Input

β = Inclination of Ground Slope Behind Face of wall (degrees)

Back slope angle $\beta := \left| \begin{array}{l} x \leftarrow \operatorname{atan}\left(\frac{0ft - 0ft}{50ft}\right) \\ \operatorname{if}(x > 0, x, 0) \end{array} \right.$ $\beta = 0 \cdot deg$

Length of wall $l_{wall} := 43.5ft$ (Approximately 43.5 ft WP to WP)

Height of wall $h_{wall} := 1632.75\ ft - 1619ft$ (Top of Wall to Bottom of Footing) $h_{wall} = 13.75\ ft$

Height of bridge seat $h_{seat} := 1629.6ft - 1619ft = 10.6\ ft$

Thickness of stem $t_{stem} := 2\ ft$

Length of toe $l_{toe} := 2ft$

Length of heel $l_{heel} := 4ft$

Thickness of footing $t_{foot} := 2.5\ ft$

Unit weight of retained soil $\gamma_{ret.sat} := 135\ pcf$

$\gamma_{ret.dry} := 120\ pcf$

Friction angle of retained soil $\phi'_{f.ret} := 35\ deg$ (Based on Geotechnical Report and/or Table 10.4.6.2.4-1)

Elevation of Bottom of Footing $elev_{foot} := 1619ft$ *Assume ledge is approximately 2.5 feet below the top of footing. If ledge is lower than elevation 1619, then will need to pour flat concrete sub footing up to elevation 1619 to build footing onto.

Elevation of Groundwater $elev_{grdwa} := 1618.5\ ft$ (From Geotechnical Report ... use 0 if water not encountered. Assumed elevation of OHW)

Elevation of water surface at Q10 $elev_{q10} := 1620.4\ ft$

Height of equivalent surcharge $h_s := 2.5ft$ (Table 3.11.6.4-1 Equivalent Height of Soil for Vehicular Loading on Abutments Perpendicular to Traffic.)

Foundation bearing material Rock

Footing method Pre-cast

Nominal bearing resistance on rock $q_{n.rock} := 70\ ksf$ (From Geotechnical Report) $q_{n.rock} = 486.111\ psi$

Concrete Class Precast

Concrete cover $d_c := 3in$

Stem Steel & Toe Steel: # 5 @ 12 in Alternate with None @ 12

Heel Steel: # 5 @ 12 in

Transverse reinforcing: # 5 @ 12 in

Go to Results

Friction angle between fill and wall taken as specified in Table 3.11.5.3-1 Friction Angle for Dissimilar Materials (U.S. Department of the Navy 1982a).

$\delta_{ka} := 35deg$

Angle of back face of wall to the horizontal as shown in Figure 3.11.5.3-1

$\theta_{ka} := 90deg$

Load Factors (3.4.1)

$\gamma_{DC.max} := 1.25$ $\gamma_{EH.max} := 1.50$ $\gamma_{EV.max} := 1.35$ $\gamma_{LS.max} := 1.75$

$\gamma_{DC.min} := 0.90$ $\gamma_{WA} := 1.00$ $\gamma_{EV.min} := 1.00$ $\gamma_{LS.min} := 0.00$

Per foot design	$b := 1ft$
Unit weight of concrete	$\gamma_{conc} := 150 \frac{lbf}{ft^3}$
Unit weight of water	$\gamma_{wa} := 62.4pcf$
Unit weight of granular backfill	$\gamma_{fill.sat} := 140pcf$ $\gamma_{fill.dry} := 125pcf$
Friction angle of granular backfill	$\phi'_{f.fill} := 34deg$
Yield strength of steel	$f_y := 60ksi$
Resistance Factor for Tension Controlled Concrete (5.5.4.2.1)	$\phi_f := 0.90$
Resistance Factor for Shear (5.5.4.2.1)	$\phi_v := 0.90$

				1		10.6
	Factors		Vertical		Horizontal	
Description	Bearing	Sliding	Load	Offset from CL Bearing	Load	Offset from BS
Superstructure Dead	1.25	0.90	161.80	0.00		
Superstructure Wearing	1.50	0.65	30.40	0.00		
Approach Slab	1.25	0.90	57.51	1.00		
Live Load	1.75	0.00	372.80	0.00		
Braking	1.75	0.00			36.00	0.00

Calculations from Input

Height of water above bottom of footing (heel) $h_{wa} := \max(elev_{q10}, elev_{grdwa}, elev_{foot}) - elev_{foot}$ $h_{wa} = 1.4\,ft$

(toe) $h_{wa.toe} := \max(\min(elev_{q10}, elev_{grdwa}), elev_{foot}) - elev_{foot}$ $h_{wa.toe} = 0\,ft$

Table 10.5.5.2.2-1 Resistance Factors for Geotechnical Resistance of Shallow Foundations at the Strength Limit State.

Bearing Resistance $\phi_b := if(bear_{mat} = \text{"Clay"}, 0.50, 0.45)$ $\phi_b = 0.45$

Sliding Resistance $\phi_t := if(bear_{mat} = \text{"Clay,"}, 0.85, if(meth_{foot} = \text{"Cast-in-Place"}, 0.80, 0.90))$ $\phi_t = 0.9$

Earth Pressure Coefficients

$$\Gamma_{ka}(\phi'_f) := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_{ka})\sin(\phi'_f - \beta)}{\sin(\theta_{ka} - \delta_{ka})\sin(\theta_{ka} + \beta)}}\right)^2$$

$$k_a(\phi'_f) := \frac{\sin(\theta_{ka} + \phi'_f)^2}{\Gamma_{ka}(\phi'_f)\cdot(\sin(\theta_{ka})^2\cdot\sin(\theta_{ka} - \delta_{ka}))}$$

$k_{a.fill} := k_a(\phi'_{f.fill})$ $k_{a.fill} = 0.259$

$k_{a.ret} := k_a(\phi'_{f.ret})$ $k_{a.ret} = 0.25$

Weights

Height of stem	$h_{stem} := h_{wall} - t_{foot}$	$h_{stem} = 11.25\,ft$
Weight of stem	$w_{stem} := \gamma_{conc} \cdot t_{stem} \cdot h_{stem} \cdot b$	$w_{stem} = 3.375 \cdot kip$
Length of footing	$l_{foot} := l_{toe} + t_{stem} + l_{heel}$	$l_{foot} = 8\,ft$
Weight of footing	$w_{foot} := \gamma_{conc} \cdot l_{foot} \cdot t_{foot} \cdot b$	$w_{foot} = 3 \cdot kip$
Height of saturated fill	$h_{fill.sat} := if(h_{wa} > t_{foot}, h_{wa} - t_{foot}, 0)$	$h_{fill.sat} = 0\,ft$
Weight of soil 1	$w_{soil.1} := \left[\left(\gamma_{fill.sat} - \gamma_{wa}\right) \cdot h_{fill.sat} + \gamma_{fill.dry} \cdot \left(h_{stem} - h_{fill.sat}\right)\right] \cdot l_{heel} \cdot b$	$w_{soil.1} = 5.625 \cdot kip$
Height of soil 2	$h_{soil.2} := l_{heel} \cdot \tan(\beta)$	$h_{soil.2} = 0\,ft$
Weight of soil 2	$w_{soil.2} := 0.5 \cdot l_{heel} \cdot h_{soil.2} \cdot \gamma_{fill.dry} \cdot b$	$w_{soil.2} = 0 \cdot kip$
Height of retained soil	$h_{ret.dry} := h_{wall} + h_{soil.2} - h_{wa}$	$h_{ret.dry} = 12.35\,ft$
Force of retained soil	$F_{ret.dry} := 0.5 \cdot \gamma_{ret.dry} \cdot k_{a.ret} \cdot h_{ret.dry}^2 \cdot b$	$F_{ret.dry} = 2.285 \cdot kip$
	$F_{ret.sat.1} := \gamma_{ret.dry} \cdot k_{a.ret} \cdot h_{ret.dry} \cdot h_{wa} \cdot b$	$F_{ret.sat.1} = 0.518 \cdot kip$
	$F_{ret.sat.2} := 0.5\left(\gamma_{ret.sat} - \gamma_{wa}\right) \cdot k_{a.ret} \cdot h_{wa}^2 \cdot b$	$F_{ret.sat.2} = 0.018 \cdot kip$
Weight of surcharge	$w_s := \gamma_{fill.dry} \cdot h_s \cdot l_{heel} \cdot b$	$w_s = 1.25 \cdot kip$
Weight of water	$w_{wa} := \gamma_{wa} \cdot h_{wa} \cdot l_{heel} \cdot b$	$w_{wa} = 0.349 \cdot kip$
	$w_{wa.toe} := \gamma_{wa} \cdot h_{wa.toe} \cdot l_{toe} \cdot b$	$w_{wa.toe} = 0 \cdot kip$

Horizontal Forces

Force of surcharge	$F_s := k_{a.ret} \cdot \gamma_{fill.dry} \cdot h_s \cdot \left(h_{wa} + h_{ret.dry}\right) \cdot b$	$F_s = 1.073 \cdot kip$
Force of water (heel)	$F_{wa} := 0.5 \cdot \gamma_{wa} \cdot h_{wa}^2 \cdot b$	$F_{wa} = 0.061 \cdot kip$
(toe)	$F_{wa.toe} := 0.5 \cdot \gamma_{wa} \cdot h_{wa.toe}^2 \cdot b$	$F_{wa.toe} = 0 \cdot kip$

Horizontal distance from toe to centroid

$x_{stem} := l_{toe} + 0.5t_{stem}$ $x_{stem} = 3\ ft$

$x_{foot} := 0.5l_{foot}$ $x_{foot} = 4\ ft$

$x_{soil.1} := l_{toe} + t_{stem} + 0.5l_{heel}$ $x_{soil.1} = 6\ ft$

$x_{soil.2} := l_{toe} + t_{stem} + \frac{2}{3}l_{heel}$ $x_{soil.2} = 6.667\ ft$

$x_{ret} := l_{foot}$ $x_{ret} = 8\ ft$

$x_s := l_{toe} + t_{stem} + 0.5l_{heel}$ $x_s = 6\ ft$

$x_{wa} := l_{toe} + t_{stem} + 0.5l_{heel}$ $x_{wa} = 6\ ft$

$x_{wa.toe} := 0.5 \cdot l_{toe}$ $x_{wa.toe} = 1\ ft$

Vertical distance from bottom of footing to Force centroid

$y_{ret.dry} := h_{wa} + \frac{1}{3}h_{ret.dry}$ $y_{ret.dry} = 5.517\ ft$

$y_{ret.sat.1} := 0.5 \cdot h_{wa}$ $y_{ret.sat.1} = 0.7\ ft$

$y_{ret.sat.2} := \frac{1}{3}h_{wa}$ $y_{ret.sat.2} = 0.467\ ft$

$y_s := 0.5\left(h_{wa} + h_{ret.dry}\right)$ $y_s = 6.875\ ft$

$y_{wa} := \frac{1}{3}h_{wa}$ $y_{wa} = 0.467\ ft$

$y_{wa.toe} := \frac{1}{3}h_{wa.toe}$ $y_{wa.toe} = 0\ ft$

11.6.3.2 Bearing Resistance

Determine Vertical Loads, Moments and Eccentricity for Bearing (See 11.5.5 For Free Body Diagram)

$$V_b := \gamma_{DC.max}\left(w_{stem} + w_{foot}\right) + \gamma_{EV.max}\left(w_{soil.1} + w_{soil.2}\right) \ldots + \gamma_{EH.max}\left(F_{ret.dry} + F_{ret.sat.1} + F_{ret.sat.2}\right)\cdot\sin(\beta) + \gamma_{LS.max}\, w_s + \gamma_{WA}\left(w_{wa} + w_{wa.toe}\right) \ldots + Load_{b.vert} \qquad V_b = 40.447\cdot kip$$

$$M_b := \gamma_{DC.max}\cdot\left[w_{stem}\cdot\left(0.5l_{foot} - x_{stem}\right) + w_{foot}\cdot\left(0.5l_{foot} - x_{foot}\right)\right] \ldots + \gamma_{EV.max}\cdot\left[w_{soil.1}\cdot\left(0.5l_{foot} - x_{soil.1}\right) + w_{soil.2}\cdot\left(0.5l_{foot} - x_{soil.2}\right)\right] \ldots + \gamma_{EH.max}\cdot\left(F_{ret.dry} + F_{ret.sat.1} + F_{ret.sat.2}\right)\cdot\sin(\beta)\cdot\left(0.5l_{foot} - x_{ret}\right) + \gamma_{LS.max}\cdot w_s\cdot\left(0.5l_{foot} - x_s\right) + \gamma_{WA}\cdot w_{wa}\cdot\left(0.5l_{foot} - x_{wa}\right) \ldots + \gamma_{EH.max}\cdot\left(F_{ret.dry}\cdot y_{ret.dry} + F_{ret.sat.1}\cdot y_{ret.sat.1} + F_{ret.sat.2}\cdot y_{ret.sat.2}\right)\cdot\cos(\beta) + \gamma_{LS.max}\cdot F_s\cdot y_s \ldots + \gamma_{WA}\cdot F_{wa}\cdot y_{wa} - \gamma_{WA}\cdot F_{wa.toe}\cdot y_{wa.toe} + \gamma_{WA}\cdot w_{wa.toe}\cdot\left(0.5l_{foot} - x_{wa.toe}\right) \ldots + Load_{b.mom} \qquad M_b = 55.715\,ft\cdot kip$$

$$e_b := \frac{M_b}{V_b} \qquad e_b = 1.377\,ft$$

Where the wall is supported by a soil foundation: the vertical stress shall be calculated assuming a uniformly distributed pressure over an effective base area as shown in Figure 1.

Effective footing width

$$l_{foot.eff} := l_{foot} - 2e_b \qquad l_{foot.eff} = 5.245\,ft$$

$$\sigma_{v.soil} := \frac{V_b}{l_{foot.eff}\cdot b} \qquad \sigma_{v.soil} = 53.552\,psi$$

Where the wall is supported by a rock foundation: the vertical stress shall be calculated assuming a linearly distributed pressure over an effective base area as shown in Figure 2.

If the resultant is within the middle one-third of the base,

$$\sigma_{v.rock.max.1} := \frac{V_b}{l_{foot}\cdot b}\cdot\left(1 + 6\cdot\frac{e_b}{l_{foot}}\right) \qquad \sigma_{v.rock.max.1} = 71.383\,psi$$

$$\sigma_{v.rock.min.1} := \frac{V_b}{l_{foot}\cdot b}\cdot\left(1 - 6\cdot\frac{e_b}{l_{foot}}\right) \qquad \sigma_{v.rock.min.1} = -1.162\,psi$$

If the resultant is outside the middle one-third of the base,

$$\sigma_{v.rock.max.2} := \frac{2\cdot V_b}{3\cdot\left(0.5l_{foot} - e_b\right)\cdot b} \qquad \sigma_{v.rock.max.2} = 71.403\,psi$$

$$\sigma_{v.rock.min.2} := 0$$

$$\sigma_{v.max} := \text{if}\left(bear_{mat} \neq \text{"Rock"}, \sigma_{v.soil}, \text{if}\left(\frac{l_{foot}}{6} \geq e_b, \sigma_{v.rock.max.1}, \sigma_{v.rock.max.2}\right)\right) \qquad \sigma_{v.max} = 71.403\,psi$$

$$\sigma_{v.min} := \text{if}\left(bear_{mat} \neq \text{"Rock"}, \sigma_{v.soil}, \text{if}\left(\frac{l_{foot}}{6} \geq e_b, \sigma_{v.rock.min.1}, \sigma_{v.rock.min.2}\right)\right) \qquad \sigma_{v.min} = 0\,psi$$

Determine location of minimum pressure

$$x_{min.press} := \min\left[l_{foot}, 3\cdot\left(0.5l_{foot} - e_b\right)\right] \qquad x_{min.press} = 7.868\,ft$$

11.6.3.3 Overturning

For foundations on soil, the location of the resultant of the reaction forces shall be within the middle one-half of the base width.
For foundations on rock, the location of the resultant of the reaction forces shall be within the middle three-fourths of the base width.

$\frac{l_{foot}}{4} = 2\,ft$ $\frac{3l_{foot}}{8} = 3\,ft$ $e_b = 1.377\,ft$

$Global_{rows(Global)+1} := Check\left[\text{"Overturning"}, \left[\left(bear_{mat} = \text{"Rock"}\right) \text{ AND } \left(\frac{3l_{foot}}{8} \ge e_b\right)\right] \text{ OR } \left(\frac{l_{foot}}{4} \ge e_b\right)\right]$

10.6.1.5 Anchorage of Inclined Footings

Footings that are founded on inclined smooth solid rock surfaces and that are not restrained by an overburden of resistant material shall be effectively anchored by means of rock anchors, rock bolts, dowels, keys or other suitable means. Shallow keying of large footings shall be avoided where blasting is required for rock removal.
Design of anchorages should include consideration of corrosion potential and protection.

10.6.2.4 Settlement Analyses

Settlement on competent rock is not an issue and will not be calculated here.

10.6.2.5 Overall Stability

Overall stability on competent rock is not an issue and will not be calculated here.

10.6.3.1 Bearing Resistance of Soil

When calculating the Bearing Resistance on Soil, this spreadsheet does not consider the effects of Overburden or Cohesion (For Clays)

Vesic Weight Factor (Table 10.6.3.1.2-1) $N_\gamma := linterp\left(Vesic_{wtfact}^{\langle 1\rangle}, Vesic_{wtfact}^{\langle 2\rangle}, \frac{\phi'_{f.ret}}{deg}\right)$ $N_\gamma = 48$

Groundwater Correction Factor

$$C_{w\gamma} := \begin{cases} .5 & \text{if } elev_{grdwa} > elev_{foot} \\ linterp\left[\begin{pmatrix} elev_{foot} - 1.5l_{foot.eff} \\ elev_{foot} \end{pmatrix}, \begin{pmatrix} 1.0 \\ 0.5 \end{pmatrix}, elev_{grdwa}\right] & \text{if } elev_{foot} \ge elev_{grdwa} \ge elev_{foot} - 1.5l_{foot.e} \\ 1.0 & \text{otherwise} \end{cases}$$

$C_{w\gamma} = 0.532$

$q_{n.soil} := 0.5 \cdot \gamma_{ret.dry} \cdot l_{foot.eff} \cdot N_\gamma \cdot C_{w\gamma}$ $q_{n.soil} = 55.784\,psi$

$q_{r.soil} := \phi_b \cdot q_{n.soil}$ $q_{r.soil} = 25.103\,psi$

10.6.3.2 Bearing Resistance of Rock

$q_{r.rock} := \phi_b \cdot q_{n.rock}$ $q_{r.rock} = 218.75 \cdot psi$

$Global_{rows(Global)+1} := Check\left(\text{"Bearing"}, \sigma_{v.max} \le if\left(bear_{mat} = \text{"Rock"}, q_{r.rock}, q_{r.soil}\right)\right)$ $\sigma_{v.max} = 71.403\,psi$

10.6.3.4 Failure by Sliding

Determine Vertical and Horizontal Forces for Sliding (See 11.5.5 For Free Body Diagram)

$$V_s := \gamma_{DC.min}\left(w_{stem} + w_{foot}\right) + \gamma_{EV.min}\left(w_{soil.1} + w_{soil.2}\right) + \gamma_{EH.max}\left(F_{ret.dry} + F_{ret.sat.1} + F_{ret.sat.2}\right)\cdot\sin(\beta) + \gamma_{LS.min}\, w_s \ldots + \gamma_{WA}\left(w_{wa} + w_{wa.toe}\right) + Load_{s.vert}$$

$$V_s = 16703.641\ \text{lbf}$$

$$P_s := \gamma_{EH.max}\cdot\left(F_{ret.dry} + F_{ret.sat.1} + F_{ret.sat.2}\right)\cdot\cos(\beta) + \gamma_{LS.max}\cdot F_s + \gamma_{WA}\cdot F_{wa} - \gamma_{WA}\cdot F_{wa.toe} + Load_{s.horz}$$

$$P_s = 6.171\cdot\text{kip}$$

Determine the coefficient of friction - Per Bridge Manual 15.1.2: Design spread footings that are not founded on solid rock on either compacted granular material, a natural subsoil of A-2 material or better, or a compacted layer of Granular Backfill for Structures.

$$\mu_s := \text{if}\left(bear_{mat} = \text{"Rock"}, .70, .55\right)\cdot\text{if}\left(meth_{foot} = \text{"Cast-in-Place"}, 1.00, 0.80\right) \qquad \mu_s = 0.56$$

$$R_t := V_s\cdot\mu_s \qquad R_t = 9.354\cdot\text{kip}$$

$$R_r := \phi_t\cdot R_t \qquad R_r = 8.419\cdot\text{kip}$$

$$Global_{rows(Global)+1} := \text{Check}\left(\text{"Sliding"}, P_s \le R_r\right)$$

10.6.4 Extreme Event Limit State Design

No extreme events (scour, earthquake, ice, vehicle or vessel impact loads) are anticipated at this substructure unit.

Check Stem Design

Calculate Stem Loads - Miscellaneous Input Loads not Currently Included

$$h_{top.wa} := h_{stem} - \left(h_{wa} - t_{foot}\right) \qquad h_{top.wa} = 12.35\ \text{ft}$$

$$h_{top.wa.toe} := h_{stem} - \left(h_{wa.toe} - t_{foot}\right) \qquad h_{top.wa.toe} = 13.75\ \text{ft}$$

$$\begin{aligned} F_h(z) := {} & \gamma_{EH.max}\cdot\text{if}\left[0 \le z \le h_{top.wa}, 0.5\cdot\gamma_{ret.dry}\cdot k_{a.ret}\cdot\left(z + h_{soil.2}\right)^2\cdot b, 0\right]\cdot\cos(\beta) \ldots \\ & + \gamma_{EH.max}\cdot\text{if}\left[h_{top.wa} \le z \le h_{stem}, 0.5\cdot\gamma_{ret.dry}\cdot k_{a.ret}\cdot\left(h_{top.wa} + h_{soil.2}\right)^2\cdot b + \gamma_{ret.dry}\cdot k_{a.ret}\cdot h_{ret.dry}\cdot\left(z - h_{top.wa}\right)\cdot b, 0\right]\cdot\cos(\beta) \ldots \\ & + \gamma_{EH.max}\cdot\text{if}\left[h_{top.wa} \le z \le h_{stem}, 0.5\left(\gamma_{ret.sat} - \gamma_{wa}\right)\cdot k_{a.ret}\cdot\left(z - h_{top.wa}\right)^2\cdot b, 0\right]\cdot\cos(\beta) \ldots \\ & + \gamma_{LS.max}\cdot\text{if}\left[0 \le z \le h_{stem}, k_{a.ret}\cdot\gamma_{fill.dry}\cdot h_s\cdot\left(z + h_{soil.2}\right)\cdot b, 0\right] \ldots \\ & + \gamma_{WA}\cdot\text{if}\left[h_{top.wa} \le z \le h_{stem}, 0.5\gamma_{wa}\cdot\left(z - h_{top.wa}\right)^2 b, 0\right] \ldots \\ & + \gamma_{WA}\cdot\text{if}\left[h_{top.wa.toe} \le z \le h_{stem}, 0.5\gamma_{wa}\cdot\left(z - h_{top.wa.toe}\right)^2 b, 0\right] \end{aligned} \qquad F_h\left(h_{stem}\right) = 4.381\cdot\text{kip}$$

$$z_{bar}(z) := \frac{\int_0^z z\cdot F_h(z)\,dz}{\int_0^z F_h(z)\,dz} \qquad z_{bar}\left(h_{stem}\right) = 8.018\ \text{ft}$$

$$M_h(z) := F_h(z)\cdot\left(z - z_{bar}(z)\right)$$

Calculate distance from extreme compression fiber to the centroid of the nonprestressed tensile reinforcement

$$d_{s.stem} := t_{stem} - d_c - 0.5 d_{b.stem} \qquad d_{s.stem} = 1.724\ \text{ft}$$

Moment Calculations

$$M_{u.stem} := M_h\left(h_{stem}\right)$$

$M_{u.stem} = 14.159\ ft \cdot kip$

$M_{r.stem} := M_r(A_{s.stem}, d_{s.stem})$

$Stem_{rows(Stem)+1} := Check(\text{"Moment Capacity"}, M_{r.stem} \geq M_{u.stem})$ $M_{r.stem} = 28.605\ ft \cdot kip$

Steel Checks

$Stem_{rows(Stem)+1} := CheckMaxReinforce(A_{s.stem}, d_{s.stem})$

$Stem_{rows(Stem)+1} := CheckMinReinforce(M_{u.stem}, M_{r.stem}, t_{stem})$

$s_{crack} := CrackSpacing\left(A_{s.stem}, d_{s.stem}, \frac{M_{u.stem}}{\gamma_{EH.max}}, d_c, t_{stem}, 1\right)$ $s_{crack} = 26.624 \cdot in$

$Stem_{rows(Stem)+1} := Check(\text{"Crack Control"}, s_{stem} \leq s_{crack})$ $s_{stem} = 12 \cdot in$

$Stem_{rows(Stem)+1} := CheckShrinkTemp(A_{s.tran}, l_{wall}, t_{stem})$

$Stem_{rows(Stem)+1} := CheckSTSpace(s_{tran} \cdot in, t_{stem})$

Shear Calculations - Miscellaneous Input Loads not Currently Included

$V_{u.stem} := F_h(h_{stem} - d_{s.stem})$ $V_{u.stem} = 3.34 \cdot kip$

$V_{r.stem} := V_r(A_{s.stem}, d_{s.stem}, t_{stem})$ $V_{r.stem} = 31.296 \cdot kip$

$Stem_{rows(Stem)+1} := Check(\text{"Shear Capacity"}, V_{u.stem} \leq 0.5 \cdot V_{r.stem})$ 5.8.2.4

Interface Shear

Assume intentionally roughened surface for the construction joint with no additional interface shear steel and no compressive help.

5.8.4.3 Cohesion and Friction Factors

$c_v := 0.24ksi$

$\mu_v := 1.0$

$K_1 := 0.25$

$K_2 := 1.5ksi$

$A_{vf} := 0in^2$

$P_c := 0kip$

$A_{cv} := b \cdot d_{s.stem}$ $A_{cv} = 1.724\ ft^2$

$A_{vf.min} := \frac{0.05 \cdot ksi \cdot A_{cv}}{f_y \cdot b}$ $A_{vf.min} = 0.207 \cdot \frac{in^2}{ft}$

$Stem_{rows(Stem)+1} := Check(\text{"Interface Shear Steel"}, A_{s.stem} \geq A_{vf.min})$

$V_{ri} := \phi_v \cdot min\left[c_v \cdot A_{cv} + \mu_v \cdot (A_{vf} \cdot f_y + P_c), K_1 \cdot f'_c \cdot A_{cv}, K_2 \cdot A_{cv}\right]$ $V_{ri} = 53.622 \cdot kip$

$Stem_{rows(Stem)+1} := Check(\text{"Interface Shear Capacity"}, V_{u.stem} \leq V_{ri})$

Check Heel Design

Weight of heel

$w_{heel} := \gamma_{conc} \cdot t_{foot} \cdot l_{heel} \cdot b$ $\qquad w_{heel} = 1.5 \cdot kip$

Horizontal distance from toe to centroid

$x_{heel} := l_{toe} + t_{stem} + 0.5 l_{heel}$ $\qquad x_{heel} = 6\ ft$

$x_{cr.heel} := l_{toe} + t_{stem}$ $\qquad x_{cr.heel} = 4\ ft$

Calculate distance from extreme compression fiber to the centroid of the nonprestressed tensile reinforcement

$d_{s.heel} := t_{foot} - d_c - 0.5 d_{b.heel}$ $\qquad d_{s.heel} = 2.224\ ft$

Moment Calculations - Miscellaneous Input Loads not Currently Included

$$M_{u.heel} := \gamma_{DC.max} w_{heel} \cdot (x_{heel} - x_{cr.heel}) + \gamma_{EV.max}\left[w_{soil.1} \cdot (x_{soil.1} - x_{cr.heel}) + w_{soil.2} \cdot (x_{soil.2} - x_{cr.heel})\right] \ldots$$
$$+ \gamma_{EH.max}(F_{ret.dry} + F_{ret.sat.1} + F_{ret.sat.2}) \cdot \sin(\beta) \cdot (l_{foot} - x_{cr.heel}) + \gamma_{LS.max} w_s \cdot (x_{heel} - x_{cr.heel}) \ldots$$
$$+ \gamma_{WA} w_{wa} \cdot (x_{heel} - x_{cr.heel})$$

$M_{u.heel} = 24.011\ ft \cdot kip$

$M_{r.heel} := M_r(A_{s.heel}, d_{s.heel})$ $\qquad M_{r.heel} = 36.975\ ft \cdot kip$

$Heel_{rows(Heel)+1} := Check(\text{"Moment Capacity"}, M_{u.heel} \le M_{r.heel})$

Steel Checks

$Heel_{rows(Heel)+1} := CheckMaxReinforce(A_{s.heel}, d_{s.heel})$

$Heel_{rows(Heel)+1} := CheckMinReinforce(M_{u.heel}, M_{r.heel}, t_{foot})$

Shear Calculations - Miscellaneous Input Loads not Currently Included

$$V_{u.heel} := \gamma_{DC.max} w_{heel} + \gamma_{EV.max}(w_{soil.1} + w_{soil.2}) + \gamma_{EH.max}(F_{ret.dry} + F_{ret.sat.1} + F_{ret.sat.2}) \cdot \sin(\beta) + \gamma_{LS.max} w_s + \gamma_{WA} w_{wa}$$

$V_{u.heel} = 12.006 \cdot kip$

$$V_{u.soil} := \begin{cases} \sigma_{v.x} \leftarrow \text{linterp}\left[\begin{pmatrix} 0 \\ x_{min.press} \end{pmatrix}, \begin{pmatrix} \sigma_{v.max} \\ \sigma_{v.min} \end{pmatrix}, l_{toe} + t_{stem}\right] \\ \quad \frac{1}{2} \cdot (x_{min.press} - l_{toe} - t_{stem}) \cdot (\sigma_{v.x} + \sigma_{v.min}) \cdot b & \text{if } bear_{mat} = \text{"Rock"} \\ \sigma_{v.max} \cdot (l_{foot.eff} - l_{toe} - t_{stem}) \cdot b & \text{otherwise} \end{cases}$$

$V_{u.soil} = 9.774 \cdot kip$

$V_{u.heel.net} := V_{u.heel} - V_{u.soil}$ $\qquad V_{u.heel.net} = 2.231 \cdot kip$

$V_{r.heel} := V_r(A_{s.heel}, d_{s.heel}, t_{foot})$ $\qquad V_{r.heel} = 40.453 \cdot kip$

$Heel_{rows(Heel)+1} := Check(\text{"Shear Capacity"}, V_{u.heel.net} \le V_{r.heel})$

$Heel_{rows(Heel)+1} := Check(\text{"Min Footing Thickness"}, t_{foot} \ge 600mm)$

Check Toe Design

Calculate distance from extreme compression fiber to the centroid of the nonprestressed tensile reinforcement

$d_{s.toe} := t_{foot} - d_c - 0.5d_{b.stem}$ $\qquad d_{s.toe} = 2.224\,ft$

Moment Calculations

$\sigma_{min.toe.m} := linterp\left[\begin{pmatrix} 0 \\ x_{min.press} \end{pmatrix}, \begin{pmatrix} \sigma_{v.max} \\ \sigma_{v.min} \end{pmatrix}, l_{toe}\right]$ $\qquad \sigma_{min.toe.m} = 53.252\,psi$

$M_{u.toe} := \sigma_{min.toe.m} \cdot l_{toe} \cdot b \cdot \frac{1}{2} \cdot l_{toe} + \frac{1}{2} \cdot \left(\sigma_{v.max} - \sigma_{min.toe.m}\right) \cdot l_{toe} \cdot b \cdot \frac{2}{3} l_{toe}$ $\qquad M_{u.toe} = 18.822\,ft \cdot kip$

$M_{r.toe} := M_r\left(A_{s.stem}, d_{s.toe}\right)$ $\qquad M_{r.toe} = 36.975\,ft \cdot kip$

$Toe_{rows(Toe)+1} := Check\left(\text{"Moment Capacity"}, M_{u.toe} \le M_{r.toe}\right)$

Steel Checks

$Toe_{rows(Toe)+1} := CheckMaxReinforce\left(A_{s.stem}, d_{s.toe}\right)$

$Toe_{rows(Toe)+1} := CheckMinReinforce\left(M_{u.toe}, M_{r.toe}, t_{foot}\right)$

Shear Calculations

Determine location of shear

$x_{v.toe} := if\left(l_{toe} - d_{s.toe} > 0, l_{toe} - d_{s.toe}, 0\right)$ $\qquad x_{v.toe} = 0\,ft$

$\sigma_{min.toe.v} := linterp\left[\begin{pmatrix} 0 \\ x_{min.press} \end{pmatrix}, \begin{pmatrix} \sigma_{v.max} \\ \sigma_{v.min} \end{pmatrix}, x_{v.toe}\right]$ $\qquad \sigma_{min.toe.v} = 71.403\,psi$

$V_{u.toe} := \sigma_{min.toe.v} \cdot x_{v.toe} \cdot b + \frac{1}{2} \cdot \left(\sigma_{v.max} - \sigma_{min.toe.v}\right) \cdot x_{v.toe} \cdot b$ $\qquad V_{u.toe} = 0 \cdot kip$

$V_{r.toe} := V_r\left(A_{s.stem}, d_{s.toe}, t_{foot}\right)$ $\qquad V_{r.toe} = 40.453 \cdot kip$

$Toe_{rows(Toe)+1} := Check\left(\text{"Shear Capacity"}, V_{u.toe} \le V_{r.toe}\right)$

Results Summary

$$Global = \begin{pmatrix} \text{"Overturning OK"} \\ \text{"Bearing OK"} \\ \text{"Sliding OK"} \end{pmatrix}$$

Go to Overturning

Go to Bearing

Go to Sliding

$$Stem = \begin{pmatrix} \text{"Moment Capacity OK"} \\ \text{"Max Reinforcing OK"} \\ \text{"Min Reinforcing OK"} \\ \text{"Crack Control OK"} \\ \text{"Shrinkage \& Temp OK"} \\ \text{"S \& T Spacing OK"} \\ \text{"Shear Capacity OK"} \\ \text{"Interface Shear Steel OK"} \\ \text{"Interface Shear Capacity OK"} \end{pmatrix}$$

Go to Stem

$$Heel = \begin{pmatrix} \text{"Moment Capacity OK"} \\ \text{"Max Reinforcing OK"} \\ \text{"Min Reinforcing OK"} \\ \text{"Shear Capacity OK"} \\ \text{"Min Footing Thickness OK"} \end{pmatrix}$$

Go to Heel

$$Toe = \begin{pmatrix} \text{"Moment Capacity OK"} \\ \text{"Max Reinforcing OK"} \\ \text{"Min Reinforcing OK"} \\ \text{"Shear Capacity OK"} \end{pmatrix}$$

Go to Toe

Go to Input

Quantities & Costs

$$qty_{conc} := \frac{w_{stem} + w_{foot}}{\gamma_{conc}}$$ $qty_{conc} = 317.922\ gal$

$$cost_{conc} := price_{conc} \cdot qty_{conc}$$ $cost_{conc} = 1180.556$

$$qty_{steel} := \gamma_{steel} \cdot \left(A_{s.stem} \cdot l_{stem.steel} \cdot b + A_{s.heel} \cdot l_{heel.steel} \cdot b + A_{s.tran} \cdot b \cdot h_{stem}\right)$$ $qty_{steel} = 37.448 \cdot lbf$

$$cost_{steel} := price_{steel} \cdot qty_{steel}$$ $cost_{steel} = 56.171$

$$Total_{cost} := concat\left[\text{" \$"}, num2str\left[round\left[\left(cost_{conc} + cost_{steel}\right) \cdot \frac{l_{wall}}{ft}, 0\right]\right]\right]$$ $Total_{cost} = \text{" \$53798"}$

Stem Design Table

$h_{stem.inc} := mod(h_{stem}, 1ft), mod(h_{stem}, 1ft) + 1ft .. h_{stem}$

$A_{s.req}(M_h(h_{stem.inc}), d_{s.stem}, t_{stem}) =$

$h_{stem.inc} =$			
0.25	ft	0	$\cdot \frac{in^2}{ft}$
1.25		0.001	
2.25		0.004	
3.25		0.01	
4.25		0.018	
5.25		0.03	
6.25		0.046	
7.25		0.067	
8.25		0.092	
9.25		0.123	
10.25		0.16	
11.25		0.203	

$OR(a, b) := a \vee b$

$AND(a, b) := a \wedge b$

$Check(a, b) := concat(a, " ", if(b, "OK", "Fails"))$

Initialize Variables

$Global_1 := 0$

$Stem_1 := 0$

$Heel_1 := 0$

$Toe_1 := 0$

Table 10.4.6.2.4-1 Correlation of *SPT* $N1_{60}$ Values to Drained Friction Angle of Granular Soils (modified after *Bowles, 1977*).

$N1_{60}$	ϕ_f
<4	25–30
4	27–32
10	30–35
30	35–40
50	38–43

$table_{concrete} :=$

	1	2	3
1	"HPC A"	4000	3605
2	"HPC B"	3500	3372
3	"Class C"	3000	3122
4	"Class D"	2500	2850
5	"Precast"	5000	4031
6			

$table_{reinf} :=$

	1	2	3
1	"# 3"	0.375	0.11
2	"# 4"	0.5	0.2
3	"# 5"	0.625	0.31
4	"# 6"	0.75	0.44
5	"# 7"	0.875	0.6
6	"# 8"	1	0.79
7	"# 9"	1.128	1
8	"# 10"	1.27	1.27
9	"# 11"	1.41	1.56
10	"# 14"	1.693	2.25
11	"# 18"	2.257	4
12	"None"	0	0

MARGIN OF SHEET 1

$f'_c := \text{vlookup}(class_{conc}, table_{concrete}, 2)_{1,1}\,psi \qquad f'_c = 5 \cdot ksi$

$A_{s.stem} := \text{vlookup}(bar_{stem.1}, table_{reinf}, 3)_{1,1} \cdot in^2 \cdot \frac{1}{s_{stem.1} \cdot in} + \text{if}\left(bar_{stem.2} = \text{"None"}, 0, \text{vlookup}(bar_{stem.2}, table_{reinf}, 3)_{1,1} \cdot in^2 \cdot \frac{1}{s_{stem.2} \cdot in}\right)$

$d_{b.stem} := \max\left(\text{vlookup}(bar_{stem.1}, table_{reinf}, 2)_{1,1}, \text{vlookup}(bar_{stem.2}, table_{reinf}, 2)_{1,1}\right) in$

$A_{s.heel} := \text{vlookup}(bar_{heel}, table_{reinf}, 3)_{1,1} \cdot in^2 \cdot \frac{1}{s_{heel} \cdot in} \qquad A_{s.heel} = 0.31 \cdot \frac{in^2}{ft} \qquad d_{b.heel} := \text{vlookup}(bar_{heel}, table_{reinf}, 2)_{1,1}\, in$

$A_{s.tran} := \text{vlookup}(bar_{tran}, table_{reinf}, 3)_{1,1} \cdot in^2 \cdot \frac{1}{s_{tran} \cdot in} \qquad A_{s.tran} = 0.31 \cdot \frac{in^2}{ft} \qquad d_{b.tran} := \text{vlookup}(bar_{tran}, table_{reinf}, 2)_{1,1}\, in$

$s_{stem} := \frac{1in}{\frac{1}{s_{stem.1}} + \text{if}\left(bar_{stem.2} = \text{"None"}, 0, \frac{1}{s_{stem.2}}\right)} \qquad s_{.stem} = 12 \cdot in$

MARGIN OF SHEET 2

$$Load_{b.vert} := In_{b.vert} \cdot kip \cdot \frac{b}{l_{wall}} = 22347.989\,lbf$$

$$Load_{b.mom} := In_{b.mom} \cdot kip \cdot ft \cdot \frac{b}{l_{wall}} = 1266122.774\,\frac{ft^2 \cdot lb}{s^2}$$

$$Load_{s.vert} := In_{s.vert} \cdot kip \cdot \frac{b}{l_{wall}} = 4991.701\,lbf$$

$$Load_{s.horz} := In_{s.horz} \cdot kip \cdot \frac{b}{l_{wall}} = 0\,lbf$$

MARGIN OF SHEET 3

$Vesic_{wtfact} :=$

	1	2
1	28	16.7
2	29	19.3
3	30	22.4
4	31	26
5	32	30.2
6	33	35.2
7	34	41.1
8	35	48

›ff

MARGIN OF SHEET 7

$$\text{SlidingHeel}(x) := \left|\begin{array}{l}
w_{foot.x} \leftarrow \gamma_{conc}\cdot\left(l_{toe} + t_{stem} + x\right)\cdot t_{foot}\cdot b \\
w_{soil.1.x} \leftarrow \left[\left(\gamma_{fill.sat} - \gamma_{wa}\right)\cdot h_{fill.sat} + \gamma_{fill.dry}\cdot\left(h_{stem} - h_{fill.sat}\right)\right]\cdot x\cdot b \\
w_{soil.2.x} \leftarrow 0.5\cdot x\cdot(x\cdot\tan(\beta))\cdot\gamma_{fill.dry}\cdot b \\
w_{s.x} \leftarrow \gamma_{fill.dry}\cdot h_s\cdot x\cdot b \\
w_{wa.x} \leftarrow \gamma_{wa}\cdot h_{wa}\cdot x\cdot b \\
h_{ret.dry.x} \leftarrow h_{wall} + x\cdot\tan(\beta) - h_{wa} \\
F_{ret.dry.x} \leftarrow 0.5\cdot\gamma_{ret.dry}\cdot k_{a.ret}\cdot h_{ret.dry.x}^{2}\cdot b \\
F_{ret.sat.1.x} \leftarrow \gamma_{ret.dry}\cdot k_{a.ret}\cdot h_{ret.dry.x}\cdot h_{wa}\cdot b \\
F_{s.x} \leftarrow k_{a.ret}\cdot\gamma_{fill.dry}\cdot h_s\cdot\left(h_{wa} + h_{ret.dry.x}\right)\cdot b \\
V_{s.x} \leftarrow \gamma_{DC.min}\left(w_{stem} + w_{foot.x}\right) + \gamma_{EV.min}\left(w_{soil.1.x} + w_{soil.2.x}\right) \ldots \\
\qquad + \gamma_{EH.max}\left(F_{ret.dry.x} + F_{ret.sat.1.x} + F_{ret.sat.2}\right)\cdot\sin(\beta) + \gamma_{LS.min}\, w_{s.x} + \gamma_{WA}\, w_{wa.x} \\
P_{s.x} \leftarrow \gamma_{EH.max}\cdot\left(F_{ret.dry.x} + F_{ret.sat.1.x} + F_{ret.sat.2}\right)\cdot\cos(\beta) + \gamma_{LS.max}\cdot F_{s.x} + \gamma_{WA}\cdot F_{wa} \\
\phi_t\cdot\mu_s\cdot V_{s.x} - P_{s.x}
\end{array}\right.$$

$l_{heel.req} := \text{root}\left(\text{SlidingHeel}\left(l_{heel}\right), l_{heel}\right)$ $\qquad l_{heel.req} = 4.29\cdot ft$

Reference:Z:\Projects-Engineering\WaldenBRF030-3(5)09b308\Structures\Design\Substructure\Final\Abutment #1\Concrete Section Che

MARGIN OF SHEET 8

$$f_r \leftarrow 0.37\sqrt{f'_c \cdot ksi} \qquad = 18.832\ ft \cdot kip$$

$$S_c \leftarrow \frac{b \cdot t_{stem}^{\ 2}}{6}$$

$$M_{cr} \leftarrow f_r \cdot S_c$$

$$\min\left(1.2 \cdot M_{cr}, 1.33 M_{u.stem}\right)$$

$$t_{stem.req} := root\left[F_h\left[h_{stem} - \left(t_{stem} - d_c - 0.5 d_{b.stem}\right)\right] - 0.5\, V_r\left(A_{s.stem}, t_{stem} - d_c - 0.5 d_{b.stem}, t_{stem}\right), t_{stem}\right]$$

$$t_{stem.req} = 0.63 \cdot ft$$

MARGIN OF SHEET 9

$$f_r \leftarrow 0.37\sqrt{f'_c \cdot ksi} \qquad = 31.935\,ft \cdot kip$$

$$S_c \leftarrow \frac{b \cdot t_{foot}^{\,2}}{6}$$

$$M_{cr} \leftarrow f_r \cdot S_c$$

$$\min\left(1.2 \cdot M_{cr}, 1.33 M_{u.heel}\right)$$

$$t_{foot.net.req} := \max\left(root\left(V_{u.heel.net} - V_r\left(A_{s.heel}, t_{foot} - d_c - 0.5 d_{b.heel}, t_{foot}\right), t_{foot}\right), 2 \cdot ft\right)$$

$$t_{foot.net.req} = 2 \cdot ft$$

MARGIN OF SHEET 10

Remove Initialization Value

$Global := submatrix(Global, 2, rows(Global), 1, 1)$

$Stem := submatrix(Stem, 2, rows(Stem), 1, 1)$

$Heel := submatrix(Heel, 2, rows(Heel), 1, 1)$

$Toe := submatrix(Toe, 2, rows(Toe), 1, 1)$

$price_{steel} := \frac{1.50}{lbf}$

$price_{conc} := \frac{750}{yd^3}$

$\gamma_{steel} := 490 \frac{lbf}{ft^3}$

$l_{stem.steel} := h_{wall} - 2d_c + l_{toe} + t_{stem} - 2d_c$ $\qquad l_{stem.steel} = 16.75\ ft$

$l_{heel.steel} := l_{foot} - 2d_c$ $\qquad l_{heel.steel} = 7.5\ ft$

MARGIN OF SHEET 12

$A_{s.stem} = 0.31 \cdot \frac{in^2}{ft}$

$d_{b.stem} = 0.052\,ft$

$d_{b.heel} = 0.052\,ft$

$d_{b.tran} = 0.052\,ft$

MARGIN OF SHEET 13