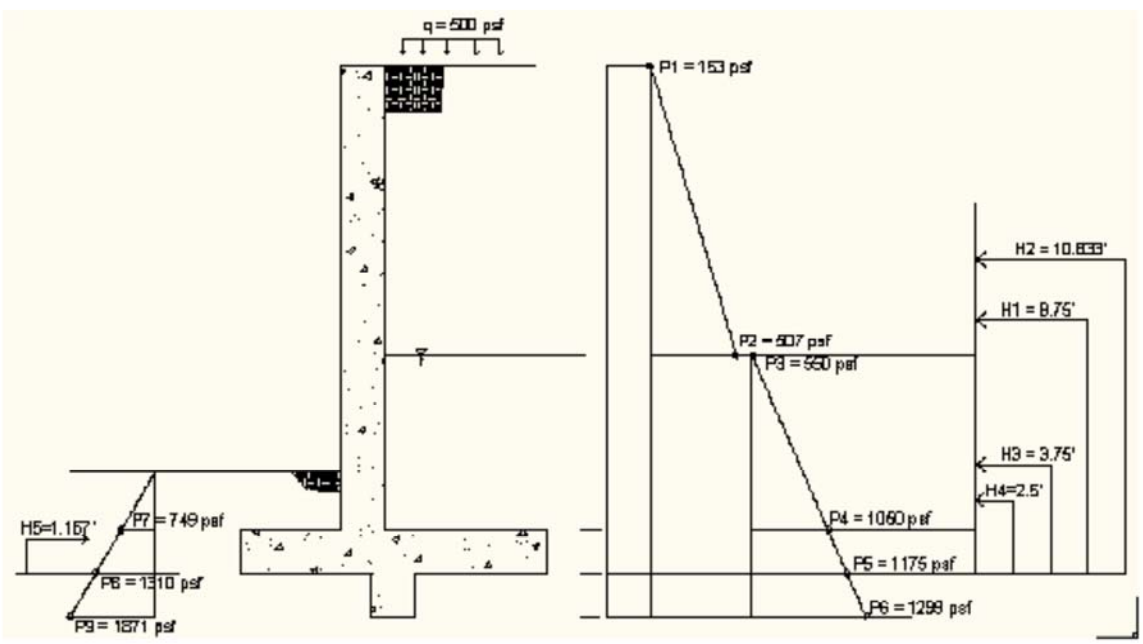
$$H_1 := \left(H_{wall} + t_{foot}\right) \cdot 0.5 = 8.75\ ft$$

$$H_2 := \left(H_{wall} - H_{water}\right) \cdot \left(\frac{1}{3}\right) + H_{water} + t_{foot} = 10.833\ ft$$

$$H_3 := \left(H_{water} + t_{foot}\right) \cdot 0.5 = 3.75\ ft$$

$$H_4 := \left(H_{water} + t_{foot}\right) \cdot \left(\frac{1}{3}\right) = 2.5\ ft$$

$$H_5 := \frac{1}{3} \cdot \left(H_{toesoil} + t_{foot}\right) = 1.167\ ft$$



Lateral Force Summations for Overturning, Sliding and Wall Design

$$LF_1 := P_1 \cdot \left(H_{wall} + t_{foot}\right) = 2.689 \ \frac{kip}{ft}$$

This value changes for all 3 calculations.

$$LF_{1slide} := LF_1 + P_1 \cdot D_{key} = 2.919 \ \frac{kip}{ft}$$

$$LF_{1wall} := P_1 \cdot \left(H_{wall}\right) = 2.458 \ \frac{kip}{ft}$$

$$LF_2 := \frac{1}{2} \cdot \left(P_2 - P_1\right) \cdot \left(H_{wall} - H_{water}\right) = 1.767 \ \frac{kip}{ft}$$

This is the same value for all 3 calculations.

$$LF_3 := \left(P_3 - P_1\right) \cdot \left(H_{water} + t_{foot}\right) = 2.973 \ \frac{kip}{ft}$$

This value changes for all 3 calculations.

$$LF_{3Slide} := LF_3 + \left(P_3 - P_1\right) \cdot D_{key} = 3.567 \ \frac{kip}{ft}$$

$$LF_{3wall} := \left(P_3 - P_1\right) \cdot H_{water} = 2.378 \ \frac{kip}{ft}$$

$$LF_4 := \left(P_5 - P_3\right) \cdot \left(\frac{1}{2}\right) \cdot \left(H_{water} + t_{foot}\right) = 2.342 \ \frac{kip}{ft}$$

This value changes for all 3 calculations.

$$LF_{4slide} := \left(P_6 - P_3\right) \cdot \left(\frac{1}{2}\right) \cdot \left(H_{water} + t_{foot} + D_{key}\right) = 3.372 \ \frac{kip}{ft}$$

$$LF_{4wall} := \left(P_4 - P_3\right) \cdot \left(\frac{1}{2}\right) \cdot H_{water} = 1.499 \ \frac{kip}{ft}$$

$$LF_5 := \frac{1}{2} \cdot P_8 \cdot \left(H_{toesoil} + t_{foot}\right) = 2.292 \ \frac{kip}{ft}$$

This value changes for all 3 calculations.

$$LF_{5slide} := \frac{1}{2} \cdot P_9 \cdot \left(H_{toesoil} + t_{foot} + D_{key}\right) = 4.678 \ \frac{kip}{ft}$$

$$LF_{5wall} := \frac{1}{2} \cdot P_7 \cdot H_{toesoil} = 0.749 \ \frac{kip}{ft}$$

Vertical Force Calculations (Service and Strength)

$w_1 := H_{wall} \cdot t_{wall} \cdot \gamma_{conc} = 3.6\ \frac{kip}{ft}$

$w_{1f} := DL_{Factor} \cdot w_1 = 4.32\ \frac{kip}{ft}$

$w_2 := t_{foot} \cdot (t_{wall} + L_{toe} + L_{heel}) \cdot \gamma_{conc} = 2.363\ \frac{kip}{ft}$

$w_{2f} := DL_{Factor} \cdot w_2 = 2.835\ \frac{kip}{ft}$

$w_3 := W_{key} \cdot D_{key} \cdot \gamma_{conc} = 0.338\ \frac{kip}{ft}$

$w_{3f} := DL_{Factor} \cdot w_3 = 0.405\ \frac{kip}{ft}$

$w_4 := L_{toe} \cdot H_{toesoil} \cdot \gamma_m = 0.805\ \frac{kip}{ft}$

$w_{4f} := DL_{Factor} \cdot w_4 = 0.966\ \frac{kip}{ft}$

$q_{total} := q \cdot L_{heel} = 2.75\ \frac{kip}{ft}$

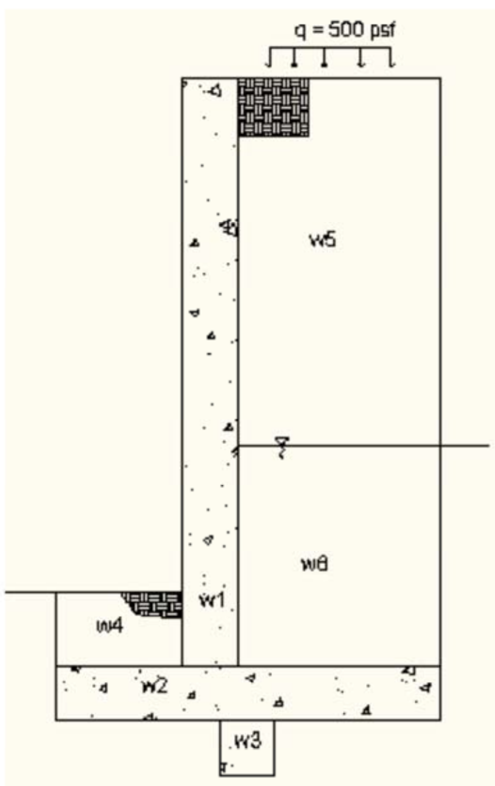
$q_{totalf} := LL_{Factor} \cdot q_{total} = 4.4\ \frac{kip}{ft}$

$w_5 := L_{heel} \cdot (H_{wall} - H_{water}) \cdot \gamma_m = 6.325\ \frac{kip}{ft}$

$w_{5f} := DL_{Factor} \cdot w_5 = 7.59\ \frac{kip}{ft}$

$w_6 := L_{heel} \cdot H_{water} \cdot \gamma_s = 4.125\ \frac{kip}{ft}$

$w_{6f} := DL_{Factor} \cdot w_6 = 4.95\ \frac{kip}{ft}$



Vertical Force Centroids

$$D_1 := L_{toe} + \frac{t_{wall}}{2} = 4.25\ ft$$

$$D_2 := \frac{L_{foot}}{2} = 5.25\ ft$$

$$D_3 := L_{key} + \frac{W_{key}}{2} = 5.25\ ft$$

$$D_4 := \frac{L_{toe}}{2} = 1.75\ ft$$

$$D_5 := L_{toe} + t_{wall} + \frac{L_{heel}}{2} = 7.75\ ft$$

$$D_6 := D_5 = 7.75\ ft$$

Stability Checks

Overturning

This check is taken from the base of the toe of the footing.

$$M_{R1} := w_1 \cdot D_1 + w_2 \cdot D_2 + w_3 \cdot D_3 + w_4 \cdot D_4 = 30.884\ kip \cdot \frac{ft}{ft}$$

$$M_{R2} := w_5 \cdot D_5 + \left(w_6 + q_{total}\right) \cdot D_6 + LF_5 \cdot H_5 = 104.975\ kip \cdot \frac{ft}{ft}$$

$$M_R := M_{R1} + M_{R2} = 135.858\ kip \cdot \frac{ft}{ft}$$

$$M_{OT} := H_1 \cdot LF_1 + H_2 \cdot LF_2 + H_3 \cdot LF_3 + H_4 \cdot LF_4 = 59.667\ kip \cdot \frac{ft}{ft}$$

$$OSF := \frac{M_R}{M_{OT}} = 2.277$$

$$UC_{OT} := \frac{SF}{OSF} = 0.659$$

This retaining wall passes the overturning check because it has greater than a 1.5 safety factor.

Sliding

This check is taken from the bottom of key elevation.

$$F_{Slide} := LF_{1slide} + LF_2 + LF_{3Slide} + LF_{4slide} = 11.625 \ \frac{kip}{ft}$$

$$R := w_1 + w_2 + w_3 + w_4 + w_5 + w_6 + q_{total} = 20.305 \ \frac{kip}{ft}$$ Total vertical force

$$F_{Friction} := R \cdot \mu = 10.153 \ \frac{kip}{ft}$$

$$LF_8 := \frac{1}{2} \cdot P_9 \cdot \left(H_{toesoil} + t_{foot} + D_{key}\right) = 4.678 \ \frac{kip}{ft}$$

$$F_{Resist} := F_{Friction} + LF_{5slide} = 14.831 \ \frac{kip}{ft}$$

The forces resisting sliding are due to both friction and passive pressure on the toe side of the footing.

$$SafetyFactor_{Sliding} := \frac{F_{Resist}}{F_{Slide}} = 1.276$$

$$UC_{Sliding} := \frac{SF}{SafetyFactor_{Sliding}} = 1.176$$

This retaining wall fails the sliding check because it has less than a 1.5 safety factor.

Designing the Wall Stem

The wall stem was poured separately from the footing. Where the wall is poured the footing has not been intentionally roughened. Footing dowels occur at both faces of the wall and are of the same size and spacing as the wall reinforcement.

$L_{wall} = 10\ ft$ $H_{wall} = 16\ ft$ $t_{wall} = 1.5\ ft$

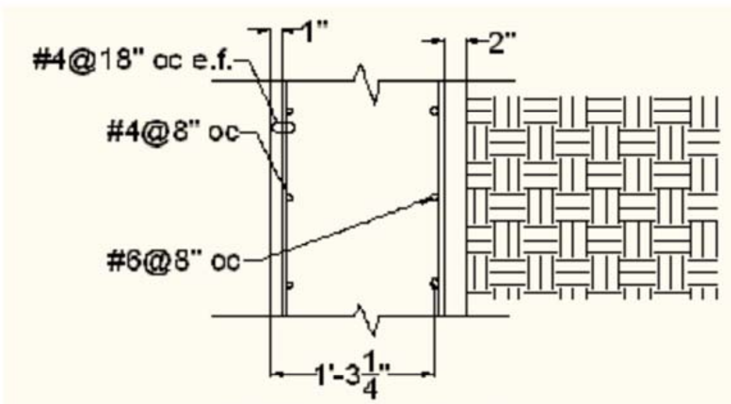
$A_{sinside} = 0.442\ in^2$ #6 bars interior. $cover_{inside} = 2\ in$

$A_{soutside} = 0.196\ in^2$ #4 bars exterior $cover_{outside} = 1\ in$

$A_{shoriz} = 0.393\ in^2$ #4 bars horizontal each face $s = 8\ in$

$Num_{faces} = 2$ $s_{wallhoriz} = 10\ in$

The outer bars are in the horizontal direction.



Wall Plan View Section

Axial and Bending Design (per foot)

These are the centroid heights of each portion of load.

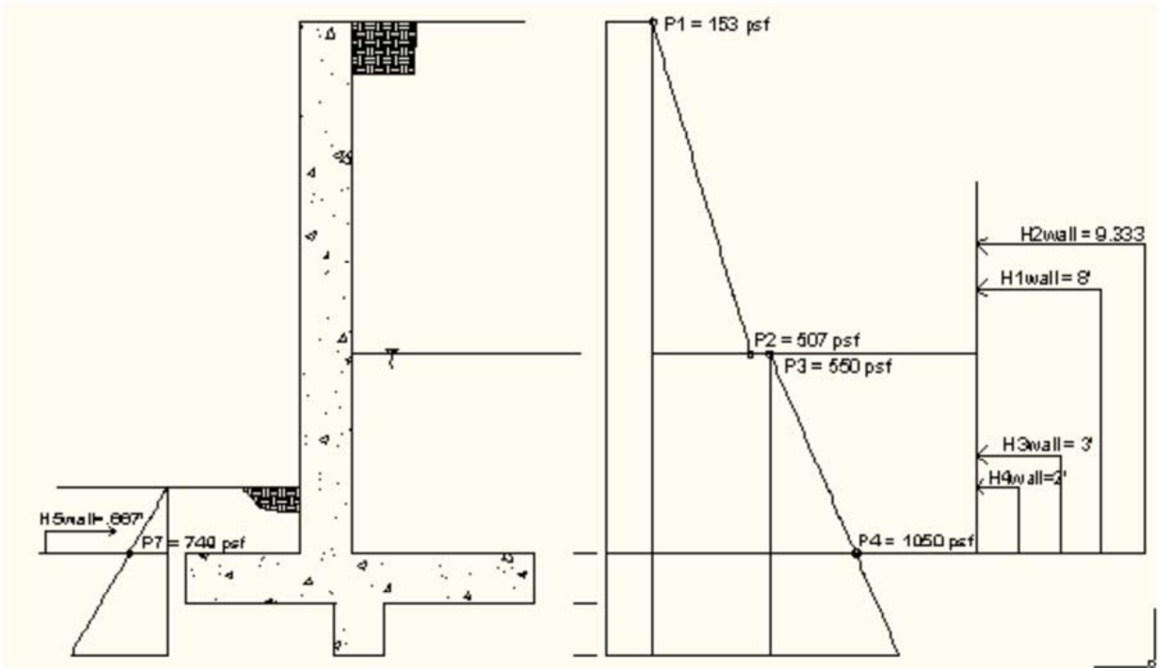
$$H_{1wall} := \frac{H_{wall}}{2} = 8\ ft$$

$$H_{2wall} := H_{water} + \frac{\left(H_{wall} - H_{water}\right)}{3} = 9.333\ ft$$

$$H_{3wall} := \frac{H_{water}}{2} = 3\ ft$$

$$H_{4wall} := \frac{H_{water}}{3} = 2\ ft$$

$$H_{5wall} := \frac{H_{toesoil}}{3} = 0.667\ ft$$



$P_u := 0 \cdot kip$

$M_{walls} := LF_{1wall} \cdot H_{1wall} + LF_2 \cdot H_{2wall} + LF_{3wall} \cdot H_{3wall} + LF_{4wall} \cdot H_{4wall} - LF_{5wall} \cdot H_{5wall}$

$M_{walls} = 45.787 \ kip \cdot \frac{ft}{ft}$

$HL_{Factor} = 1.6$

$M_{wallf} := HL_{Factor} \cdot M_{walls} = 73.26 \ kip \cdot \frac{ft}{ft}$

$d_{cant} := t_{wall} - cover_{inside} - d_{bhoriz} - \frac{d_{binside}}{2} = 15.125 \ in$

$d_{prime} := cover_{outside} + d_{bhoriz} + \frac{d_{boutside}}{2} = 1.75 \ in$

$a_{wall} := \frac{A_{sinside} \cdot f_y}{0.85 \cdot f_c \cdot s} = 0.975 \ in$ $a_{prime} := \frac{A_{soutside} \cdot f_y}{0.85 \cdot f_c \cdot s} = 0.433 \ in$

$M_{nwall} := \frac{A_{sinside} \cdot f_y \cdot \left(d_{cant} - \frac{a_{wall}}{2}\right)}{12} \cdot \frac{12}{s}$

$M_{nwall} = 48.501 \ kip \cdot \frac{ft}{ft}$ This is the moment capacity in the wall not considering compression reinforcement

$$\phi_{wall} := 0.9$$

$$PhiMn_{wall} := \phi_{wall} \cdot M_{nwall} = 43.651 \ kip \cdot \frac{ft}{ft}$$

Note: The program takes into account compression reinforcement as well, so the program reported value is a little larger (44.029).

$$Bending_{Interaction} := \frac{M_{wallf}}{PhiMn_{wall}} = 1.678$$

<u>Reinforcement Provided Checks (for entire wall)</u>

Horizontal Reinforcement

$$Bars_{Horiz1} := Num_{faces} \cdot \frac{H_{wall}}{s_{wallhoriz}} = 38.4$$

$$Bars_{Horiz} := \text{round}\left(Bars_{Horiz1}\right) = 38$$ The total number of horizontal bars in the wall.

$$As_{provh} := Bars_{Horiz} \cdot \frac{A_{shoriz}}{2} = 7.461 \ in^2$$ As provided (H)

$$rho_{provh} := \frac{As_{provh}}{12 \cdot H_{wall} \cdot t_{wall}} = 1.799 \cdot 10^{-4}$$ Rho Provided (H)

$$rho_{minh} := .002$$ Rho min (H)

$$A_{sminh} := rho_{minh} \cdot H_{wall} \cdot t_{wall} = 6.912 \ in^2$$ As min (H)

Inside Face Vertical Reinforcement

$$Bars_{VertInt1} := \frac{L_{wall}}{s} = 15$$

$$Bars_{VertInt} := \text{round}\left(Bars_{VertInt1}\right) = 15$$ The total number of interior vertical bars in the wall.

$$As_{provint} := Bars_{VertInt} \cdot A_{sinside} = 6.627 \ in^2$$ Int As Provided (V)

$$rho_{provint} := \frac{As_{provint}}{L_{wall} \cdot t_{wall} \cdot 12} = 2.557 \cdot 10^{-4}$$ Int rho Provided (V)

Outside Face Vertical Reinforcement

$$Bars_{VertExt1} := \frac{L_{wall} \cdot 12}{s} = 180$$

$$Bars_{VertExt} := \text{round}\left(Bars_{VertExt1}\right) = 180$$ The total number of exterior vertical bars in the wall.

$$As_{provext} := Bars_{VertExt} \cdot A_{soutside} = 35.343\ in^2$$ Ext As Provided (V)

$$rho_{provext} := \frac{As_{provext}}{L_{wall} \cdot t_{wall} \cdot 12} = 0.001$$ Ext rho Provided (V)

Total Vertical Reinforcement

$$rho_{minv} := .0015$$ rho min (V)

$$A_{sminv} := rho_{minv} \cdot L_{wall} \cdot 12 \cdot t_{wall} = 38.88\ in^2$$ As min (V)

Shear Design

Concrete check:

$$V_{wallds1} := LF_{1wall} \cdot \frac{H_{wall} - d_{cant}}{H_{wall}} + LF_{3wall} \cdot \left(\frac{H_{water} - d_{cant}}{H_{water}}\right) + LF_2 = 5.91\ \frac{kip}{ft}$$

$$V_{wallds2} := \frac{P_4 - P_3}{2} \cdot \left(\frac{\left(H_{water} - d_{cant}\right)^2}{H_{water}}\right) - \frac{P_7}{2} \cdot \frac{\left(H_{toesoil} - d_{cant}\right)^2}{H_{toesoil}} = 0.833\ \frac{kip}{ft}$$

For the concrete check we are using the shear force at a distance d from the base.

$$V_{wallds} := V_{wallds1} + V_{wallds2} = 6.743\ \frac{kip}{ft}$$

$$f_c := 4000 \cdot \frac{lbf^2}{in^4}$$

$$V_{walldf} := HL_{Factor} \cdot V_{wallds} = 10.788\ \frac{kip}{ft}$$

$$\phi_v := 0.75$$

$$V_c := 2 \cdot \sqrt{f_c} \cdot d_{cant} = \left(2.2958 \cdot 10^4\right)\ \frac{lbf}{ft}$$

$$PhiVc_{wall} := \phi_v \cdot V_c = \left(1.7219 \cdot 10^4\right) \frac{lbf}{ft}$$

$$ShearConc_{Interaction} := \frac{V_{walldf}}{PhiVc_{wall}} = 0.627$$

Steel Check (shear friction)

In this example the wall is not poured monolithically with the footing.
All code references are per the ACI 318-11.

$$V_{wallbases} := LF_{1wall} + LF_2 + LF_{3wall} + LF_{4wall} - LF_{5wall} = 7.353 \frac{kip}{ft}$$

$$V_{wallbasef} := HL_{Factor} \cdot V_{wallbases} = 11.765 \frac{kip}{ft}$$

$$A_{vf} := \frac{\left(A_{sinside} + A_{soutside}\right) \cdot 12 \cdot \frac{in}{ft}}{s} = 0.957 \frac{in^2}{ft}$$

Here we are using the As of the wall reinforcing, as the dowels from the foundation match the wall r/f.

$$f_y = 60 \ ksi$$

$$\mu_{conc} := 0.6$$

This assumes that the surface of the footing where the wall is poured is not intentionally roughened.

$$V_n := A_{vf} \cdot f_y \cdot \mu_{conc} = 113.056 \frac{1}{m} \cdot kip$$

Equation 11-25

Per Section 11.6.6 fy must be taken <= 60 ksi.

$$t_{wall} = 18 \ in \qquad l_{wall} := 12 \cdot \frac{in}{ft}$$

per foot distance

$$A_c := t_{wall} \cdot l_{wall} = 216 \frac{in^2}{ft} \qquad f_c := 4 \cdot ksi$$

The equations below are based on section 11.6.5. Note that the provisions are different in the ACI 318-02 and ACI 318-05 and come from section 11.7.5.

$$V_{n1} := 0.2 \cdot f_c \cdot A_c = 172.8\ \frac{kip}{ft}$$

$$V_{n2} := \left(480 \cdot psi + 0.08 \cdot f_c\right) \cdot A_c = 172.8\ \frac{kip}{ft}$$

$$V_{n4} := 0.2 \cdot f_c \cdot A_c = 172.8\ \frac{kip}{ft}$$

$$V_{n3} := 1600 \cdot psi \cdot A_c = 345.6\ \frac{kip}{ft}$$

$$V_{n5} := 800 \cdot psi \cdot A_c = 172.8\ \frac{kip}{ft}$$

$$V_{nrough} := min\left(V_n, V_{n1}, V_{n2}, V_{n3}\right)$$

$$V_{nsmooth} := min\left(V_n, V_{n4}, V_{n5}\right) = 34.459\ \frac{kip}{ft}$$

$$SteelConc_{Interaction} := \frac{V_{wallbasef}}{\phi_v \cdot V_{nsmooth}} = 0.455$$

Designing the Footing

Soil Pressure Calculation (for Footing Design)

$$M_{OTS} := HL_{Factor} \cdot \left(H_1 \cdot LF_1 + H_2 \cdot LF_2 + H_3 \cdot LF_3 + H_4 \cdot LF_4\right) = 95.467\ \frac{kip \cdot ft}{ft}$$

$$M_{RS1} := DL_{Factor} \cdot \left(w_1 \cdot D_1 + w_2 \cdot D_2 + w_3 \cdot D_3 + w_4 \cdot D_4 + w_5 \cdot D_5 + w_6 \cdot D_6\right)$$

$$M_{RS2} := LL_{Factor} \cdot q_{total} \cdot D_6 + HL_{Factor} \cdot LF_5 \cdot H_5$$

$$M_{RS} := M_{RS1} + M_{RS2} = 172.625\ \frac{kip \cdot ft}{ft}$$

$$R_S := DL_{Factor} \cdot \left(w_1 + w_2 + w_3 + w_4 + w_5 + w_6\right) + LL_{Factor} \cdot q_{total} = 25.466\ \frac{kip}{ft}$$

$$x_{RS} := \frac{M_{RS} - M_{OTS}}{R_S} = 3.03\ ft$$

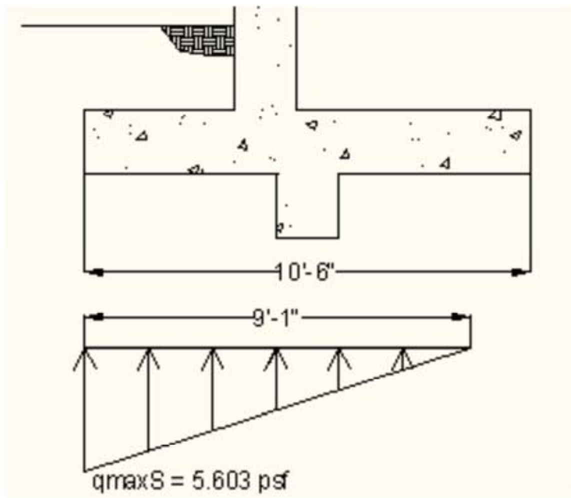
$$e_{1S} := \frac{L_{foot}}{2} - x_{RS} = 2.22\ ft$$

$$\frac{L_{foot}}{6} = 1.75\ ft$$

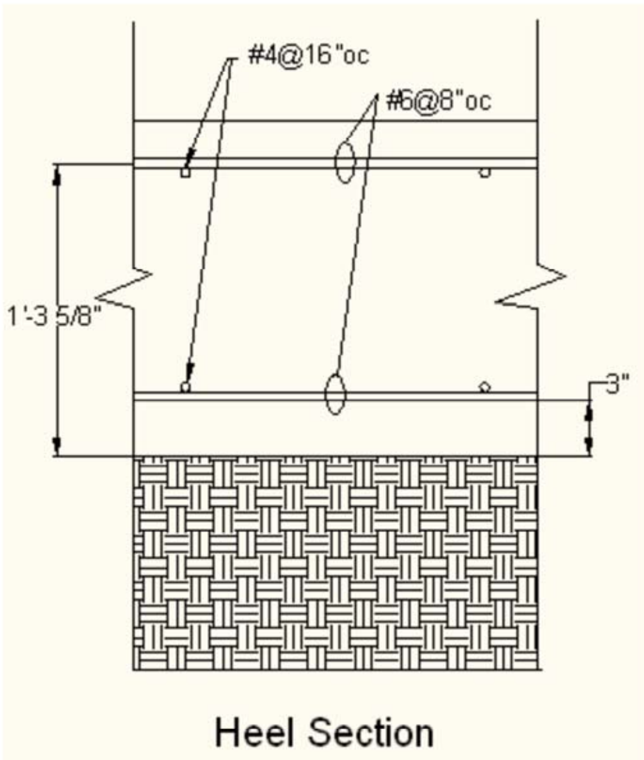
$$L_{basesoilS} := 3 \cdot x_{RS} = 9.09\ ft$$

$$q_{maxS} := \text{if } e_{1S} < \frac{L_{foot}}{6} \quad = 5.603\ ksf$$
$$\left\| \frac{R_S}{L_{foot}} + \frac{6 \cdot (R_S \cdot e_{1S})}{L_{foot}^{\ 2}} \right.$$
$$\text{else}$$
$$\left\| \frac{4 \cdot R_S}{3 \cdot (L_{foot} - 2 \cdot e_{1S})} \right.$$

$$q_{minS} := \text{if } e_{1S} < \frac{L_{foot}}{6} \quad = 0\ ksf$$
$$\left\| \frac{R_S}{L_{foot}} - \frac{6 \cdot (R_S \cdot e_{1S})}{L_{foot}^{\ 2}} \right.$$
$$\text{else}$$
$$\left\| 0 \cdot ksf \right.$$



Design of the Heel (Shear)



$cover_{top} = 2\ in$

$d_{btop} = 0.75\ in$

$d_{blong} = 0.5\ in$

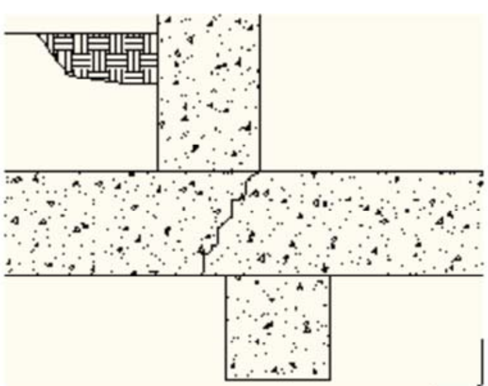
$s_{top} = 8\ in$

$s_{long} = 16\ in$

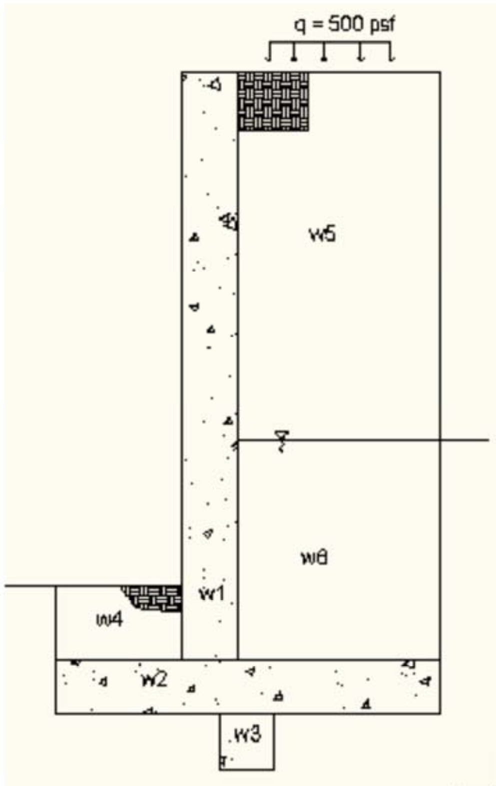
$A_{stop} = 0.442\ in^2$

$A_{slong} = 0.393\ in^2$

$$d_{heel} := t_{foot} - cover_{top} - \frac{d_{btop}}{2} = 15.625\ in$$



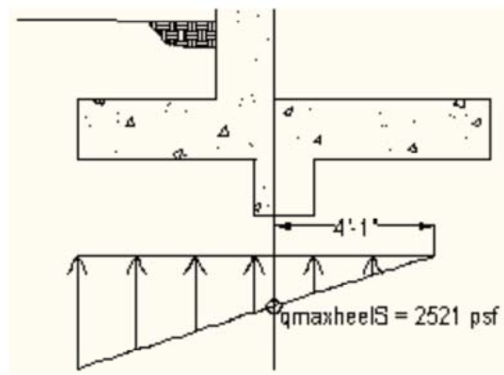
Because the footing will tend to shear off as shown here, the shear check should occur at the face of wall.



$$q_{totalf} = 4.4\ \frac{kip}{ft}$$

$$w_{5f} = 7.59\ \frac{kip}{ft}$$

$$w_{6f} = 4.95\ \frac{kip}{ft}$$



$$V_{uheel1} := w_{5f} + w_{6f} + q_{totalf} + DL_{Factor} \cdot \gamma_{conc} \cdot t_{foot} \cdot L_{heel} = 18.425\ \frac{kip}{ft}$$

$$L_{soilheelS} := L_{basesoilS} - L_{toe} - t_{wall} = 4.09\ ft$$

$$q_{maxheelS} := q_{maxS} \cdot \frac{\left(L_{basesoilS} - L_{toe} - t_{wall}\right)}{L_{basesoilS}} = 2.521\ ksf$$

$$V_{uheel2} := \frac{1}{2} \cdot L_{soilheelS} \cdot q_{maxheelS} = 5.155\ \frac{kip}{ft}$$

$$V_{uheel} := V_{uheel1} - V_{uheel2} = 13.27\ \frac{kip}{ft}$$

Vuheel1 is the total downward shear force on the heel. Vuheel2 is the total upward shear force on the heel. Because the net force is downward, the location of the shearing is confirmed.

$$f_c := 4000 \cdot \frac{lbf^2}{in^4}$$

$$V_{cheel} := 2 \cdot \sqrt{f_c} \cdot d_{heel} = 23.717 \ \frac{kip}{ft}$$

$$PhiV_{cheel} := \phi_v \cdot V_{cheel} = 17.788 \ \frac{kip}{ft}$$

$$Shearheel_{Interaction} := \frac{V_{uheel}}{PhiV_{cheel}} = 0.746$$

Design of the Heel (Moment)

$$M_{uheel} := V_{uheel1} \cdot \frac{L_{heel}}{2} - V_{uheel2} \cdot \frac{1}{3} \cdot L_{soilheelS} = 43.642 \ \frac{kip \cdot ft}{ft}$$

$$f_c := 4 \cdot ksi$$

$$a_{heel} := \frac{\frac{12 \cdot in}{s_{top}} \cdot A_{stop} \cdot f_y}{0.85 \cdot 12 \cdot in \cdot f_c} = 0.975 \ in$$

$$A_{stop1} := \frac{A_{stop}}{1 \cdot ft} = 0.442 \ \frac{in^2}{ft}$$

$$M_{nheel} := \frac{12 \cdot in}{s_{top}} \cdot A_{stop1} \cdot f_y \cdot \left(d_{heel} - \frac{a_{heel}}{2}\right) = 50.157 \ \frac{kip \cdot ft}{ft}$$

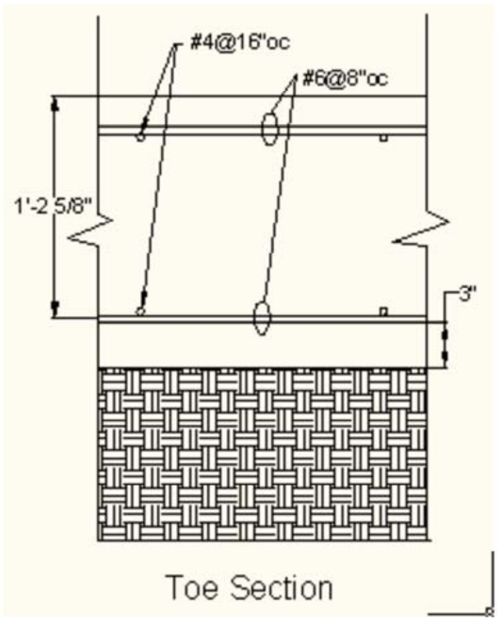
The reinforcement spacing is at 8" oc, so the moment capacity is normalized to be per foot.

$$\phi_{wall} = 0.9$$

$$PhiMn_{heel} := \phi_{wall} \cdot M_{nheel} = 45.142 \ \frac{kip \cdot ft}{ft}$$

$$Bendheel_{Interaction} := \frac{M_{uheel}}{PhiMn_{heel}} = 0.967$$

Design of the Toe (Shear)



$cover_{bot} = 3\ in$

$d_{bbot} = 0.75\ in$

$d_{blong} = 0.5\ in$

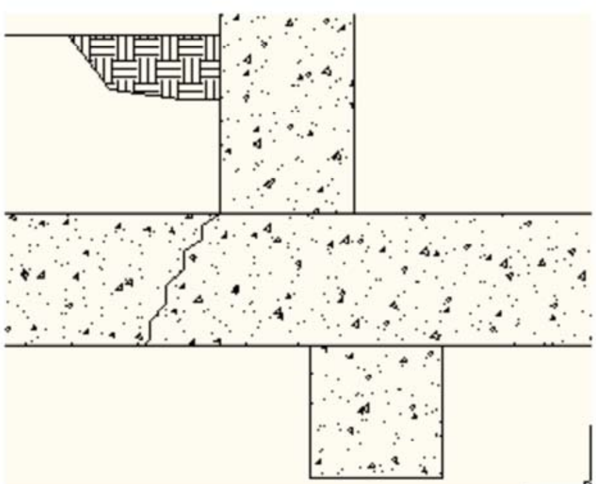
$s_{bot} = 8\ in$

$s_{long} = 16\ in$

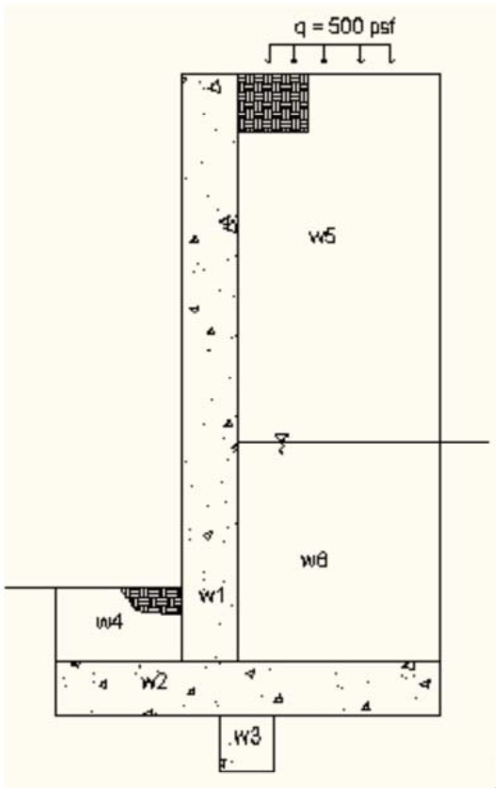
$A_{sbot} = 0.442\ in^2$

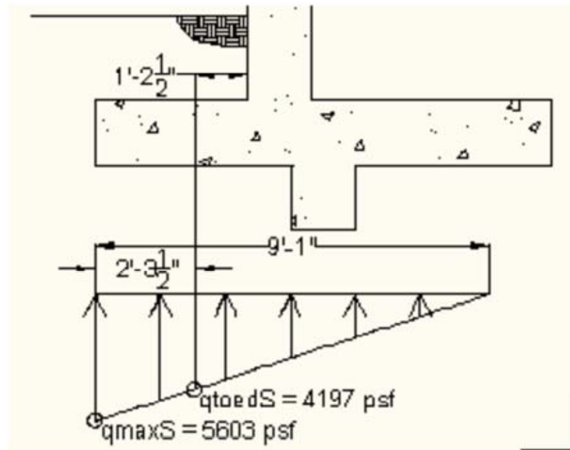
$A_{slong} = 0.393\ in^2$

$d_{toe} := t_{foot} - cover_{bot} - \frac{d_{bbot}}{2} = 14.625\ in$



Because the footing will tend to shear off as shown above, the shear check should occur at a distance d from the face of wall.





$$q_{toedS} := \frac{\left(L_{basesoilS} - L_{toe} + d_{toe}\right) \cdot q_{maxS}}{L_{basesoilS}} = 4.197\ ksf$$

$$V_{utoeOT} := \left(L_{toe} - d_{toe}\right) \cdot \left(q_{toedS} + \frac{1}{2} \cdot \left(q_{maxS} - q_{toedS}\right)\right) = 11.179\ \frac{kip}{ft}$$

$$V_{utoeR} := \left(w_{4f} + DL_{Factor} \cdot \gamma_{conc} \cdot t_{foot} \cdot L_{toe}\right) \cdot \left(\frac{L_{toe} - d_{toe}}{L_{toe}}\right) = 1.246\ \frac{kip}{ft}$$

$$f_c := 4000 \cdot \frac{lbf^2}{in^4}$$

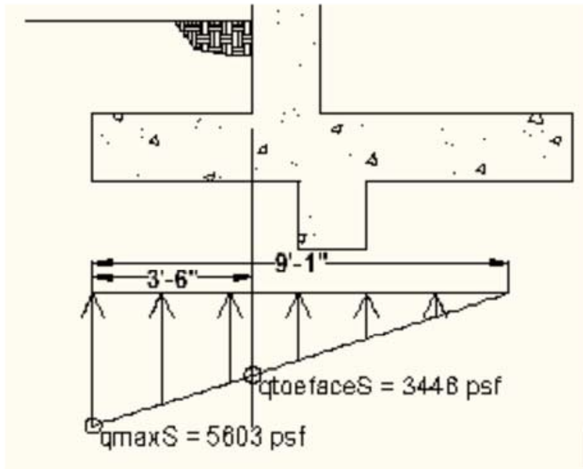
$$V_{utoe} := V_{utoeOT} - V_{utoeR} = 9.933\ \frac{kip}{ft} \qquad V_{ctoe} := 2 \cdot \sqrt{f_c} \cdot d_{toe} = 22.199\ \frac{kip}{ft}$$

$$PhiV_{ctoe} := \phi_v \cdot V_{ctoe} = 16.649\ \frac{kip}{ft}$$

$$Sheartoe_{Interaction} := \frac{V_{utoe}}{PhiV_{ctoe}} = 0.597$$

Design of the Toe (Moment)

$$q_{toefaceS} := \frac{\left(L_{basesoilS} - L_{toe}\right) \cdot q_{maxS}}{L_{basesoilS}} = 3.446 \ ksf$$



$$M_{utoeOS} := L_{toe} \cdot q_{toefaceS} \cdot \left(\frac{L_{toe}}{2}\right) + \frac{1}{2} \cdot L_{toe} \cdot \left(q_{maxS} - q_{toefaceS}\right) \cdot \left(\frac{2}{3} \cdot L_{toe}\right)$$

$$M_{utoeOS} = 29.916 \ \frac{kip \cdot ft}{ft}$$

$$V_{utoeRbend} := V_{utoeR} \cdot \frac{L_{toe}}{L_{toe} - d_{toe}} = 1.911 \ \frac{kip}{ft}$$

$$M_{utoeR} := V_{utoeRbend} \cdot \left(\frac{L_{toe}}{2}\right) = 3.344 \ \frac{kip \cdot ft}{ft}$$

$$M_{utoe} := M_{utoeOS} - M_{utoeR} = 26.571 \ \frac{kip \cdot ft}{ft}$$

$$f_c := 4 \cdot ksi$$

$$A_{sbot1} := \frac{A_{sbot}}{1 \cdot ft} = 0.442 \ \frac{in^2}{ft}$$

$$a_{toe} := \frac{\frac{12 \cdot in}{s_{bot}} \cdot A_{sbot} \cdot f_y}{0.85 \cdot 12 \cdot in \cdot f_c} = 0.975 \ in$$

$$M_{ntoe} := \frac{12 \cdot in}{s_{bot}} \cdot A_{sbot1} \cdot f_y \cdot \left(d_{toe} - \frac{a_{toe}}{2}\right) = 46.844 \ \frac{kip \cdot ft}{ft}$$

$$\phi_{wall} = 0.9$$

$$PhiMn_{toe} := \phi_{wall} \cdot M_{ntoe} = 42.16 \ \frac{kip \cdot ft}{ft}$$

$$Bendtoe_{Interaction} := \frac{M_{utoe}}{PhiMn_{toe}} = 0.63$$