City of La Center
Brezee Creek Culvert Replacement & 4th Street Widening
PBS Job No. 71486.000

BREZEE CREEK - 4TH STREET PROJECT

Design Calculations – *Retaining Walls*

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Table of Contents

This calculation package covers the retaining walls for the Brezee Creek Culvert Replacement. There are three groups of cast-in-place concrete wall calculations and one group of soldier pile wall calculations. Each group of cast-in-place concrete wall calculations has a section at the end calculating the Mononobe Okabe seismic forces for the wall group. The soldier pile wall calculations include the wall piles and the tieback / deadman calculations. The appendix of the calculation package contains the referenced Mathcad files used in the calculations.

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user | Unique modification by the user

Variable (to be input by user) | Internal result (for reference) | Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states:	$\phi_{svc} := 1.00$	Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified:	$\phi_{EQ} := 1.0$	Section 11.5.8
	$\phi_{EQ\_Stab} := 0.9$	Section 11.5.8
	$\phi_{EQ\_BRG} := 0.8$	Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

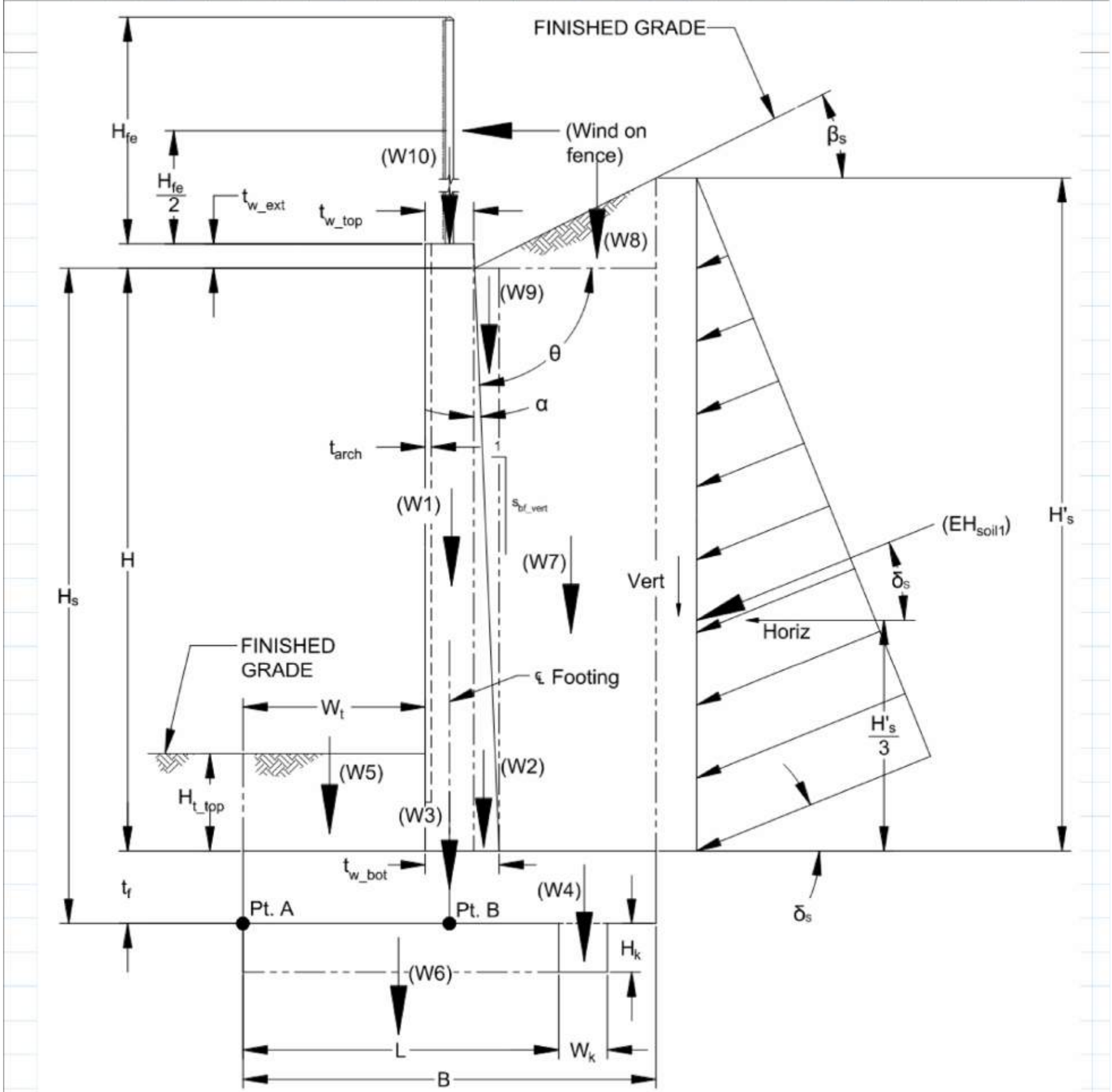


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 7.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $H_s = 8.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 24$

Total wall thickness (top): $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \frac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 15.75\ in$

Angle of wall backslope $\alpha := \text{atan}\left(\frac{1}{s_{bf\_vert}}\right)$ $\alpha = 2.39\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 87.61\ deg$

Set back from toe to face of wall: $W_t := 2.00\ ft$

Footing width: $B := 5.25\ ft$

Key width: $W_k := 1.00\ ft$

Key depth: $H_k := 1.50\ ft$

Set back from toe to face of key: $L := \text{if } H_k > 0\ in \ \|\ B - H_k - W_k \ \text{else} \ \|\ 0\ in$ $L = 2.75\ ft$

Depth of soil over toe: $H_{t\_top} := 1.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \frac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ — Stem wall clear cover

$CLR_{side} := 2.00\ in$ — side of footing clear cover

$CLR_{top} := 2.00\ in$ — top of footing clear cover

$CLR_{bot} := 3.00\ in$ — bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ — Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ — Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ — Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$$n_{mod} = 6.00$$

Modulus of rupture: $\lambda := 1.0$ — Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ — per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 25\ deg$ — 2H:1V backfill

Effective soil friction angle: $\phi'_f := 36\ deg$ — per geotechnical report, Ref. 4

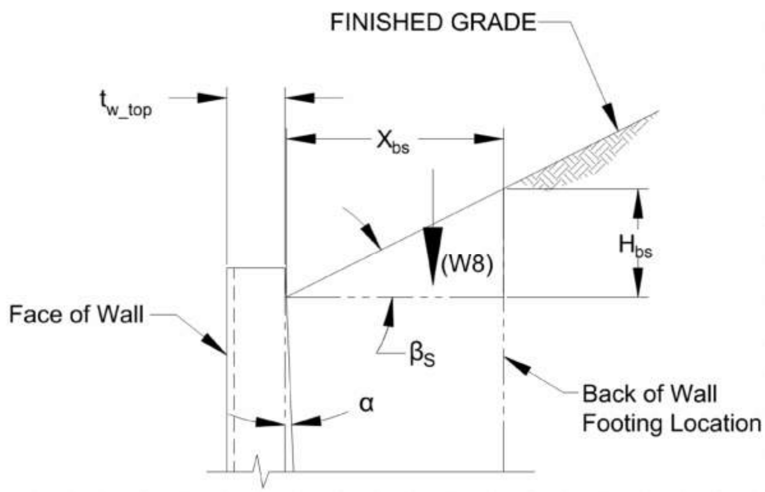


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete):	$\mu_{s\_c} := 0.60$	per geotechnical report, Ref. 4
Coefficient of friction (soil/soil):	$\mu_{s\_s} := \tan(\phi'_f)$	$\mu_{s\_s} = 0.73$
		Section C10.6.3.4
Ultimate soil bearing pressure:	$Q_n := 5.50\ ksf$	
Factored soil bearing pressure	$Q_R := Q_n \cdot \phi_{brg}$	$Q_R = 2.48\ ksf$
Friction angle between fill and wall:	$\delta_s := 22\ deg$	Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.07$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.369$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \frac{\left(2.5 \cdot \ln\left(\frac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \frac{2.56}{10^6} \cdot \left(\frac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 6.00\ ft$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \frac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\frac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.015\ \frac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 2.25\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan\left(\beta_s\right) \cdot X_{bs}$	$H_{bs} = 1.05\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 9.55\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s)
$R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$
$R_{EH} = 2.18 \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height)
$R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$
$R_{WS} = 0.24 \frac{kip}{ft}$

OVERTURNING MOMENTS:

Moment Arm: (about point A in Fig.1) — Overturning Moment:

Active earth pressure resultant:
$L_{EH} := \frac{H'_s}{3}$ $\quad M_{EH} := R_{EH} \cdot L_{EH}$
$L_{EH} = 3.18\ ft$ $\quad M_{EH} = 6.95 \frac{kip \cdot ft}{ft}$

Wind load on fence:
$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $\quad M_{WS} := R_{WS} \cdot L_{WS}$
$L_{WS} = 11.75\ ft$ $\quad M_{WS} = 2.84 \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 1.09 \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.17 \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 1.22 \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.23 \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.26 \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 0.54 \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 1.76 \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 0.15 \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.14 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)		Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$	$L_1 = 2.5\ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 2.71 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$	$L_2 = 3.6\ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 0.61 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$	$L_3 = 2.63\ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 3.20 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$	$L_4 = 3.25\ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 0.76 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$	$L_5 = 1\ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 0.26 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.		
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$	$L_7 = 4.28\ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 7.55 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$	$L_8 = 4.50\ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 0.69 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $\quad M_9 := W_9 \cdot L_9$

$L_9 = 3.21\ ft$ $\quad M_9 = 0.46\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $\quad L_{10} = 2.50\ ft$ $\quad M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.23\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 12.51\ \frac{kip \cdot ft}{ft}$

Factored resisting forces:

$$W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_min} = 6.07\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_min} = 22.16\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $\quad e_{A\_str} = 1.59\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $\quad e_{B\_str} = 1.03\ ft$

Check location of resultant:

$$Check_{Resultant\_str} := \begin{cases} \text{"OK"} & \text{if } \frac{-B}{4} \le e_{B\_str} \le \frac{B}{4} \\ \text{"NG"} & \text{else} \end{cases}$$

$Check_{Resultant\_str} = \text{"OK"}$

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $\quad P_{sliding} = 3.28\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\frac{W_{R\_min}}{B-2\cdot e_{B\_str}}\right)$ $\sigma_v = 1.91\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B-2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s}\cdot\mu_{s\_s}\cdot(\sigma_v\cdot(B-2\cdot e_{B\_str}) + \gamma_{pEVmin}\cdot W_6) \\ \text{also if } L < (B-2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s}\cdot\mu_{s\_s}\cdot(\sigma_v\cdot(B-2\cdot e_{B\_str}) + \gamma_{pEVmin}\cdot W_6) + \phi_{T\_s\_c}\cdot\mu_{s\_c}\cdot\sigma_v\cdot(B-2\cdot e_{B\_str}-L) \\ \text{else} \\ \quad \phi_{T\_s\_c}\cdot\mu_{s\_c}\cdot\sigma_v\cdot(B-2\cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 4.71\ \frac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \frac{1}{2}\cdot P_p\cdot(H_{t\_top} - 1.00\ ft + t_f + H_k)^2$ $P_{pass} = 2.25\ \frac{kip}{ft}$

The top 1.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding}\cdot P_{Fric} + \phi_{pass}\cdot P_{pass}$ $P_{resist} = 5.84\ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces: $W_{R\_max} := \gamma_{pDCmax}\cdot(W_1+W_2+W_3+W_4+W_{10}) + \gamma_{pEVmax}\cdot(W_5+W_7+W_8+W_9) + \gamma_{pEHmax}\cdot R_{EH}\cdot \sin(\delta_s)$

$W_{R\_max} = 7.86\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_max} := \gamma_{pDCmax}\cdot(M_1+M_2+M_3+M_4+M_{10}) + \gamma_{pEVmax}\cdot(M_5+M_7+M_8+M_9) + \gamma_{pEHmax}\cdot R_{EH}\cdot B\cdot \sin(\delta_s)$

$M_{R\_max} = 27.93\ \frac{kip\cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$ $e_{A\_BR} = 1.96\ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.66\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 2.00\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$ $Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$

$M_{o\_ser} = 7.30\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_ser} = 5.94\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_ser} = 20.77\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 2.84$

Service limit state OT Check: $OT_{check\_ser} :=$ if $OT_{FOS} \geq 1.5$ "OK" else "NG" $OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 2.27\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.36\ ft$

Check location of resultant: $Check_{Resultant\_svc} := \text{if } \frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} = \text{"OK"}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 1.31\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 2.10\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 4.54\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 5.94\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 8.19\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 3.9$

Service limit state sliding Check: $Sliding_{check\_ser} := \text{if } Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} = \text{"OK"}$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 1.58 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 4.83\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 18.94 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 6.66 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 25.27 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 0.95\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 1.67\ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \ \text{“OK”} \ \text{else} \ \text{“NG”}$$

$$Check_{Resultant\_EQ} = \text{“OK”}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $P_{slidingEQ} = 4.50 \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$ $\sigma_{vEQ} = 3.50\ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $BRG_{EQ} = 1.90\ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$P_{Fric\_EQ} :=$ if $L > (BRG_{EQ}) \land H_k > 0\ ft$

$\mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6)$

also if $L < (BRG_{EQ}) \land H_k > 0\ ft$

$\mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L)$

else

$\mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ})$

$P_{Fric\_EQ} = 5.23 \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $P_{resist\_EQ} = 7.48 \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} =$ "OK"

BEARING PRESSURE - SEISMIC:

Factored resisting forces: $W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$

$W_{R\_maxEQ} = 8.45 \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 31.03 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 1.43 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 1.19 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}} \right) \qquad \sigma_{BR\_EQ} = 2.95 \ ksf$$

Bearing pressure check:

$Check_{Bearing\_EQ} :=$ if $\sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n$
    "OK"
else
    "NG"

$Check_{Bearing\_EQ} =$ "OK"

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

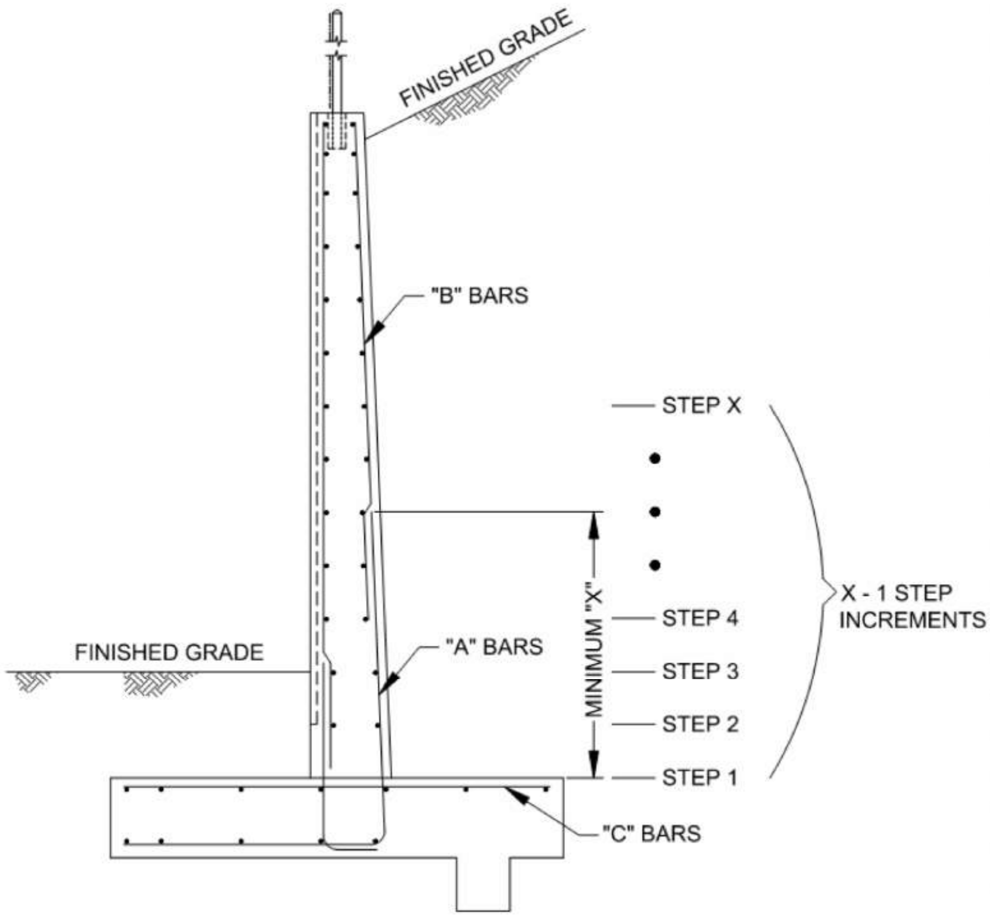


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\quad step = 6.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \;\; \left\| \; H_{st_i} \leftarrow H - (i) \cdot z \;\; ; \;\; H_{st} \right.$$

$$H_{st}^{T} = [7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{\mathrm{T}} = [1.44 \;\; 1.10 \;\; 0.81 \;\; 0.57 \;\; 0.36 \;\; 0.21 \;\; 0.09] \, \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{\mathrm{T}} = [2.40 \;\; 1.90 \;\; 1.46 \;\; 1.09 \;\; 0.79 \;\; 0.55 \;\; 0.38] \, \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{\mathrm{T}} = [8.21 \;\; 6.07 \;\; 4.39 \;\; 3.12 \;\; 2.19 \;\; 1.52 \;\; 1.06] \, \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{\mathrm{T}} = [4.62 \;\; 3.28 \;\; 2.26 \;\; 1.50 \;\; 0.96 \;\; 0.61 \;\; 0.39] \, \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\frac{H}{step+1}\right) \cdot \left(\frac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^{T} = [14.75\ \ 14.25\ \ 13.75\ \ 13.25\ \ 12.75\ \ 12.25\ \ 11.75]\ \boldsymbol{in}$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left\| \begin{array}{l} S_{s_i} \leftarrow \frac{t_{w_i}^{2}}{6} \\ S_s \end{array} \right.$$

$$S_s^{T} = [435\ \ 406\ \ 378\ \ 351\ \ 325\ \ 300\ \ 276]\ \frac{\boldsymbol{in}^3}{\boldsymbol{ft}}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$ — Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$ — Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_s)$

$$M_{cr}^{T} = [18.7\ \ 17.4\ \ 16.2\ \ 15.1\ \ 13.9\ \ 12.9\ \ 11.8]\ \frac{\boldsymbol{kip \cdot ft}}{\boldsymbol{ft}}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^{T} = [10.92\ \ 8.07\ \ 5.84\ \ 4.15\ \ 2.91\ \ 2.03\ \ 1.41]\ \frac{\boldsymbol{kip \cdot ft}}{\boldsymbol{ft}}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 5$ $s_A := 12\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 0.31\ in^2$ $A_{s\_A} = 0.31\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 12.94\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function $\phi M_{n\_A} = 17.73\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.002$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.14$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 15\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 1.81\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.2$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 36.53\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 18.00\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 12.71\ in$

Factored shear resistance (assumes Av equal to zero and s_v equal to 12 in):

$$\phi V_{n\_1} := \phi V_n\left(0\ in^2, 12\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 17.4 \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 15.29 \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 17.73\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 17.4\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 4$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b\left(B_B\right)}{s_B}$ $A_{s\_B} = 0.20\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b\left(B_B\right)}{2}$ $d_{s\_2} = 11\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 9.77\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \dfrac{A_{s\_B}}{12 \frac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0015$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.13$

Maximum reinforcing stress due to service load: $f_{s\_2} := \dfrac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \frac{k_2}{3}\right)}$ $f_{s\_2} = 5\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \dfrac{d_b(B_B)}{2}$ $d_{c\_2} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \dfrac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.23$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \dfrac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 100.49\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12 \frac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 10.85\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n \left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 14.8\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{“OK”}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 4.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 1.94\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 4.61\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 5.39\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 3.90\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 648.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel})$ $M_{cr\_heel} = 27.79\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3) $M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$

$M_{D\_heel} = 7.17\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 4$ $s_C := 12\ in$

$A_{s\_C} := \frac{A_b(B_C)}{s_C}$ $A_{s\_C} = 0.2\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2}$ $d_{s\_heel} = 15.75\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 14.04\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0011$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod})$ $k_h = 0.11$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft}$ $f_{s\_h} = 15.39\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$$

$d_{c\_h} = 2.25\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.2$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 33.27\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_heel} = 15.60\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 12in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 12\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_heel} = 21.30\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity: $check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 5.49 \; \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00 \; ft \qquad M_{D\_toe\_1} = 5.49 \; kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00 \; ft$$

$$M_{D\_svc\_t} = 2.15 \; \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79 \; kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 7.30 \; kip \; ft$$

Toe reinforcing bar size and spacing:

$B_{toe} := B_A$ $\quad B_{toe} = 5.00$

$s_{toe} := s_A$ $\quad s_{toe} = 12.00 \; in$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 0.31 \; \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.69 \; in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n \left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c \right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 20.17\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc} \left(M_{D\_toe}, \phi M_{n\_toe} \right) = \text{“OK”}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12 \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0018$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot (\rho_t \cdot n_{mod}) + (\rho_t \cdot n_{mod})^2} - (\rho_t \cdot n_{mod})$ $k_t = 0.14$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3} \right)}$ $f_{s\_t} = 6\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b \left(B_{toe} \right)}{2}$ $d_{c\_t} = 3.31\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot \left(t_f - d_{c\_t} \right)}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.32$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 82.49\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min \left(s_{max\_t}, 18\ in, 1.5 \cdot t_f \right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc} \left(s_{toe}, s'_{max\_t} \right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$$d_{v\_toe} = 14.46\ in$$

Factored shear resistance (assumes Av equal to zero and s_v equal to 12in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 12\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 19.7\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$$B_{temp\_stem} := 4 \qquad s_{temp\_stem} := 12\ in$$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.4\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \begin{array}{|l} A_{temp} \leftarrow \frac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \\ \text{return } A_{temp} \end{array}$$

$$A_{s\_temp\_1} = 0.15\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_1} = 18.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 11$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.42\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.80\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \dfrac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.15\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} 12\ in & \text{if } t_f > 18.00\ in \\ min(3.0 \cdot t_f, 18.0\ in) & \text{else} \end{cases}$$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - KEY, STEM INTERFACE

Key Check (to determine if key reinforcing is required):

It is assumed that the footing and the key will be placed monolithically. The ϕV_n function as used below simply returns the shear resistance per the simplified procedure for non prestressed sections without transverse reinforcement as described in AASHTO Section 5.7.3.3 and 5.7.4.3.

Conservatively design for the full lateral demand forces, neglecting the reduction in loading on the key due to the passive resistance in front of wall and any reduction in the applied load from sliding friction in front of the key.

Echo of calculated factored demand forces from above (for comparison only)

$P_{sliding} = 3.28\ \frac{kip}{ft}$ $\quad P_{slidingEQ} = 4.5\ \frac{kip}{ft}$

Factored shear resistance - (A_v equal to zero and s_v equal to 12 in):

$\phi V_{n\_key} := \phi V_n(0\ in^2, 12\ in, f_y, 12\ in, W_k, f'_c)$

$\phi V_{n\_key} = 16.38\ kip$

Compare the shear demand to the shear capacity:

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft, \phi V_{n\_key}) = \text{"OK"}$

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $\quad A_{cv} = 177.00\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.148\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 0.31\ in^2$$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{"OK"}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c) \qquad 5.7.4.3\text{-}3$$

$$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv} \qquad 5.7.4.3\text{-}4$$

$$V_{ni\_3} := K_2 \cdot A_{cv} \qquad 5.7.4.3\text{-}5$$

$V_{ni\_1} = 24.44\ kip$ $\quad V_{ni\_2} = 141.60\ kip$

$V_{ni\_3} = 141.60\ kip$

Controlling nominal concrete shear capacity:

$$V_{niMax} := \text{if } min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1}$$
$$\quad \| \ min(V_{ni\_2}, V_{ni\_3})$$
$$\text{else}$$
$$\quad \| \ V_{ni\_1}$$

$V_{niMax} = 24.44\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$

$V_{ri} = 21.99\ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max\left(P_{sliding}, P_{slidingEQ}\right) \cdot 1\ ft$
‖ "OK"
else
‖ "NG"

$InterfaceCheck_{stem} = \text{"OK"}$

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{"OK"}$

$Sliding_{check\_str} = \text{"OK"}$

$Bearing_{check\_str} = \text{"OK"}$

$OT_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_svc} = \text{"OK"}$

$Sliding_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_EQ} = \text{"OK"}$

$Sliding_{check\_EQ} = \text{"OK"}$

$Check_{Bearing\_EQ} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{"OK"}$

$check_{dc}\left(\max\left(P_{sliding}, P_{slidingEQ}\right) \cdot 1\ ft, \phi V_{n\_key}\right) = \text{"OK"}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{"OK"}$

$InterfaceCheck_{stem} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 7.00\ ft$
Footing width:	$B = 5.25\ ft$
Footing depth:	$t_f = 1.50\ ft$
Wall setback:	$W_t = 2.00\ ft$
Key location:	$L = 2.75\ ft$
Key depth:	$H_k = 1.50\ ft$
Key width:	$W_k = 1.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 5.00$	$s_A = 12.00\ in$	
Main stem reinforcing	$B_B = 4.00$	$s_B = 12.00\ in$	
Heel reinforcing:	$B_C = 4.00$	$s_C = 12.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 12.00\ in$	listed bars provided each face

Temperature reinforcing - footing: $B_{temp\_ftg} = 4.00$ $N_{temp\_ftg} = 11.00$ total number of bars for footing

Shear reinforcing -stem: no shear reinforcement

Shear reinforcing -heel: no shear reinforcement

Shear reinforcing -toe: no shear reinforcement

Shear reinforcing -shear key: no shear reinforcement

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user | Unique modification by the user

Variable (to be input by user) | Internal result (for reference) | Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states: $\phi_{svc} := 1.00$ — Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified: $\phi_{EQ} := 1.0$ — Section 11.5.8

$\phi_{EQ\_Stab} := 0.9$ — Section 11.5.8

$\phi_{EQ\_BRG} := 0.8$ — Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

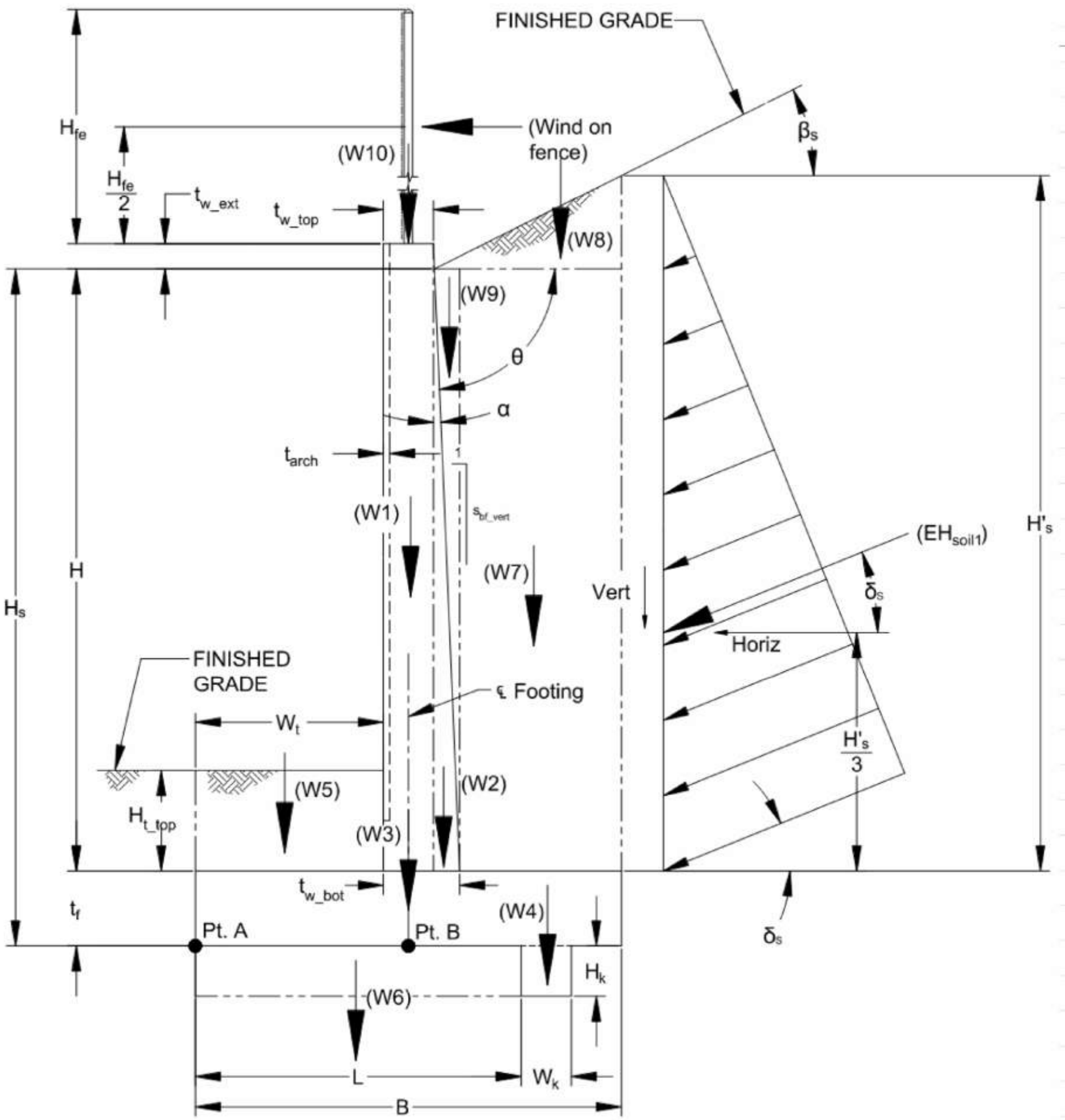


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 9.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $H_s = 10.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 24$

Total wall thickness (top) $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \dfrac{H + t_{w\_ext}}{s_{bf\_vert}}$ $\quad t_{w\_bot} = 16.75\ in$

Angle of wall backslope $\alpha := \operatorname{atan}\left(\dfrac{1}{s_{bf\_vert}}\right)$ $\quad \alpha = 2.39\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\quad \theta = 87.61\ deg$

Set back from toe to face of wall: $W_t := 2.00\ ft$

Footing width: $B := 7.00\ ft$

Key width: $W_k := 1.00\ ft$

Key depth: $H_k := 1.50\ ft$

Set back from toe to face of key: $L := \begin{cases} B - H_k - W_k & \text{if } H_k > 0\ in \\ 0\ in & \text{else} \end{cases}$ $\quad L = 4.50\ ft$

Depth of soil over toe: $H_{t\_top} := 1.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \dfrac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ — Stem wall clear cover

$CLR_{side} := 2.00\ in$ — side of footing clear cover

$CLR_{top} := 2.00\ in$ — top of footing clear cover

$CLR_{bot} := 3.00\ in$ — bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ — Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ — Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ — Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$$n_{mod} = 6.00$$

Modulus of rupture: $\lambda := 1.0$ — Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ — per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 25\ deg$ — 2H:1V backfill

Effective soil friction angle: $\phi'_f := 36\ deg$ — per geotechnical report, Ref. 4

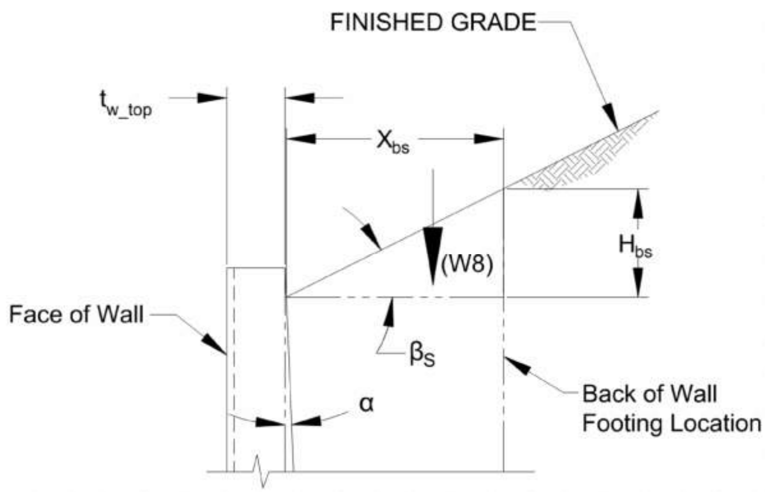


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete): $\mu_{s\_c} := 0.60$ — per geotechnical report, Ref. 4

Coefficient of friction (soil/soil): $\mu_{s\_s} := \tan(\phi'_f)$ — $\mu_{s\_s} = 0.73$

Section C10.6.3.4

Ultimate soil bearing pressure: $Q_n := 6.50\ ksf$

Factored soil bearing pressure: $Q_R := Q_n \cdot \phi_{brg}$ — $Q_R = 2.93\ ksf$

Friction angle between fill and wall: $\delta_s := 22\ deg$ — Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.07$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.369$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ — per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \dfrac{\left(2.5 \cdot \ln\left(\dfrac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \dfrac{2.56}{10^6} \cdot \left(\dfrac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 6.00\ ft$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \dfrac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\dfrac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.015\ \dfrac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 4.00\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 1.87\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 12.37\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $R_{EH} = 3.66 \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.24 \frac{kip}{ft}$

OVERTURNING MOMENTS:

	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Active earth pressure resultant:	$L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 4.12\ ft$	$M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 15.10 \frac{kip \cdot ft}{ft}$
Wind load on fence:	$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 13.75\ ft$	$M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 3.33 \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 1.40 \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.28 \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 1.63 \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.23 \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.26 \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 0.88 \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 4.22 \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 0.48 \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.23 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)		Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$	$L_1 = 2.5\ ft$	$M_1 := W_1 \cdot L_1$; $M_1 = 3.49 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$	$L_2 = 3.63\ ft$	$M_2 := W_2 \cdot L_2$; $M_2 = 1.00 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$	$L_3 = 3.5\ ft$	$M_3 := W_3 \cdot L_3$; $M_3 = 5.70 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$	$L_4 = 5.00\ ft$	$M_4 := W_4 \cdot L_4$; $M_4 = 1.16 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$	$L_5 = 1\ ft$	$M_5 := W_5 \cdot L_5$; $M_5 = 0.26 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.		
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$	$L_7 = 5.20\ ft$	$M_7 := W_7 \cdot L_7$; $M_7 = 21.92 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$	$L_8 = 5.67\ ft$	$M_8 := W_8 \cdot L_8$; $M_8 = 2.75 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $M_9 := W_9 \cdot L_9$

$L_9 = 3.26\ ft$ $M_9 = 0.76\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $L_{10} = 2.50\ ft$ $M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.23\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 24.32\ \frac{kip \cdot ft}{ft}$

Factored resisting forces:

$$W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_min} = 10.51\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_min} = 50.51\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $e_{A\_str} = 2.49\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $e_{B\_str} = 1.01\ ft$

Check location of resultant:

$$Check_{Resultant\_str} := \begin{cases} \text{"OK"} & \text{if } \frac{-B}{4} \le e_{B\_str} \le \frac{B}{4} \\ \text{"NG"} & \text{else} \end{cases}$$

$Check_{Resultant\_str} = \text{"OK"}$

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $P_{sliding} = 5.34\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2):

$$\sigma_v := \left(\frac{W_{R\_min}}{B - 2 \cdot e_{B\_str}}\right)$$

$\sigma_v = 2.11\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 7.94\ \frac{kip}{ft}$

Sliding resistance - passive pressure:

$$P_{pass} := \frac{1}{2} \cdot P_p \cdot (H_{t\_top} - 1.00\ ft + t_f + H_k)^2$$

$P_{pass} = 2.25\ \frac{kip}{ft}$

The top 1.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric} + \phi_{pass} \cdot P_{pass}$

$P_{resist} = 9.06\ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces:

$$W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_max} = 13.6\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_max} = 63.55\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A:

$$e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$$

$e_{A\_BR} = 2.88\ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.62\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 2.36\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}\left(\sigma_{BR}, Q_R\right)$ $Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos\left(\delta_s\right) + \gamma_{WSsvc1} \cdot M_{WS}$

$M_{o\_ser} = 14.99\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_ser} := \gamma_{DCsvc} \cdot \left(W_1 + W_2 + W_3 + W_4 + W_{10}\right) + \gamma_{EVsvc} \cdot \left(W_5 + W_7 + W_8 + W_9\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$

$W_{R\_ser} = 10.19\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_ser} := \gamma_{DCsvc} \cdot \left(M_1 + M_2 + M_3 + M_4 + M_{10}\right) + \gamma_{EVsvc} \cdot \left(M_5 + M_7 + M_8 + M_9\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin\left(\delta_s\right)$

$M_{R\_ser} = 46.87\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 3.13$

Service limit state OT Check: $OT_{check\_ser} :=$ if $OT_{FOS} \ge 1.5$ "OK" else "NG" $OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{\left(M_{R\_ser} - M_{o\_ser}\right)}{W_{R\_ser}}$ $e_{A\_svc} = 3.13\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.37\ ft$

Check location of resultant:

$$Check_{Resultant\_svc} := \text{if } \frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4} \;\; \text{“OK”} \;\; \text{else} \;\; \text{“NG”}$$

$$Check_{Resultant\_svc} = \text{“OK”}$$

Vertical stress (per foot of wall such that units are kip/ft^2):

$$\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right) \qquad \sigma_{v\_svc} = 1.63\ \mathbf{ksf}$$

Factored sliding force:

$$P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos\left(\delta_s\right) + \gamma_{WSsvc1} \cdot R_{WS}$$

$$P_{sliding\_svc} = 3.47\ \frac{\mathbf{kip}}{\mathbf{ft}}$$

Bearing width for service calculation:

$$BRG_{svc} := B - 2 \cdot e_{B\_svc} \qquad BRG_{svc} = 6.26\ \mathbf{ft}$$

Sliding resistance -friction:

$$P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc} \qquad P_{Fric\_svc} = 10.19\ \frac{\mathbf{kip}}{\mathbf{ft}}$$

Total sliding resistance:

$$P_{resist\_svc} := \phi_{svc} \cdot \left(P_{Fric\_svc} + P_{pass}\right) \qquad P_{resist\_svc} = 12.44\ \frac{\mathbf{kip}}{\mathbf{ft}}$$

Sliding factor of safety:

$$Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}} \qquad Sliding_{FoS} = 3.59$$

Service limit state sliding Check:

$$Sliding_{check\_ser} := \text{if } Sliding_{FoS} > 1.2 \;\; \text{“OK”} \;\; \text{else} \;\; \text{“NG”}$$

$$Sliding_{check\_ser} = \text{“OK”}$$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 2.88 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 6.52\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 42.41 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 11.59 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 58.06 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A: $e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}}$ $\quad e_{A\_EQ} = 1.35\ ft$

Distance to resultant from Point B: $e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ}$ $\quad e_{B\_EQ} = 2.15\ ft$

Check location of resultant:

$$Check_{Resultant\_EQ} := \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \text{ “OK” else “NG”}$$

$Check_{Resultant\_EQ} = \text{“OK”}$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $\quad P_{slidingEQ} = 7.76 \ \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$ $\quad \sigma_{vEQ} = 4.29 \ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $\quad BRG_{EQ} = 2.70 \ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 9.06 \ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $\quad P_{resist\_EQ} = 11.31 \ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} = \text{"OK"}$

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$W_{R\_maxEQ} = 14.68 \ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 71.11 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 1.96 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 1.54 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}}\right) \qquad \sigma_{BR\_EQ} = 3.75 \ ksf$$

Bearing pressure check:

$Check_{Bearing\_EQ} :=$ if $\sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n$
  "OK"
else
  "NG"

$Check_{Bearing\_EQ} =$ "OK"

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

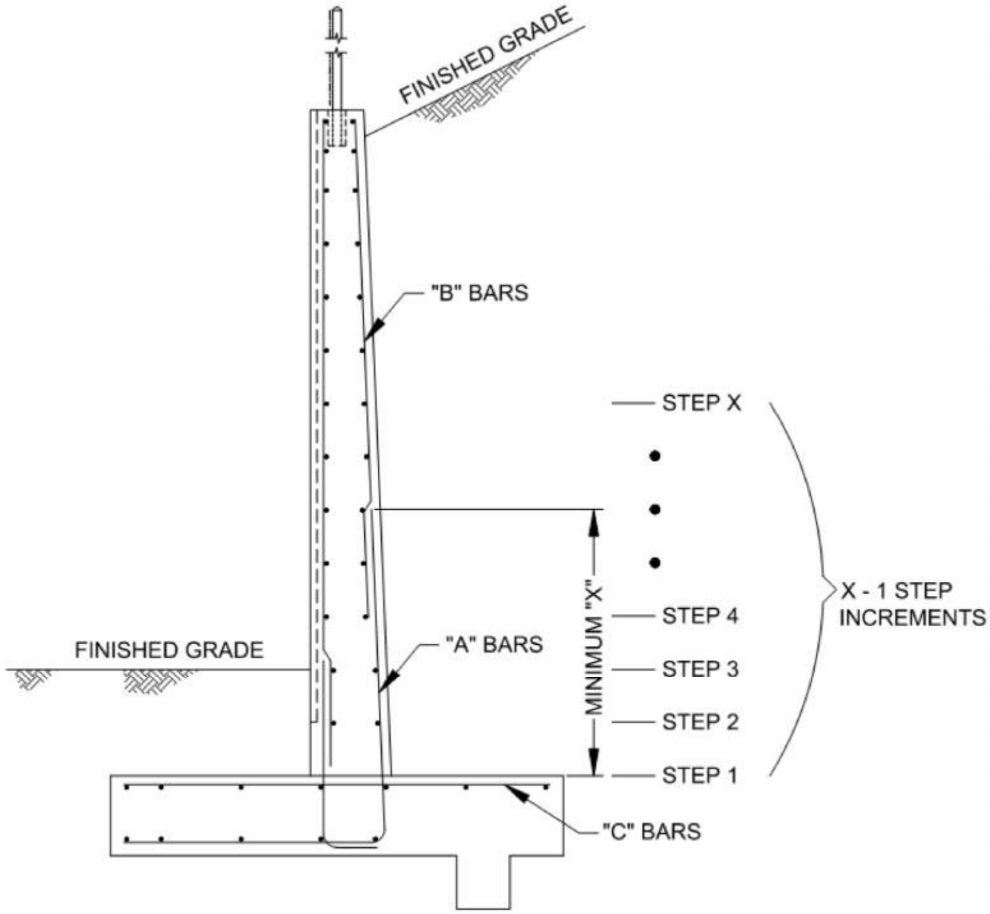


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\quad step = 8.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \quad \left| \begin{array}{l} H_{st_i} \leftarrow H - (i) \cdot z \\ H_{st} \end{array} \right.$$

$$H_{st}^{T} = [9.0\ \ 8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{T} = [2.62\ \ 2.16\ \ 1.75\ \ 1.37\ \ 1.05\ \ 0.76\ \ 0.53\ \ 0.33\ \ 0.18]\ \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{T} = [4.17\ \ 3.48\ \ 2.86\ \ 2.30\ \ 1.81\ \ 1.39\ \ 1.03\ \ 0.74\ \ 0.52]\ \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{T} = [17.15\ \ 13.32\ \ 10.16\ \ 7.58\ \ 5.53\ \ 3.93\ \ 2.73\ \ 1.85\ \ 1.23]\ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{T} = [10.40\ \ 7.94\ \ 5.92\ \ 4.29\ \ 3.01\ \ 2.04\ \ 1.32\ \ 0.83\ \ 0.50]\ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\frac{H}{step+1}\right) \cdot \left(\frac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^T = [15.75 \;\; 15.25 \;\; 14.75 \;\; 14.25 \;\; 13.75 \;\; 13.25 \;\; 12.75 \;\; 12.25 \;\; 11.75] \; in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} S_{s_i} \leftarrow \frac{t_{w_i}^{\,2}}{6} \\ S_s \end{array} \right.$$

$$S_s^T = [496 \;\; 465 \;\; 435 \;\; 406 \;\; 378 \;\; 351 \;\; 325 \;\; 300 \;\; 276] \; \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$ Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$ Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^T = [21.3 \;\; 19.9 \;\; 18.7 \;\; 17.4 \;\; 16.2 \;\; 15.1 \;\; 13.9 \;\; 12.9 \;\; 11.8] \; \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^T = [21.27 \;\; 17.72 \;\; 13.51 \;\; 10.08 \;\; 7.35 \;\; 5.23 \;\; 3.63 \;\; 2.46 \;\; 1.63] \; \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 7$ $s_A := 12\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 0.60\ in^2$

$A_{s\_A} = 0.60\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 13.81\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A} = 36.10\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{“OK”}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.0036$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.19$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 16\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 1.94\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$$\beta_{s\_1} = 1.2$$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$$s_{max\_1} = 32.41\ in$$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$$s'_{max\_1} = 18.00\ in$$

Check reinforcing spacing:

$$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$$d_{v\_1} = 13.37\ in$$

Factored shear resistance (assumes Av equal to zero and s_v equal to 12 in):

$$\phi V_{n\_1} := \phi V_n\left(0\ in^2, 12\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$$\phi V_{n\_1} = 18.3 \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$$M_{sD\_EQ} = 34.56 \frac{kip \cdot ft}{ft}$$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 36.10\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{“OK”}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 18.3\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{“OK”}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 4$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b(B_B)}{s_B}$ $A_{s\_B} = 0.20\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b(B_B)}{2}$ $d_{s\_2} = 12\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 10.67\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{“OK”}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \dfrac{A_{s\_B}}{12 \dfrac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0014$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.12$

Maximum reinforcing stress due to service load: $f_{s\_2} := \dfrac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \dfrac{k_2}{3}\right)}$ $f_{s\_2} = 16\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \dfrac{d_b(B_B)}{2}$ $d_{c\_2} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \dfrac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.21$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \dfrac{700 \dfrac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 33.41\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\dfrac{M_n\left(A_{s\_B}, f_y, 12 \dfrac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$ $d_{v\_2} = 11.85\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n \left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 16.2\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 4.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 3.6\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 9.57\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 21.13\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 15.53\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads:

$$S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6} \qquad S_{c\_heel} = 648.00\ in^3$$

Heel cracking moment:

$$M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel}) \qquad M_{cr\_heel} = 27.79\ kip \cdot ft$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3)

$$M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$$

$$M_{D\_heel} = 27.79\ kip \cdot ft$$

Heel reinforcing bar size and spacing:

$$B_C := 6 \qquad s_C := 12\ in$$

$$A_{s\_C} := \frac{A_b(B_C)}{s_C} \qquad A_{s\_C} = 0.44\ \frac{in^2}{ft}$$

Reference workbook function

Depth of reinforcing

$$d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2} \qquad d_{s\_heel} = 15.63\ in$$

Factored moment resistance:

$$\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$$

Reference workbook function

$$\phi M_{n\_heel} = 30.3\ kip \cdot ft$$

Compare the moment demand to the moment capacity:

$$check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$$

Reinforcing Ratio

$$\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}} \qquad \rho_h = 0.0023$$

Neutral axis depth factor:

$$k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod}) \qquad k_h = 0.15$$

Maximum reinforcing stress due to service load:

$$f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft} \qquad f_{s\_h} = 28.57\ ksi$$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$$

$d_{c\_h} = 2.38\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.22$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 15.38\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 15.38\ in$

Check reinforcing spacing:

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1.
Using reference book function.

$d_{v\_heel} = 15.30\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 12in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 12\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_heel} = 20.89\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem: $V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$

$V_{D\_toe} = 7.09 \frac{kip}{ft}$

Toe factored demand moment at face of stem: $M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00\ ft$ $\quad M_{D\_toe\_1} = 7.09\ kip \cdot ft$

Toe service demand moment at face of stem: $M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00\ ft$

$M_{D\_svc\_t} = 2.79 \frac{kip \cdot ft}{ft}$

Toe cracking moment: $M_{cr\_toe} := M_{cr\_heel}$ $\quad M_{cr\_toe} = 27.79\ kip \cdot ft$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3): $M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$

$M_{D\_toe} = 9.43\ kip\ ft$

Toe reinforcing bar size and spacing: $B_{toe} := B_A$ $\quad B_{toe} = 7.00$

$s_{toe} := s_A$ $\quad s_{toe} = 12.00\ in$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function: $A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}}$ $\quad A_{s\_toe} = 0.6 \frac{in^2}{ft}$

Depth of reinforcing: $d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2}$ $\quad d_{s\_toe} = 14.56\ in$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n \left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c \right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 38.13\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc} \left(M_{D\_toe}, \phi M_{n\_toe} \right) = \text{“OK”}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12 \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0034$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot (\rho_t \cdot n_{mod}) + (\rho_t \cdot n_{mod})^2} - (\rho_t \cdot n_{mod})$ $k_t = 0.18$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3} \right)}$ $f_{s\_t} = 4\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b(B_{toe})}{2}$ $d_{c\_t} = 3.44\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot (t_f - d_{c\_t})}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.34$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 121.28\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min \left(s_{max\_t}, 18\ in, 1.5 \cdot t_f \right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc} \left(s_{toe}, s'_{max\_t} \right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_toe} = 14.12\ in$

Factored shear resistance (assumes Av equal to zero and s_v equal to 12in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 12\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 19.3\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$B_{temp\_stem} := 4$

$s_{temp\_stem} := 12\ in$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.4\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \left\| \begin{array}{l} A_{temp} \leftarrow \dfrac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \right. \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \right. \\ \text{return } A_{temp} \end{array} \right.$$

$$A_{s\_temp\_1} = 0.16\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$s_{max\_temp\_1} = 18.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$

$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$B_{temp\_ftg} := 4$ $\quad N_{temp\_ftg} := 15$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$A_{s\_temp\_p2} = 0.43\ \frac{in^2}{ft}$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1}$$

$s_{temp\_ftg} = 11.43\ in$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \frac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$A_{s\_temp\_2} = 0.16\ \frac{in^2}{ft}$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0\ in) \end{cases}$$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - KEY, STEM INTERFACE

Key Check (to determine if key reinforcing is required):

It is assumed that the footing and the key will be placed monolithically. The ϕV_n function as used below simply returns the shear resistance per the simplified procedure for non prestressed sections without transverse reinforcement as described in AASHTO Section 5.7.3.3 and 5.7.4.3.

Conservatively design for the full lateral demand forces, neglecting the reduction in loading on the key due to the passive resistance in front of wall and any reduction in the applied load from sliding friction in front of the key.

Echo of calculated factored demand forces from above (for comparison only)

$P_{sliding} = 5.34\ \frac{kip}{ft}$ $P_{slidingEQ} = 7.8\ \frac{kip}{ft}$

Factored shear resistance - (A_v equal to zero and s_v equal to 12 in):

$\phi V_{n\_key} := \phi V_n(0\ in^2, 12\ in, f_y, 12\ in, W_k, f'_c)$

$\phi V_{n\_key} = 16.38\ kip$

Compare the shear demand to the shear capacity:

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft, \phi V_{n\_key}) = \text{"OK"}$

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $A_{cv} = 189.00\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement: $A_{vf\_min} := \dfrac{0.05 \cdot A_{cv}}{f_y} \cdot ksi$ $\quad A_{vf\_min} = 0.158\ in^2$

$A_{vf} := \left| \dfrac{A_b(B_A) \cdot 12\ in}{s_A} \right|$ $\quad A_{vf} = 0.60\ in^2$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{"OK"}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ 5.7.4.3-5

$V_{ni\_1} = 35.78\ kip$ $\quad V_{ni\_2} = 151.20\ kip$

$V_{ni\_3} = 151.20\ kip$

Controlling nominal concrete shear capacity:

$$V_{niMax} := \text{if } min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1}$$
$$\quad \| min(V_{ni\_2}, V_{ni\_3})$$
$$\text{else}$$
$$\quad \| V_{ni\_1}$$

$V_{niMax} = 35.78\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $\quad V_{ri} = 32.20\ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft$
  "OK"
else
  "NG"

$InterfaceCheck_{stem} =$ "OK"

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} =$ "OK"

$Sliding_{check\_str} =$ "OK"

$Bearing_{check\_str} =$ "OK"

$OT_{check\_ser} =$ "OK"

$Check_{Resultant\_svc} =$ "OK"

$Sliding_{check\_ser} =$ "OK"

$Check_{Resultant\_EQ} =$ "OK"

$Sliding_{check\_EQ} =$ "OK"

$Check_{Bearing\_EQ} =$ "OK"

$check_{dc}(M_{sD_{xa}}, \phi M_{n\_A}) =$ "OK"

$check_{dc}(s_A, s'_{max\_1}) =$ "OK"

$check_{dc}(V_{str_{xa}}, \phi V_{n\_1}) =$ "OK"

$check_{dc}(M_{sD\_EQ}, \phi M_{n\_A\_EQ}) =$ "OK"

$check_{dc}(P_{slidingEQ}, \phi V_{n\_EQ}) =$ "OK"

$check_{dc}(V_{D\_heel}, \phi V_{n\_heel}) =$ "OK"

$check_{dc}(M_{D\_toe}, \phi M_{n\_toe}) =$ "OK"

$check_{dc}(s_{toe}, s'_{max\_t}) =$ "OK"

$check_{dc}(V_{D\_toe}, \phi V_{n\_toe}) =$ "OK"

$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) =$ "OK"

$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) =$ "OK"

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) =$ "OK"

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) =$ "OK"

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft, \phi V_{n\_key}) =$ "OK"

$check_{dc}(A_{vf\_min}, A_{vf}) =$ "OK"

$InterfaceCheck_{stem} =$ "OK"

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 9.00\ ft$
Footing width:	$B = 7.00\ ft$
Footing depth:	$t_f = 1.50\ ft$
Wall setback:	$W_t = 2.00\ ft$
Key location:	$L = 4.50\ ft$
Key depth:	$H_k = 1.50\ ft$
Key width:	$W_k = 1.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 7.00$	$s_A = 12.00\ in$	
Main stem reinforcing	$B_B = 4.00$	$s_B = 12.00\ in$	
Heel reinforcing:	$B_C = 6.00$	$s_C = 12.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 12.00\ in$	listed bars provided each face

Temperature reinforcing - footing:	$B_{temp\_ftg} = 4.00$	$N_{temp\_ftg} = 15.00$	total number of bars for footing

Shear reinforcing -stem: no shear reinforcement

Shear reinforcing -heel: no shear reinforcement

Shear reinforcing -toe: no shear reinforcement

Shear reinforcing -shear key: no shear reinforcement

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user — Unique modification by the user

Variable (to be input by user) — Internal result (for reference) — Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states: $\phi_{svc} := 1.00$ — Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified: $\phi_{EQ} := 1.0$ — Section 11.5.8

$\phi_{EQ\_Stab} := 0.9$ — Section 11.5.8

$\phi_{EQ\_BRG} := 0.8$ — Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

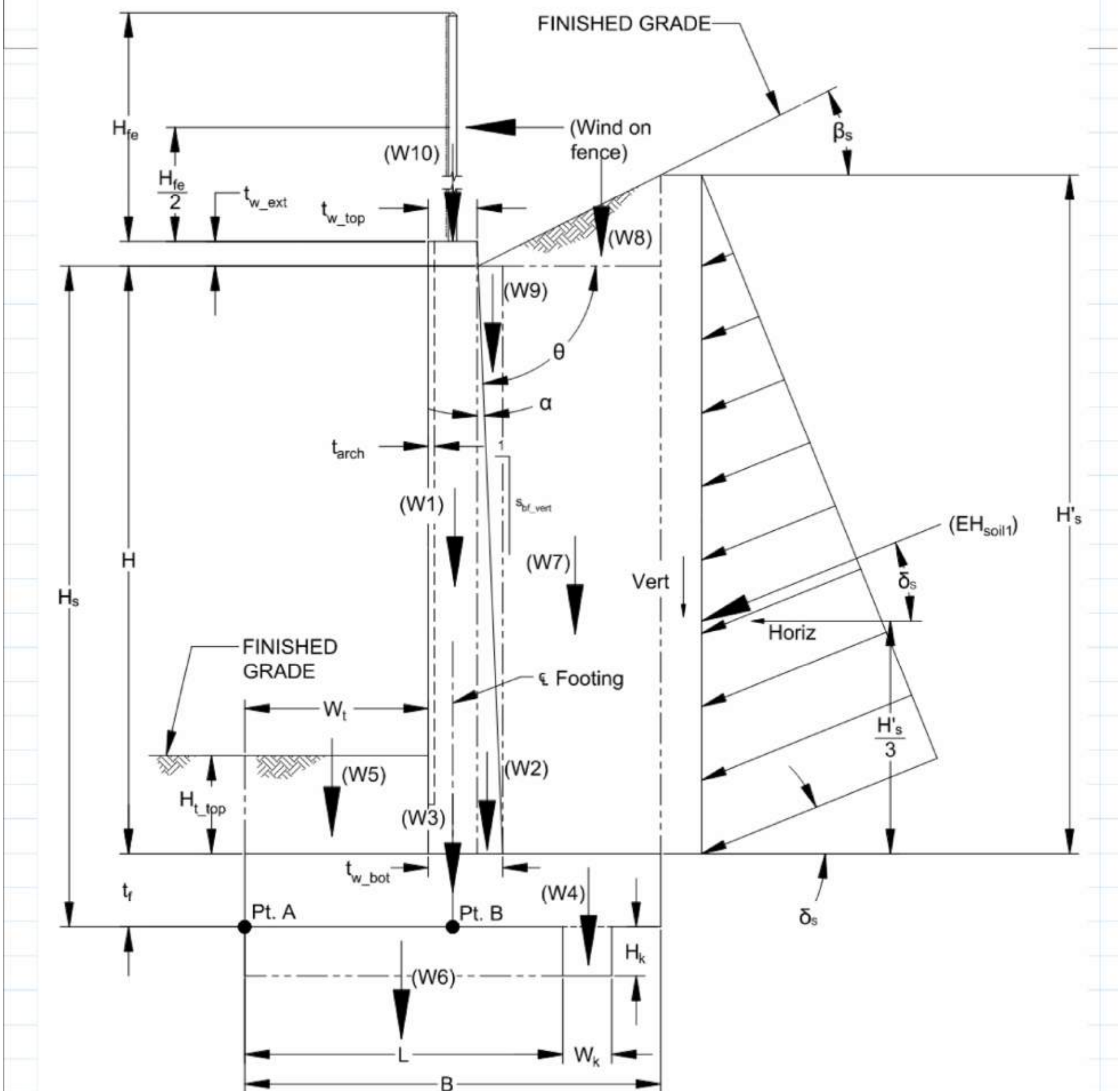


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 13.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 14.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 24$

Total wall thickness (top) $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \dfrac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 18.75\ in$

Angle of wall backslope $\alpha := \operatorname{atan}\left(\dfrac{1}{s_{bf\_vert}}\right)$ $\alpha = 2.39\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 87.61\ deg$

Set back from toe to face of wall: $W_t := 3.00\ ft$

Footing width: $B := 9.75\ ft$

Key width: $W_k := 1.00\ ft$

Key depth: $H_k := 1.50\ ft$

Set back from toe to face of key: $L := \begin{cases} B - H_k - W_k & \text{if } H_k > 0\ in \\ 0\ in & \text{else} \end{cases}$ $L = 7.25\ ft$

Depth of soil over toe: $H_{t\_top} := 1.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \dfrac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ — Stem wall clear cover

$CLR_{side} := 2.00\ in$ — side of footing clear cover

$CLR_{top} := 2.00\ in$ — top of footing clear cover

$CLR_{bot} := 3.00\ in$ — bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ — Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ — Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ — Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$n_{mod} = 6.00$

Modulus of rupture: $\lambda := 1.0$ — Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ — per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 25\ deg$ — 2H:1V backfill

Effective soil friction angle: $\phi'_f := 36\ deg$ — per geotechnical report, Ref. 4

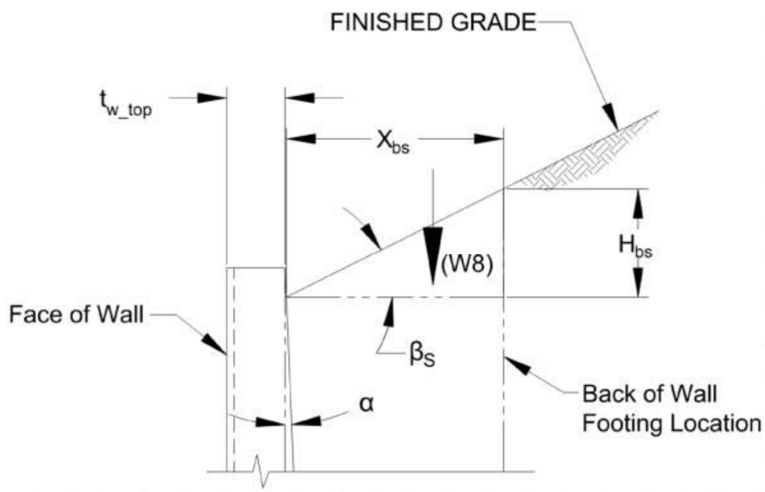


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete):	$\mu_{s\_c} := 0.60$	per geotechnical report, Ref. 4
Coefficient of friction (soil/soil):	$\mu_{s\_s} := \tan\left(\phi'_f\right)$	$\mu_{s\_s} = 0.73$
		Section C10.6.3.4
Ultimate soil bearing pressure:	$Q_n := 8.00\ ksf$	
Factored soil bearing pressure	$Q_R := Q_n \cdot \phi_{brg}$	$Q_R = 3.6\ ksf$
Friction angle between fill and wall:	$\delta_s := 22\ deg$	Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin\left(\phi'_f + \delta_s\right) \cdot \sin\left(\phi'_f - \beta_s\right)}{\sin\left(\theta - \delta_s\right) \cdot \sin\left(\theta + \beta_s\right)}}\right)^2$$

$$\Gamma_a = 2.07$$

$$k_{af} := \frac{\sin\left(\theta + \phi'_f\right)^2}{\Gamma_a \cdot \left(\sin\left(\theta\right)^2 \cdot \sin\left(\theta - \delta_s\right)\right)} \qquad k_{af} = 0.369$$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \frac{\left(2.5 \cdot \ln\left(\frac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \frac{2.56}{10^6} \cdot \left(\frac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 6.00\ ft$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \frac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\frac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.015\ \frac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 5.75\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan\left(\beta_s\right) \cdot X_{bs}$	$H_{bs} = 2.68\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 17.18\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s)

$R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $\quad R_{EH} = 7.07 \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height)

$R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $\quad R_{WS} = 0.24 \frac{kip}{ft}$

OVERTURNING MOMENTS:

Moment Arm: (about point A in Fig.1) — Overturning Moment:

Active earth pressure resultant:

$L_{EH} := \frac{H'_s}{3}$ $\quad M_{EH} := R_{EH} \cdot L_{EH}$

$L_{EH} = 5.73\ ft$ $\quad M_{EH} = 40.50 \frac{kip \cdot ft}{ft}$

Wind load on fence:

$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $\quad M_{WS} := R_{WS} \cdot L_{WS}$

$L_{WS} = 17.75\ ft$ $\quad M_{WS} = 4.29 \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 2.02 \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.57 \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 2.27 \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.23 \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.39 \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 1.41 \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 8.77 \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 1.00 \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.48 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$; $L_1 = 3.5\ ft$	$M_1 := W_1 \cdot L_1$; $M_1 = 7.05 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$; $L_2 = 4.69\ ft$	$M_2 := W_2 \cdot L_2$; $M_2 = 2.66 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$; $L_3 = 4.88\ ft$	$M_3 := W_3 \cdot L_3$; $M_3 = 11.05 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$; $L_4 = 7.75\ ft$	$M_4 := W_4 \cdot L_4$; $M_4 = 1.80 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$; $L_5 = 1.5\ ft$	$M_5 := W_5 \cdot L_5$; $M_5 = 0.59 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.	
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$; $L_7 = 7.16\ ft$	$M_7 := W_7 \cdot L_7$; $M_7 = 62.74 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$; $L_8 = 7.83\ ft$	$M_8 := W_8 \cdot L_8$; $M_8 = 7.85 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $\quad M_9 := W_9 \cdot L_9$

$L_9 = 4.38\ ft$ $\quad M_9 = 2.08\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $\quad L_{10} = 3.50\ ft$ $\quad M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.32\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 60.62\ \frac{kip \cdot ft}{ft}$

Factored resisting forces:

$$W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_min} = 19.26\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_min} = 132.59\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $\quad e_{A\_str} = 3.74\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $\quad e_{B\_str} = 1.14\ ft$

Check location of resultant:

$$Check_{Resultant\_str} := \begin{cases} \text{"OK"} & \text{if } \frac{-B}{4} \le e_{B\_str} \le \frac{B}{4} \\ \text{"NG"} & \text{else} \end{cases}$$

$Check_{Resultant\_str} = \text{"OK"}$

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $\quad P_{sliding} = 10.08\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\frac{W_{R\_min}}{B - 2 \cdot e_{B\_str}}\right)$ $\sigma_v = 2.58\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$P_{Fric} :=$
- if $L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft$
  - $\phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6)$
- also if $L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft$
  - $\phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L)$
- else
  - $\phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str})$

$P_{Fric} = 13.80\ \frac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \frac{1}{2} \cdot P_p \cdot (H_{t\_top} - 1.00\ ft + t_f + H_k)^2$ $P_{pass} = 2.25\ \frac{kip}{ft}$

The top 1.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric} + \phi_{pass} \cdot P_{pass}$ $P_{resist} = 14.92\ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} =$ "OK"

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces: $W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_max} = 24.8\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_max} = 166.24\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$ $e_{A\_BR} = 4.26\ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.62\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 2.91\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$ $Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$

$M_{o\_ser} = 38.84\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_ser} = 18.46\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_ser} = 121.96\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 3.14$

Service limit state OT Check: $OT_{check\_ser} :=$ if $OT_{FOS} \geq 1.5$ "OK" else "NG" $OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 4.50\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.37\ ft$

Check location of resultant: $Check_{Resultant\_svc} := \text{if } \frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} = \text{"OK"}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 2.05\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 6.63\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 9.01\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 18.46\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 20.71\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 3.12$

Service limit state sliding Check: $Sliding_{check\_ser} := \text{if } Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} = \text{"OK"}$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 5.90 \ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 9.34 \ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 115.62 \ \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 21.47 \ \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 154.14 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 1.79 \ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 3.08 \ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \begin{cases} \text{"OK"} & \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \\ \text{"NG"} & \text{else} \end{cases}$$

$$Check_{Resultant\_EQ} = \text{"OK"}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $P_{slidingEQ} = 15.30 \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}} \right)$ $\sigma_{vEQ} = 5.99\ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $BRG_{EQ} = 3.59\ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0\ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0\ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 16.63 \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $P_{resist\_EQ} = 18.88 \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} = \text{"OK"}$

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$W_{R\_maxEQ} = 27.01 \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 187.79 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 2.67 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 2.20 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}}\right) \qquad \sigma_{BR\_EQ} = 5.05 \ ksf$$

Bearing pressure check:

$$Check_{Bearing\_EQ} := \text{if } \sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n \ \text{"OK"} \ \text{else} \ \text{"NG"}$$

$$Check_{Bearing\_EQ} = \text{"OK"}$$

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

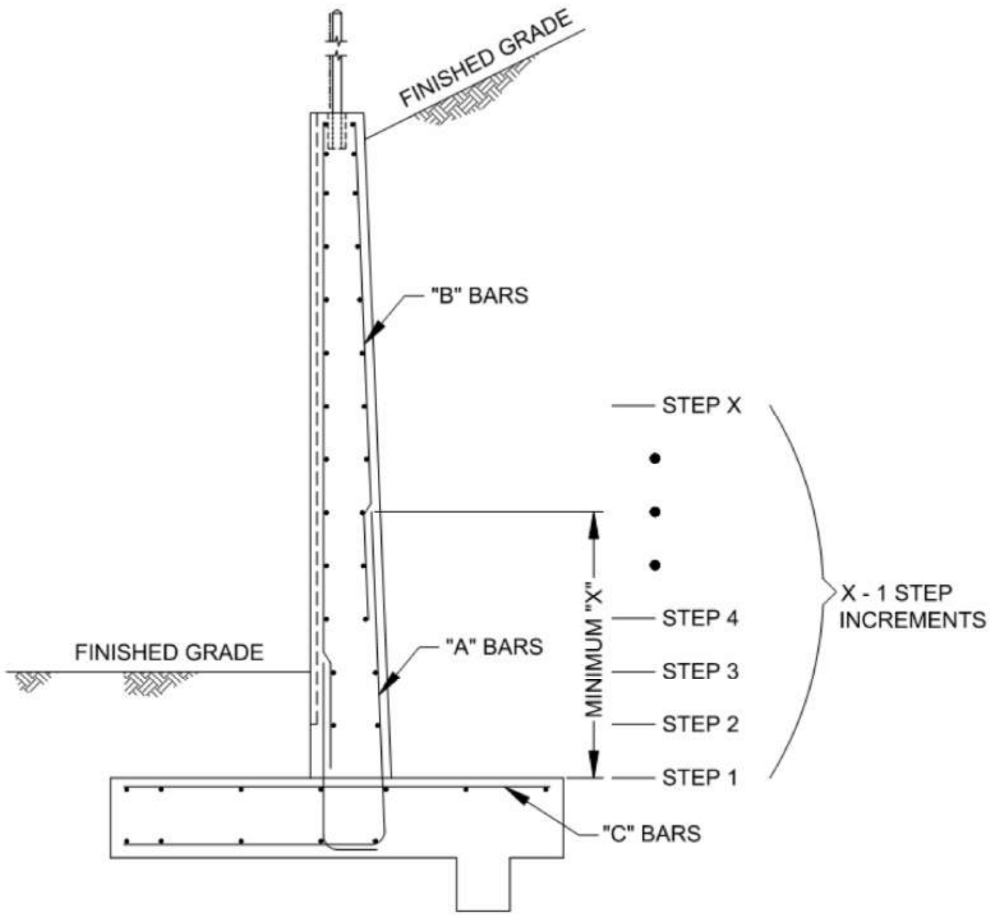


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\qquad step = 12.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} H_{st_i} \leftarrow H - (i) \cdot z \\ H_{st} \end{array} \right.$$

$$H_{st}^{\mathrm{T}} = [13.0\ \ 12.0\ \ 11.0\ \ 10.0\ \ 9.0\ \ 8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{T} = [5.46\ \ 4.79\ \ 4.16\ \ 3.57\ \ 3.03\ \ 2.53\ \ 2.08\ \ 1.67\ \ 1.31\ \ 0.99\ \ 0.72\ \ 0.49\ \ 0.30]\ \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{T} = [8.43\ \ 7.42\ \ 6.48\ \ 5.60\ \ 4.79\ \ 4.04\ \ 3.36\ \ 2.75\ \ 2.21\ \ 1.73\ \ 1.32\ \ 0.97\ \ \ldots]\ \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{T} = [46.69\ \ 38.77\ \ 31.82\ \ 25.79\ \ 20.60\ \ 16.19\ \ 12.50\ \ 9.44\ \ 6.97\ \ 5.01\ \ 3.49\ \ 2.35\ \ \ldots]\ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{T} = [29.74\ \ 24.55\ \ 20.01\ \ 16.08\ \ 12.71\ \ 9.86\ \ 7.48\ \ 5.53\ \ 3.97\ \ 2.75\ \ 1.83\ \ 1.16\ \ \ldots]\ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\dfrac{H}{step+1}\right)\cdot\left(\dfrac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^{T} = [17.75\;\; 17.25\;\; 16.75\;\; 16.25\;\; 15.75\;\; 15.25\;\; 14.75\;\; 14.25\;\; 13.75\;\; 13.25\;\; 12.75\;\; 12.25\;\; \ldots]\; in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} S_{s_i} \leftarrow \dfrac{{t_{w_i}}^2}{6} \\ S_s \end{array} \right.$$

$$S_s^{T} = [630\;\; 595\;\; 561\;\; 528\;\; 496\;\; 465\;\; 435\;\; 406\;\; 378\;\; 351\;\; 325\;\; 300\;\; \ldots]\; \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$ — Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$ — Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^{T} = [27.0\;\; 25.5\;\; 24.1\;\; 22.6\;\; 21.3\;\; 19.9\;\; 18.7\;\; 17.4\;\; 16.2\;\; 15.1\;\; 13.9\;\; 12.9\;\; \ldots]\; \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^{T} = [27.02\;\; 25.52\;\; 24.06\;\; 22.65\;\; 21.27\;\; 19.94\;\; 16.62\;\; 12.56\;\; 9.27\;\; 6.66\;\; 4.64\;\; 3.12\;\; \ldots]\; \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 8$ $\quad s_A := 6\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $\quad A_b(B_A) = 0.79\ in^2$ $\quad A_{s\_A} = 1.58\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $\quad xa := Steps_A$ $\quad xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $\quad d_{s\_1} = 15.75\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function $\quad \phi M_{n\_A} = 103.72\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\quad \rho_1 = 0.0084$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $\quad k_1 = 0.27$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $\quad f_{s\_1} = 16\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ $\quad$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $\quad d_{c\_1} = 2\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.18$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \, \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 33.58 \; in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18 \; in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 18.00 \; in$

Check reinforcing spacing: $check_{dc}\left(s_A, s'_{max\_1}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \, \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 14.59 \; in$

Factored shear resistance (assumes Av equal to zero and s_v equal to 12 in):

$$\phi V_{n\_1} := \phi V_n\left(0 \; in^2, 12 \; in, f_y, 12 \; in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 19.9 \; \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{“OK”}$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 97.79 \; \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 103.72\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 19.9\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 6$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b(B_B)}{s_B}$ $A_{s\_B} = 0.44\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b(B_B)}{2}$ $d_{s\_2} = 13.88\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 26.83\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \frac{A_{s\_B}}{12 \frac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0026$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.16$

Maximum reinforcing stress due to service load: $f_{s\_2} := \frac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \frac{k_2}{3}\right)}$ $f_{s\_2} = 26\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \frac{d_b(B_B)}{2}$ $d_{c\_2} = 1.88\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \frac{d_{c\_2}}{0.7 \cdot (t_{w_{xb}} - d_{c\_2})}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.19$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 18.46\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}})$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 18.00\ in$

Check reinforcing spacing: $check_{dc}(s_B, s'_{max\_2}) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12 \frac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 13.55\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 18.5\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{“OK”}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 4.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 5.19\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 18.61\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 59.42\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 43.63\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads:

$$S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6} \qquad S_{c\_heel} = 648.00\ in^3$$

Heel cracking moment:

$$M_{cr\_heel} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r \right) \cdot S_{c\_heel} \right) \qquad M_{cr\_heel} = 27.79\ kip \cdot ft$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3)

$$M_{D\_heel} := min\left(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1} \right)$$

$$M_{D\_heel} = 27.79\ kip \cdot ft$$

Heel reinforcing bar size and spacing:

$$B_C := 6 \qquad s_C := 6\ in$$

$$A_{s\_C} := \frac{A_b\left(B_C\right)}{s_C} \qquad A_{s\_C} = 0.88\ \frac{in^2}{ft}$$

Reference workbook function

Depth of reinforcing

$$d_{s\_heel} := t_f - CLR_{top} - \frac{d_b\left(B_C\right)}{2} \qquad d_{s\_heel} = 15.63\ in$$

Factored moment resistance:

$$\phi M_{n\_heel} := \phi M_n \left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c \right) \cdot 1.00\ ft$$

Reference workbook function

$$\phi M_{n\_heel} = 59.31\ kip \cdot ft$$

Compare the moment demand to the moment capacity:

$$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel} \right) = \text{"OK"}$$

Reinforcing Ratio

$$\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}} \qquad \rho_h = 0.0047$$

Neutral axis depth factor:

$$k_h := \sqrt{2 \cdot \left(\rho_h \cdot n_{mod} \right) + \left(\rho_h \cdot n_{mod} \right)^2} - \left(\rho_h \cdot n_{mod} \right) \qquad k_h = 0.21$$

Maximum reinforcing stress due to service load:

$$f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3} \right) \cdot 1.00\ ft} \qquad f_{s\_h} = 40.95\ ksi$$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$$

$d_{c\_h} = 2.38\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.22$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 9.29\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 9.29\ in$

Check reinforcing spacing:

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1.
Using reference book function.

$d_{v\_heel} = 14.98\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 12in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 12\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_heel} = 20.45\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{“OK”}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 14.53\ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00\ ft \qquad M_{D\_toe\_1} = 21.8\ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00\ ft$$

$$M_{D\_svc\_t} = 5.45\ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79\ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 27.79\ kip\ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 8.00$$

$$s_{toe} := s_A \qquad s_{toe} = 6.00\ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 1.58\ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.5\ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n\left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 94.83\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \dfrac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0091$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot (\rho_t \cdot n_{mod}) + (\rho_t \cdot n_{mod})^2} - (\rho_t \cdot n_{mod})$ $k_t = 0.28$

Maximum reinforcing stress due to service load: $f_{s\_t} := \dfrac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 3\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \dfrac{d_b(B_{toe})}{2}$ $d_{c\_t} = 3.5\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \dfrac{d_{c\_t}}{0.7 \cdot (t_f - d_{c\_t})}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.34$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \dfrac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 158.33\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe}\cdot f_y}, 0.9\cdot d_{s\_toe}, 0.72\cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$$d_{v\_toe} = 13.34\ in$$

Factored shear resistance (assumes Av equal to zero and s_v equal to 12in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 12\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right)\cdot\frac{1}{ft}$$

$$\phi V_{n\_toe} = 18.2\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$$B_{temp\_stem} := 4 \qquad s_{temp\_stem} := 12\ in$$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right|\cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.4\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \left| \begin{array}{l} A_{temp} \leftarrow \frac{1.3\cdot\left(H + t_{w\_ext}\right)\cdot t_{w\_bot}}{2\cdot\left(H + t_{w\_ext} + t_{w\_bot}\right)\cdot f_y}\cdot\frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad \left| A_{temp} \leftarrow 0.11\cdot\frac{in^2}{ft} \right. \\ \text{else if } A_{temp} > 0.60\cdot\frac{in^2}{ft} \\ \quad \left| A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \right. \\ \text{return } A_{temp} \end{array} \right.$$

$$A_{s\_temp\_1} = 0.18\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00 \, in \\ \quad 12 \, in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0 \, in) \end{cases}$$

$$s_{max\_temp\_1} = 12.00 \, in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 20$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.41 \, \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.89 \, in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \frac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11 \, \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60 \, \frac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.17 \, \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0\ in) \end{cases}$$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - KEY, STEM INTERFACE

Key Check (to determine if key reinforcing is required):

It is assumed that the footing and the key will be placed monolithically. The ϕV_n function as used below simply returns the shear resistance per the simplified procedure for non prestressed sections without transverse reinforcement as described in AASHTO Section 5.7.3.3 and 5.7.4.3.

Conservatively design for the full lateral demand forces, neglecting the reduction in loading on the key due to the passive resistance in front of wall and any reduction in the applied load from sliding friction in front of the key.

Echo of calculated factored demand forces from above (for comparison only)

$P_{sliding} = 10.08\ \frac{kip}{ft}$ $\quad P_{slidingEQ} = 15.3\ \frac{kip}{ft}$

Factored shear resistance - (A_v equal to zero and s_v equal to 12 in):

$\phi V_{n\_key} := \phi V_n(0\ in^2, 12\ in, f_y, 12\ in, W_k, f'_c)$

$\phi V_{n\_key} = 16.38\ kip$

Compare the shear demand to the shear capacity:

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft, \phi V_{n\_key}) = \text{"OK"}$

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $\quad A_{cv} = 213.00\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.178\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 1.58\ in^2$$

$check_{dc}(A_{vf\_min}, A_{vf}) =$ "OK"

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ 5.7.4.3-5

$V_{ni\_1} = 72.86\ kip$ $V_{ni\_2} = 170.40\ kip$

$V_{ni\_3} = 170.40\ kip$

Controlling nominal concrete shear capacity:

$V_{niMax} :=$ if $min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1}$
    $min(V_{ni\_2}, V_{ni\_3})$
else
    V_{ni_1}

$V_{niMax} = 72.86\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $V_{ri} = 65.57\ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft$
  "OK"
else
  "NG"

$InterfaceCheck_{stem} =$ "OK"

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} =$ "OK"

$Sliding_{check\_str} =$ "OK"

$Bearing_{check\_str} =$ "OK"

$OT_{check\_ser} =$ "OK"

$Check_{Resultant\_svc} =$ "OK"

$Sliding_{check\_ser} =$ "OK"

$Check_{Resultant\_EQ} =$ "OK"

$Sliding_{check\_EQ} =$ "OK"

$Check_{Bearing\_EQ} =$ "OK"

$check_{dc}(M_{sD_{xa}}, \phi M_{n\_A}) =$ "OK"

$check_{dc}(s_A, s'_{max\_1}) =$ "OK"

$check_{dc}(V_{str_{xa}}, \phi V_{n\_1}) =$ "OK"

$check_{dc}(M_{sD\_EQ}, \phi M_{n\_A\_EQ}) =$ "OK"

$check_{dc}(P_{slidingEQ}, \phi V_{n\_EQ}) =$ "OK"

$check_{dc}(V_{D\_heel}, \phi V_{n\_heel}) =$ "OK"

$check_{dc}(M_{D\_toe}, \phi M_{n\_toe}) =$ "OK"

$check_{dc}(s_{toe}, s'_{max\_t}) =$ "OK"

$check_{dc}(V_{D\_toe}, \phi V_{n\_toe}) =$ "OK"

$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) =$ "OK"

$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) =$ "OK"

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) =$ "OK"

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) =$ "OK"

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft, \phi V_{n\_key}) =$ "OK"

$check_{dc}(A_{vf\_min}, A_{vf}) =$ "OK"

$InterfaceCheck_{stem} =$ "OK"

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 13.00\ ft$
Footing width:	$B = 9.75\ ft$
Footing depth:	$t_f = 1.50\ ft$
Wall setback:	$W_t = 3.00\ ft$
Key location:	$L = 7.25\ ft$
Key depth:	$H_k = 1.50\ ft$
Key width:	$W_k = 1.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 8.00$	$s_A = 6.00\ in$	
Main stem reinforcing	$B_B = 6.00$	$s_B = 12.00\ in$	
Heel reinforcing:	$B_C = 6.00$	$s_C = 6.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 12.00\ in$	listed bars provided each face

Temperature reinforcing - footing:	$B_{temp\_ftg} = 4.00$	$N_{temp\_ftg} = 20.00$	total number of bars for footing

Shear reinforcing -stem: no shear reinforcement

Shear reinforcing -heel: no shear reinforcement

Shear reinforcing -toe: no shear reinforcement

Shear reinforcing -shear key: no shear reinforcement

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user   Unique modification by the user

Variable (to be input by user)   Internal result (for reference)   Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states: $\phi_{svc} := 1.00$ Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified: $\phi_{EQ} := 1.0$ Section 11.5.8

$\phi_{EQ\_Stab} := 0.9$ Section 11.5.8

$\phi_{EQ\_BRG} := 0.8$ Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

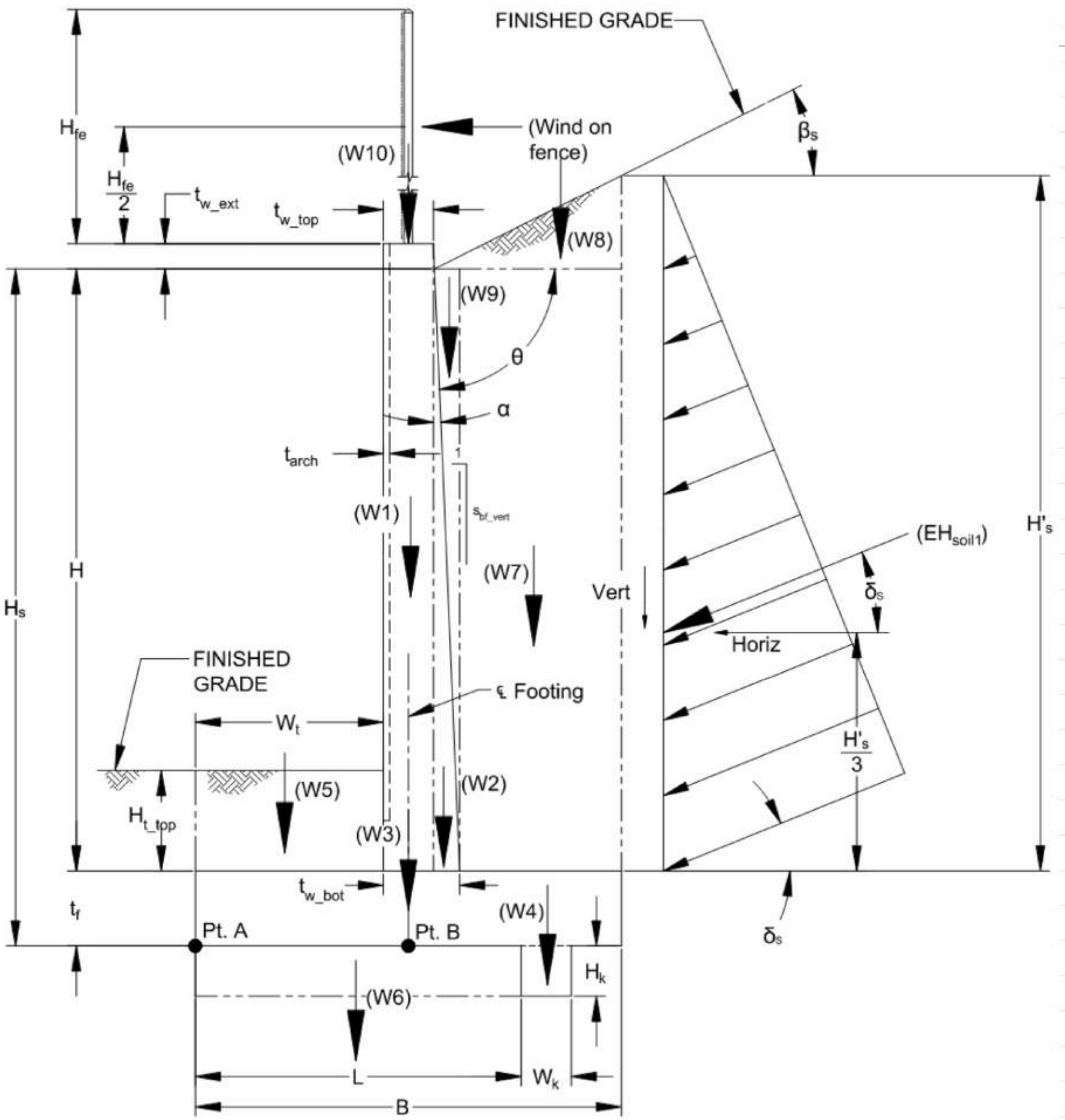


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 15.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 16.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 24$

Total wall thickness (top) $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \dfrac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 19.75\ in$

Angle of wall backslope $\alpha := \operatorname{atan}\left(\dfrac{1}{s_{bf\_vert}}\right)$ $\alpha = 2.39\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 87.61\ deg$

Set back from toe to face of wall: $W_t := 4.00\ ft$

Footing width: $B := 11.50\ ft$

Key width: $W_k := 1.00\ ft$

Key depth: $H_k := 1.50\ ft$

Set back from toe to face of key: $L := \begin{cases} B - H_k - W_k & \text{if } H_k > 0\ in \\ 0\ in & \text{else} \end{cases}$ $L = 9.00\ ft$

Depth of soil over toe: $H_{t\_top} := 1.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \dfrac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ Stem wall clear cover

$CLR_{side} := 2.00\ in$ side of footing clear cover

$CLR_{top} := 2.00\ in$ top of footing clear cover

$CLR_{bot} := 3.00\ in$ bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$$n_{mod} = 6.00$$

Modulus of rupture: $\lambda := 1.0$ Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 25\ deg$ 2H:1V backfill

Effective soil friction angle: $\phi'_f := 36\ deg$ per geotechnical report, Ref. 4

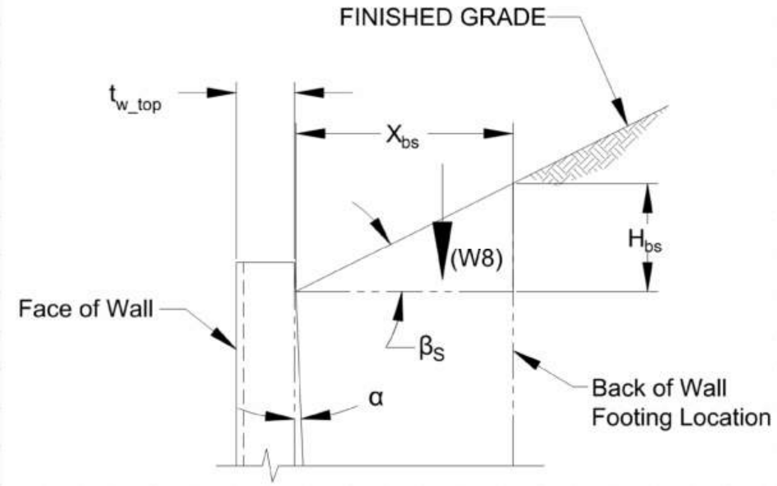


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete):	$\mu_{s\_c} := 0.60$	per geotechnical report, Ref. 4
Coefficient of friction (soil/soil):	$\mu_{s\_s} := \tan(\phi'_f)$	$\mu_{s\_s} = 0.73$
		Section C10.6.3.4
Ultimate soil bearing pressure:	$Q_n := 9.50\ ksf$	
Factored soil bearing pressure	$Q_R := Q_n \cdot \phi_{brg}$	$Q_R = 4.28\ ksf$
Friction angle between fill and wall:	$\delta_s := 22\ deg$	Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.07$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.369$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \frac{\left(2.5 \cdot \ln\left(\frac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \frac{2.56}{10^6} \cdot \left(\frac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 6.00\ ft$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \frac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\frac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.015\ \frac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 6.50\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 3.03\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 19.53\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $R_{EH} = 9.14 \ \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.24 \ \frac{kip}{ft}$

OVERTURNING MOMENTS:

	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Active earth pressure resultant:	$L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 6.51 \ ft$	$M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 59.49 \ \frac{kip \cdot ft}{ft}$
Wind load on fence:	$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 19.75 \ ft$	$M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 4.78 \ \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 2.33 \ \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.75 \ \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 2.67 \ \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.23 \ \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.52 \ \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 1.76 \ \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 11.42 \ \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 1.28 \ \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.63 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$ $L_1 = 4.5\ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 10.46 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $L_2 = 5.72\ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 4.29 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$ $L_3 = 5.75\ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 15.37 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$ $L_4 = 9.50\ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 2.21 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$ $L_5 = 2\ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 1.04 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.	
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$ $L_7 = 8.57\ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 97.87 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$ $L_8 = 9.33\ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 11.95 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $M_9 := W_9 \cdot L_9$

$L_9 = 5.43\ ft$ $M_9 = 3.42\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $L_{10} = 4.50\ ft$ $M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.42\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 87.51\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_min} = 24.45\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_min} = 202.80\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $e_{A\_str} = 4.72\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $e_{B\_str} = 1.03\ ft$

Check location of resultant:

$Check_{Resultant\_str} :=$ if $\frac{-B}{4} \le e_{B\_str} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_str} =$ "OK"

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $P_{sliding} = 12.95\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\frac{W_{R\_min}}{B - 2 \cdot e_{B\_str}}\right)$ $\sigma_v = 2.59\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$P_{Fric} :=$ if $L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft$
$\quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6)$
also if $L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft$
$\quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L)$
else
$\quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str})$

$P_{Fric} = 17.67\ \frac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \frac{1}{2} \cdot P_p \cdot (H_{t\_top} - 1.00\ ft + t_f + H_k)^2$ $P_{pass} = 2.25\ \frac{kip}{ft}$

The top 1.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric} + \phi_{pass} \cdot P_{pass}$ $P_{resist} = 18.80\ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces: $W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_max} = 31.42\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_max} = 254.26\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$ $e_{A\_BR} = 5.31\ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.44\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 2.96\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$ $Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$

$$M_{o\_ser} = 56.59\ \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$$

$$W_{R\_ser} = 23.34\ \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_ser} = 186.39\ \frac{kip \cdot ft}{ft}$$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 3.29$

Service limit state OT Check:

$$OT_{check\_ser} := \begin{cases} \text{"OK"} & \text{if } OT_{FOS} \geq 1.5 \\ \text{"NG"} & \text{else} \end{cases}$$

$OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 5.56\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.19\ ft$

Check location of resultant:

$$Check_{Resultant\_svc} := \begin{array}{l} \text{if } \frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4} \\ \quad \text{"OK"} \\ \text{else} \\ \quad \text{"NG"} \end{array}$$

$$Check_{Resultant\_svc} = \text{"OK"}$$

Vertical stress (per foot of wall such that units are kip/ft^2):

$$\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}} \right) \qquad \sigma_{v\_svc} = 2.10\ \mathbf{ksf}$$

Factored sliding force:

$$P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos\left(\delta_s\right) + \gamma_{WSsvc1} \cdot R_{WS}$$

$$P_{sliding\_svc} = 8.54\ \frac{\mathbf{kip}}{\mathbf{ft}}$$

Bearing width for service calculation:

$$BRG_{svc} := B - 2 \cdot e_{B\_svc} \qquad BRG_{svc} = 11.12\ \mathbf{ft}$$

Sliding resistance -friction:

$$P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc} \qquad P_{Fric\_svc} = 23.34\ \frac{\mathbf{kip}}{\mathbf{ft}}$$

Total sliding resistance:

$$P_{resist\_svc} := \phi_{svc} \cdot \left(P_{Fric\_svc} + P_{pass}\right) \qquad P_{resist\_svc} = 25.59\ \frac{\mathbf{kip}}{\mathbf{ft}}$$

Sliding factor of safety:

$$Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}} \qquad Sliding_{FoS} = 3$$

Service limit state sliding Check:

$$Sliding_{check\_ser} := \begin{array}{l} \text{if } Sliding_{FoS} > 1.2 \\ \quad \text{"OK"} \\ \text{else} \\ \quad \text{"NG"} \end{array}$$

$$Sliding_{check\_ser} = \text{"OK"}$$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 7.92 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 10.82\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 173.20 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 27.41 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 236.92 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 2.32\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 3.43\ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \text{ then “OK” else “NG”}$$

$$Check_{Resultant\_EQ} = \text{“OK”}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $\quad P_{slidingEQ} = 20.05 \ \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$ $\quad \sigma_{vEQ} = 5.90 \ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $\quad BRG_{EQ} = 4.65 \ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 21.19 \ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $\quad P_{resist\_EQ} = 23.44 \ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} = \text{"OK"}$

BEARING PRESSURE - SEISMIC:

Factored resisting forces: $W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$

$W_{R\_maxEQ} = 34.39 \ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 288.38 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 3.35\ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 2.40\ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}}\right) \qquad \sigma_{BR\_EQ} = 5.13\ ksf$$

Bearing pressure check:

$Check_{Bearing\_EQ} :=$ if $\sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n$
  "OK"
else
  "NG"

$Check_{Bearing\_EQ} =$ "OK"

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

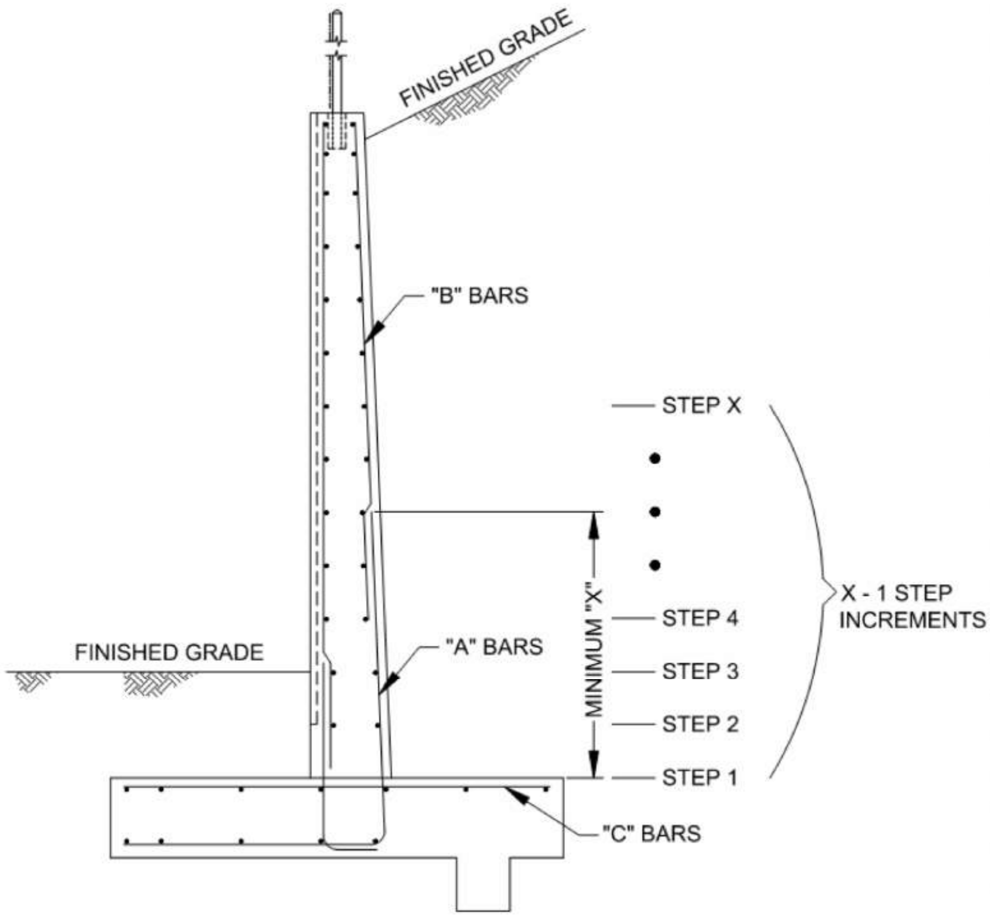


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$

user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\quad step = 14.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \quad \| \; H_{st_i} \leftarrow H - (i) \cdot z \quad H_{st}$$

$$H_{st}^{T} = [15.0\ \ 14.0\ \ 13.0\ \ 12.0\ \ 11.0\ \ 10.0\ \ 9.0\ \ 8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ \ldots]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{T} = [7.22\ \ 6.44\ \ 5.71\ \ 5.02\ \ 4.37\ \ 3.77\ \ 3.21\ \ 2.70\ \ 2.23\ \ 1.81\ \ 1.43\ \ 1.10\ \ 0.81\ \ \ldots] \ \frac{kip}{ft}$$

Shear:
Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{T} = [11.07\ \ 9.90\ \ 8.80\ \ 7.77\ \ 6.80\ \ 5.90\ \ 5.06\ \ 4.30\ \ 3.59\ \ 2.96\ \ 2.39\ \ 1.89\ \ \ldots] \ \frac{kip}{ft}$$

Flexure:
Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{T} = [69.45\ \ 58.97\ \ 49.62\ \ 41.34\ \ 34.06\ \ 27.72\ \ 22.24\ \ 17.57\ \ 13.63\ \ 10.36\ \ 7.69\ \ 5.55\ \ \ldots] \ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{T} = [44.74\ \ 37.84\ \ 31.70\ \ 26.27\ \ 21.50\ \ 17.36\ \ 13.80\ \ 10.77\ \ 8.23\ \ 6.14\ \ 4.45\ \ 3.12\ \ \ldots] \ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left| \; t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\frac{H}{step+1}\right) \cdot \left(\frac{i}{s_{bf\_vert}}\right) \;;\; t_w \right.$$

$$t_w^{\mathrm{T}} = [18.75 \;\; 18.25 \;\; 17.75 \;\; 17.25 \;\; 16.75 \;\; 16.25 \;\; 15.75 \;\; 15.25 \;\; 14.75 \;\; 14.25 \;\; 13.75 \;\; 13.25 \;\; \ldots] \; in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left| \; S_{s_i} \leftarrow \frac{{t_{w_i}}^2}{6} \;;\; S_s \right.$$

$$S_s^{\mathrm{T}} = [703 \;\; 666 \;\; 630 \;\; 595 \;\; 561 \;\; 528 \;\; 496 \;\; 465 \;\; 435 \;\; 406 \;\; 378 \;\; 351 \;\; \ldots] \; \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$ — Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$ — Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^{\mathrm{T}} = [30.2 \;\; 28.6 \;\; 27.0 \;\; 25.5 \;\; 24.1 \;\; 22.6 \;\; 21.3 \;\; 19.9 \;\; 18.7 \;\; 17.4 \;\; 16.2 \;\; 15.1 \;\; \ldots] \; \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left| \; M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \;;\; M_{sD} \right.$$

$$M_{sD}^{\mathrm{T}} = [30.15 \;\; 28.56 \;\; 27.02 \;\; 25.52 \;\; 24.06 \;\; 22.65 \;\; 21.27 \;\; 19.94 \;\; 18.13 \;\; 13.77 \;\; 10.22 \;\; 7.39 \;\; \ldots] \; \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 9$ $s_A := 4\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 1.00\ in^2$

$A_{s\_A} = 3.00\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 16.69\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A} = 195.48\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.015$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.34$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 12\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 2.06\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.18$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 44.98\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 18.00\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 15.02\ in$

Factored shear resistance (assumes Av equal to #4 bar and s_v equal to 12 in):

$$\phi V_{n\_1} := \phi V_n\left(A_b(4), 12\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 34.0\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 148.91\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 195.48\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 34.0\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 6$ $s_B := 8\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b(B_B)}{s_B}$ $A_{s\_B} = 0.66\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b(B_B)}{2}$ $d_{s\_2} = 14.88\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 42.74\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \dfrac{A_{s\_B}}{12 \dfrac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0037$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.19$

Maximum reinforcing stress due to service load: $f_{s\_2} := \dfrac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \dfrac{k_2}{3}\right)}$ $f_{s\_2} = 28\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \dfrac{d_b(B_B)}{2}$ $d_{c\_2} = 1.88\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \dfrac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.18$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \dfrac{700 \dfrac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 17.39\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 17.39\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12 \dfrac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$ $d_{v\_2} = 14.39\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n \left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 19.6\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 4.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 5.85\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 23.82\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 85.99\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 63.06\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads:

$$S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6} \qquad S_{c\_heel} = 648.00\ in^3$$

Heel cracking moment:

$$M_{cr\_heel} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_{c\_heel}\right) \qquad M_{cr\_heel} = 27.79\ kip \cdot ft$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3)

$$M_{D\_heel} := min\left(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1}\right)$$

$$M_{D\_heel} = 27.79\ kip \cdot ft$$

Heel reinforcing bar size and spacing:

$$B_C := 6 \qquad s_C := 4\ in$$

$$A_{s\_C} := \frac{A_b\left(B_C\right)}{s_C} \qquad A_{s\_C} = 1.32\ \frac{in^2}{ft}$$

Reference workbook function

Depth of reinforcing

$$d_{s\_heel} := t_f - CLR_{top} - \frac{d_b\left(B_C\right)}{2} \qquad d_{s\_heel} = 15.63\ in$$

Factored moment resistance:

$$\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$$

Reference workbook function

$$\phi M_{n\_heel} = 87.05\ kip \cdot ft$$

Compare the moment demand to the moment capacity:

$$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$$

Reinforcing Ratio

$$\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}} \qquad \rho_h = 0.007$$

Neutral axis depth factor:

$$k_h := \sqrt{2 \cdot \left(\rho_h \cdot n_{mod}\right) + \left(\rho_h \cdot n_{mod}\right)^2} - \left(\rho_h \cdot n_{mod}\right) \qquad k_h = 0.25$$

Maximum reinforcing stress due to service load:

$$f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft} \qquad f_{s\_h} = 40.04\ ksi$$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$$

$d_{c\_h} = 2.38\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.22$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 9.61\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 9.61\ in$

Check reinforcing spacing:

$check_{dc}(s_C, s'_{max\_h}) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_heel} = 14.65\ in$

Factored shear resistance (assumes Av equal to #4 bar and set s_v equal to 12in):

$$\phi V_{n\_heel} := \phi V_n(A_b(4), 12\ in, f_y, 12\ in, d_{v\_heel}, f'_c) \cdot \frac{1}{ft}$$

$\phi V_{n\_heel} = 33.19\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}(V_{D\_heel}, \phi V_{n\_heel}) = \text{"OK"}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 19.70 \ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00 \ ft \qquad M_{D\_toe\_1} = 39.39 \ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00 \ ft$$

$$M_{D\_svc\_t} = 7.47 \ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79 \ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 27.79 \ kip \ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 9.00$$

$$s_{toe} := s_A \qquad s_{toe} = 4.00 \ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 3 \ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.44 \ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n\left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 165.11\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0173$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot \left(\rho_t \cdot n_{mod}\right) + \left(\rho_t \cdot n_{mod}\right)^2} - \left(\rho_t \cdot n_{mod}\right)$ $k_t = 0.36$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 2\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b\left(B_{toe}\right)}{2}$ $d_{c\_t} = 3.56\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot \left(t_f - d_{c\_t}\right)}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.35$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 212.70\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

Using reference workbook function $check\left(demand, capacity\right)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$$d_{v\_toe} = 12.99\ in$$

Factored shear resistance (assumes Av equal to #4 bar and s_v equal to 12in):

$$\phi V_{n\_toe} := \phi V_n\left(A_b(4), 12\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 29.4\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$$B_{temp\_stem} := 4 \qquad s_{temp\_stem} := 12\ in$$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.4\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \begin{aligned} & A_{temp} \leftarrow \frac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \frac{ksi}{12} \\ & \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ & \quad A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \\ & \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ & \quad A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \\ & \text{return } A_{temp} \end{aligned}$$

$$A_{s\_temp\_1} = 0.19\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_1} = 12.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 24$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.42\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.65\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \dfrac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.17\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$s_{max\_temp\_2} :=$ if $t_f > 18.00\ in$ → $12\ in$; else → $min(3.0 \cdot t_f, 18.0\ in)$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - KEY, STEM INTERFACE

Key Check (to determine if key reinforcing is required):

It is assumed that the footing and the key will be placed monolithically. The ϕV_n function as used below simply returns the shear resistance per the simplified procedure for non prestressed sections without transverse reinforcement as described in AASHTO Section 5.7.3.3 and 5.7.4.3.

Conservatively design for the full lateral demand forces, neglecting the reduction in loading on the key due to the passive resistance in front of wall and any reduction in the applied load from sliding friction in front of the key.

Echo of calculated factored demand forces from above (for comparison only)

$P_{sliding} = 12.95\ \frac{kip}{ft}$ $\quad P_{slidingEQ} = 20.1\ \frac{kip}{ft}$

Factored shear resistance - (A_v equal to #4 bar and s_v equal to 12 in):

$\phi V_{n\_key} := \phi V_n(A_b(4), 12\ in, f_y, 12\ in, W_k, f'_c)$

$\phi V_{n\_key} = 27.18\ kip$

Compare the shear demand to the shear capacity:

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft, \phi V_{n\_key}) = \text{"OK"}$

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $\quad A_{cv} = 225.00\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.188\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 3.00\ in^2$$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{“OK”}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ — 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ — 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ — 5.7.4.3-5

$V_{ni\_1} = 124.88\ kip$ $\qquad V_{ni\_2} = 180.00\ kip$

$V_{ni\_3} = 180.00\ kip$

Controlling nominal concrete shear capacity:

$$V_{niMax} := \text{if } min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1} \;\; \| \; min(V_{ni\_2}, V_{ni\_3}) \;\; \text{else} \;\; \| \; V_{ni\_1}$$

$V_{niMax} = 124.88\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $V_{ri} = 112.39\ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft$
  "OK"
else
  "NG"

$InterfaceCheck_{stem} = \text{"OK"}$

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{"OK"}$

$Sliding_{check\_str} = \text{"OK"}$

$Bearing_{check\_str} = \text{"OK"}$

$OT_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_svc} = \text{"OK"}$

$Sliding_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_EQ} = \text{"OK"}$

$Sliding_{check\_EQ} = \text{"OK"}$

$Check_{Bearing\_EQ} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{"OK"}$

$check_{dc}\left(\max\left(P_{sliding}, P_{slidingEQ}\right) \cdot 1\ ft, \phi V_{n\_key}\right) = \text{"OK"}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{"OK"}$

$InterfaceCheck_{stem} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 15.00\ ft$
Footing width:	$B = 11.50\ ft$
Footing depth:	$t_f = 1.50\ ft$
Wall setback:	$W_t = 4.00\ ft$
Key location:	$L = 9.00\ ft$
Key depth:	$H_k = 1.50\ ft$
Key width:	$W_k = 1.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 9.00$	$s_A = 4.00\ in$	
Main stem reinforcing	$B_B = 6.00$	$s_B = 8.00\ in$	
Heel reinforcing:	$B_C = 6.00$	$s_C = 4.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 12.00\ in$	listed bars provided each face

Temperature reinforcing - footing: $B_{temp\_ftg} = 4.00$ $N_{temp\_ftg} = 24.00$ total number of bars for footing

Shear reinforcing -stem: #4@12" $Min_X = 4.00\ ft$ from top of footing

Shear reinforcing -heel: #4@12 in. provide ties or stirrups

Shear reinforcing -toe: #4@12 in.

Shear reinforcing -shear key: #4@12 in.

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user   Unique modification by the user

Variable (to be input by user)   Internal result (for reference)   Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states: $\phi_{svc} := 1.00$ Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified: $\phi_{EQ} := 1.0$ Section 11.5.8

$\phi_{EQ\_Stab} := 0.9$ Section 11.5.8

$\phi_{EQ\_BRG} := 0.8$ Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

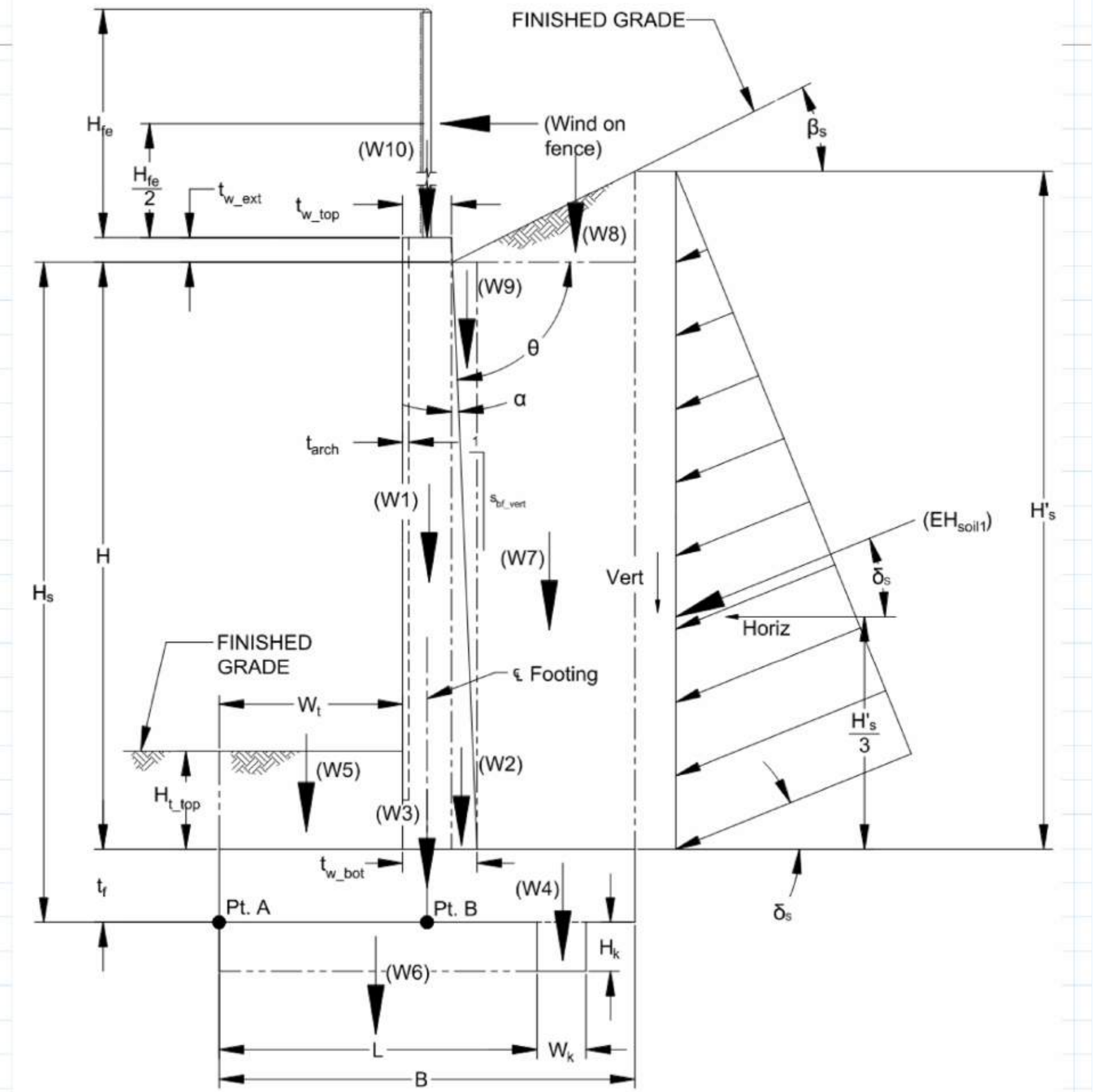


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 17.00\ ft$

Footing thickness: $t_f := 1.75\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 18.75\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 24$

Total wall thickness (top) $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \frac{H + t_{w\_ext}}{s_{bf\_vert}}$ $\quad t_{w\_bot} = 20.75\ in$

Angle of wall backslope $\alpha := \operatorname{atan}\left(\frac{1}{s_{bf\_vert}}\right)$ $\quad \alpha = 2.39\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\quad \theta = 87.61\ deg$

Set back from toe to face of wall: $W_t := 5.00\ ft$

Footing width: $B := 13.00\ ft$

Key width: $W_k := 1.00\ ft$

Key depth: $H_k := 1.50\ ft$

Set back from toe to face of key: $L := \text{if } H_k > 0\ in \ \| B - H_k - W_k \ \text{else} \ \| 0\ in$ $\quad L = 10.50\ ft$

Depth of soil over toe: $H_{t\_top} := 1.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \frac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:	$CLR_{stem} := 1.50\ in$	Stem wall clear cover
	$CLR_{side} := 2.00\ in$	side of footing clear cover
	$CLR_{top} := 2.00\ in$	top of footing clear cover
	$CLR_{bot} := 3.00\ in$	bottom of footing clear cover
Specified compressive strength of concrete:	$f'_c := 4.000\ ksi$	
Reinforcement yield strength:	$f_y := 60\ ksi$	
Correction factor for source of aggregate:	$K_1 := 1.0$	Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test
Minimum yield strength of reinforcing bars:	$f_y := 60\ ksi$	Section 5.5.3.2
Reinforcement modulus of elasticity:	$E_s := 29000\ ksi$	Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$$n_{mod} = 6.00$$

Modulus of rupture: $\lambda := 1.0$ — Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil:	$\gamma_s := 0.130\ kcf$	per geotechnical report, Ref. 4
Backfill slope angle:	$\beta_s := 25\ deg$	2H:1V backfill
Effective soil friction angle:	$\phi'_f := 36\ deg$	per geotechnical report, Ref. 4

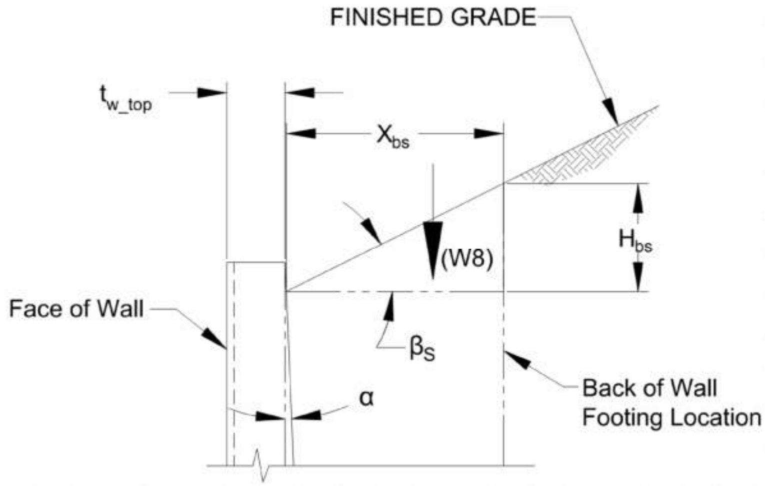


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete):	$\mu_{s\_c} := 0.60$	per geotechnical report, Ref. 4
Coefficient of friction (soil/soil):	$\mu_{s\_s} := \tan(\phi'_f)$	$\mu_{s\_s} = 0.73$
		Section C10.6.3.4
Ultimate soil bearing pressure:	$Q_n := 9.80\ ksf$	
Factored soil bearing pressure	$Q_R := Q_n \cdot \phi_{brg}$	$Q_R = 4.41\ ksf$
Friction angle between fill and wall:	$\delta_s := 22\ deg$	Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.07$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.369$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \frac{\left(2.5 \cdot \ln\left(\frac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \frac{2.56}{10^6} \cdot \left(\frac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 6.00\ ft$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \frac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\frac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.015\ \frac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 7.00\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 3.26\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 22.01\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $R_{EH} = 11.61 \; \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.24 \; \frac{kip}{ft}$

OVERTURNING MOMENTS:

Moment Arm: (about point A in Fig.1) — Overturning Moment:

Active earth pressure resultant: $L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 7.34 \; ft$ $M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 85.18 \; \frac{kip \cdot ft}{ft}$

Wind load on fence: $L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 22.00 \; ft$ $M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 5.32 \; \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 2.64 \; \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.96 \; \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 3.53 \; \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.23 \; \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.65 \; \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 2.05 \; \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 13.86 \; \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 1.49 \; \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.81 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)		Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$	$L_1 = 5.5\ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 14.49 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$	$L_2 = 6.74\ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 6.48 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$	$L_3 = 6.5\ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 22.92 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$	$L_4 = 11.00\ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 2.56 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$	$L_5 = 2.5\ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 1.63 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.		
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$	$L_7 = 9.86\ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 136.71 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$	$L_8 = 10.67\ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 15.84 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $M_9 := W_9 \cdot L_9$

$L_9 = 6.49\ ft$ $M_9 = 5.23\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $L_{10} = 5.50\ ft$ $M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.51\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 123.79\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_min} = 30.02\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_min} = 286.46\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $e_{A\_str} = 5.42\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $e_{B\_str} = 1.08\ ft$

Check location of resultant:

$Check_{Resultant\_str} :=$ if $\frac{-B}{4} \le e_{B\_str} \le \frac{B}{4}$
  "OK"
else
  "NG"

$Check_{Resultant\_str} =$ "OK"

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $P_{sliding} = 16.39\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\frac{W_{R\_min}}{B - 2 \cdot e_{B\_str}} \right)$ $\sigma_v = 2.77 \ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 21.42 \ \frac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \frac{1}{2} \cdot P_p \cdot (H_{t\_top} - 1.00\ ft + t_f + H_k)^2$ $P_{pass} = 2.64 \ \frac{kip}{ft}$

The top 1.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric} + \phi_{pass} \cdot P_{pass}$ $P_{resist} = 22.74 \ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces: $W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_max} = 38.51 \ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_max} = 358.69 \ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$ $e_{A\_BR} = 6.10 \ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.40\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 3.16\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}\left(\sigma_{BR}, Q_R\right)$ $Bearing_{check\_str} = \text{“OK”}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos\left(\delta_s\right) + \gamma_{WSsvc1} \cdot M_{WS}$

$M_{o\_ser} = 80.58\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_ser} := \gamma_{DCsvc} \cdot \left(W_1 + W_2 + W_3 + W_4 + W_{10}\right) + \gamma_{EVsvc} \cdot \left(W_5 + W_7 + W_8 + W_9\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$

$W_{R\_ser} = 28.60\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_ser} := \gamma_{DCsvc} \cdot \left(M_1 + M_2 + M_3 + M_4 + M_{10}\right) + \gamma_{EVsvc} \cdot \left(M_5 + M_7 + M_8 + M_9\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin\left(\delta_s\right)$

$M_{R\_ser} = 262.89\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 3.26$

Service limit state OT Check: $OT_{check\_ser} :=$ if $OT_{FOS} \geq 1.5$ → “OK”, else → “NG” $OT_{check\_ser} = \text{“OK”}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{\left(M_{R\_ser} - M_{o\_ser}\right)}{W_{R\_ser}}$ $e_{A\_svc} = 6.38\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.12\ ft$

Check location of resultant:

$$Check_{Resultant\_svc} := \begin{cases} \text{"OK"} & \text{if } \frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4} \\ \text{"NG"} & \text{else} \end{cases}$$

$$Check_{Resultant\_svc} = \text{"OK"}$$

Vertical stress (per foot of wall such that units are kip/ft^2):

$$\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right) \qquad \sigma_{v\_svc} = 2.24\ ksf$$

Factored sliding force:

$$P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$$

$$P_{sliding\_svc} = 10.84\ \frac{kip}{ft}$$

Bearing width for service calculation:

$$BRG_{svc} := B - 2 \cdot e_{B\_svc} \qquad BRG_{svc} = 12.75\ ft$$

Sliding resistance -friction:

$$P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc} \qquad P_{Fric\_svc} = 28.60\ \frac{kip}{ft}$$

Total sliding resistance:

$$P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass}) \qquad P_{resist\_svc} = 31.24\ \frac{kip}{ft}$$

Sliding factor of safety:

$$Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}} \qquad Sliding_{FoS} = 2.88$$

Service limit state sliding Check:

$$Sliding_{check\_ser} := \begin{cases} \text{"OK"} & \text{if } Sliding_{FoS} > 1.2 \\ \text{"NG"} & \text{else} \end{cases}$$

$$Sliding_{check\_ser} = \text{"OK"}$$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 10.00 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 12.16\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 247.44 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 33.77 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 335.16 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 2.60\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 3.90\ ft$$

Check location of resultant:

$Check_{Resultant\_EQ} :=$ if $\frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3}$
  "OK"
else
  "NG"

$Check_{Resultant\_EQ} =$ "OK"

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $\quad P_{slidingEQ} = 25.42 \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$ $\quad \sigma_{vEQ} = 6.50\ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $\quad BRG_{EQ} = 5.19\ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0\ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0\ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$$P_{Fric\_EQ} = 26.02 \frac{kip}{ft}$$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $\quad P_{resist\_EQ} = 28.66 \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$$Sliding_{check\_EQ} = \text{“OK”}$$

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_maxEQ} = 42.26 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 407.39 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 3.79 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 2.71 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}} \right) \qquad \sigma_{BR\_EQ} = 5.58 \ ksf$$

Bearing pressure check:

$Check_{Bearing\_EQ} :=$ if $\sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n$
    "OK"
else
    "NG"

$Check_{Bearing\_EQ} =$ "OK"

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

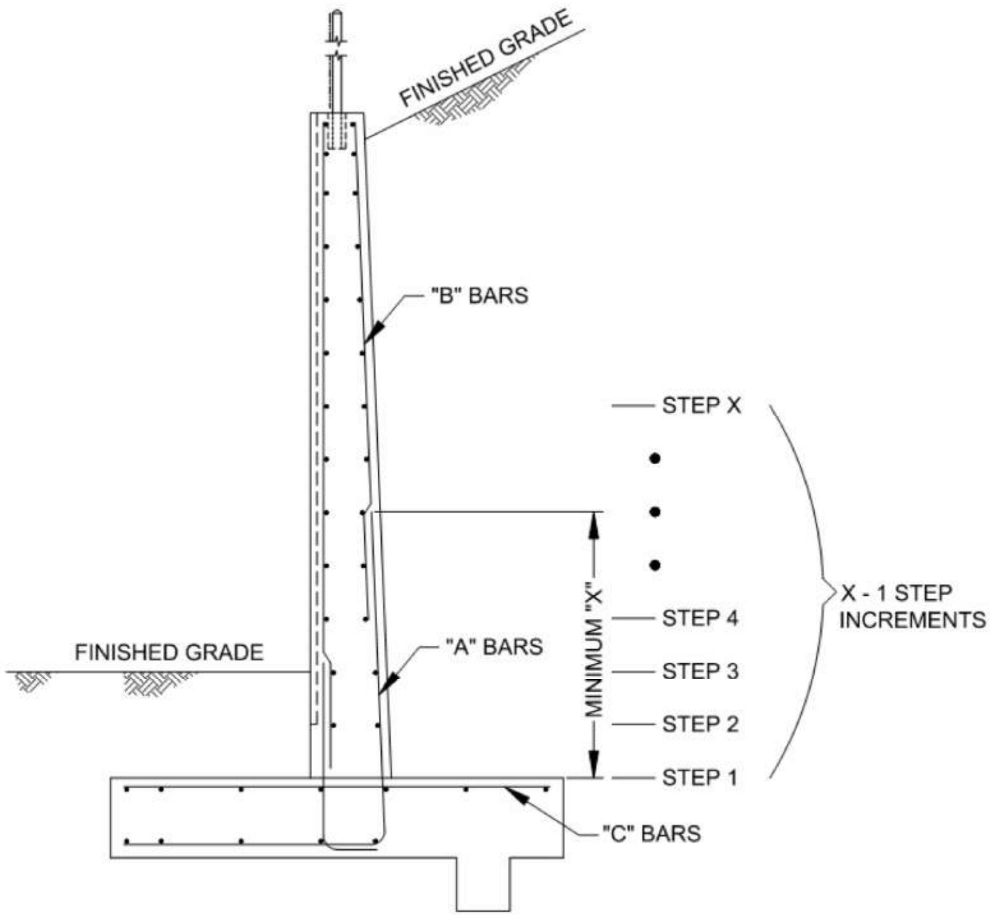


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\qquad step = 16.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \quad \| \; H_{st_i} \leftarrow H - (i) \cdot z \quad ; \quad H_{st}$$

$$H_{st}^{T} = [17.0\ \ 16.0\ \ 15.0\ \ 14.0\ \ 13.0\ \ 12.0\ \ 11.0\ \ 10.0\ \ 9.0\ \ 8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ \ldots]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{\mathrm{T}} = [9.12 \;\; 8.24 \;\; 7.41 \;\; 6.62 \;\; 5.87 \;\; 5.17 \;\; 4.52 \;\; 3.91 \;\; 3.34 \;\; 2.82 \;\; 2.34 \;\; 1.91 \;\; 1.52 \;\; \dots] \; \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{\mathrm{T}} = [13.92 \;\; 12.61 \;\; 11.35 \;\; 10.17 \;\; 9.05 \;\; 8.00 \;\; 7.02 \;\; 6.10 \;\; 5.25 \;\; 4.47 \;\; 3.75 \;\; 3.10 \;\; \dots] \; \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{\mathrm{T}} = [97.24 \;\; 83.99 \;\; 72.01 \;\; 61.25 \;\; 51.65 \;\; 43.12 \;\; 35.62 \;\; 29.06 \;\; 23.39 \;\; 18.53 \;\; 14.43 \;\; 11.01 \;\; \dots] \; \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{\mathrm{T}} = [63.09 \;\; 54.34 \;\; 46.45 \;\; 39.36 \;\; 33.05 \;\; 27.45 \;\; 22.54 \;\; 18.26 \;\; 14.56 \;\; 11.42 \;\; 8.77 \;\; 6.58 \;\; \dots] \; \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\dfrac{H}{step+1}\right) \cdot \left(\dfrac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^{\mathrm{T}} = [19.75\ \ 19.25\ \ 18.75\ \ 18.25\ \ 17.75\ \ 17.25\ \ 16.75\ \ 16.25\ \ 15.75\ \ 15.25\ \ 14.75\ \ 14.25\ \ \ldots]\ in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left\| \begin{array}{l} S_{s_i} \leftarrow \dfrac{{t_{w_i}}^2}{6} \\ S_s \end{array} \right.$$

$$S_s^{\mathrm{T}} = [780\ \ 741\ \ 703\ \ 666\ \ 630\ \ 595\ \ 561\ \ 528\ \ 496\ \ 465\ \ 435\ \ 406\ \ \ldots]\ \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$

Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$

Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_s)$

$$M_{cr}^{\mathrm{T}} = [33.5\ \ 31.8\ \ 30.2\ \ 28.6\ \ 27.0\ \ 25.5\ \ 24.1\ \ 22.6\ \ 21.3\ \ 19.9\ \ 18.7\ \ 17.4\ \ \ldots]\ \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^{\mathrm{T}} = [33.45\ \ 31.78\ \ 30.15\ \ 28.56\ \ 27.02\ \ 25.52\ \ 24.06\ \ 22.65\ \ 21.27\ \ 19.94\ \ 18.66\ \ 14.64\ \ \ldots]\ \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 10$ $s_A := 4\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 1.27\ in^2$

$A_{s\_A} = 3.81\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 17.62\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A} = 253.98\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.018$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.37$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 13\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 2.14\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.17$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 42.11\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 18.00\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 15.85\ in$

Factored shear resistance (assumes Av equal to #4 bar and s_v equal to 12in):

$$\phi V_{n\_1} := \phi V_n\left(A_b(4), 12\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 35.9\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 209.99\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\,\frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 253.98\,\frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{“OK”}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 35.9\,\frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{“OK”}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 6$ $s_B := 8\,in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b(B_B)}{s_B}$ $A_{s\_B} = 0.66\,\frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b(B_B)}{2}$ $d_{s\_2} = 15.88\,in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\,in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 45.71\,\frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{“OK”}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \frac{A_{s\_B}}{12 \frac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0035$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.18$

Maximum reinforcing stress due to service load: $f_{s\_2} := \frac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \frac{k_2}{3}\right)}$ $f_{s\_2} = 40\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \frac{d_b(B_B)}{2}$ $d_{c\_2} = 1.88\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \frac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.17$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 11.10\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 11.10\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12 \frac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 15.39\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n \left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 21.0\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 4.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 6.27\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 29.13\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 113.32\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 82.90\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 882.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel})$ $M_{cr\_heel} = 37.82\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3) $M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$

$M_{D\_heel} = 37.82\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 6$ $s_C := 4\ in$

$A_{s\_C} := \frac{A_b(B_C)}{s_C}$ $A_{s\_C} = 1.32\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2}$ $d_{s\_heel} = 18.63\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 104.87\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0059$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod})$ $k_h = 0.23$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft}$ $f_{s\_h} = 43.87\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$$

$d_{c\_h} = 2.38\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.18$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 8.75\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 8.75\ in$

Check reinforcing spacing: $check_{dc}\left(s_C, s'_{max\_h}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_heel} = 17.65\ in$

Factored shear resistance (assumes Av equal to #4 bar and s_v equal to 12in):

$$\phi V_{n\_heel} := \phi V_n\left(A_b(4), 12\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_heel} = 39.99\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity: $check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{“OK”}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 26.69\ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00\ ft \qquad M_{D\_toe\_1} = 66.73\ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00\ ft$$

$$M_{D\_svc\_t} = 9.86\ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 37.82\ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := \min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 37.82\ kip\ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 10.00$$

$$s_{toe} := s_A \qquad s_{toe} = 4.00\ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 3.81\ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 17.37\ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n\left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 91.13\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{“OK”}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0183$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot (\rho_t \cdot n_{mod}) + (\rho_t \cdot n_{mod})^2} - (\rho_t \cdot n_{mod})$ $k_t = 0.37$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 2\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b(B_{toe})}{2}$ $d_{c\_t} = 3.64\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot (t_f - d_{c\_t})}$ Equation 5.6.7-2

$\beta_{s\_t} = 1.3$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$ Equation 5.6.7-1

$s_{max\_t} = 256.84\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2 $s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe}\cdot f_y}, 0.9\cdot d_{s\_toe}, 0.72\cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1.
Using reference book function.

$$d_{v\_toe} = 15.63\ in$$

Factored shear resistance (assumes Av equal to #4 bar and s_v equal to 12in):

$$\phi V_{n\_toe} := \phi V_n\left(A_b(4), 12\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right)\cdot\frac{1}{ft}$$

$$\phi V_{n\_toe} = 35.4\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$$B_{temp\_stem} := 4 \qquad s_{temp\_stem} := 12\ in$$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right|\cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.4\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \left\| \begin{array}{l} A_{temp} \leftarrow \dfrac{1.3\cdot\left(H + t_{w\_ext}\right)\cdot t_{w\_bot}}{2\cdot\left(H + t_{w\_ext} + t_{w\_bot}\right)\cdot f_y}\cdot\dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.11\cdot\dfrac{in^2}{ft} \right. \\ \text{else if } A_{temp} > 0.60\cdot\dfrac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \right. \\ \text{return } A_{temp} \end{array} \right.$$

$$A_{s\_temp\_1} = 0.2\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_1} = 12.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 28$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.43\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.26\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \frac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.2\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00 \, in \\ \quad 12 \, in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0 \, in) \end{cases}$$

$s_{max\_temp\_2} = 12.00 \, in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - KEY, STEM INTERFACE

Key Check (to determine if key reinforcing is required):

It is assumed that the footing and the key will be placed monolithically. The ϕV_n function as used below simply returns the shear resistance per the simplified procedure for non prestressed sections without transverse reinforcement as described in AASHTO Section 5.7.3.3 and 5.7.4.3.

Conservatively design for the full lateral demand forces, neglecting the reduction in loading on the key due to the passive resistance in front of wall and any reduction in the applied load from sliding friction in front of the key.

Echo of calculated factored demand forces from above (for comparison only)

$P_{sliding} = 16.39 \, \frac{kip}{ft}$ $P_{slidingEQ} = 25.4 \, \frac{kip}{ft}$

Factored shear resistance - (A_v equal to #4 bar and s_v equal to 12 in):

$\phi V_{n\_key} := \phi V_n(A_b(4), 12 \, in, f_y, 12 \, in, W_k, f'_c)$

$\phi V_{n\_key} = 27.18 \, kip$

Compare the shear demand to the shear capacity:

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1 \, ft, \phi V_{n\_key}) = \text{"OK"}$

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12 \, in$ $A_{cv} = 237.00 \, in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.198\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 3.81\ in^2$$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{“OK”}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ 5.7.4.3-5

$V_{ni\_1} = 154.94\ kip$ $V_{ni\_2} = 189.60\ kip$

$V_{ni\_3} = 189.60\ kip$

Controlling nominal concrete shear capacity:

$$V_{niMax} := \text{if } min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1} \ \| \ min(V_{ni\_2}, V_{ni\_3}) \ \text{else} \ \| \ V_{ni\_1}$$

$V_{niMax} = 154.94\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$$V_{ri} := 0.90 \cdot V_{niMax}$$

$$V_{ri} = 139.44\ kip$$

$$InterfaceCheck_{stem} := \text{if } V_{ri} > \max\left(P_{sliding}, P_{slidingEQ}\right) \cdot 1\ ft \;\; \| \text{"OK"} \;\; \text{else} \;\; \| \text{"NG"}$$

$$InterfaceCheck_{stem} = \text{"OK"}$$

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{"OK"}$

$Sliding_{check\_str} = \text{"OK"}$

$Bearing_{check\_str} = \text{"OK"}$

$OT_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_svc} = \text{"OK"}$

$Sliding_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_EQ} = \text{"OK"}$

$Sliding_{check\_EQ} = \text{"OK"}$

$Check_{Bearing\_EQ} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{"OK"}$

$check_{dc}\left(\max\left(P_{sliding}, P_{slidingEQ}\right) \cdot 1\ ft, \phi V_{n\_key}\right) = \text{"OK"}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{"OK"}$

$InterfaceCheck_{stem} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 17.00\ ft$
Footing width:	$B = 13.00\ ft$
Footing depth:	$t_f = 1.75\ ft$
Wall setback:	$W_t = 5.00\ ft$
Key location:	$L = 10.50\ ft$
Key depth:	$H_k = 1.50\ ft$
Key width:	$W_k = 1.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 10.00$	$s_A = 4.00\ in$	
Main stem reinforcing	$B_B = 6.00$	$s_B = 8.00\ in$	
Heel reinforcing:	$B_C = 6.00$	$s_C = 4.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 12.00\ in$	listed bars provided each face

Temperature reinforcing - footing: $B_{temp\_ftg} = 4.00$ $N_{temp\_ftg} = 28.00$ total number of bars for footing

Shear reinforcing -stem: #4@12" $Min_X = 4.00$ ft from top of slab

Shear reinforcing -heel: #4@12 in. provide ties or stirrups

Shear reinforcing -toe: #4@12 in.

Shear reinforcing -shear key: #4@12 in.

END OF WORKBOOK

MONONABE-OKABE SEISMIC ACTIVE EARTH PRESSURE

Determine the active earth pressure coefficient using the Mononobe-Okabe solution described in Appendix A11 of reference 1 listed below. It is up to the designer to determine if the total active static and seismic earth force is to be used for the design or if the separate components off the active static and seismic earth forces are to be used.

Currently, the choice has been made to use only the increase in earth forces caused by the seismic loading since the active static component has been calculated in the main calculation workbook.

Legend

Variable (to be input by user) | Internal result (for reference) | Final result of interest

Commentary / instructions to the user | Unique modification by the user

References

1. AASHTO LRFD Bridge Specifications, 9th Edition

All section, table, equation and figure references are to reference 1 unless otherwise noted.

Standard user defined units: $kcf := \frac{kip}{ft^3}$

Inputs

Horizontal earthquake acceleration (g): $k_h := \frac{1}{2} \cdot 0.34$ $k_h = 0.17$

1/2 of the Design PGA per the project geotechnical report

Vertical earthquake acceleration (g): $k_v := 0 \cdot k_h$ $k_v = 0$

Effective soil friction angle (from main calculation workbook): $\phi := 36.0\ deg$

Backfill slope angle (from main calculation workbook): $\alpha := 25.00\ deg$

Friction angle between fill and wall (from main calculation workbook): $\delta := 22\ deg$ Table 3.11.5.3-1

Angle of wall backslope (from main calculation workbook): $\beta' := 2.39\ deg$

This variable is used in Appendix A11 equations. The prime has been added for these calculations to differentiate from the β value used in the main calculation workbook.

Active static pressure coefficient (from main calculation workbook): $K_a := 0.384$

Unit weight of soil: $\gamma_s := 0.130\ kcf$ From project geotechnical report

Wall batter from horizontal: $\theta_{MO} := \operatorname{atan}\left(\frac{k_h}{1-k_v}\right)$ $\theta_{MO} = 9.65\ deg$

Section A11.3.1

Seismic active pressure coefficient:

$$K_{ae} := \frac{\cos(\phi - \theta_{MO} - \beta')^2}{\cos(\theta_{MO}) \cdot \cos(\beta')^2 \cdot \cos(\delta + \theta_{MO} + \beta')} \cdot \left(1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \theta_{MO} - \alpha)}{\cos(\delta + \theta_{MO} + \beta') \cdot \cos(\alpha - \beta')}}\right)^{-2}$$

Equation A11.3.1-1 $K_{ae} = 0.759$

Design Calculations 7 ft. Wall

Height of soil face at back of footing: $H_1 := 7.00\ ft + (5.25\ ft - 2.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 8.05\ ft$

Active static earth pressure resultant: $P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot K_a$ $P_a = 1.62\ \frac{kip}{ft}$

Total active static and seismic earth force: $E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot (1 - k_v) \cdot K_{ae}$ $E_{ae} = 3.20\ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := E_{ae} - P_a$ $\Delta E_{ae} = 1.58\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 0.6 \cdot H_1$ $z_{\Delta Eae} = 4.83\ ft$

Section A11.3.1

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 3.74\ ft$

Design Calculations 9 ft. Wall

Height of soil face at back of footing:

$H_1 := 9.00\ ft + (7.00\ ft - 2.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 10.87\ ft$

Active static earth pressure resultant:

$P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot K_a$

$P_a = 2.95\ \frac{kip}{ft}$

Total active static and seismic earth force:

$E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot (1 - k_v) \cdot K_{ae}$

$E_{ae} = 5.82\ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component):

$\Delta E_{ae} := E_{ae} - P_a$

$\Delta E_{ae} = 2.88\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing):

$z_{\Delta Eae} := 0.6 \cdot H_1$

Section A11.3.1

$z_{\Delta Eae} = 6.52\ ft$

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 5.05\ ft$

Design Calculations 13 ft. Wall

Height of soil face at back of footing:

$H_1 := 13.00\ ft + (9.50\ ft - 3.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 15.56\ ft$

Active static earth pressure resultant:	$P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot K_a$	$P_a = 6.05\ \frac{kip}{ft}$
Total active static and seismic earth force:	$E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot (1 - k_v) \cdot K_{ae}$	$E_{ae} = 11.95\ \frac{kip}{ft}$
Active seismic earth force resultant (separated from active static component):	$\Delta E_{ae} := E_{ae} - P_a$	$\Delta E_{ae} = 5.90\ \frac{kip}{ft}$
Point of application for active seismic earth force (from top of footing):	$z_{\Delta Eae} := 0.6 \cdot H_1$ Section A11.3.1	$z_{\Delta Eae} = 9.34\ ft$
Point of application for active static and seismic earth force (from top of footing):	$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$	$z_{bar} = 7.24\ ft$

Design Calculations 15 ft. Wall

Height of soil face at back of footing: $H_1 := 15.00\ ft + (11.50\ ft - 4.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 18.03\ ft$

Active static earth pressure resultant:	$P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot K_a$	$P_a = 8.11\ \frac{kip}{ft}$
Total active static and seismic earth force:	$E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot (1 - k_v) \cdot K_{ae}$	$E_{ae} = 16.03\ \frac{kip}{ft}$
Active seismic earth force resultant (separated from active static component):	$\Delta E_{ae} := E_{ae} - P_a$	$\Delta E_{ae} = 7.92\ \frac{kip}{ft}$
Point of application for active seismic earth force (from top of footing):	$z_{\Delta Eae} := 0.6 \cdot H_1$ Section A11.3.1	$z_{\Delta Eae} = 10.82\ ft$

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 8.39\ ft$

Design Calculations 17 ft. Wall

Height of soil face at back of footing:

$H_1 := 17.00\ ft + (13.00\ ft - 5.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

$H_1 = 20.26\ ft$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

Active static earth pressure resultant:

$P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot K_a$

$P_a = 10.25\ \frac{kip}{ft}$

Total active static and seismic earth force:

$E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot (1 - k_v) \cdot K_{ae}$

$E_{ae} = 20.25\ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component):

$\Delta E_{ae} := E_{ae} - P_a$

$\Delta E_{ae} = 10.00\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing):

$z_{\Delta Eae} := 0.6 \cdot H_1$

$z_{\Delta Eae} = 12.16\ ft$

Section A11.3.1

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 9.42\ ft$

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user   Unique modification by the user

Variable (to be input by user)   Internal result (for reference)   Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states:	$\phi_{svc} := 1.00$	Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified:	$\phi_{EQ} := 1.0$	Section 11.5.8
	$\phi_{EQ\_Stab} := 0.9$	Section 11.5.8
	$\phi_{EQ\_BRG} := 0.8$	Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

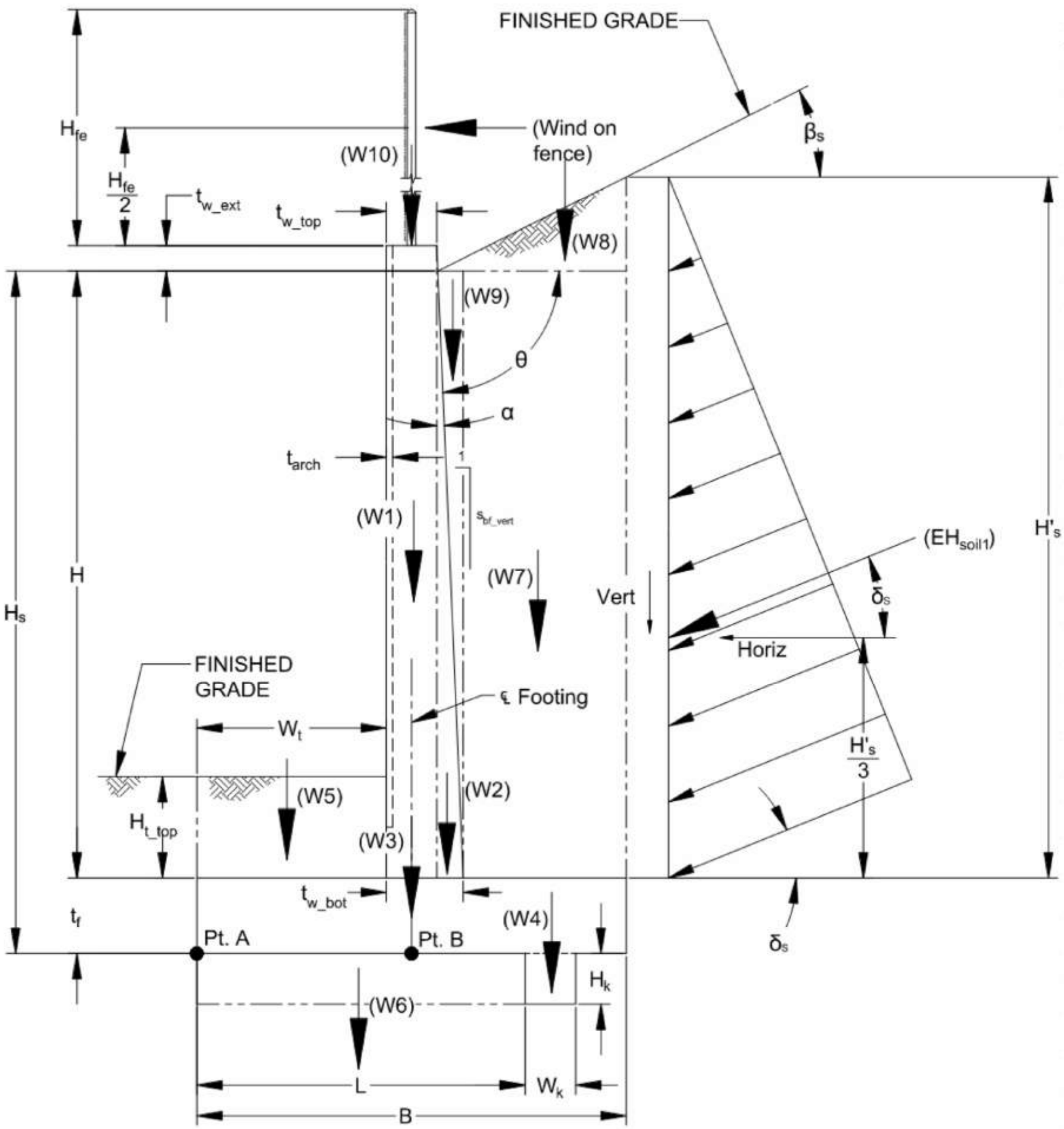


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 6.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 7.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 100000$

Total wall thickness (top): $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \frac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 12.00\ in$

Angle of wall backslope $\alpha := \text{atan}\left(\frac{1}{s_{bf\_vert}}\right)$ $\alpha = 0.00\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 90.00\ deg$

Set back from toe to face of wall: $W_t := 1.00\ ft$

Footing width: $B := 3.75\ ft$

Key width: $W_k := 0.00\ ft$

Key depth: $H_k := 0.00\ ft$

Set back from toe to face of key: $L := \text{if } H_k > 0\ in \ \| B - H_k - W_k \ \text{else} \ \| 0\ in$ $L = 0.00\ ft$

Depth of soil over toe: $H_{t\_top} := 2.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \frac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ — Stem wall clear cover

$CLR_{side} := 2.00\ in$ — side of footing clear cover

$CLR_{top} := 2.00\ in$ — top of footing clear cover

$CLR_{bot} := 3.00\ in$ — bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ — Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ — Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ — Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$$n_{mod} = 6.00$$

Modulus of rupture: $\lambda := 1.0$ — Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ — per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 0.00\ deg$ — Level backfill

Effective soil friction angle: $\phi'_f := 35\ deg$ — per geotechnical report, Ref. 4

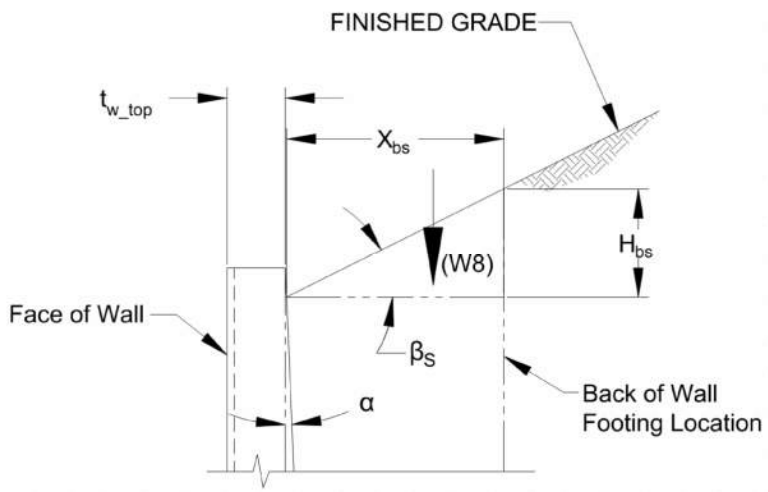


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete): $\mu_{s\_c} := 0.60$ per geotechnical report, Ref. 4

Coefficient of friction (soil/soil): $\mu_{s\_s} := \tan(\phi'_f)$ $\mu_{s\_s} = 0.7$

Section C10.6.3.4

Ultimate soil bearing pressure: $Q_n := 4.50\ ksf$

Factored soil bearing pressure $Q_R := Q_n \cdot \phi_{brg}$ $Q_R = 2.03\ ksf$

Friction angle between fill and wall: $\delta_s := 22\ deg$ Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.959$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.245$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \frac{\left(2.5 \cdot \ln\left(\frac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \frac{2.56}{10^6} \cdot \left(\frac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 42.00\ in$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \frac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\frac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.009\ \frac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 1.75\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 0.00\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 7.50\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $R_{EH} = 0.89 \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.15 \frac{kip}{ft}$

OVERTURNING MOMENTS:

	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Active earth pressure resultant:	$L_{EH} := \frac{H'_s}{3}$	$M_{EH} := R_{EH} \cdot L_{EH}$
	$L_{EH} = 2.50\ ft$	$M_{EH} = 2.24 \frac{kip \cdot ft}{ft}$
Wind load on fence:	$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$	$M_{WS} := R_{WS} \cdot L_{WS}$
	$L_{WS} = 9.50\ ft$	$M_{WS} = 1.41 \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 0.93 \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.00 \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 0.87 \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.00 \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.26 \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 0.00 \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 1.36 \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 0.00 \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $\quad W_9 = 0.00 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $\quad W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$; $L_1 = 1.5\ ft$	$M_1 := W_1 \cdot L_1$; $M_1 = 1.40 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$; $L_2 = 2.5\ ft$	$M_2 := W_2 \cdot L_2$; $M_2 = 0.00 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$; $L_3 = 1.88\ ft$	$M_3 := W_3 \cdot L_3$; $M_3 = 1.63 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$; $L_4 = 0.00\ ft$	$M_4 := W_4 \cdot L_4$; $M_4 = 0.00 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$; $L_5 = 0.5\ ft$	$M_5 := W_5 \cdot L_5$; $M_5 = 0.13 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.	
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$; $L_7 = 2.88\ ft$	$M_7 := W_7 \cdot L_7$; $M_7 = 3.92 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$; $L_8 = 3.17\ ft$	$M_8 := W_8 \cdot L_8$; $M_8 = 0 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $M_9 := W_9 \cdot L_9$

$L_9 = 2.00\ ft$ $M_9 = 0\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $L_{10} = 1.50\ ft$ $M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.13\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 4.52\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_min} = 3.83\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_min} = 8.78\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $e_{A\_str} = 1.11\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $e_{B\_str} = 0.76\ ft$

Check location of resultant:

$Check_{Resultant\_str} :=$ if $\frac{-B}{4} \le e_{B\_str} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_str} =$ "OK"

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $P_{sliding} = 1.39\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\frac{W_{R\_min}}{B - 2 \cdot e_{B\_str}}\right)$ $\sigma_v = 1.72\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \land H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \land H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 1.84\ \frac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \frac{1}{2} \cdot P_p \cdot (H_{t\_top} - 2.00\ ft + t_f + H_k)^2$ $P_{pass} = 0.56\ \frac{kip}{ft}$

The top 2.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric}$ $P_{resist} = 1.84\ \frac{kip}{ft}$

Only friction is considered for sliding resistance.

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces:

$$W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_max} = 5.06\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_max} = 11.31\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A:

$$e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$$

$e_{A\_BR} = 1.34\ ft$

Distance to resultant from Point B:

$$e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$$

$e_{B\_BR} = 0.53\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1):

$$\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$$

$\sigma_{BR} = 1.88\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$

$Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment:

$$M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$$

$M_{o\_ser} = 2.50\ \frac{kip \cdot ft}{ft}$

Factored resisting forces:

$$W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_ser} = 3.85\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_ser} = 8.47\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety:

$$OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$$

$OT_{FOS} = 3.39$

Service limit state OT Check:

$$OT_{check\_ser} := \begin{cases} \text{"OK"} & \text{if } OT_{FOS} \geq 1.5 \\ \text{"NG"} & \text{else} \end{cases}$$

$OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 1.55\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.32\ ft$

Check location of resultant: $Check_{Resultant\_svc} :=$ if $\frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} = \text{"OK"}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 1.24\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 0.87\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 3.10\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 3.85\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 4.41\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 5.05$

Service limit state sliding Check: $Sliding_{check\_ser} :=$ if $Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} = \text{"OK"}$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 0.26 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 3.60\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 4.34 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 3.92 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 9.15 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 1.23\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 0.65\ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \begin{cases} \text{“OK”} & \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \\ \text{“NG”} & \text{else} \end{cases}$$

$$Check_{Resultant\_EQ} = \text{“OK”}$$

Factored sliding forces:

$$P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$$

$$P_{slidingEQ} = 1.48 \ \frac{kip}{ft}$$

Vertical stress:

$$\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}} \right)$$

$$\sigma_{vEQ} = 1.60 \ ksf$$

Bearing Width for seismic calculation:

$$BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$$

$$BRG_{EQ} = 2.45 \ ft$$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$$P_{Fric\_EQ} = 2.35 \ \frac{kip}{ft}$$

Total sliding resistance:

$$P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$$

$$P_{resist\_EQ} = 2.92 \ \frac{kip}{ft}$$

Compare sliding demand vs. calculated capacity:

$$Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$$

$$Sliding_{check\_EQ} = \text{"OK"}$$

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_maxEQ} = 5.15 \ \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 11.67 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 1.42 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 0.45 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}}\right) \qquad \sigma_{BR\_EQ} = 1.81 \ ksf$$

Bearing pressure check:

$$Check_{Bearing\_EQ} := \text{if } \sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n \ \text{“OK”} \ \text{else} \ \text{“NG”}$$

$$Check_{Bearing\_EQ} = \text{“OK”}$$

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

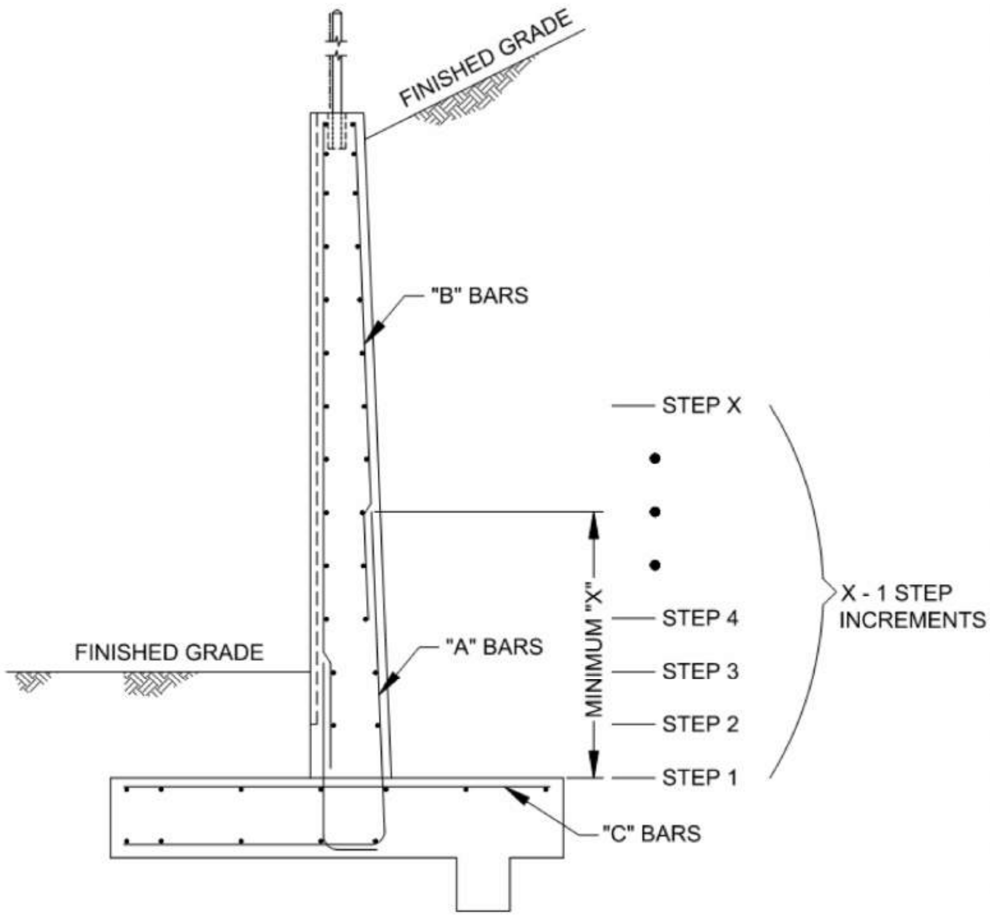


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$

user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\quad step = 5.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} H_{st_i} \leftarrow H - (i) \cdot z \\ H_{st} \end{array} \right.$$

$$H_{st}^{T} = [6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{\mathrm{T}} = [0.53\ \ 0.37\ \ 0.24\ \ 0.13\ \ 0.06\ \ 0.01]\ \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{\mathrm{T}} = [0.94\ \ 0.70\ \ 0.50\ \ 0.35\ \ 0.24\ \ 0.17]\ \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{\mathrm{T}} = [2.75\ \ 1.93\ \ 1.33\ \ 0.91\ \ 0.62\ \ 0.42]\ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{\mathrm{T}} = [1.43\ \ 0.94\ \ 0.59\ \ 0.37\ \ 0.23\ \ 0.15]\ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\dfrac{H}{step+1}\right) \cdot \left(\dfrac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^{T} = [11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00]\ in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left\| \begin{array}{l} S_{s_i} \leftarrow \dfrac{t_{w_i}^{\ 2}}{6} \\ S_s \end{array} \right.$$

$$S_s^{T} = [242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242]\ \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$

Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$

Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^{T} = [10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4]\ \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^{T} = [3.65\ \ 2.56\ \ 1.77\ \ 1.21\ \ 0.82\ \ 0.55]\ \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 4$ $s_A := 12\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 0.20\ in^2$ $A_{s\_A} = 0.20\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 9.25\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function $\phi M_{n\_A} = 8.19\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{“OK”}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.0018$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.14$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 10\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.27$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 53.22\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 9.10\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_1} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 12.4\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 3.61\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 8.19\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 12.4\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 4$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b(B_B)}{s_B}$ $A_{s\_B} = 0.2\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 3$ $xb := Steps_B$ $xb = 3.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b(B_B)}{2}$ $d_{s\_2} = 9.25\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 8.19\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \dfrac{A_{s\_B}}{12\ \dfrac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0018$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.14$

Maximum reinforcing stress due to service load: $f_{s\_2} := \dfrac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \dfrac{k_2}{3}\right)}$ $f_{s\_2} = 2\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \dfrac{d_b(B_B)}{2}$ $d_{c\_2} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \dfrac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.27$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \dfrac{700\ \dfrac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 217.36\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 16.50\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\dfrac{M_n\left(A_{s\_B}, f_y, 12\ \dfrac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 9.10\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 12.4\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 3.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 1.75\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 2.85\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 2.94\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 2.14\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 648.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel})$ $M_{cr\_heel} = 27.79\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3): $M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$

$M_{D\_heel} = 3.91\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 4$ $s_C := 12\ in$

$A_{s\_C} := \frac{A_b(B_C)}{s_C}$ $A_{s\_C} = 0.2\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2}$ $d_{s\_heel} = 15.75\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 14.04\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0011$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod})$ $k_h = 0.11$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft}$ $f_{s\_h} = 8.44\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$ $d_{c\_h} = 2.25\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.2$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 64.39\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1.
Using reference book function.

$d_{v\_heel} = 15.60\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_heel} = 21.30\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$V_{D\_toe} := W_t \cdot (\max(\sigma_{BR}, \sigma_{BR\_EQ}) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f)$

$V_{D\_toe} = 1.68 \ \frac{kip}{ft}$

Toe factored demand moment at face of stem:

$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00 \ ft$ $M_{D\_toe\_1} = 0.84 \ kip \cdot ft$

Toe service demand moment at face of stem:

$M_{D\_svc\_t} := W_t \cdot (\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f) \cdot 1.00 \ ft$

$M_{D\_svc\_t} = 1.01 \ \frac{kip \cdot ft}{ft}$

Toe cracking moment:

$M_{cr\_toe} := M_{cr\_heel}$ $M_{cr\_toe} = 27.79 \ kip \cdot ft$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$M_{D\_toe} := min(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1})$

$M_{D\_toe} = 1.11 \ kip \ ft$

Toe reinforcing bar size and spacing:

$B_{toe} := B_A$ $B_{toe} = 4.00$

$s_{toe} := s_A$ $s_{toe} = 12.00 \ in$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$A_{s\_toe} := \frac{A_b(B_{toe})}{s_{toe}}$ $A_{s\_toe} = 0.2 \ \frac{in^2}{ft}$

Depth of reinforcing:

$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b(B_{toe})}{2}$ $d_{s\_toe} = 14.75 \ in$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n\left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 13.14\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_toe}, \phi M_{n\_toe}) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0011$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot (\rho_t \cdot n_{mod}) + (\rho_t \cdot n_{mod})^2} - (\rho_t \cdot n_{mod})$ $k_t = 0.11$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 4\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b(B_{toe})}{2}$ $d_{c\_t} = 3.25\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot (t_f - d_{c\_t})}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.31$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 118.70\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min(s_{max\_t}, 18\ in, 1.5 \cdot t_f)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}(s_{toe}, s'_{max\_t}) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$$d_{v\_toe} = 14.6\ in$$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 19.9\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$$B_{temp\_stem} := 4 \qquad s_{temp\_stem} := 18\ in$$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.27\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \begin{array}{|l} A_{temp} \leftarrow \dfrac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{array}$$

$$A_{s\_temp\_1} = 0.11\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min\left(3.0 \cdot t_{w\_bot}, 18.0\ in\right) \end{cases}$$

$$s_{max\_temp\_1} = 18.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{"OK"}$$

$$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 8$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{\left|A_b\left(B_{temp\_ftg}\right)\right| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.43\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{\left(B - 2 \cdot CLR_{side}\right) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.71\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \dfrac{1.3 \cdot t_f \cdot B}{2 \cdot \left(t_f + B\right) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.14\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0\ in) \end{cases}$$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - STEM INTERFACE

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $A_{cv} = 132.01\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement: $A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi$ $A_{vf\_min} = 0.110\ in^2$

$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right|$ $A_{vf} = 0.20\ in^2$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{"OK"}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ 5.7.4.3-5

$V_{ni\_1} = 17.10\ kip$ $V_{ni\_2} = 105.61\ kip$

$V_{ni\_3} = 105.61\ kip$

Controlling nominal concrete shear capacity:

$V_{niMax} :=$ if $min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1}$
  $min(V_{ni\_2}, V_{ni\_3})$
else
  V_{ni_1}

$V_{niMax} = 17.10\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $V_{ri} = 15.39\ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft$
  "OK"
else
  "NG"

$InterfaceCheck_{stem} =$ "OK"

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{“OK”}$

$Sliding_{check\_str} = \text{“OK”}$

$Bearing_{check\_str} = \text{“OK”}$

$OT_{check\_ser} = \text{“OK”}$

$Check_{Resultant\_svc} = \text{“OK”}$

$Sliding_{check\_ser} = \text{“OK”}$

$Check_{Resultant\_EQ} = \text{“OK”}$

$Sliding_{check\_EQ} = \text{“OK”}$

$Check_{Bearing\_EQ} = \text{“OK”}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{“OK”}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{“OK”}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{“OK”}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{“OK”}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{“OK”}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{“OK”}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{“OK”}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{“OK”}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{“OK”}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{“OK”}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{“OK”}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{“OK”}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{“OK”}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{“OK”}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{“OK”}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{“OK”}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{“OK”}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{“OK”}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{“OK”}$

$InterfaceCheck_{stem} = \text{“OK”}$

SUMMARY OF WALL GEOMETRY

Design height:	$H=6.00\ ft$
Footing width:	$B=3.75\ ft$
Footing depth:	$t_f=1.50\ ft$
Wall setback:	$W_t=1.00\ ft$
Key location:	$L=0.00\ ft$
Key depth:	$H_k=0.00\ ft$
Key width:	$W_k=0.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A=4.00$	$s_A=12.00\ in$	
Main stem reinforcing	$B_B=4.00$	$s_B=12.00\ in$	
Heel reinforcing:	$B_C=4.00$	$s_C=12.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X=3.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem}=4.00$	$s_{temp\_stem}=18.00\ in$	listed bars provided each face
Temperature reinforcing - footing:	$B_{temp\_ftg}=4.00$	$N_{temp\_ftg}=8.00$	total number of bars for footing

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user   Unique modification by the user

Variable (to be input by user)   Internal result (for reference)   Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states:	$\phi_{svc} := 1.00$	Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified:	$\phi_{EQ} := 1.0$	Section 11.5.8
	$\phi_{EQ\_Stab} := 0.9$	Section 11.5.8
	$\phi_{EQ\_BRG} := 0.8$	Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

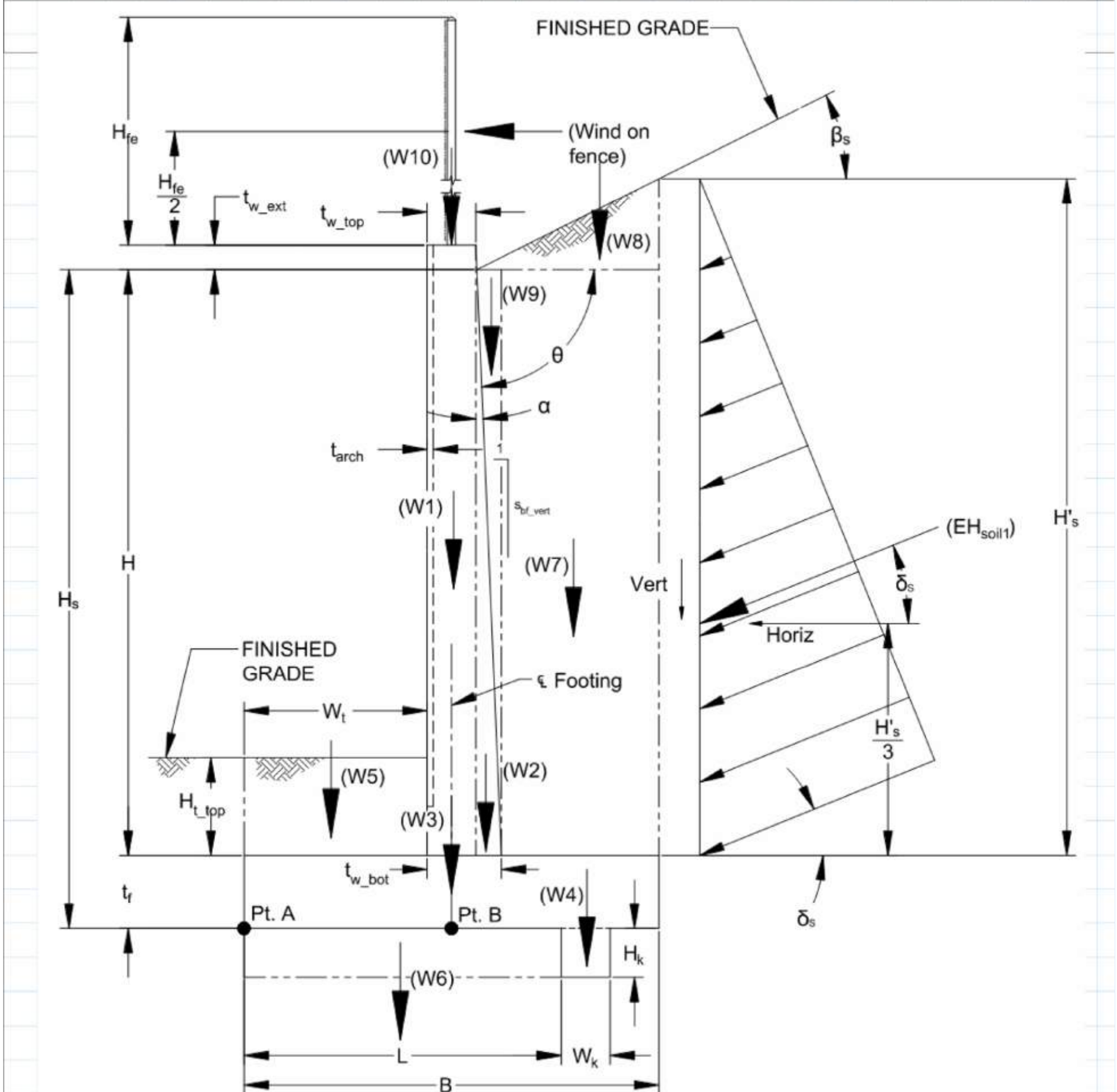


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 8.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 9.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 100000$

Total wall thickness (top) $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \frac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 12.00\ in$

Angle of wall backslope $\alpha := \text{atan}\left(\frac{1}{s_{bf\_vert}}\right)$ $\alpha = 0.00\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 90.00\ deg$

Set back from toe to face of wall: $W_t := 2.00\ ft$

Footing width: $B := 4.50\ ft$

Key width: $W_k := 0.00\ ft$

Key depth: $H_k := 0.00\ ft$

Set back from toe to face of key: $L := \begin{cases} B - H_k - W_k & \text{if } H_k > 0\ in \\ 0\ in & \text{else} \end{cases}$ $L = 0.00\ ft$

Depth of soil over toe: $H_{t\_top} := 2.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \frac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ Stem wall clear cover

$CLR_{side} := 2.00\ in$ side of footing clear cover

$CLR_{top} := 2.00\ in$ top of footing clear cover

$CLR_{bot} := 3.00\ in$ bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$n_{mod} = 6.00$

Modulus of rupture: $\lambda := 1.0$ Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 0.00\ deg$ Level backfill

Effective soil friction angle: $\phi'_f := 35\ deg$ per geotechnical report, Ref. 4

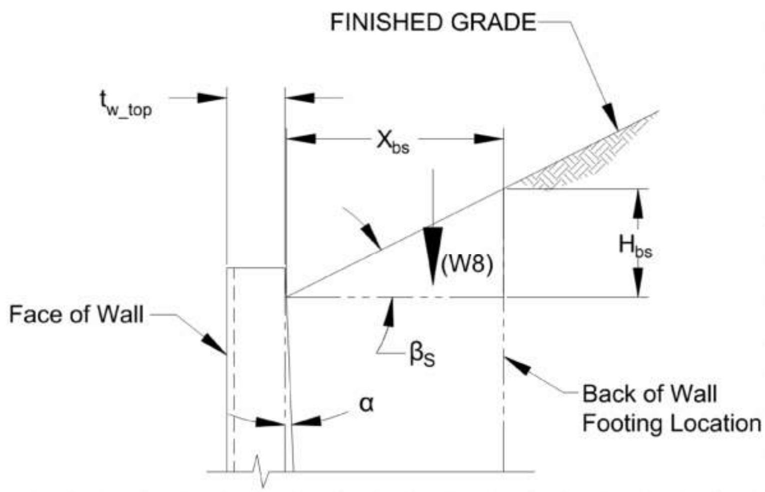


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete):	$\mu_{s\_c} := 0.60$	per geotechnical report, Ref. 4
Coefficient of friction (soil/soil):	$\mu_{s\_s} := \tan(\phi'_f)$	$\mu_{s\_s} = 0.7$
		Section C10.6.3.4
Ultimate soil bearing pressure:	$Q_n := 5.00\ ksf$	
Factored soil bearing pressure	$Q_R := Q_n \cdot \phi_{brg}$	$Q_R = 2.25\ ksf$
Friction angle between fill and wall:	$\delta_s := 22\ deg$	Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$$\Gamma_a = 2.959$$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)} \qquad k_{af} = 0.245$$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \frac{\left(2.5 \cdot \ln\left(\frac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \frac{2.56}{10^6} \cdot \left(\frac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 42.00\ in$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \frac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\frac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.009\ \frac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 1.50\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 0.00\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 9.50\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s)
$R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$
$R_{EH} = 1.43\ \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height)
$R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$
$R_{WS} = 0.15\ \frac{kip}{ft}$

OVERTURNING MOMENTS:

	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Active earth pressure resultant:	$L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 3.17\ ft$	$M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 4.54\ \frac{kip \cdot ft}{ft}$
Wind load on fence:	$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 11.50\ ft$	$M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 1.71\ \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 1.24\ \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.00\ \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 1.05\ \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.00\ \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.52\ \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 0.00\ \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 1.56\ \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 0.00\ \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $\quad W_9 = 0.00 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $\quad W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)		Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$	$L_1 = 2.5\ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 3.10 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$	$L_2 = 3.5\ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 0.00 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$	$L_3 = 2.25\ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 2.35 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$	$L_4 = 0.00\ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 0.00 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$	$L_5 = 1\ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 0.52 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.		
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$	$L_7 = 3.75\ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 5.85 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$	$L_8 = 4.00\ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 0 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $M_9 := W_9 \cdot L_9$

$L_9 = 3.00\ ft$ $M_9 = 0\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $L_{10} = 2.50\ ft$ $M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.22\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 8.03\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_min} = 5.02\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_min} = 15.10\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $e_{A\_str} = 1.41\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $e_{B\_str} = 0.84\ ft$

Check location of resultant:

$Check_{Resultant\_str} :=$ if $\frac{-B}{4} \le e_{B\_str} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_str} =$ "OK"

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $P_{sliding} = 2.14\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\frac{W_{R\_min}}{B - 2 \cdot e_{B\_str}}\right)$

$\sigma_v = 1.78\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 2.41\ \frac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \frac{1}{2} \cdot P_p \cdot \left(H_{t\_top} - 2.00\ ft + t_f + H_k\right)^2$

$P_{pass} = 0.56\ \frac{kip}{ft}$

The top 2.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric}$

$P_{resist} = 2.41\ \frac{kip}{ft}$

Only friction is considered for sliding resistance.

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces:

$$W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_max} = 6.58\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_max} = 19.31\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$ $e_{A\_BR} = 1.71\ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.54\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 1.92\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$ $Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$

$M_{o\_ser} = 4.73\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_ser} = 4.99\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_ser} = 14.46\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 3.06$

Service limit state OT Check: $OT_{check\_ser} :=$ if $OT_{FOS} \geq 1.5$ "OK" else "NG" $OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 1.95\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.30\ ft$

Check location of resultant: $Check_{Resultant\_svc} :=$ if $\frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} = \text{"OK"}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 1.28\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 1.37\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 3.90\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 4.99\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 5.55\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 4.04$

Service limit state sliding Check: $Sliding_{check\_ser} :=$ if $Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} = \text{"OK"}$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 0.47\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 4.8\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 9.06\ \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 5.20\ \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 15.89\ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}}$$

$$e_{A\_EQ} = 1.31\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ}$$

$$e_{B\_EQ} = 0.94\ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \text{ then "OK" else "NG"}$$

$$Check_{Resultant\_EQ} = \text{"OK"}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $P_{slidingEQ} = 2.43 \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$ $\sigma_{vEQ} = 1.98\ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $BRG_{EQ} = 2.63\ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0\ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0\ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 3.12 \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $P_{resist\_EQ} = 3.68 \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} =$ "OK"

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$W_{R\_maxEQ} = 6.76 \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 20.11 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}}$$

$$e_{A\_BR\_EQ} = 1.63 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ}$$

$$e_{B\_BR\_EQ} = 0.62 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}}\right)$$

$$\sigma_{BR\_EQ} = 2.07 \ ksf$$

Bearing pressure check:

$$Check_{Bearing\_EQ} := \text{if } \sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n \ \text{“OK”} \ \text{else} \ \text{“NG”}$$

$$Check_{Bearing\_EQ} = \text{“OK”}$$

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

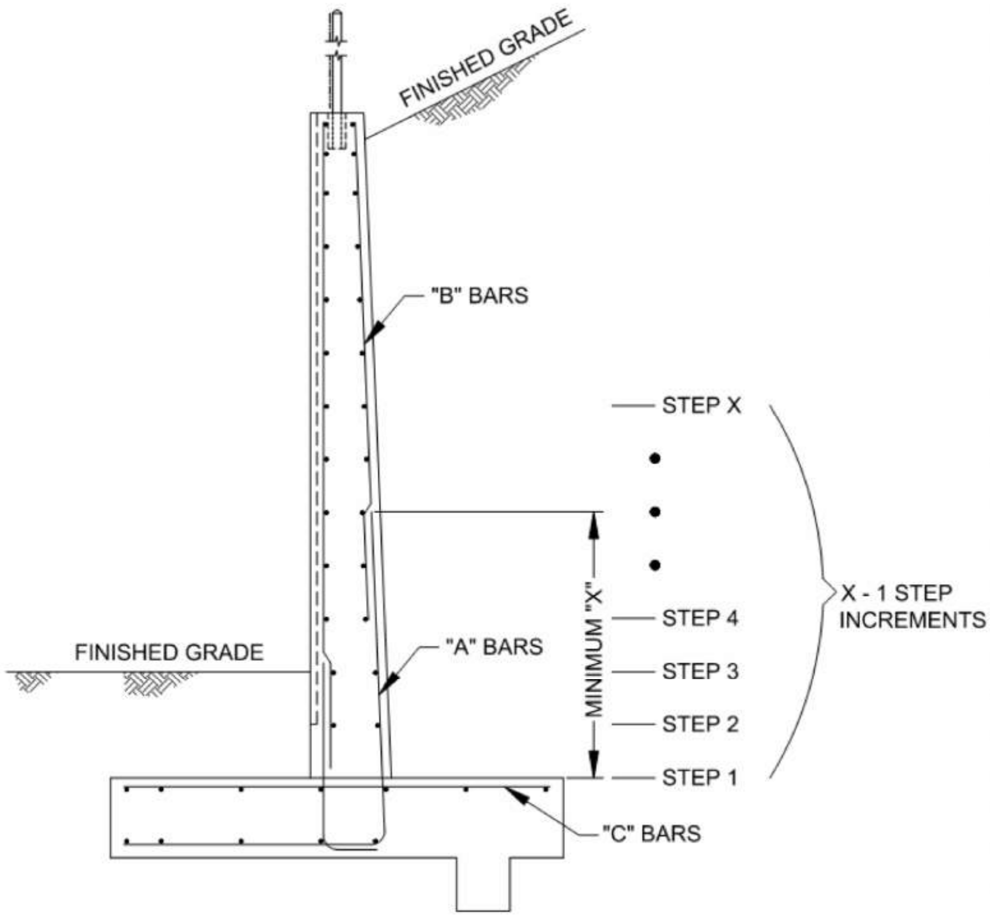


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\quad step = 7.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} H_{st_i} \leftarrow H - (i) \cdot z \\ H_{st} \end{array} \right.$$

$$H_{st}^{T} = [8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{T} = [0.94 \ \ 0.72 \ \ 0.53 \ \ 0.37 \ \ 0.24 \ \ 0.13 \ \ 0.06 \ \ 0.01] \ \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{T} = [1.56 \ \ 1.23 \ \ 0.94 \ \ 0.70 \ \ 0.50 \ \ 0.35 \ \ 0.24 \ \ 0.17] \ \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{T} = [5.22 \ \ 3.83 \ \ 2.75 \ \ 1.93 \ \ 1.33 \ \ 0.91 \ \ 0.62 \ \ 0.42] \ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{T} = [2.97 \ \ 2.10 \ \ 1.43 \ \ 0.94 \ \ 0.59 \ \ 0.37 \ \ 0.23 \ \ 0.15] \ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\dfrac{H}{step+1}\right) \cdot \left(\dfrac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^{T} = [11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00]\ in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left\| \begin{array}{l} S_{s_i} \leftarrow \dfrac{t_{w_i}^{2}}{6} \\ S_s \end{array} \right.$$

$$S_s^{T} = [242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242]\ \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$ — Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$ — Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^{T} = [10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4]\ \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^{T} = [6.95\ \ 5.09\ \ 3.65\ \ 2.56\ \ 1.77\ \ 1.21\ \ 0.82\ \ 0.55]\ \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 4$ $s_A := 12\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 0.20\ in^2$

$A_{s\_A} = 0.20\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 9.25\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A} = 8.19\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.0018$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.14$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 20\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.27$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 23.78\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 9.10\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_1} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 12.4\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

Reference workbook function

<u>WALL STEM - Base of Wall Location - SEISMIC Check:</u>

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 7.32\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 8.19\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 12.4\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 4$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b\left(B_B\right)}{s_B}$ $A_{s\_B} = 0.2\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 3$ $xb := Steps_B$ $xb = 3.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b\left(B_B\right)}{2}$ $d_{s\_2} = 9.25\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 8.19\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \frac{A_{s\_B}}{12 \frac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0018$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.14$

Maximum reinforcing stress due to service load: $f_{s\_2} := \frac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \frac{k_2}{3}\right)}$ $f_{s\_2} = 6\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \frac{d_b(B_B)}{2}$ $d_{c\_2} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \frac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.27$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 82.96\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 16.50\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12 \frac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 9.10\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n \left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 12.4\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 3.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 1.5\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 3.35\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 3.12\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 2.24\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 648.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel})$ $M_{cr\_heel} = 27.79\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3): $M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$

$M_{D\_heel} = 4.14\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 4$ $s_C := 12\ in$

$A_{s\_C} := \frac{A_b(B_C)}{s_C}$ $A_{s\_C} = 0.2\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2}$ $d_{s\_heel} = 15.75\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 14.04\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0011$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod})$ $k_h = 0.11$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft}$ $f_{s\_h} = 8.84\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$ $d_{c\_h} = 2.25\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.2$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 61.28\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12 \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1.
Using reference book function.

$d_{v\_heel} = 15.60\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$\phi V_{n\_heel} = 21.30 \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 3.71 \ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00 \ ft \qquad M_{D\_toe\_1} = 3.71 \ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00 \ ft$$

$$M_{D\_svc\_t} = 2.09 \ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79 \ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 4.94 \ kip \ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 4.00$$

$$s_{toe} := s_A \qquad s_{toe} = 12.00 \ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 0.2 \ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.75 \ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n \left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c \right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 13.14\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0011$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot \left(\rho_t \cdot n_{mod}\right) + \left(\rho_t \cdot n_{mod}\right)^2} - \left(\rho_t \cdot n_{mod}\right)$ $k_t = 0.11$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 9\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b\left(B_{toe}\right)}{2}$ $d_{c\_t} = 3.25\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot \left(t_f - d_{c\_t}\right)}$ Equation 5.6.7-2

$\beta_{s\_t} = 1.31$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$ Equation 5.6.7-1

$s_{max\_t} = 53.73\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2 $s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_toe} = 14.6\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 19.9\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{“OK”}$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$B_{temp\_stem} := 4$

$s_{temp\_stem} := 18\ in$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}}$$

$A_{s\_temp\_p1} = 0.27\ \frac{in^2}{ft}$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \left| \begin{array}{l} A_{temp} \leftarrow \dfrac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \right. \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \right. \\ \text{return } A_{temp} \end{array} \right.$$

$A_{s\_temp\_1} = 0.12\ \frac{in^2}{ft}$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_1} = 18.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 10$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.44\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.11\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \dfrac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.15\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0\ in) \end{cases}$$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - STEM INTERFACE

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $\quad A_{cv} = 132.01\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.110\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 0.20\ in^2$$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{"OK"}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$$ 5.7.4.3-3

$$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$$ 5.7.4.3-4

$$V_{ni\_3} := K_2 \cdot A_{cv}$$ 5.7.4.3-5

$V_{ni\_1} = 17.10\ kip$ $V_{ni\_2} = 105.61\ kip$

$V_{ni\_3} = 105.61\ kip$

Controlling nominal concrete shear capacity:

$$V_{niMax} := \text{if } min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1} \;\; \| \; min(V_{ni\_2}, V_{ni\_3}) \;\; \text{else} \;\; \| \; V_{ni\_1}$$

$V_{niMax} = 17.10\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $V_{ri} = 15.39\ kip$

$$InterfaceCheck_{stem} := \text{if } V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft \;\; \| \; \text{"OK"} \;\; \text{else} \;\; \| \; \text{"NG"}$$

$InterfaceCheck_{stem} = \text{"OK"}$

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{"OK"}$

$Sliding_{check\_str} = \text{"OK"}$

$Bearing_{check\_str} = \text{"OK"}$

$OT_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_svc} = \text{"OK"}$

$Sliding_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_EQ} = \text{"OK"}$

$Sliding_{check\_EQ} = \text{"OK"}$

$Check_{Bearing\_EQ} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{"OK"}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{"OK"}$

$InterfaceCheck_{stem} = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 8.00\ ft$
Footing width:	$B = 4.50\ ft$
Footing depth:	$t_f = 1.50\ ft$
Wall setback:	$W_t = 2.00\ ft$
Key location:	$L = 0.00\ ft$
Key depth:	$H_k = 0.00\ ft$
Key width:	$W_k = 0.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 4.00$	$s_A = 12.00\ in$	
Main stem reinforcing	$B_B = 4.00$	$s_B = 12.00\ in$	
Heel reinforcing:	$B_C = 4.00$	$s_C = 12.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 3.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 18.00\ in$	listed bars provided each face
Temperature reinforcing - footing:	$B_{temp\_ftg} = 4.00$	$N_{temp\_ftg} = 10.00$	total number of bars for footing

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user Unique modification by the user

Variable (to be input by user) Internal result (for reference) Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 8th Edition with 2018 errata
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states: $\phi_{svc} := 1.00$ Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified: $\phi_{EQ} := 1.0$ Section 11.5.8

$\phi_{EQ\_Stab} := 0.9$ Section 11.5.8

$\phi_{EQ\_BRG} := 0.8$ Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

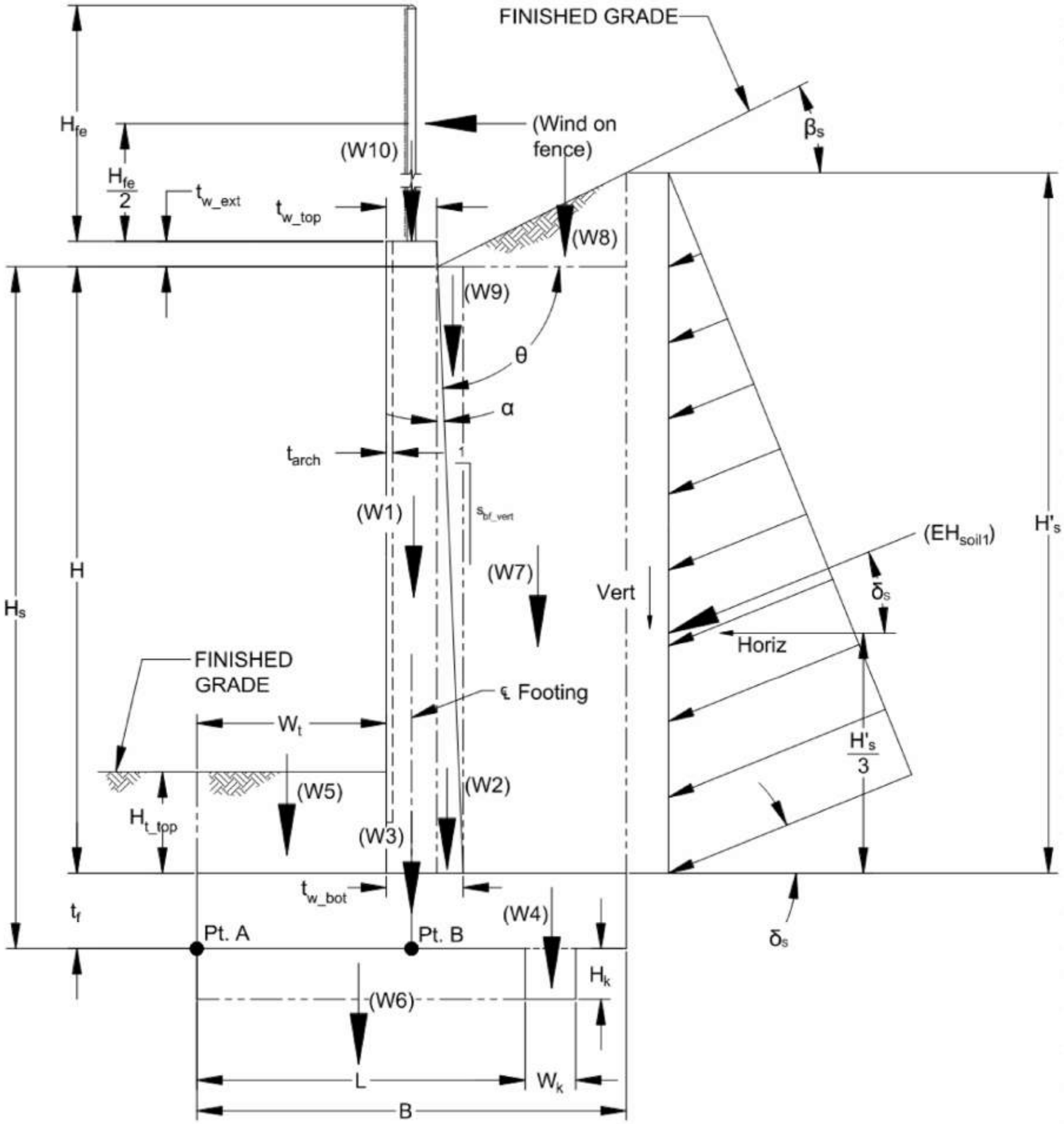


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 10.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\qquad H_s = 11.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 100000$

Total wall thickness (top) $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \dfrac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 12.00\ in$

Angle of wall backslope $\alpha := \mathrm{atan}\left(\dfrac{1}{s_{bf\_vert}}\right)$ $\alpha = 0.00\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 90.00\ deg$

Set back from toe to face of wall: $W_t := 2.00\ ft$

Footing width: $B := 5.50\ ft$

Key width: $W_k := 0.00\ ft$

Key depth: $H_k := 0.00\ ft$

Set back from toe to face of key: $L := \begin{cases} B - H_k - W_k & \text{if } H_k > 0\ in \\ 0\ in & \text{else} \end{cases}$ $L = 0.00\ ft$

Depth of soil over toe: $H_{t\_top} := 2.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \dfrac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ Stem wall clear cover

$CLR_{side} := 2.00\ in$ side of footing clear cover

$CLR_{top} := 2.00\ in$ top of footing clear cover

$CLR_{bot} := 3.00\ in$ bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity: $E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi$ $E_c = 4555\ ksi$

Equation 5.4.2.4-1

Modular ratios:

$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$ Section 5.6.1

$n_{mod} = 6.00$

Modulus of rupture: $\lambda := 1.0$ Section 5.4.2.8 for normal weight concrete

$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi$ $f_r = 0.48\ ksi$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 0.00\ deg$ Level backfill

Effective soil friction angle: $\phi'_f := 35\ deg$ per geotechnical report, Ref. 4

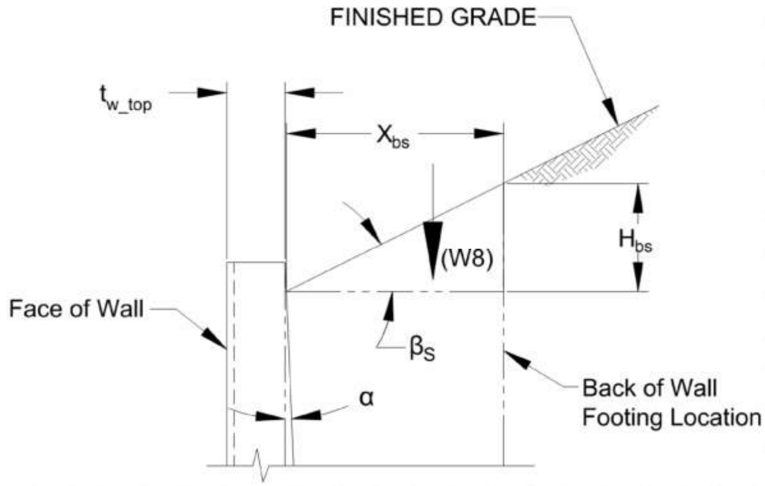


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete): $\mu_{s\_c} := 0.60$ — per geotechnical report, Ref. 4

Coefficient of friction (soil/soil): $\mu_{s\_s} := \tan(\phi'_f)$ — $\mu_{s\_s} = 0.7$

Section C10.6.3.4

Ultimate soil bearing pressure: $Q_n := 5.50\ ksf$

Factored soil bearing pressure: $Q_R := Q_n \cdot \phi_{brg}$ — $Q_R = 2.48\ ksf$

Friction angle between fill and wall: $\delta_s := 22\ deg$ — Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.959$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.245$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ — per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \dfrac{\left(2.5 \cdot \ln\left(\dfrac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \dfrac{2.56}{10^6} \cdot \left(\dfrac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 42.00\ in$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \dfrac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\dfrac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.009\ \dfrac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 2.50\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 0.00\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 11.50\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $R_{EH} = 2.10 \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.15 \frac{kip}{ft}$

OVERTURNING MOMENTS:

	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Active earth pressure resultant:	$L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 3.83\ ft$	$M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 8.06 \frac{kip \cdot ft}{ft}$
Wind load on fence:	$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 13.50\ ft$	$M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 2.01 \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 1.55 \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.00 \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 1.28 \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.00 \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.52 \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 0.00 \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 3.25 \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 0.00 \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.00 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)		Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$	$L_1 = 2.5\ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 3.88 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$	$L_2 = 3.5\ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 0.00 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$	$L_3 = 2.75\ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 3.52 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$	$L_4 = 0.00\ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 0.00 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$	$L_5 = 1\ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 0.52 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.		
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$	$L_7 = 4.25\ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 13.81 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$	$L_8 = 4.67\ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 0 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $M_9 := W_9 \cdot L_9$

$L_9 = 3.00\ ft$ $M_9 = 0\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $L_{10} = 2.50\ ft$ $M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.22\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 13.22\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_min} = 7.57\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_min} = 27.68\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $e_{A\_str} = 1.91\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $e_{B\_str} = 0.84\ ft$

Check location of resultant:

$Check_{Resultant\_str} :=$ if $\frac{-B}{4} \le e_{B\_str} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_str} =$ "OK"

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $P_{sliding} = 3.07\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\frac{W_{R\_min}}{B - 2 \cdot e_{B\_str}} \right)$ $\sigma_v = 1.98\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \land H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \land H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 3.64\ \frac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \frac{1}{2} \cdot P_p \cdot (H_{t\_top} - 2.00\ ft + t_f + H_k)^2$ $P_{pass} = 0.56\ \frac{kip}{ft}$

Remove for slope?

The top 2.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric}$ $P_{resist} = 3.64\ \frac{kip}{ft}$

Only friction is considered for sliding resistance.

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{“OK”}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces:

$$W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_max} = 9.91\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_max} = 35.35\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$ $e_{A\_BR} = 2.23\ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.52\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 2.22\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$ $Bearing_{check\_str} =$ "OK"

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$

$M_{o\_ser} = 8.07\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_ser} = 7.47\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_ser} = 26.27\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 3.25$

Service limit state OT Check: $OT_{check\_ser} :=$ if $OT_{FOS} \geq 1.5$ "OK" else "NG"

$OT_{check\_ser} =$ "OK"

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 2.44\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.31\ ft$

Check location of resultant: $Check_{Resultant\_svc} :=$ if $\frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} = \text{"OK"}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 1.53\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 1.99\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 4.87\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 7.47\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 8.04\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 4.03$

Service limit state sliding Check: $Sliding_{check\_ser} :=$ if $Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} = \text{"OK"}$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 0.73 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 6.00\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 16.28 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 7.85 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 29.18 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 1.64\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 1.11\ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \text{ then “OK” else “NG”}$$

$$Check_{Resultant\_EQ} = \text{“OK”}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $\quad P_{slidingEQ} = 3.60 \ \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$ $\quad \sigma_{vEQ} = 2.39 \ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $\quad BRG_{EQ} = 3.29 \ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 4.71 \ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $\quad P_{resist\_EQ} = 5.27 \ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} = \text{“OK”}$

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$W_{R\_maxEQ} = 10.19 \ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 36.86 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 2.02 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 0.73 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}}\right) \qquad \sigma_{BR\_EQ} = 2.52 \ ksf$$

Bearing pressure check:

$Check_{Bearing\_EQ} :=$ if $\sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n$
  "OK"
else
  "NG"

$Check_{Bearing\_EQ} =$ "OK"

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

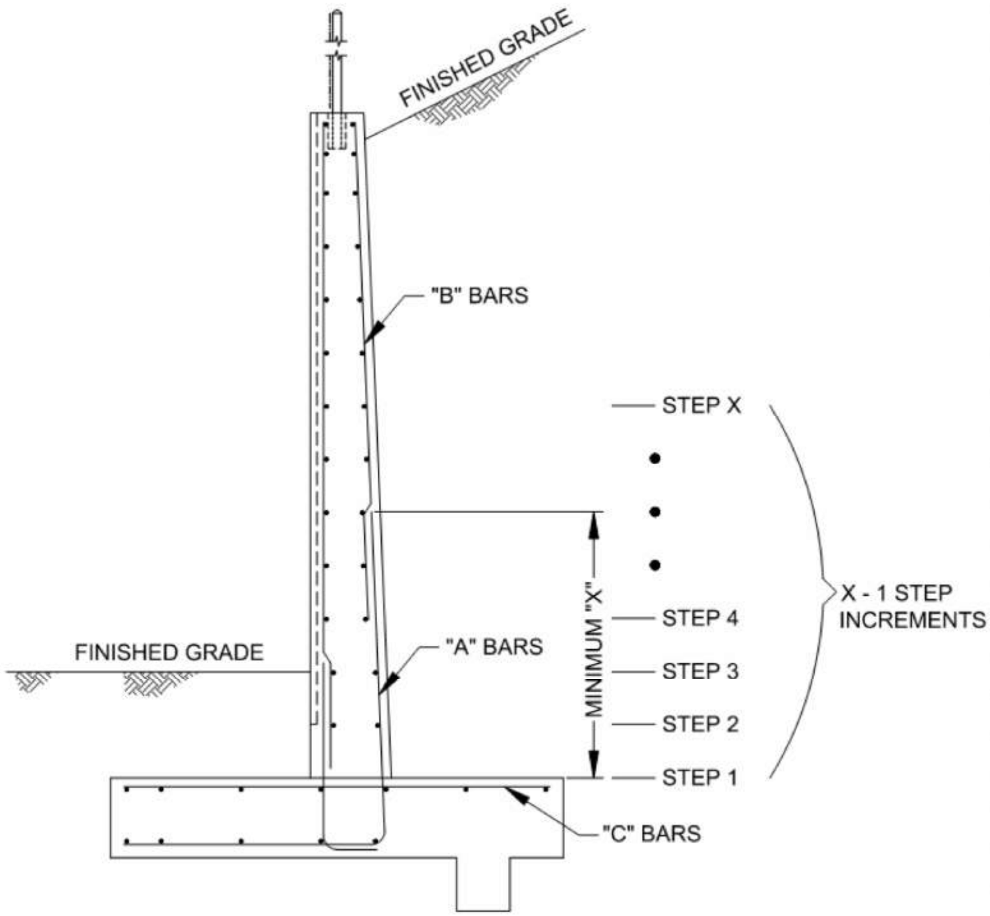


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\quad step = 9.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0 .. step \;\; \left\| \begin{array}{l} H_{st_i} \leftarrow H - (i) \cdot z \\ H_{st} \end{array} \right.$$

$$H_{st}^{\mathrm{T}} = [10.0\ \ 9.0\ \ 8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{T} = [1.47\ \ 1.19\ \ 0.94\ \ 0.72\ \ 0.53\ \ 0.37\ \ 0.24\ \ 0.13\ \ 0.06\ \ 0.01]\ \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{T} = [2.36\ \ 1.94\ \ 1.56\ \ 1.23\ \ 0.94\ \ 0.70\ \ 0.50\ \ 0.35\ \ 0.24\ \ 0.17]\ \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{T} = [9.12\ \ 6.97\ \ 5.22\ \ 3.83\ \ 2.75\ \ 1.93\ \ 1.33\ \ 0.91\ \ 0.62\ \ 0.42]\ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{T} = [5.46\ \ 4.08\ \ 2.97\ \ 2.10\ \ 1.43\ \ 0.94\ \ 0.59\ \ 0.37\ \ 0.23\ \ 0.15]\ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\frac{H}{step+1}\right) \cdot \left(\frac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^T = [11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00]\ in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left\| \begin{array}{l} S_{s_i} \leftarrow \frac{{t_{w_i}}^2}{6} \\ S_s \end{array} \right.$$

$$S_s^T = [242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242]\ \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$ — Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$ — Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^T = [10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4]\ \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^T = [10.38\ \ 9.27\ \ 6.95\ \ 5.09\ \ 3.65\ \ 2.56\ \ 1.77\ \ 1.21\ \ 0.82\ \ 0.55]\ \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 6$ $s_A := 12\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 0.44\ in^2$

$A_{s\_A} = 0.44\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 9.13\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A} = 17.43\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.004$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.2$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 17\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 1.88\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.29$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 27.24\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 8.80\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_1} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 12.0\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 13.18\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\,\frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 17.43\,\frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 12.0\,\frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 4$ $s_B := 12\,in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b\left(B_B\right)}{s_B}$ $A_{s\_B} = 0.2\,\frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 3$ $xb := Steps_B$ $xb = 3.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b\left(B_B\right)}{2}$ $d_{s\_2} = 9.25\,in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\,in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 8.19\,\frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \dfrac{A_{s\_B}}{12\ \dfrac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0018$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.14$

Maximum reinforcing stress due to service load: $f_{s\_2} := \dfrac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \dfrac{k_2}{3}\right)}$ $f_{s\_2} = 14\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \dfrac{d_b(B_B)}{2}$ $d_{c\_2} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \dfrac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.27$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \dfrac{700\ \dfrac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 35.15\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 16.50\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12\ \dfrac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 9.10\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 12.4\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 3.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 2.5\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 6.3\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 9.35\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 6.76\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 648.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel})$ $M_{cr\_heel} = 27.79\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3) $M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$

$M_{D\_heel} = 12.43\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 4$ $s_C := 12\ in$

$A_{s\_C} := \frac{A_b(B_C)}{s_C}$ $A_{s\_C} = 0.2\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2}$ $d_{s\_heel} = 15.75\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n \left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 14.04\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0011$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod})$ $k_h = 0.11$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft}$ $f_{s\_h} = 26.69\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$ $d_{c\_h} = 2.25\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.2$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 17.28\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12 \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1.
Using reference book function.

$d_{v\_heel} = 15.60\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$\phi V_{n\_heel} = 21.30\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 4.63\ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00\ ft \qquad M_{D\_toe\_1} = 4.63\ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00\ ft$$

$$M_{D\_svc\_t} = 2.60\ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79\ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 6.15\ kip\ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 6.00$$

$$s_{toe} := s_A \qquad s_{toe} = 12.00\ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 0.44\ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.63\ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n\left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 28.32\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0025$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot \left(\rho_t \cdot n_{mod}\right) + \left(\rho_t \cdot n_{mod}\right)^2} - \left(\rho_t \cdot n_{mod}\right)$ $k_t = 0.16$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 5\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b\left(B_{toe}\right)}{2}$ $d_{c\_t} = 3.38\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot \left(t_f - d_{c\_t}\right)}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.33$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 95.93\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$$d_{v\_toe} = 14.3\ in$$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 19.5\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{“OK”}$$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$$B_{temp\_stem} := 4 \qquad s_{temp\_stem} := 18\ in$$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.27\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \left\| \begin{array}{l} A_{temp} \leftarrow \dfrac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \right. \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \right. \\ \text{return } A_{temp} \end{array} \right.$$

$$A_{s\_temp\_1} = 0.12\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_1} = 18.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 12$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.44\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.27\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \dfrac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.15\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0\ in) \end{cases}$$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{“OK”}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{“OK”}$

ADDITIONAL DESIGN CHECKS - KEY, STEM INTERFACE

Key Check (to determine if key reinforcing is required):

It is assumed that the footing and the key will be placed monolithically. The ϕV_n function as used below simply returns the shear resistance per the simplified procedure for non prestressed sections without transverse reinforcement as described in AASHTO Section 5.7.3.3 and 5.7.4.3.

Conservatively design for the full lateral demand forces, neglecting the reduction in loading on the key due to the passive resistance in front of wall and any reduction in the applied load from sliding friction in front of the key.

Echo of calculated factored demand forces from above (for comparison only)

$P_{sliding} = 3.07\ \frac{kip}{ft}$ $P_{slidingEQ} = 3.6\ \frac{kip}{ft}$

Factored shear resistance - (A_v equal to zero and s_v equal to 1000in):

$\phi V_{n\_key} := \phi V_n(0\ in^2, 1000\ in, f_y, 12\ in, W_k, f'_c)$

$\phi V_{n\_key} = 0.00\ kip$

Compare the shear demand to the shear capacity:

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft, \phi V_{n\_key}) = \text{“NG”}$

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $A_{cv} = 132.02\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.110\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 0.44\ in^2$$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{"OK"}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ 5.7.4.3-5

$V_{ni\_1} = 25.74\ kip$ $V_{ni\_2} = 105.61\ kip$

$V_{ni\_3} = 105.61\ kip$

Controlling nominal concrete shear capacity:

$$V_{niMax} := \text{if } min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1} \ \| \ min(V_{ni\_2}, V_{ni\_3}) \ \text{else} \ \| \ V_{ni\_1}$$

$V_{niMax} = 25.74\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $\quad V_{ri} = 23.17\ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft$
  "OK"
else
  "NG"

$InterfaceCheck_{stem} =$ "OK"

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} =$ "OK"

$Sliding_{check\_str} =$ "OK"

$Bearing_{check\_str} =$ "OK"

$OT_{check\_ser} =$ "OK"

$Check_{Resultant\_svc} =$ "OK"

$Sliding_{check\_ser} =$ "OK"

$Check_{Resultant\_EQ} =$ "OK"

$Sliding_{check\_EQ} =$ "OK"

$Check_{Bearing\_EQ} =$ "OK"

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) =$ "OK"

$check_{dc}(s_A, s'_{max\_1}) =$ "OK"

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) =$ "OK"

$check_{dc}(M_{sD\_EQ}, \phi M_{n\_A\_EQ}) =$ "OK"

$check_{dc}(P_{slidingEQ}, \phi V_{n\_EQ}) =$ "OK"

$check_{dc}(V_{D\_heel}, \phi V_{n\_heel}) =$ "OK"

$check_{dc}(M_{D\_toe}, \phi M_{n\_toe}) =$ "OK"

$check_{dc}(s_{toe}, s'_{max\_t}) =$ "OK"

$check_{dc}(V_{D\_toe}, \phi V_{n\_toe}) =$ "OK"

$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) =$ "OK"

$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) =$ "OK"

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) =$ "OK"

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) =$ "OK"

$check_{dc}(\max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft, \phi V_{n\_key}) =$ "NG"

$check_{dc}(A_{vf\_min}, A_{vf}) =$ "OK"

$InterfaceCheck_{stem} =$ "OK"

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 10.00\ ft$
Footing width:	$B = 5.50\ ft$
Footing depth:	$t_f = 1.50\ ft$
Wall setback:	$W_t = 2.00\ ft$
Key location:	$L = 0.00\ ft$
Key depth:	$H_k = 0.00\ ft$
Key width:	$W_k = 0.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 6.00$	$s_A = 12.00\ in$	
Main stem reinforcing	$B_B = 4.00$	$s_B = 12.00\ in$	
Heel reinforcing:	$B_C = 4.00$	$s_C = 12.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 3.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 18.00\ in$	listed bars provided each face

Temperature reinforcing - footing:	$B_{temp\_ftg}=4.00$	$N_{temp\_ftg}=12.00$	total number of bars for footing

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user | Unique modification by the user

Variable (to be input by user) | Internal result (for reference) | Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states: $\phi_{svc} := 1.00$ Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified: $\phi_{EQ} := 1.0$ Section 11.5.8

$\phi_{EQ\_Stab} := 0.9$ Section 11.5.8

$\phi_{EQ\_BRG} := 0.8$ Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

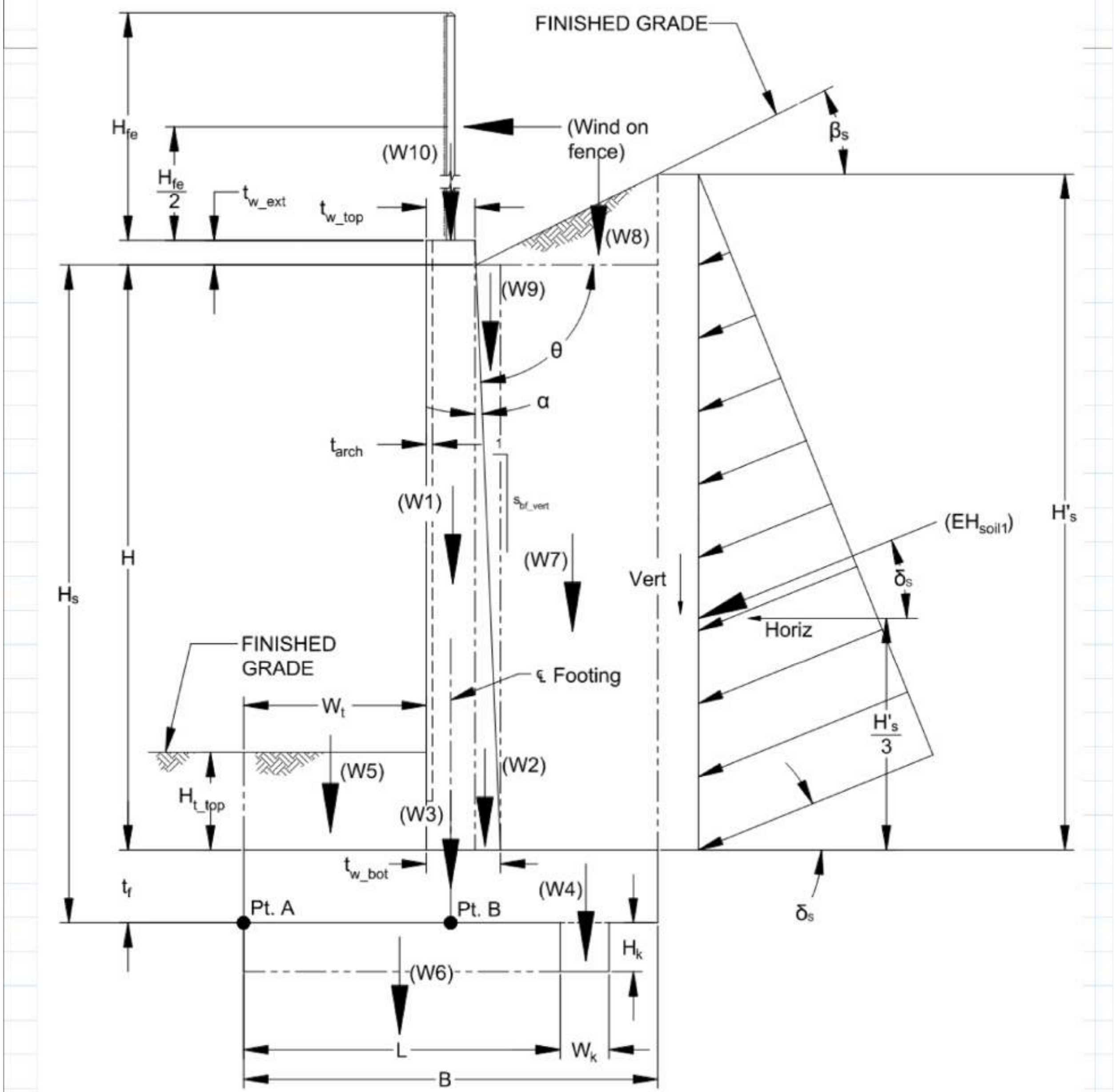


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 12.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 13.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 100000$

Total wall thickness (top) $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \frac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 12.00\ in$

Angle of wall backslope $\alpha := \operatorname{atan}\left(\frac{1}{s_{bf\_vert}}\right)$ $\alpha = 0.00\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 90.00\ deg$

Set back from toe to face of wall: $W_t := 2.00\ ft$

Footing width: $B := 6.50\ ft$

Key width: $W_k := 0.00\ ft$

Key depth: $H_k := 0.00\ ft$

Set back from toe to face of key: $L := \text{if } H_k > 0\ in \text{ then } B - H_k - W_k \text{ else } 0\ in$ $L = 0.00\ ft$

Depth of soil over toe: $H_{t\_top} := 2.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \frac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ Stem wall clear cover

$CLR_{side} := 2.00\ in$ side of footing clear cover

$CLR_{top} := 2.00\ in$ top of footing clear cover

$CLR_{bot} := 3.00\ in$ bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity: $E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi$ $E_c = 4555\ ksi$

Equation 5.4.2.4-1

Modular ratios:

$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$ Section 5.6.1

$n_{mod} = 6.00$

Modulus of rupture: $\lambda := 1.0$ Section 5.4.2.8 for normal weight concrete

$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi$ $f_r = 0.48\ ksi$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 0.00\ deg$ Level backfill

Effective soil friction angle: $\phi'_f := 35\ deg$ per geotechnical report, Ref. 4

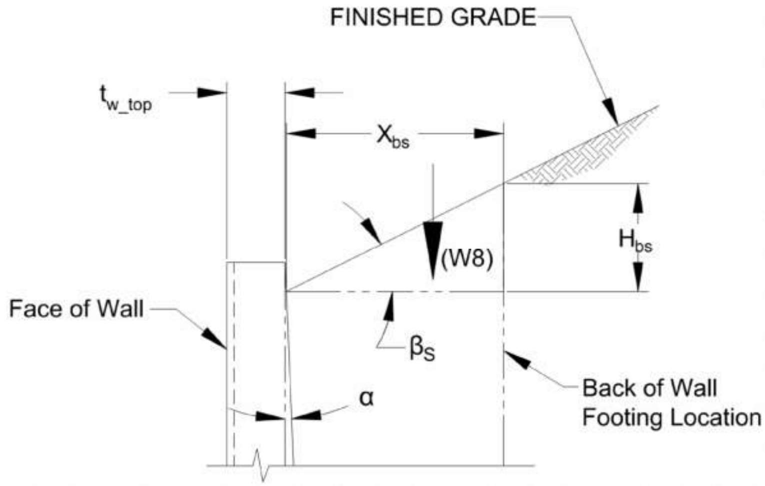


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete): $\mu_{s\_c} := 0.60$ — per geotechnical report, Ref. 4

Coefficient of friction (soil/soil): $\mu_{s\_s} := \tan\left(\phi'_f\right)$ — $\mu_{s\_s} = 0.7$

Section C10.6.3.4

Ultimate soil bearing pressure: $Q_n := 6.00\ ksf$

Factored soil bearing pressure: $Q_R := Q_n \cdot \phi_{brg}$ — $Q_R = 2.70\ ksf$

Friction angle between fill and wall: $\delta_s := 22\ deg$ — Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin\left(\phi'_f + \delta_s\right) \cdot \sin\left(\phi'_f - \beta_s\right)}{\sin\left(\theta - \delta_s\right) \cdot \sin\left(\theta + \beta_s\right)}}\right)^2$$

$\Gamma_a = 2.959$

$$k_{af} := \frac{\sin\left(\theta + \phi'_f\right)^2}{\Gamma_a \cdot \left(\sin\left(\theta\right)^2 \cdot \sin\left(\theta - \delta_s\right)\right)}$$

$k_{af} = 0.245$

Passive pressure: $P_p := \dfrac{500\ psf}{1\ ft}$ — per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \dfrac{\left(2.5 \cdot \ln\left(\dfrac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \dfrac{2.56}{10^6} \cdot \left(\dfrac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 42.00\ in$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \dfrac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\dfrac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.009\ \dfrac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 3.50\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 0.00\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 13.50\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $R_{EH} = 2.90 \ \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.15 \ \frac{kip}{ft}$

OVERTURNING MOMENTS:

	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Active earth pressure resultant:	$L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 4.50 \ ft$	$M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 13.04 \ \frac{kip \cdot ft}{ft}$
Wind load on fence:	$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 15.50 \ ft$	$M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 2.31 \ \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 1.86 \ \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.00 \ \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 1.51 \ \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.00 \ \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.52 \ \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 0.00 \ \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 5.46 \ \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 0.00 \ \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.00 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)		Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$	$L_1 = 2.5\ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 4.65 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$	$L_2 = 3.5\ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 0.00 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$	$L_3 = 3.25\ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 4.91 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$	$L_4 = 0.00\ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 0.00 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$	$L_5 = 1\ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 0.52 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.		
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$	$L_7 = 4.75\ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 25.93 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$	$L_8 = 5.33\ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 0 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $M_9 := W_9 \cdot L_9$

$L_9 = 3.00\ ft$ $M_9 = 0\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $L_{10} = 2.50\ ft$ $M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.22\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 20.44\ \frac{kip \cdot ft}{ft}$

Factored resisting forces:

$$W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_min} = 10.72\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_min} = 45.84\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $e_{A\_str} = 2.37\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $e_{B\_str} = 0.88\ ft$

Check location of resultant:

$$Check_{Resultant\_str} := \begin{cases} \text{"OK"} & \text{if } \frac{-B}{4} \le e_{B\_str} \le \frac{B}{4} \\ \text{"NG"} & \text{else} \end{cases}$$

$Check_{Resultant\_str} = \text{"OK"}$

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $P_{sliding} = 4.18\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2):

$$\sigma_v := \left(\frac{W_{R\_min}}{B - 2 \cdot e_{B\_str}}\right)$$

$\sigma_v = 2.26\ ksf$

Sliding resistance - friction:

Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 5.15\ \frac{kip}{ft}$

Sliding resistance - passive pressure:

$$P_{pass} := \frac{1}{2} \cdot P_p \cdot (H_{t\_top} - 2.00\ ft + t_f + H_k)^2$$

$P_{pass} = 0.56\ \frac{kip}{ft}$

The top 2.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric}$

$P_{resist} = 5.15\ \frac{kip}{ft}$

Only friction is considered for sliding resistance.

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{“OK”}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces:

$$W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_max} = 14.02\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_max} = 58.52\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A:
$$e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$$
$$e_{A\_BR} = 2.72\ ft$$

Distance to resultant from Point B:
$$e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$$
$$e_{B\_BR} = 0.53\ ft$$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1):
$$\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$$
$$\sigma_{BR} = 2.58\ ksf$$

Equation 11.6.3.2-1

Bearing Check:
$$Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$$
$$Bearing_{check\_str} = \text{"OK"}$$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment:
$$M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$$
$$M_{o\_ser} = 12.78\ \frac{kip \cdot ft}{ft}$$

Factored resisting forces:
$$W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$$
$$W_{R\_ser} = 10.52\ \frac{kip}{ft}$$

Factored resisting moment:
$$M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$
$$M_{R\_ser} = 43.29\ \frac{kip \cdot ft}{ft}$$

Overturning Factor of safety:
$$OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$$
$$OT_{FOS} = 3.39$$

Service limit state OT Check:
$$OT_{check\_ser} := \begin{cases} \text{"OK"} & \text{if } OT_{FOS} \geq 1.5 \\ \text{"NG"} & \text{else} \end{cases}$$
$$OT_{check\_ser} = \text{"OK"}$$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 2.90\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.35\ ft$

Check location of resultant: $Check_{Resultant\_svc} :=$ if $\frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} =$ "OK"

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 1.81\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 2.73\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 5.80\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 10.52\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 11.09\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 4.06$

Service limit state sliding Check: $Sliding_{check\_ser} :=$ if $Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} =$ "OK"

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 1.05 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 7.20\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 26.60 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 11.11 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 48.39 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}}$$

$$e_{A\_EQ} = 1.96\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ}$$

$$e_{B\_EQ} = 1.29\ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \text{ “OK” else “NG”}$$

$$Check_{Resultant\_EQ} = \text{“OK”}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$

$P_{slidingEQ} = 5.00 \ \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}} \right)$

$\sigma_{vEQ} = 2.83 \ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$

$BRG_{EQ} = 3.92 \ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 6.67 \ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$

$P_{resist\_EQ} = 7.23 \ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} = \text{“OK”}$

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$W_{R\_maxEQ} = 14.42 \ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 61.07 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}}$$

$$e_{A\_BR\_EQ} = 2.39\ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ}$$

$$e_{B\_BR\_EQ} = 0.86\ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}}\right)$$

$$\sigma_{BR\_EQ} = 3.01\ ksf$$

Bearing pressure check:

$$Check_{Bearing\_EQ} := \text{if } \sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n \ \text{“OK”} \ \text{else} \ \text{“NG”}$$

$$Check_{Bearing\_EQ} = \text{“OK”}$$

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

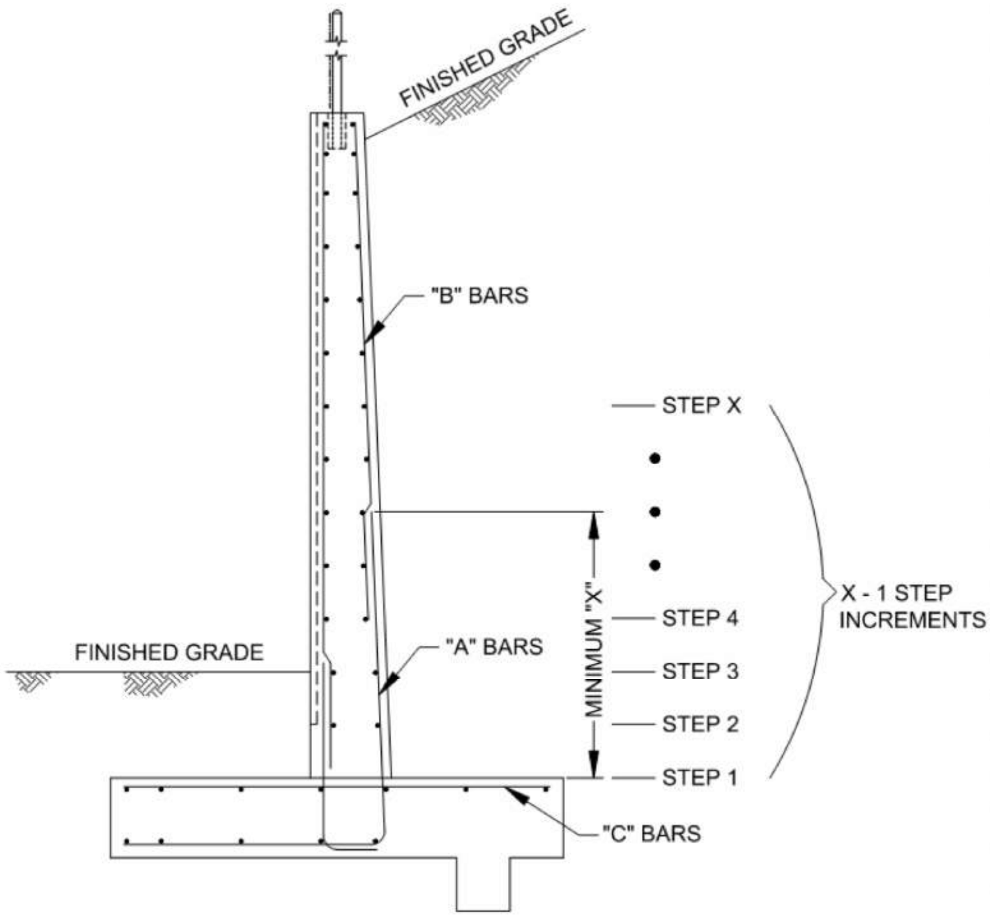


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\qquad step = 11.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} H_{st_i} \leftarrow H - (i) \cdot z \\ H_{st} \end{array} \right.$$

$$H_{st}^{T} = [12.0\ \ 11.0\ \ 10.0\ \ 9.0\ \ 8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{T} = [2.12\ \ 1.78\ \ 1.47\ \ 1.19\ \ 0.94\ \ 0.72\ \ 0.53\ \ 0.37\ \ 0.24\ \ 0.13\ \ 0.06\ \ 0.01]\ \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{T} = [3.33\ \ 2.82\ \ 2.36\ \ 1.94\ \ 1.56\ \ 1.23\ \ 0.94\ \ 0.70\ \ 0.50\ \ 0.35\ \ 0.24\ \ 0.17]\ \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{T} = [14.78\ \ 11.71\ \ 9.12\ \ 6.97\ \ 5.22\ \ 3.83\ \ 2.75\ \ 1.93\ \ 1.33\ \ 0.91\ \ 0.62\ \ 0.42]\ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{T} = [9.13\ \ 7.13\ \ 5.46\ \ 4.08\ \ 2.97\ \ 2.10\ \ 1.43\ \ 0.94\ \ 0.59\ \ 0.37\ \ 0.23\ \ 0.15]\ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\frac{H}{step+1}\right)\cdot\left(\frac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^{T} = [11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00]\ in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left| \begin{array}{l} S_{s_i} \leftarrow \frac{t_{w_i}^{2}}{6} \\ S_s \end{array} \right.$$

$$S_s^{T} = [242\ 242\ 242\ 242\ 242\ 242\ 242\ 242\ 242\ 242\ 242\ 242]\ \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$

Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$

Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^{T} = [10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4]\ \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^{T} = [10.38\ 10.38\ 10.38\ 9.27\ 6.95\ 5.09\ 3.65\ 2.56\ 1.77\ 1.21\ 0.82\ 0.55]\ \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 7$ $s_A := 12\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 0.60\ in^2$

$A_{s\_A} = 0.60\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 9.06\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A} = 23.28\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.0055$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.23$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 22\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 1.94\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.31$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 20.75\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 8.62\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_1} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 11.8\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{“OK”}$

Reference workbook function

<u>WALL STEM - Base of Wall Location - SEISMIC Check:</u>

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 21.79\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 23.28\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 11.8\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 4$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b\left(B_B\right)}{s_B}$ $A_{s\_B} = 0.2\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b\left(B_B\right)}{2}$ $d_{s\_2} = 9.25\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 8.19\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio

$$\rho_2 := \frac{A_{s\_B}}{12 \frac{in}{ft} \cdot d_{s\_2}}$$

$\rho_2 = 0.0018$

Neutral axis depth factor:

$$k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$$

$k_2 = 0.14$

Maximum reinforcing stress due to service load:

$$f_{s\_2} := \frac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \frac{k_2}{3}\right)}$$

$f_{s\_2} = 20\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_2} := CLR_{stem} + \frac{d_b(B_B)}{2}$$

$d_{c\_2} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_2} := 1 + \frac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$$

Equation 5.6.7-2

$\beta_{s\_2} = 1.27$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_2} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$$

Equation 5.6.7-1

$s_{max\_2} = 23.78\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12 \frac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 9.10\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in): $\phi V_{n\_2} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$

$\phi V_{n\_2} = 12.4\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3): $Min_X := Steps_B \cdot z$ $Min_X = 4.00\ ft$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing: $Heel := B - W_t - t_{w\_bot}$ $Heel = 3.5\ ft$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$V_{D\_heel} = 10.02\ \frac{kip}{ft}$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$M_{D\_heel\_1} = 20.38\ kip \cdot ft$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$M_{D\_svc} = 14.78\ kip \cdot ft$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 648.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel})$ $M_{cr\_heel} = 27.79\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3) $M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$

$M_{D\_heel} = 27.1\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 6$ $s_C := 12\ in$

$A_{s\_C} := \frac{A_b(B_C)}{s_C}$ $A_{s\_C} = 0.44\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2}$ $d_{s\_heel} = 15.63\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 30.3\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0023$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod})$ $k_h = 0.15$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft}$ $f_{s\_h} = 27.19\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$ $d_{c\_h} = 2.38\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.22$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 16.40\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 16.40\ in$

Check reinforcing spacing:

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12 \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_heel} = 15.30\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$\phi V_{n\_heel} = 20.89\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{“OK”}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 5.61 \ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00 \ ft \qquad M_{D\_toe\_1} = 5.61 \ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00 \ ft$$

$$M_{D\_svc\_t} = 3.16 \ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79 \ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 7.46 \ kip \ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 7.00$$

$$s_{toe} := s_A \qquad s_{toe} = 12.00 \ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 0.6 \ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.56 \ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n \left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c \right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 38.13\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12 \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0034$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot (\rho_t \cdot n_{mod}) + (\rho_t \cdot n_{mod})^2} - (\rho_t \cdot n_{mod})$ $k_t = 0.18$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 5\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b\left(B_{toe}\right)}{2}$ $d_{c\_t} = 3.44\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot \left(t_f - d_{c\_t}\right)}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.34$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 106.20\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1.
Using reference book function.

$d_{v\_toe} = 14.12\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 19.3\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$B_{temp\_stem} := 4$ $\qquad s_{temp\_stem} := 18\ in$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.27\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \left| \begin{array}{l} A_{temp} \leftarrow \frac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \right. \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \right. \\ \text{return } A_{temp} \end{array} \right.$$

$$A_{s\_temp\_1} = 0.12\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min\left(3.0 \cdot t_{w\_bot}, 18.0\ in\right) \end{cases}$$

$$s_{max\_temp\_1} = 18.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{“OK”}$$

$$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{“OK”}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 14$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{\left|A_b\left(B_{temp\_ftg}\right)\right| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.43\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{\left(B - 2 \cdot CLR_{side}\right) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.38\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \dfrac{1.3 \cdot t_f \cdot B}{2 \cdot \left(t_f + B\right) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.16\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \text{if } t_f > 18.00\ in \;\; \| 12\ in \;\; \text{else} \;\; \| min(3.0 \cdot t_f, 18.0\ in)$$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - STEM INTERFACE

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $\quad A_{cv} = 132.02\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.110\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 0.60\ in^2$$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{"OK"}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ 5.7.4.3-5

$V_{ni\_1} = 31.50\ kip$ $V_{ni\_2} = 105.61\ kip$

$V_{ni\_3} = 105.61\ kip$

Controlling nominal concrete shear capacity:

$V_{niMax} :=$ if $min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1}$
  $min(V_{ni\_2}, V_{ni\_3})$
else
  V_{ni_1}

$V_{niMax} = 31.50\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $V_{ri} = 28.35\ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft$
  "OK"
else
  "NG"

$InterfaceCheck_{stem} =$ "OK"

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{"OK"}$

$Sliding_{check\_str} = \text{"OK"}$

$Bearing_{check\_str} = \text{"OK"}$

$OT_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_svc} = \text{"OK"}$

$Sliding_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_EQ} = \text{"OK"}$

$Sliding_{check\_EQ} = \text{"OK"}$

$Check_{Bearing\_EQ} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{"OK"}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{"OK"}$

$InterfaceCheck_{stem} = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H=12.00\ ft$
Footing width:	$B=6.50\ ft$
Footing depth:	$t_f=1.50\ ft$
Wall setback:	$W_t=2.00\ ft$
Key location:	$L=0.00\ ft$
Key depth:	$H_k=0.00\ ft$
Key width:	$W_k=0.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A=7.00$	$s_A=12.00\ in$	
Main stem reinforcing	$B_B=4.00$	$s_B=12.00\ in$	
Heel reinforcing:	$B_C=6.00$	$s_C=12.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X=4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem}=4.00$	$s_{temp\_stem}=18.00\ in$	listed bars provided each face
Temperature reinforcing - footing:	$B_{temp\_ftg}=4.00$	$N_{temp\_ftg}=14.00$	total number of bars for footing

END OF WORKBOOK

MONONABE-OKABE SEISMIC ACTIVE EARTH PRESSURE

Determine the active earth pressure coefficient using the Mononobe-Okabe solution described in Appendix A11 of reference 1 listed below. It is up to the designer to determine if the total active static and seismic earth force is to be used for the design or if the separate components off the active static and seismic earth forces are to be used.

Currently, the choice has been made to use only the increase in earth forces caused by the seismic loading since the active static component has been calculated in the main calculation workbook.

Legend

Variable (to be input by user) | Internal result (for reference) | Final result of interest

Commentary / instructions to the user | Unique modification by the user

References

1. AASHTO LRFD Bridge Specifications, 8th Edition with 2018 errata

All section, table, equation and figure references are to reference 1 unless otherwise noted.

Standard user defined units: $kcf := \frac{kip}{ft^3}$

Inputs

Horizontal earthquake acceleration (g): $k_h := \frac{1}{2} \cdot 0.34$ $k_h = 0.17$

1/2 of the Design PGA per the project geotechnical report

Vertical earthquake acceleration (g): $k_v := 0 \cdot k_h$ $k_v = 0$

Effective soil friction angle (from main calculation workbook): $\phi := 35.0\ deg$

Backfill slope angle (from main calculation workbook): $\alpha := 0.00\ deg$

Friction angle between fill and wall (from main calculation workbook): $\delta := 22\ deg$ Table 3.11.5.3-1

Angle of wall backslope (from main calculation workbook): $\beta' := 0.00\ deg$

This variable is used in Appendix A11 equations. The prime has been added for these calculations to differentiate from the β value used in the main calculation workbook.

Active static pressure coefficient (from main calculation workbook): $K_a := 0.245$

Unit weight of soil: $\gamma_s := 0.130\ kcf$ From project geotechnical report

Wall batter from horizontal: $\theta_{MO} := \operatorname{atan}\left(\frac{k_h}{1-k_v}\right)$ $\theta_{MO} = 9.65\ deg$

Section A11.3.1

Seismic active pressure coefficient:

$$K_{ae} := \frac{\cos(\phi - \theta_{MO} - \beta')^2}{\cos(\theta_{MO}) \cdot \cos(\beta')^2 \cdot \cos(\delta + \theta_{MO} + \beta')} \cdot \left(1 + \sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi - \theta_{MO} - \alpha)}{\cos(\delta + \theta_{MO} + \beta') \cdot \cos(\alpha - \beta')}}\right)^{-2}$$

Equation A11.3.1-1 $K_{ae} = 0.358$

Design Calculations 12 ft. Wall

Height of soil face at back of footing: $H_1 := 12.00\ ft + (6.50\ ft - 2.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 12.00\ ft$

Active static earth pressure resultant: $P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot K_a$ $P_a = 2.29\ \frac{kip}{ft}$

Total active static and seismic earth force: $E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot (1 - k_v) \cdot K_{ae}$ $E_{ae} = 3.35\ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := E_{ae} - P_a$ $\Delta E_{ae} = 1.05\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 0.6 \cdot H_1$ $z_{\Delta Eae} = 7.20\ ft$

Section A11.3.1

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 5.01\ ft$

Design Calculations 10 ft. Wall

Height of soil face at back of footing: $H_1 := 10.00\ ft + (5.50\ ft - 2.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 10.00\ ft$

Active static earth pressure resultant: $P_a := \frac{1}{2} \cdot \gamma_s \cdot {H_1}^2 \cdot K_a$ $\quad P_a = 1.59\ \frac{kip}{ft}$

Total active static and seismic earth force: $E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot {H_1}^2 \cdot (1 - k_v) \cdot K_{ae}$ $\quad E_{ae} = 2.32\ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := E_{ae} - P_a$ $\quad \Delta E_{ae} = 0.73\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 0.6 \cdot H_1$ $\quad z_{\Delta Eae} = 6.00\ ft$

Section A11.3.1

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 4.17\ ft$

Design Calculations 8 ft. Wall

Height of soil face at back of footing: $H_1 := 8.00\ ft + (4.50\ ft - 2.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

$H_1 = 8.00\ ft$

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

Active static earth pressure resultant: $P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot K_a$ $\quad P_a = 1.02 \ \frac{kip}{ft}$

Total active static and seismic earth force: $E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot (1 - k_v) \cdot K_{ae}$ $\quad E_{ae} = 1.49 \ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := E_{ae} - P_a$ $\quad \Delta E_{ae} = 0.47 \ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 0.6 \cdot H_1$ $\quad z_{\Delta Eae} = 4.80 \ ft$

Section A11.3.1

Point of application for active static and seismic earth force (from top of footing): $z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$ $\quad z_{bar} = 3.34 \ ft$

Design Calculations 6 ft. Wall

Height of soil face at back of footing: $H_1 := 6.00 \ ft + (3.75 \ ft - 1.00 \ ft - 1.00 \ ft) \cdot \tan(\alpha)$ $\quad H_1 = 6.00 \ ft$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

Active static earth pressure resultant: $P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot K_a$ $\quad P_a = 0.57 \ \frac{kip}{ft}$

Total active static and seismic earth force: $E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot (1 - k_v) \cdot K_{ae}$ $\quad E_{ae} = 0.84 \ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := E_{ae} - P_a$ $\quad \Delta E_{ae} = 0.26 \ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing):

$z_{\Delta Eae} := 0.6 \cdot H_1$

Section A11.3.1

$z_{\Delta Eae} = 3.60\ ft$

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 2.50\ ft$

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user   Unique modification by the user

Variable (to be input by user)   Internal result (for reference)   Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states: $\phi_{svc} := 1.00$ Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified: $\phi_{EQ} := 1.0$ Section 11.5.8

$\phi_{EQ\_Stab} := 0.9$ Section 11.5.8

$\phi_{EQ\_BRG} := 0.8$ Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC

$\gamma_{pDCmin} := 0.90$ STR I and III

$\gamma_{pDCmax} := 1.25$ STR I and III

$\gamma_{DCsvc} := 1.00$ Service

Horizontal Earth Pressure - Active, EH

$\gamma_{pEHmin} := 0.90$ STR I and III

$\gamma_{pEHmax} := 1.50$ STR I and III

$\gamma_{EHsvc} := 1.00$ Service

Vertical Earth Pressure - Retaining Wall and Abutments, EV

$\gamma_{pEVmin} := 1.00$ STR I and III

$\gamma_{pEVmax} := 1.35$ STR I and III

$\gamma_{EVsvc} := 1.00$ Service

Wind on Structure, WS

$\gamma_{WSstr3} := 1.00$ STR III

$\gamma_{WSsvc1} := 0.30$ Service

Earthquake earth pressure Loading, EQ

$\gamma_{EQ} := 1.00$ Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

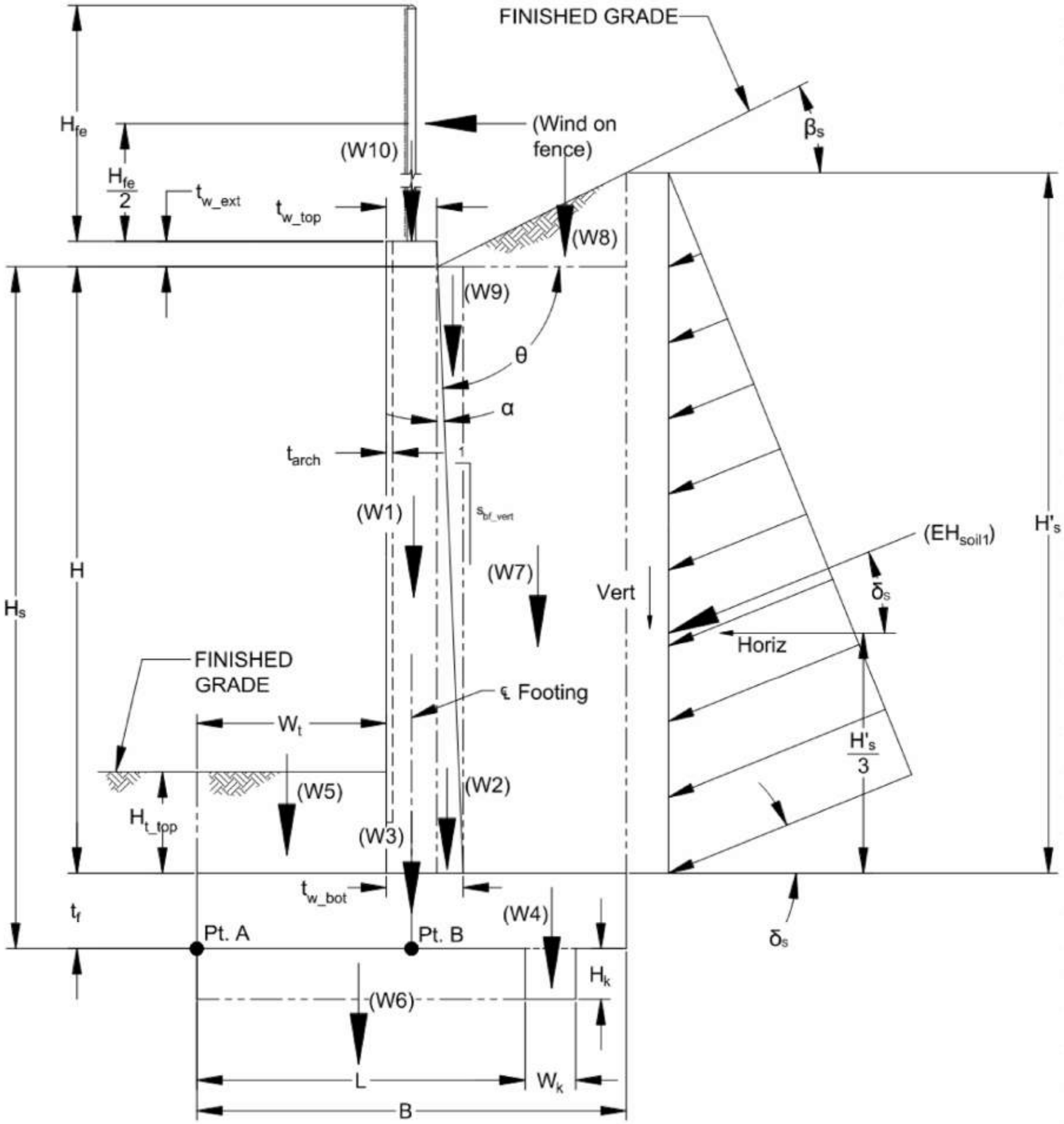


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 8.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 9.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 100000$

Total wall thickness (top) $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \frac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 12.00\ in$

Angle of wall backslope $\alpha := \operatorname{atan}\left(\frac{1}{s_{bf\_vert}}\right)$ $\alpha = 0.00\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 90.00\ deg$

Set back from toe to face of wall: $W_t := 2.00\ ft$

Footing width: $B := 6.25\ ft$

Key width: $W_k := 0.00\ ft$

Key depth: $H_k := 0.00\ ft$

Set back from toe to face of key: $L := \begin{cases} B - H_k - W_k & \text{if } H_k > 0\ in \\ 0\ in & \text{else} \end{cases}$ $L = 0.00\ ft$

Depth of soil over toe: $H_{t\_top} := 2.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \frac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ Stem wall clear cover

$CLR_{side} := 2.00\ in$ side of footing clear cover

$CLR_{top} := 2.00\ in$ top of footing clear cover

$CLR_{bot} := 3.00\ in$ bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity: $E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi$ $E_c = 4555\ ksi$

Equation 5.4.2.4-1

Modular ratios: $n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$ Section 5.6.1

$n_{mod} = 6.00$

Modulus of rupture: $\lambda := 1.0$ Section 5.4.2.8 for normal weight concrete

$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi$ $f_r = 0.48\ ksi$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 25\ deg$ 2H:1V backfill

Effective soil friction angle: $\phi'_f := 36\ deg$ per geotechnical report, Ref. 4

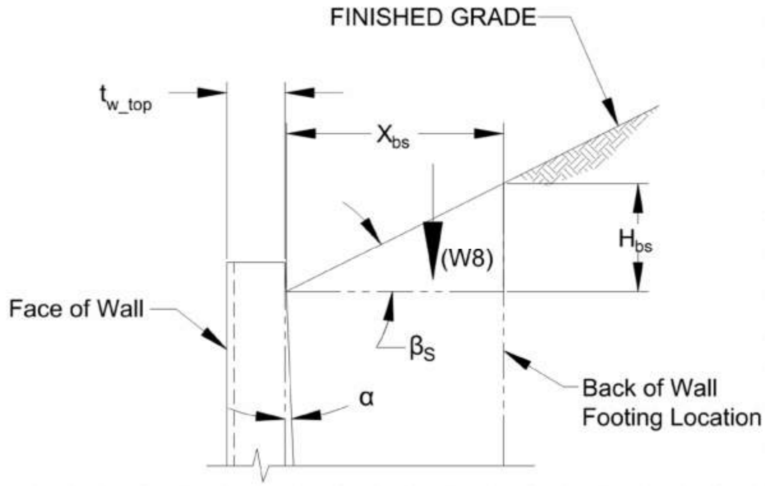


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete): $\mu_{s\_c} := 0.60$ — per geotechnical report, Ref. 4

Coefficient of friction (soil/soil): $\mu_{s\_s} := \tan(\phi'_f)$ — $\mu_{s\_s} = 0.73$

Section C10.6.3.4

Ultimate soil bearing pressure: $Q_n := 6.00\ ksf$

Factored soil bearing pressure: $Q_R := Q_n \cdot \phi_{brg}$ — $Q_R = 2.7\ ksf$

Friction angle between fill and wall: $\delta_s := 22\ deg$ — Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.07$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.341$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ — per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \frac{\left(2.5 \cdot \ln\left(\frac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \frac{2.56}{10^6} \cdot \left(\frac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 42.00\ in$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \frac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\frac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.009\ \frac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 3.25\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan\left(\beta_s\right) \cdot X_{bs}$	$H_{bs} = 1.52\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 11.02\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $R_{EH} = 2.69\ \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.15\ \frac{kip}{ft}$

OVERTURNING MOMENTS:

	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Active earth pressure resultant:	$L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 3.67\ ft$	$M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 9.88\ \frac{kip \cdot ft}{ft}$
Wind load on fence:	$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 11.50\ ft$	$M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 1.71\ \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 1.24\ \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.00\ \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 1.45\ \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.00\ \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.52\ \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 0.00\ \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 3.38\ \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 0.32\ \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $\quad W_9 = 0.00 \ \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $\quad W_{10} = 0.09 \ \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$ $L_1 = 2.5 \ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 3.10 \ \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $L_2 = 3.5 \ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 0.00 \ \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$ $L_3 = 3.13 \ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 4.54 \ \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$ $L_4 = 0.00 \ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 0.00 \ \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$ $L_5 = 1 \ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 0.52 \ \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.	
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$ $L_7 = 4.63 \ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 15.63 \ \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$ $L_8 = 5.17 \ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 1.65 \ \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $\quad M_9 := W_9 \cdot L_9$

$L_9 = 3.00\ ft$ $\quad M_9 = 0\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $\quad L_{10} = 2.50\ ft$ $\quad M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.22\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 15.45\ \frac{kip \cdot ft}{ft}$

Factored resisting forces:

$$W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_min} = 8.23\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_min} = 34.32\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $\quad e_{A\_str} = 2.29\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $\quad e_{B\_str} = 0.83\ ft$

Check location of resultant:

$$Check_{Resultant\_str} := \begin{cases} \text{"OK"} & \text{if } \frac{-B}{4} \le e_{B\_str} \le \frac{B}{4} \\ \text{"NG"} & \text{else} \end{cases}$$

$Check_{Resultant\_str} = \text{"OK"}$

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $\quad P_{sliding} = 3.89\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\dfrac{W_{R\_min}}{B - 2 \cdot e_{B\_str}}\right)$ $\sigma_v = 1.80\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 3.95\ \dfrac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \dfrac{1}{2} \cdot P_p \cdot (H_{t\_top} - 2.00\ ft + t_f + H_k)^2$ $P_{pass} = 0.56\ \dfrac{kip}{ft}$

The top 2.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric}$ $P_{resist} = 3.95\ \dfrac{kip}{ft}$

Only friction is considered for sliding resistance.

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces: $W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_max} = 10.68\ \dfrac{kip}{ft}$

Factored resisting moment: $M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_max} = 43.30\ \dfrac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$ $e_{A\_BR} = 2.61\ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.52\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 2.05\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$ $Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$

$M_{o\_ser} = 9.67\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_ser} = 8.01\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_ser} = 31.96\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 3.31$

Service limit state OT Check: $OT_{check\_ser} :=$ if $OT_{FOS} \geq 1.5$ "OK" else "NG" $OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 2.78\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.34\ ft$

Check location of resultant: $Check_{Resultant\_svc} :=$ if $\frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} = \text{“OK”}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 1.44\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 2.54\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 5.57\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 8.01\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 8.57\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 3.38$

Service limit state sliding Check: $Sliding_{check\_ser} :=$ if $Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} = \text{“OK”}$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 1.94 \ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 5.71 \ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 26.70 \ \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 8.96 \ \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 38.86 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 1.36 \ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 1.77 \ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \ \text{“OK”} \ \text{else} \ \text{“NG”}$$

$$Check_{Resultant\_EQ} = \text{“OK”}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $P_{slidingEQ} = 5.54 \ \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$ $\sigma_{vEQ} = 3.30 \ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $BRG_{EQ} = 2.71 \ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 5.38 \ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $P_{resist\_EQ} = 5.94 \ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} = \text{"OK"}$

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$W_{R\_maxEQ} = 11.41 \ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 47.85 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 1.85 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 1.27 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}} \right) \qquad \sigma_{BR\_EQ} = 3.08 \ ksf$$

Bearing pressure check:

$$Check_{Bearing\_EQ} := \text{if } \sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n \ \text{“OK”} \ \text{else} \ \text{“NG”}$$

$$Check_{Bearing\_EQ} = \text{“OK”}$$

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

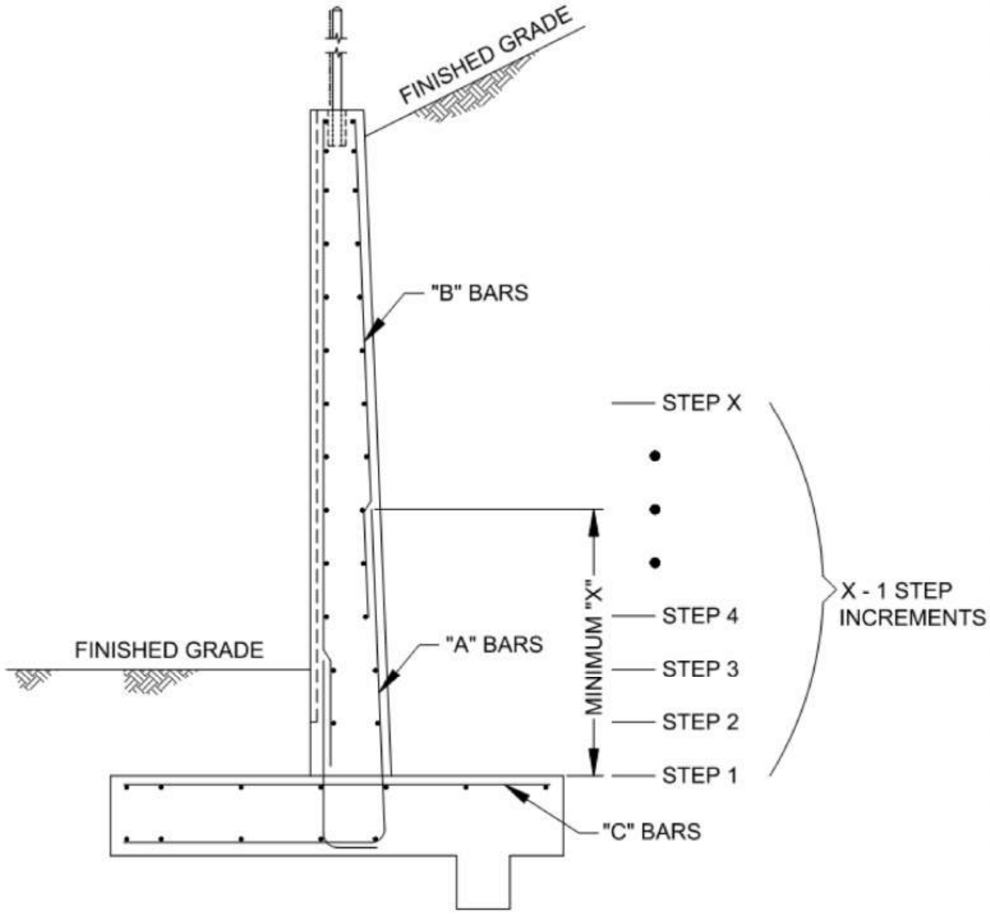


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$

user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\qquad step = 7.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \;\; \left\| \begin{array}{l} H_{st_i} \leftarrow H - (i) \cdot z \\ H_{st} \end{array} \right.$$

$$H_{st}^{T} = [8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{T} = [1.86\ \ 1.49\ \ 1.16\ \ 0.87\ \ 0.63\ \ 0.42\ \ 0.25\ \ 0.13]\ \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{T} = [2.94\ \ 2.38\ \ 1.89\ \ 1.46\ \ 1.09\ \ 0.78\ \ 0.53\ \ 0.34]\ \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{T} = [10.30\ \ 7.65\ \ 5.52\ \ 3.85\ \ 2.58\ \ 1.65\ \ 1.00\ \ 0.57]\ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{T} = [6.36\ \ 4.64\ \ 3.28\ \ 2.22\ \ 1.43\ \ 0.87\ \ 0.49\ \ 0.25]\ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\dfrac{H}{step+1}\right) \cdot \left(\dfrac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^{T} = [11.00 \;\; 11.00 \;\; 11.00 \;\; 11.00 \;\; 11.00 \;\; 11.00 \;\; 11.00 \;\; 11.00] \; in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left\| \begin{array}{l} S_{s_i} \leftarrow \dfrac{t_{w_i}^{\;2}}{6} \\ S_s \end{array} \right.$$

$$S_s^{T} = [242 \;\; 242 \;\; 242 \;\; 242 \;\; 242 \;\; 242 \;\; 242 \;\; 242] \; \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$

Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$

Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r \right) \cdot S_s \right)$

$$M_{cr}^{T} = [10.4 \;\; 10.4 \;\; 10.4 \;\; 10.4 \;\; 10.4 \;\; 10.4 \;\; 10.4 \;\; 10.4] \; \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}} \right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^{T} = [10.38 \;\; 10.17 \;\; 7.34 \;\; 5.12 \;\; 3.43 \;\; 2.20 \;\; 1.34 \;\; 0.76] \; \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 7$ $s_A := 12\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 0.60\ in^2$ $A_{s\_A} = 0.60\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 9.06\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function $\phi M_{n\_A} = 23.28\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{“OK”}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.0055$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.23$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 15\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 1.94\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.31$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 31.45\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 8.62\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_1} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 11.8\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

Reference workbook function

<u>WALL STEM - Base of Wall Location - SEISMIC Check:</u>

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 20.58\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 23.28\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{“OK”}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 11.8\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{“OK”}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 4$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b(B_B)}{s_B}$ $A_{s\_B} = 0.20\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b(B_B)}{2}$ $d_{s\_2} = 9.25\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 8.19\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{“OK”}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \frac{A_{s\_B}}{12 \frac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0018$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.14$

Maximum reinforcing stress due to service load: $f_{s\_2} := \frac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \frac{k_2}{3}\right)}$ $f_{s\_2} = 10\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \frac{d_b(B_B)}{2}$ $d_{c\_2} = 1.75\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \frac{d_{c\_2}}{0.7 \cdot (t_{w_{xb}} - d_{c\_2})}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.27$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 53.27\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}})$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 16.50\ in$

Check reinforcing spacing: $check_{dc}(s_B, s'_{max\_2}) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12 \frac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 9.10\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 12.4\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 4.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 3.25\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 7.34\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\begin{array}{l} \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) \\ + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) \\ + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel \end{array}\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 14.55\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\begin{array}{l} \gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) \\ + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) \\ + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel \end{array}\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 10.69\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 648.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r \right) \cdot S_{c\_heel} \right)$ $M_{cr\_heel} = 27.79\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3) $M_{D\_heel} := min\left(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1} \right)$

$M_{D\_heel} = 19.36\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 5$ $s_C := 12\ in$

$A_{s\_C} := \frac{A_b\left(B_C\right)}{s_C}$ $A_{s\_C} = 0.31\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b\left(B_C\right)}{2}$ $d_{s\_heel} = 15.69\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c \right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 21.57\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel} \right) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0016$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot \left(\rho_h \cdot n_{mod} \right) + \left(\rho_h \cdot n_{mod} \right)^2} - \left(\rho_h \cdot n_{mod} \right)$ $k_h = 0.13$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3} \right) \cdot 1.00\ ft}$ $f_{s\_h} = 27.58\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$$

$d_{c\_h} = 2.31\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.21$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 16.34\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 16.34\ in$

Check reinforcing spacing:

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_heel} = 15.46\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$\phi V_{n\_heel} = 21.10\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 5.74\ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00\ ft \qquad M_{D\_toe\_1} = 5.74\ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00\ ft$$

$$M_{D\_svc\_t} = 2.41\ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79\ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 7.63\ kip\ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 7.00$$

$$s_{toe} := s_A \qquad s_{toe} = 12.00\ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 0.6\ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.56\ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n\left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 38.13\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \dfrac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0034$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot \left(\rho_t \cdot n_{mod}\right) + \left(\rho_t \cdot n_{mod}\right)^2} - \left(\rho_t \cdot n_{mod}\right)$ $k_t = 0.18$

Maximum reinforcing stress due to service load: $f_{s\_t} := \dfrac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 4\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \dfrac{d_b\left(B_{toe}\right)}{2}$ $d_{c\_t} = 3.44\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \dfrac{d_{c\_t}}{0.7 \cdot \left(t_f - d_{c\_t}\right)}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.34$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \dfrac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 141.53\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

Using reference workbook function $check\left(demand, capacity\right)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1.
Using reference book function.

$d_{v\_toe} = 14.12\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$\phi V_{n\_toe} = 19.3\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{“OK”}$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$B_{temp\_stem} := 4$

$s_{temp\_stem} := 18\ in$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}}$$

$A_{s\_temp\_p1} = 0.27\ \frac{in^2}{ft}$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \begin{array}{l} A_{temp} \leftarrow \frac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \\ \text{return } A_{temp} \end{array}$$

$A_{s\_temp\_1} = 0.12\ \frac{in^2}{ft}$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_1} = 18.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 13$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.42\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.83\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \dfrac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.16\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0\ in) \end{cases}$$

$s_{max\_temp\_2} = 12.00\ in$

Check provided temperature reinforcing quantity and spacing:

$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$

$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$

ADDITIONAL DESIGN CHECKS - STEM INTERFACE

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $\qquad A_{cv} = 132.01\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement: $A_{vf\_min} := \dfrac{0.05 \cdot A_{cv}}{f_y} \cdot ksi$ $\qquad A_{vf\_min} = 0.110\ in^2$

$A_{vf} := \left| \dfrac{A_b(B_A) \cdot 12\ in}{s_A} \right|$ $\qquad A_{vf} = 0.60\ in^2$

$check_{dc}(A_{vf\_min}, A_{vf}) = \text{"OK"}$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem:

$P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ 5.7.4.3-5

$V_{ni\_1} = 31.50 \ kip$ $V_{ni\_2} = 105.61 \ kip$

$V_{ni\_3} = 105.61 \ kip$

Controlling nominal concrete shear capacity:

$V_{niMax} :=$ if $min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1}$
‖ $min(V_{ni\_2}, V_{ni\_3})$
else
‖ V_{ni_1}

$V_{niMax} = 31.50 \ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $V_{ri} = 28.35 \ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1 \ ft$
‖ "OK"
else
‖ "NG"

$InterfaceCheck_{stem} =$ "OK"

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{“OK”}$

$Sliding_{check\_str} = \text{“OK”}$

$Bearing_{check\_str} = \text{“OK”}$

$OT_{check\_ser} = \text{“OK”}$

$Check_{Resultant\_svc} = \text{“OK”}$

$Sliding_{check\_ser} = \text{“OK”}$

$Check_{Resultant\_EQ} = \text{“OK”}$

$Sliding_{check\_EQ} = \text{“OK”}$

$Check_{Bearing\_EQ} = \text{“OK”}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{“OK”}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{“OK”}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{“OK”}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{“OK”}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{“OK”}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{“OK”}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{“OK”}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{“OK”}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{“OK”}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{“OK”}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{“OK”}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{“OK”}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{“OK”}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{“OK”}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{“OK”}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{“OK”}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{“OK”}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{“OK”}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{“OK”}$

$InterfaceCheck_{stem} = \text{“OK”}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 8.00\ ft$
Footing width:	$B = 6.25\ ft$
Footing depth:	$t_f = 1.50\ ft$
Wall setback:	$W_t = 2.00\ ft$
Key location:	$L = 0.00\ ft$
Key depth:	$H_k = 0.00\ ft$
Key width:	$W_k = 0.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 7.00$	$s_A = 12.00\ in$	
Main stem reinforcing	$B_B = 4.00$	$s_B = 12.00\ in$	
Heel reinforcing:	$B_C = 5.00$	$s_C = 12.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 18.00\ in$	listed bars provided each face
Temperature reinforcing - footing:	$B_{temp\_ftg} = 4.00$	$N_{temp\_ftg} = 13.00$	total number of bars for footing

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user   Unique modification by the user

Variable (to be input by user)   Internal result (for reference)   Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states: $\phi_{svc} := 1.00$ Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified: $\phi_{EQ} := 1.0$ Section 11.5.8

$\phi_{EQ\_Stab} := 0.9$ Section 11.5.8

$\phi_{EQ\_BRG} := 0.8$ Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

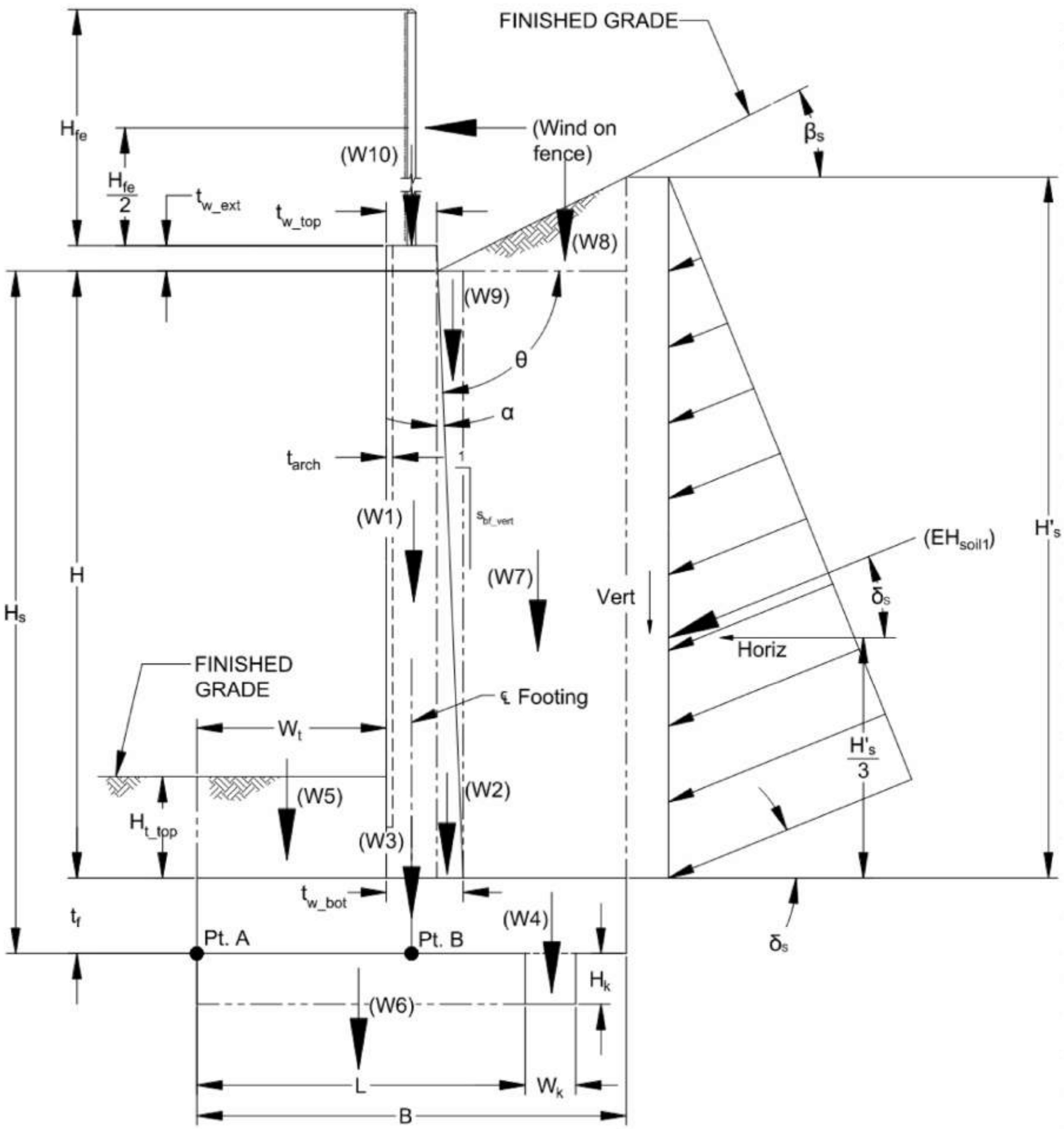


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 10.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 11.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 100000$

Total wall thickness (top): $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \frac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 12.00\ in$

Angle of wall backslope $\alpha := \text{atan}\left(\frac{1}{s_{bf\_vert}}\right)$ $\alpha = 0.00\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 90.00\ deg$

Set back from toe to face of wall: $W_t := 2.00\ ft$

Footing width: $B := 7.50\ ft$

Key width: $W_k := 0.00\ ft$

Key depth: $H_k := 0.00\ ft$

Set back from toe to face of key: $L := \begin{cases} B - H_k - W_k & \text{if } H_k > 0\ in \\ 0\ in & \text{else} \end{cases}$ $L = 0.00\ ft$

Depth of soil over toe: $H_{t\_top} := 2.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \frac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:	$CLR_{stem} := 1.50\ in$	Stem wall clear cover
	$CLR_{side} := 2.00\ in$	side of footing clear cover
	$CLR_{top} := 2.00\ in$	top of footing clear cover
	$CLR_{bot} := 3.00\ in$	bottom of footing clear cover
Specified compressive strength of concrete:	$f'_c := 4.000\ ksi$	
Reinforcement yield strength:	$f_y := 60\ ksi$	
Correction factor for source of aggregate:	$K_1 := 1.0$	Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test
Minimum yield strength of reinforcing bars:	$f_y := 60\ ksi$	Section 5.5.3.2
Reinforcement modulus of elasticity:	$E_s := 29000\ ksi$	Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$$n_{mod} = 6.00$$

Modulus of rupture: $\lambda := 1.0$ — Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil:	$\gamma_s := 0.130\ kcf$	per geotechnical report, Ref. 4
Backfill slope angle:	$\beta_s := 25\ deg$	2H:1V backfill
Effective soil friction angle:	$\phi'_f := 36\ deg$	per geotechnical report, Ref. 4

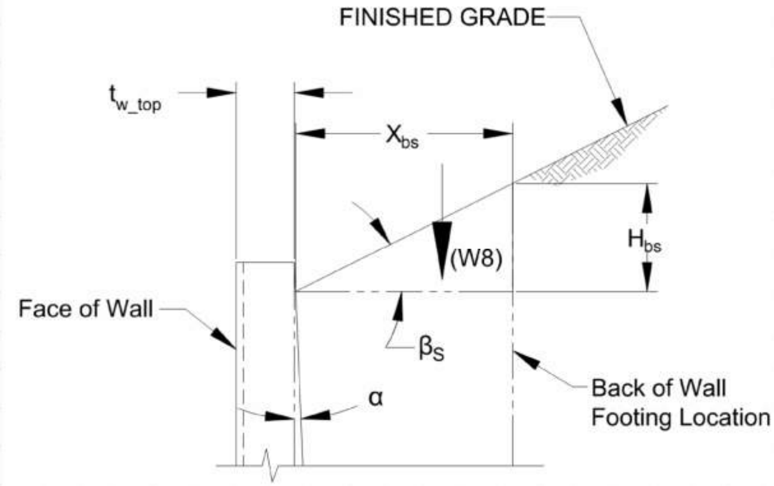


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete):	$\mu_{s\_c} := 0.60$	per geotechnical report, Ref. 4
Coefficient of friction (soil/soil):	$\mu_{s\_s} := \tan(\phi'_f)$	$\mu_{s\_s} = 0.73$
		Section C10.6.3.4
Ultimate soil bearing pressure:	$Q_n := 7.00\ ksf$	
Factored soil bearing pressure	$Q_R := Q_n \cdot \phi_{brg}$	$Q_R = 3.15\ ksf$
Friction angle between fill and wall:	$\delta_s := 22\ deg$	Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.07$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.341$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \dfrac{\left(2.5 \cdot \ln\left(\dfrac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \dfrac{2.56}{10^6} \cdot \left(\dfrac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 42.00\ in$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \dfrac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\dfrac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.009\ \dfrac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 4.50\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 2.10\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 13.60\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot {H'_s}^2$ $R_{EH} = 4.10 \ \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.15 \ \frac{kip}{ft}$

OVERTURNING MOMENTS:

	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Active earth pressure resultant:	$L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 4.53 \ ft$	$M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 18.58 \ \frac{kip \cdot ft}{ft}$
Wind load on fence:	$L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 13.50 \ ft$	$M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 2.01 \ \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components:	Weights:	
Rectangular stem:	$W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$	$W_1 = 1.55 \ \frac{kip}{ft}$
Stem batter:	$W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$	$W_2 = 0.00 \ \frac{kip}{ft}$
Footing:	$W_3 := t_f \cdot B \cdot \gamma_{conc}$	$W_3 = 1.74 \ \frac{kip}{ft}$
Key:	$W_4 := W_k \cdot H_k \cdot \gamma_{conc}$	$W_4 = 0.00 \ \frac{kip}{ft}$
Toe soil:	$W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$	$W_5 = 0.52 \ \frac{kip}{ft}$
Key soil (Sliding resistance only):	$W_6 := L \cdot H_k \cdot \gamma_s$	$W_6 = 0.00 \ \frac{kip}{ft}$
Rectangular backfill:	$W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$	$W_7 = 5.85 \ \frac{kip}{ft}$
Sloped backfill:	$W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$	$W_8 = 0.61 \ \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.00 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)		Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$	$L_1 = 2.5\ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 3.88 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$	$L_2 = 3.5\ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 0.00 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$	$L_3 = 3.75\ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 6.54 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$	$L_4 = 0.00\ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 0.00 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$	$L_5 = 1\ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 0.52 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.		
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$	$L_7 = 5.25\ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 30.71 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$	$L_8 = 6.00\ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 3.68 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $\quad M_9 := W_9 \cdot L_9$

$L_9 = 3.00\ ft$ $\quad M_9 = 0\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $\quad L_{10} = 2.50\ ft$ $\quad M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.22\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 27.85\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_min} = 12.33\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_min} = 61.75\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $\quad e_{A\_str} = 2.75\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $\quad e_{B\_str} = 1.00\ ft$

Check location of resultant:

$Check_{Resultant\_str} :=$ if $\frac{-B}{4} \le e_{B\_str} \le \frac{B}{4}$ then "OK" else "NG"

$Check_{Resultant\_str} = \text{“OK”}$

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $\quad P_{sliding} = 5.85\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\frac{W_{R\_min}}{B-2 \cdot e_{B\_str}}\right)$ $\sigma_v = 2.24\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 5.92\ \frac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \frac{1}{2} \cdot P_p \cdot (H_{t\_top} - 2.00\ ft + t_f + H_k)^2$ $P_{pass} = 0.56\ \frac{kip}{ft}$

The top 2.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric}$ $P_{resist} = 5.92\ \frac{kip}{ft}$

Only friction is considered for sliding resistance.

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces: $W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_max} = 15.96\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_max} = 77.70\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A:

$$e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$$

$e_{A\_BR} = 3.12\ ft$

Distance to resultant from Point B:

$$e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$$

$e_{B\_BR} = 0.63\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1):

$$\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$$

$\sigma_{BR} = 2.55\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$ $Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment:

$$M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$$

$M_{o\_ser} = 17.83\ \frac{kip \cdot ft}{ft}$

Factored resisting forces:

$$W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_ser} = 11.90\ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_ser} = 57.06\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety:

$$OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$$

$OT_{FOS} = 3.2$

Service limit state OT Check:

$$OT_{check\_ser} := \begin{cases} \text{if } OT_{FOS} \ge 1.5 \\ \quad \text{"OK"} \\ \text{else} \\ \quad \text{"NG"} \end{cases}$$

$OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 3.30\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.45\ ft$

Check location of resultant: $Check_{Resultant\_svc} :=$ if $\frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} = \text{"OK"}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 1.80\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 3.84\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 6.59\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 11.90\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 12.46\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 3.24$

Service limit state sliding Check: $Sliding_{check\_ser} :=$ if $Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} = \text{"OK"}$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 3.14 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 7.26\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 51.34 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 13.51 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 70.58 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 1.42\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 2.33\ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \begin{cases} \text{"OK"} & \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \\ \text{"NG"} & \text{else} \end{cases}$$

$$Check_{Resultant\_EQ} = \text{"OK"}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$ $\qquad P_{slidingEQ} = 8.61 \ \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$ $\qquad \sigma_{vEQ} = 4.74 \ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$ $\qquad BRG_{EQ} = 2.85 \ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 8.10 \ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$ $\qquad P_{resist\_EQ} = 8.67 \ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} = \text{"OK"}$

BEARING PRESSURE - SEISMIC:

Factored resisting forces:

$$W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$W_{R\_maxEQ} = 17.13 \ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 86.52 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 2.05 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 1.70 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}} \right) \qquad \sigma_{BR\_EQ} = 4.17 \ ksf$$

Bearing pressure check:

$$Check_{Bearing\_EQ} := \text{if } \sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n \ \text{“OK”} \ \text{else} \ \text{“NG”}$$

$$Check_{Bearing\_EQ} = \text{“OK”}$$

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

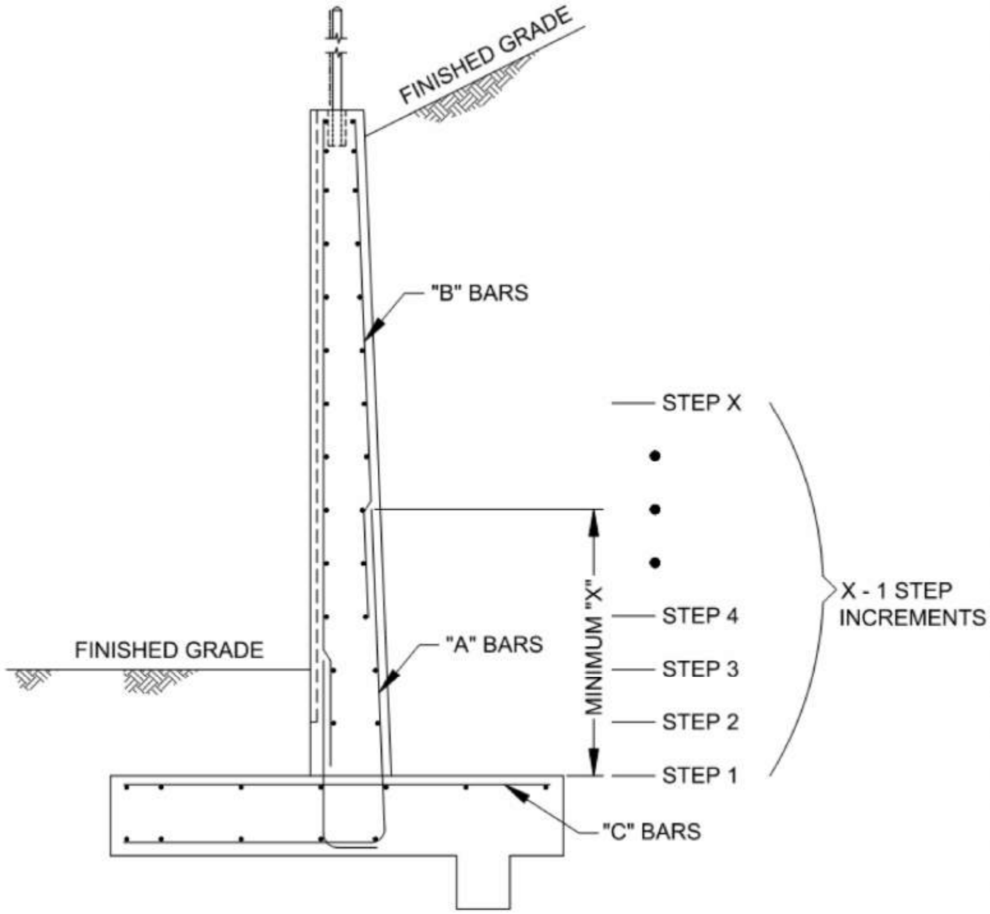


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\quad step = 9.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \;\; \| \; H_{st_i} \leftarrow H - (i) \cdot z \;\; \| \; H_{st}$$

$$H_{st}^{T} = [10.0\ \ 9.0\ \ 8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}{}^{T} = [3.01\ \ 2.53\ \ 2.10\ \ 1.70\ \ 1.35\ \ 1.04\ \ 0.76\ \ 0.53\ \ 0.35\ \ 0.20]\ \frac{kip}{ft}$$

Shear:

Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}{}^{T} = [4.66\ \ 3.95\ \ 3.29\ \ 2.70\ \ 2.17\ \ 1.70\ \ 1.30\ \ 0.95\ \ 0.67\ \ 0.44]\ \frac{kip}{ft}$$

Flexure:

Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}{}^{T} = [19.95\ \ 15.65\ \ 12.03\ \ 9.04\ \ 6.61\ \ 4.68\ \ 3.19\ \ 2.07\ \ 1.27\ \ 0.72]\ \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}{}^{T} = [12.68\ \ 9.87\ \ 7.51\ \ 5.57\ \ 4.01\ \ 2.77\ \ 1.83\ \ 1.14\ \ 0.66\ \ 0.35]\ \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\frac{H}{step+1}\right) \cdot \left(\frac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^{T} = [11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00\ \ 11.00]\ in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left\| \begin{array}{l} S_{s_i} \leftarrow \frac{{t_{w_i}}^2}{6} \\ S_s \end{array} \right.$$

$$S_s^{T} = [242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242\ \ 242]\ \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$ — Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$ — Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^{T} = [10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4\ \ 10.4]\ \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^{T} = [10.38\ \ 10.38\ \ 10.38\ \ 10.38\ \ 8.79\ \ 6.22\ \ 4.24\ \ 2.75\ \ 1.68\ \ 0.95]\ \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 10$ $s_A := 12\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 1.27\ in^2$

$A_{s\_A} = 1.27\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 8.87\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A} = 45.33\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{“OK”}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.0119$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.31$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 15\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 2.14\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.34$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 30.25\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 16.50\ in$

Check reinforcing spacing: $check_{dc}\left(s_A, s'_{max\_1}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12 \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 7.98\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_1} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 10.9\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{“OK”}$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 41.08\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 45.33\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 10.9\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 5$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b\left(B_B\right)}{s_B}$ $A_{s\_B} = 0.31\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b\left(B_B\right)}{2}$ $d_{s\_2} = 9.19\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 12.5\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \dfrac{A_{s\_B}}{12 \dfrac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.0028$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.17$

Maximum reinforcing stress due to service load: $f_{s\_2} := \dfrac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \dfrac{k_2}{3}\right)}$ $f_{s\_2} = 18\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \dfrac{d_b(B_B)}{2}$ $d_{c\_2} = 1.81\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \dfrac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.28$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \dfrac{700 \dfrac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 26.92\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 16.50\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\dfrac{M_n\left(A_{s\_B}, f_y, 12 \dfrac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 8.96\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 12.2\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 4.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 4.5\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 12.12\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 32.92\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 24.27\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 648.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel})$ $M_{cr\_heel} = 27.79\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3) $M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$

$M_{D\_heel} = 27.79\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 7$ $s_C := 12\ in$

$A_{s\_C} := \frac{A_b(B_C)}{s_C}$ $A_{s\_C} = 0.6\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2}$ $d_{s\_heel} = 15.56\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 40.83\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0032$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod})$ $k_h = 0.18$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft}$ $f_{s\_h} = 33.15\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$$

$d_{c\_h} = 2.44\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.22$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 12.38\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 12.38\ in$

Check reinforcing spacing:

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{“OK”}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_heel} = 15.12\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$\phi V_{n\_heel} = 20.64\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{“OK”}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 7.93 \ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00 \ ft \qquad M_{D\_toe\_1} = 7.93 \ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00 \ ft$$

$$M_{D\_svc\_t} = 3.14 \ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79 \ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 10.54 \ kip \ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 10.00$$

$$s_{toe} := s_A \qquad s_{toe} = 12.00 \ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 1.27 \ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.37 \ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n\left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 76.76\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0074$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot \left(\rho_t \cdot n_{mod}\right) + \left(\rho_t \cdot n_{mod}\right)^2} - \left(\rho_t \cdot n_{mod}\right)$ $k_t = 0.26$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 2\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b\left(B_{toe}\right)}{2}$ $d_{c\_t} = 3.64\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot \left(t_f - d_{c\_t}\right)}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.36$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 220.09\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\ \frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$$d_{v\_toe} = 13.43\ in$$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 18.3\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$$B_{temp\_stem} := 4 \qquad s_{temp\_stem} := 18\ in$$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}} \qquad A_{s\_temp\_p1} = 0.27\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \left\| \begin{array}{l} A_{temp} \leftarrow \frac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \right. \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad \left\| A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \right. \\ \text{return } A_{temp} \end{array} \right.$$

$$A_{s\_temp\_1} = 0.12\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_1} = 18.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$$B_{temp\_ftg} := 4 \qquad N_{temp\_ftg} := 16$$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.43\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1} \qquad s_{temp\_ftg} = 11.47\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \dfrac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \dfrac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \dfrac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \dfrac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \dfrac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.16\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_2} = 12.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{“OK”}$$

$$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{“OK”}$$

ADDITIONAL DESIGN CHECKS - STEM INTERFACE

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $\quad A_{cv} = 132.02\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.110\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 1.27\ in^2$$

$$check_{dc}(A_{vf\_min}, A_{vf}) = \text{“OK”}$$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$$ 5.7.4.3-3

$$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$$ 5.7.4.3-4

$$V_{ni\_3} := K_2 \cdot A_{cv}$$ 5.7.4.3-5

$V_{ni\_1} = 55.62\ kip$ $V_{ni\_2} = 105.61\ kip$

$V_{ni\_3} = 105.61\ kip$

Controlling nominal concrete shear capacity:

$$V_{niMax} := \text{if } min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1}$$
$$\quad \| min(V_{ni\_2}, V_{ni\_3})$$
$$\text{else}$$
$$\quad \| V_{ni\_1}$$

$V_{niMax} = 55.62\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $V_{ri} = 50.06\ kip$

$$InterfaceCheck_{stem} := \text{if } V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft$$
$$\quad \| \text{“OK”}$$
$$\text{else}$$
$$\quad \| \text{“NG”}$$

$InterfaceCheck_{stem} = \text{“OK”}$

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{“OK”}$

$Sliding_{check\_str} = \text{“OK”}$

$Bearing_{check\_str} = \text{“OK”}$

$OT_{check\_ser} = \text{“OK”}$

$Check_{Resultant\_svc} = \text{“OK”}$

$Sliding_{check\_ser} = \text{“OK”}$

$Check_{Resultant\_EQ} = \text{“OK”}$

$Sliding_{check\_EQ} = \text{“OK”}$

$Check_{Bearing\_EQ} = \text{“OK”}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{“OK”}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{“OK”}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{“OK”}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{“OK”}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{“OK”}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{“OK”}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{“OK”}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{“OK”}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{“OK”}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{“OK”}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{“OK”}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{“OK”}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{“OK”}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{“OK”}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{“OK”}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{“OK”}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{“OK”}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{“OK”}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{“OK”}$

$InterfaceCheck_{stem} = \text{“OK”}$

SUMMARY OF WALL GEOMETRY

Design height:	$H = 10.00\ ft$
Footing width:	$B = 7.50\ ft$
Footing depth:	$t_f = 1.50\ ft$
Wall setback:	$W_t = 2.00\ ft$
Key location:	$L = 0.00\ ft$
Key depth:	$H_k = 0.00\ ft$
Key width:	$W_k = 0.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A = 10.00$	$s_A = 12.00\ in$	
Main stem reinforcing	$B_B = 5.00$	$s_B = 12.00\ in$	
Heel reinforcing:	$B_C = 7.00$	$s_C = 12.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X = 4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem} = 4.00$	$s_{temp\_stem} = 18.00\ in$	listed bars provided each face
Temperature reinforcing - footing:	$B_{temp\_ftg} = 4.00$	$N_{temp\_ftg} = 16.00$	total number of bars for footing

END OF WORKBOOK

CAST-IN-PLACE CONCRETE GRAVITY RETAINING WALL DESIGN

Legend

Commentary / instructions to the user | Unique modification by the user

Variable (to be input by user) | Internal result (for reference) | Final result of interest

References

This MathCAD file aides in the design of cast-in-place (CIP) concrete cantilever retaining walls. The workbook assumes there is no hydrostatic pressure behind the retaining wall and that adequate drainage behind the wall is provided. The design equations utilized assume bearing on soil as opposed to rock. This workbook does not check global slope stability. Active earth pressure is assumed, granular fill, non-rigid wall Coulomb theory. Not for broken back-slopes.

1. AASHTO LRFD Bridge Specifications, 9th Edition
2. WSDOT Bridge Design Manual (BDM), July 2019
3. WSDOT Geotechnical Design Manual (GDM), July 2019
4. PBS Geotechnical Engineering Report, Brezee Creek Culvert Replacement, Sept. 3, 2020

All section, table, equation and figure references are to reference 1 unless otherwise noted.

MathCAD external reference files use:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Resistance Factors

STRENGTH LIMIT STATE:

Bearing Resistance:	$\phi_{brg} := 0.45$	Ref. 4, Sect. 3.3.2.3
Sliding:	$\phi_{sliding} := 1.0$	Table 11.5.7-1
Passive Earth Pressure (component of sliding resistance):	$\phi_{pass} := 0.50$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, cast-in-place concrete on sand:	$\phi_{T\_s\_c} := 0.80$	Table 10.5.5.2.2-1
Sliding resistance factor for shallow foundations, soil-on-soil:	$\phi_{T\_s\_s} := 0.90$	Table 10.5.5.2.2-1

SERVICE LIMIT STATE:

Resistance factor for all service limit states:	$\phi_{svc} := 1.00$	Section 11.5.7

EXTREME LIMIT STATE:

Extreme Event Limit State - unless otherwise specified:	$\phi_{EQ} := 1.0$	Section 11.5.8
	$\phi_{EQ\_Stab} := 0.9$	Section 11.5.8
	$\phi_{EQ\_BRG} := 0.8$	Section 11.5.8

Load Combinations and Load Factors

Only Strength I, Service I and Extreme Event I load combinations will be evaluated. Wind on structure (WS) from the Strength III load combination will be conservatively added to the Strength I load combination for wind acting on fence extensions at top of the retaining wall.

Per Table 3.4.1.1:

Dead Load of Components and Attachments, DC	$\gamma_{pDCmin} := 0.90$	STR I and III
	$\gamma_{pDCmax} := 1.25$	STR I and III
	$\gamma_{DCsvc} := 1.00$	Service
Horizontal Earth Pressure - Active, EH	$\gamma_{pEHmin} := 0.90$	STR I and III
	$\gamma_{pEHmax} := 1.50$	STR I and III
	$\gamma_{EHsvc} := 1.00$	Service
Vertical Earth Pressure - Retaining Wall and Abutments, EV	$\gamma_{pEVmin} := 1.00$	STR I and III
	$\gamma_{pEVmax} := 1.35$	STR I and III
	$\gamma_{EVsvc} := 1.00$	Service
Wind on Structure, WS	$\gamma_{WSstr3} := 1.00$	STR III
	$\gamma_{WSsvc1} := 0.30$	Service
Earthquake earth pressure Loading, EQ	$\gamma_{EQ} := 1.00$	Extreme Event I

CIP Wall Dimensions, Materials & Soil Properties

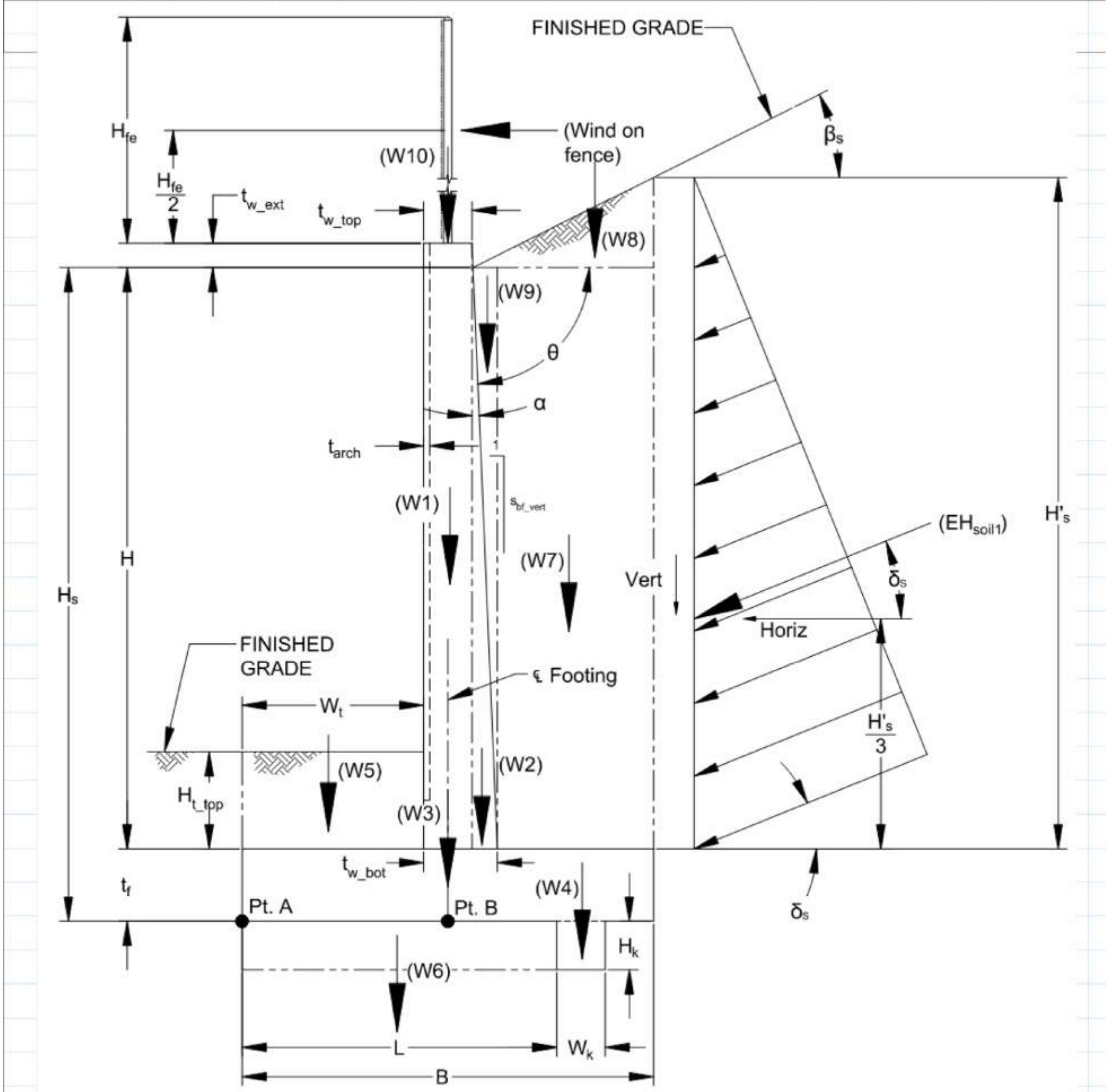


Figure 1 - Wall Loading and Variables

Wall Dimensions:

Wall base height: $H := 12.00\ ft$

Footing thickness: $t_f := 1.50\ ft$

Height of soil at back of stem: $H_s := H + t_f$ $\quad H_s = 13.50\ ft$

Wall back face slope (1:vertical): $s_{bf\_vert} := 100000$

Total wall thickness (top): $t_{w\_top} := 12.00\ in$

Top of wall extension: $t_{w\_ext} := 6.00\ in$

Architectural facing thickness (non-structural): $t_{arch} := 1.00\ in$

Total wall thickness (bottom): $t_{w\_bot} := t_{w\_top} + \frac{H + t_{w\_ext}}{s_{bf\_vert}}$ $t_{w\_bot} = 12.00\ in$

Angle of wall backslope $\alpha := \operatorname{atan}\left(\frac{1}{s_{bf\_vert}}\right)$ $\alpha = 0.00\ deg$

Angle of back face of wall to Horizontal: $\theta := 90\ deg - \alpha$ $\theta = 90.00\ deg$

Set back from toe to face of wall: $W_t := 2.00\ ft$

Footing width: $B := 9.25\ ft$

Key width: $W_k := 0.00\ ft$

Key depth: $H_k := 0.00\ ft$

Set back from toe to face of key: $L := \begin{cases} B - H_k - W_k & \text{if } H_k > 0\ in \\ 0\ in & \text{else} \end{cases}$ $L = 0.00\ ft$

Depth of soil over toe: $H_{t\_top} := 2.00\ ft$

Wall Material Properties:

Unit weight of normal weight concrete: $\gamma_{conc} := 0.155\ \frac{kip}{ft^3}$ WSDOT BDM Table 3.8-1

Reinforcing clear distance, Table 5.10.1-1:

$CLR_{stem} := 1.50\ in$ Stem wall clear cover

$CLR_{side} := 2.00\ in$ side of footing clear cover

$CLR_{top} := 2.00\ in$ top of footing clear cover

$CLR_{bot} := 3.00\ in$ bottom of footing clear cover

Specified compressive strength of concrete: $f'_c := 4.000\ ksi$

Reinforcement yield strength: $f_y := 60\ ksi$

Correction factor for source of aggregate: $K_1 := 1.0$ Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test

Minimum yield strength of reinforcing bars: $f_y := 60\ ksi$ Section 5.5.3.2

Reinforcement modulus of elasticity: $E_s := 29000\ ksi$ Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity:

$$E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi \qquad E_c = 4555\ ksi$$

Equation 5.4.2.4-1

Modular ratios:

$$n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$$

Section 5.6.1

$$n_{mod} = 6.00$$

Modulus of rupture: $\lambda := 1.0$ Section 5.4.2.8 for normal weight concrete

$$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi \qquad f_r = 0.48\ ksi$$

Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Soil Properties:

Unit weight of soil: $\gamma_s := 0.130\ kcf$ per geotechnical report, Ref. 4

Backfill slope angle: $\beta_s := 25\ deg$ 2H:1V backfill

Effective soil friction angle: $\phi'_f := 36\ deg$ per geotechnical report, Ref. 4

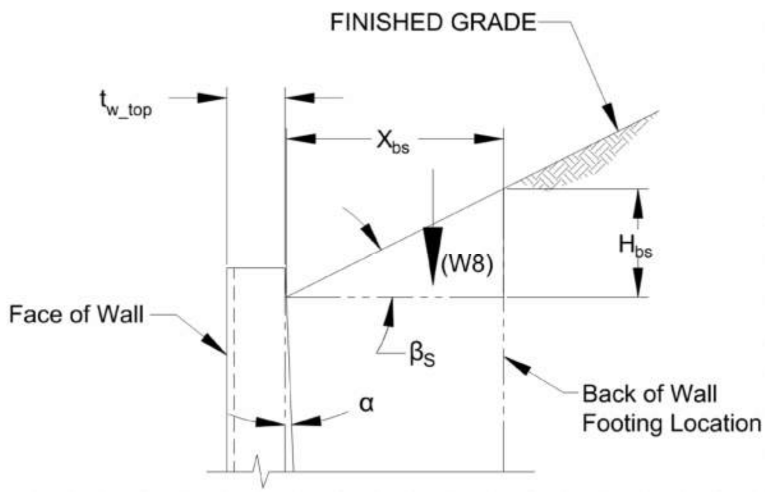


Figure 2 - Sloped Backfill

Coefficient of friction (soil/concrete):	$\mu_{s\_c} := 0.60$	per geotechnical report, Ref. 4
Coefficient of friction (soil/soil):	$\mu_{s\_s} := \tan(\phi'_f)$	$\mu_{s\_s} = 0.73$
		Section C10.6.3.4
Ultimate soil bearing pressure:	$Q_n := 8.00\ ksf$	
Factored soil bearing pressure	$Q_R := Q_n \cdot \phi_{brg}$	$Q_R = 3.6\ ksf$
Friction angle between fill and wall:	$\delta_s := 22\ deg$	Table 3.11.5.3-1

Formed Concrete against Clean gravel, gravel-sand mixture, well graded rock fill with spalls.

Active pressure coefficient (Coulomb Theory):

$$\Gamma_a := \left(1 + \sqrt{\frac{\sin(\phi'_f + \delta_s) \cdot \sin(\phi'_f - \beta_s)}{\sin(\theta - \delta_s) \cdot \sin(\theta + \beta_s)}}\right)^2$$

$\Gamma_a = 2.07$

$$k_{af} := \frac{\sin(\theta + \phi'_f)^2}{\Gamma_a \cdot \left(\sin(\theta)^2 \cdot \sin(\theta - \delta_s)\right)}$$

$k_{af} = 0.341$

Passive pressure: $P_p := \frac{500\ psf}{1\ ft}$ per geotechnical report, Ref. 4

Additional Loads

Design 3-second gust wind speed:	$V := 110\ mph$	Figure 3.8.1.1.2-1
Structure height used in determining the pressure coefficient:	$Z := 33.0$ [feet]	Section 3.8.1.2
Pressure exposure and elevation coefficient:	$K_z := \dfrac{\left(2.5 \cdot \ln\left(\dfrac{Z}{0.0984}\right) + 7.35\right)^2}{478.4}$	Equation 3.8.1.2.1-3, assumes exposure category C $K_z = 1.00$
Gust effect factor:	$G_z := 1.00$	Table 3.8.1.2.1-1
Drag coefficient:	$C_D := 1.2$	Table 3.8.1.2.1-2, for sound barriers
Design wing pressure:	$P_Z := \dfrac{2.56}{10^6} \cdot \left(\dfrac{V}{mph}\right)^2 \cdot K_z \cdot G_z \cdot C_D \cdot ksf$	Equation 3.8.1.2.1-1 $P_Z = 0.037\ ksf$
Height of fence/railing above top of wall:	$H_{fe} := 42.00\ in$	
Weight of 8ft height chain link fence:	$P_{8ft} := 0.020\ \dfrac{kip}{ft}$	TXDOT Standard Drawing CLF-RO -- 8ft Chain Link Fence
Vertical load for actual fence height:	$P_{fe} := \left(\dfrac{P_{8ft}}{8\ ft}\right) \cdot H_{fe}$	$P_{fe} = 0.009\ \dfrac{kip}{ft}$

Stability - Overturning, Bearing Pressure & Sliding

Sloped backfill width over the heel (see figure 2):	$X_{bs} := B - W_t - t_{w\_top}$	$X_{bs} = 6.25\ ft$
Additional height of soil due to sloped backfill (see figure 2)	$H_{bs} := \tan(\beta_s) \cdot X_{bs}$	$H_{bs} = 2.91\ ft$
Design height of soil at back of footing:	$H'_s := H_s + H_{bs}$	$H'_s = 16.41\ ft$

HORIZONTAL FORCE RESULTANTS:

Active earth pressure resultant: (applied at 1/3 H'_s) $R_{EH} := \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot H'^2_s$ $R_{EH} = 5.97 \frac{kip}{ft}$

Wind load on fence: (applied at fence mid height) $R_{WS} := P_Z \cdot (H_{fe} + t_{w\_ext})$ $R_{WS} = 0.15 \frac{kip}{ft}$

OVERTURNING MOMENTS:

Moment Arm: (about point A in Fig.1) | Overturning Moment:

Active earth pressure resultant: $L_{EH} := \frac{H'_s}{3}$ $L_{EH} = 5.47\ ft$ $M_{EH} := R_{EH} \cdot L_{EH}$ $M_{EH} = 32.67 \frac{kip \cdot ft}{ft}$

Wind load on fence: $L_{WS} := H_s + \frac{H_{fe} + t_{w\_ext}}{2}$ $L_{WS} = 15.50\ ft$ $M_{WS} := R_{WS} \cdot L_{WS}$ $M_{WS} = 2.31 \frac{kip \cdot ft}{ft}$

RESISTING FORCES:

Components: | Weights:

Rectangular stem: $W_1 := t_{w\_top} \cdot H \cdot \gamma_{conc}$ $W_1 = 1.86 \frac{kip}{ft}$

Stem batter: $W_2 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_{conc}$ $W_2 = 0.00 \frac{kip}{ft}$

Footing: $W_3 := t_f \cdot B \cdot \gamma_{conc}$ $W_3 = 2.15 \frac{kip}{ft}$

Key: $W_4 := W_k \cdot H_k \cdot \gamma_{conc}$ $W_4 = 0.00 \frac{kip}{ft}$

Toe soil: $W_5 := W_t \cdot H_{t\_top} \cdot \gamma_s$ $W_5 = 0.52 \frac{kip}{ft}$

Key soil (Sliding resistance only): $W_6 := L \cdot H_k \cdot \gamma_s$ $W_6 = 0.00 \frac{kip}{ft}$

Rectangular backfill: $W_7 := (B - W_t - t_{w\_bot}) \cdot H \cdot \gamma_s$ $W_7 = 9.75 \frac{kip}{ft}$

Sloped backfill: $W_8 := \frac{1}{2} \cdot X_{bs} \cdot H_{bs} \cdot \gamma_s$ $W_8 = 1.18 \frac{kip}{ft}$

Batter backfill: $W_9 := \frac{1}{2} \cdot (t_{w\_bot} - t_{w\_top}) \cdot H \cdot \gamma_s$ $W_9 = 0.00 \frac{kip}{ft}$

Fence & wall extension: $W_{10} := (P_{fe} + t_{w\_ext} \cdot t_{w\_top} \cdot \gamma_{conc})$ $W_{10} = 0.09 \frac{kip}{ft}$

RESISTING MOMENTS:

Components:	Moment Arm: (about point A in Fig.1)	Overturning Moment:
Rectangular stem:	$L_1 := W_t + \frac{1}{2} \cdot t_{w\_top}$ $L_1 = 2.5\ ft$	$M_1 := W_1 \cdot L_1$ $M_1 = 4.65 \frac{kip \cdot ft}{ft}$
Stem batter:	$L_2 := L_1 + t_{w\_top} + \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $L_2 = 3.5\ ft$	$M_2 := W_2 \cdot L_2$ $M_2 = 0.00 \frac{kip \cdot ft}{ft}$
Footing:	$L_3 := \frac{1}{2} \cdot B$ $L_3 = 4.63\ ft$	$M_3 := W_3 \cdot L_3$ $M_3 = 9.95 \frac{kip \cdot ft}{ft}$
Key:	$L_4 := L + \frac{1}{2} \cdot W_k$ $L_4 = 0.00\ ft$	$M_4 := W_4 \cdot L_4$ $M_4 = 0.00 \frac{kip \cdot ft}{ft}$
Toe soil:	$L_5 := \frac{1}{2} \cdot W_t$ $L_5 = 1\ ft$	$M_5 := W_5 \cdot L_5$ $M_5 = 0.52 \frac{kip \cdot ft}{ft}$
Key soil (Sliding resistance only):	Neglected for resisting moment calculations.	
Rectangular backfill:	$L_7 := B - \frac{1}{2} \cdot (B - W_t - t_{w\_bot})$ $L_7 = 6.13\ ft$	$M_7 := W_7 \cdot L_7$ $M_7 = 59.72 \frac{kip \cdot ft}{ft}$
Sloped backfill:	$L_8 := B - \frac{1}{3} \cdot X_{bs}$ $L_8 = 7.17\ ft$	$M_8 := W_8 \cdot L_8$ $M_8 = 8.49 \frac{kip \cdot ft}{ft}$

Batter backfill: $L_9 := W_t + t_{w\_bot} - \frac{1}{3} \cdot (t_{w\_bot} - t_{w\_top})$ $M_9 := W_9 \cdot L_9$

$L_9 = 3.00\ ft$ $M_9 = 0\ \frac{kip \cdot ft}{ft}$

Fence & wall extension: $L_{10} := L_1$ $L_{10} = 2.50\ ft$ $M_{10} := W_{10} \cdot L_{10}$

$M_{10} = 0.22\ \frac{kip \cdot ft}{ft}$

ECCENTRICITY AND SLIDING - STRENGTH:

Factored overturning moment: $M_o := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot M_{WS}$

$M_o = 47.75\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_min} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_min} = 18.50\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_min} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_min} = 113.09\ \frac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_str} := \frac{(M_{R\_min} - M_o)}{W_{R\_min}}$ $e_{A\_str} = 3.53\ ft$

Distance to resultant from Point B: $e_{B\_str} := \frac{B}{2} - e_{A\_str}$ $e_{B\_str} = 1.09\ ft$

Check location of resultant:

$Check_{Resultant\_str} :=$ if $\frac{-B}{4} \le e_{B\_str} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_str} =$ "OK"

Factored sliding forces: $P_{sliding} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSstr3} \cdot R_{WS}$ $P_{sliding} = 8.45\ \frac{kip}{ft}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_v := \left(\dfrac{W_{R\_min}}{B - 2 \cdot e_{B\_str}}\right)$ $\sigma_v = 2.62\ ksf$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s).

$$P_{Fric} := \begin{cases} \text{if } L > (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (B - 2\ e_{B\_str}) \wedge H_k > 0\ ft \\ \quad \phi_{T\_s\_s} \cdot \mu_{s\_s} \cdot (\sigma_v \cdot (B - 2 \cdot e_{B\_str}) + \gamma_{pEVmin} \cdot W_6) + \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str} - L) \\ \text{else} \\ \quad \phi_{T\_s\_c} \cdot \mu_{s\_c} \cdot \sigma_v \cdot (B - 2 \cdot e_{B\_str}) \end{cases}$$

$P_{Fric} = 8.88\ \dfrac{kip}{ft}$

Sliding resistance - passive pressure: $P_{pass} := \dfrac{1}{2} \cdot P_p \cdot (H_{t\_top} - 2.00\ ft + t_f + H_k)^2$ $P_{pass} = 0.56\ \dfrac{kip}{ft}$

The top 2.00 ft of soil over the toe is ignored for the passive pressure resistance calculations.

Total sliding resistance: $P_{resist} := \phi_{sliding} \cdot P_{Fric}$ $P_{resist} = 8.88\ \dfrac{kip}{ft}$

Only friction is considered for sliding resistance.

Compare sliding demand vs. calculated capacity: $Sliding_{check\_str} := check_{dc}(P_{sliding}, P_{resist})$

$Sliding_{check\_str} = \text{"OK"}$

BEARING PRESSURE CHECK - STRENGTH:

Factored resisting forces:

$$W_{R\_max} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s)$$

$W_{R\_max} = 23.94\ \dfrac{kip}{ft}$

Factored resisting moment:

$$M_{R\_max} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$$

$M_{R\_max} = 142.33\ \dfrac{kip \cdot ft}{ft}$

Distance to resultant from Point A: $e_{A\_BR} := \frac{(M_{R\_max} - M_o)}{W_{R\_max}}$ $e_{A\_BR} = 3.95\ ft$

Distance to resultant from Point B: $e_{B\_BR} := \frac{B}{2} - e_{A\_BR}$ $e_{B\_BR} = 0.67\ ft$

Maximum bearing pressure (uniform bearing pressure - AASHTO Fig. 11.6.3.2-1): $\sigma_{BR} := \frac{W_{R\_max}}{B - 2 \cdot e_{B\_BR}}$ $\sigma_{BR} = 3.03\ ksf$

Equation 11.6.3.2-1

Bearing Check: $Bearing_{check\_str} := check_{dc}(\sigma_{BR}, Q_R)$ $Bearing_{check\_str} = \text{"OK"}$

Service Limit States:

Service Limit States will be checked per WSDOT BDM 8.1.3.B for overturning, sliding and eccentricity.

Factored overturning moment: $M_{o\_ser} := \gamma_{EHsvc} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot M_{WS}$

$M_{o\_ser} = 30.99\ \frac{kip \cdot ft}{ft}$

Factored resisting forces: $W_{R\_ser} := \gamma_{DCsvc} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{EVsvc} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin(\delta_s)$

$W_{R\_ser} = 17.79\ \frac{kip}{ft}$

Factored resisting moment: $M_{R\_ser} := \gamma_{DCsvc} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{EVsvc} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{EHsvc} \cdot R_{EH} \cdot B \cdot \sin(\delta_s)$

$M_{R\_ser} = 104.23\ \frac{kip \cdot ft}{ft}$

Overturning Factor of safety: $OT_{FOS} := \frac{M_{R\_ser}}{M_{o\_ser}}$ $OT_{FOS} = 3.36$

Service limit state OT Check: $OT_{check\_ser} :=$ if $OT_{FOS} \geq 1.5$ then "OK" else "NG"

$OT_{check\_ser} = \text{"OK"}$

Distance to resultant from Pont A: $e_{A\_svc} := \frac{(M_{R\_ser} - M_{o\_ser})}{W_{R\_ser}}$ $e_{A\_svc} = 4.12\ ft$

Distance to resultant from Point B: $e_{B\_svc} := \frac{B}{2} - e_{A\_svc}$ $e_{B\_svc} = 0.51\ ft$

Check location of resultant: $Check_{Resultant\_svc} :=$ if $\frac{-B}{4} \le e_{B\_svc} \le \frac{B}{4}$ "OK" else "NG"

$Check_{Resultant\_svc} = \text{"OK"}$

Vertical stress (per foot of wall such that units are kip/ft^2): $\sigma_{v\_svc} := \left(\frac{W_{R\_ser}}{B - 2 \cdot e_{B\_svc}}\right)$ $\sigma_{v\_svc} = 2.16\ ksf$

Factored sliding force: $P_{sliding\_svc} := \gamma_{EHsvc} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{WSsvc1} \cdot R_{WS}$

$P_{sliding\_svc} = 5.58\ \frac{kip}{ft}$

Bearing width for service calculation: $BRG_{svc} := B - 2 \cdot e_{B\_svc}$ $BRG_{svc} = 8.23\ ft$

Sliding resistance -friction: $P_{Fric\_svc} := \sigma_{v\_svc} \cdot BRG_{svc}$ $P_{Fric\_svc} = 17.79\ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_svc} := \phi_{svc} \cdot (P_{Fric\_svc} + P_{pass})$ $P_{resist\_svc} = 18.35\ \frac{kip}{ft}$

Sliding factor of safety: $Sliding_{FoS} := \frac{P_{resist\_svc}}{P_{sliding\_svc}}$ $Sliding_{FoS} = 3.29$

Service limit state sliding Check: $Sliding_{check\_ser} :=$ if $Sliding_{FoS} > 1.2$ "OK" else "NG"

$Sliding_{check\_ser} = \text{"OK"}$

Eccentricity and Sliding - Seismic

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := 4.77 \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 8.95\ ft$

See separate calculation workbook for determination of Mononabe-Okabe force and lever arm per Appendix A11. The orientation of ΔE_{ae} us the same as that of the active static earth resultant.

Factored overturning moment:

$$M_{oEQ} := \gamma_{pEHmax} \cdot M_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot (z_{\Delta Eae} + t_f) \cdot \cos(\delta_s)$$

$$M_{oEQ} = 91.66 \frac{kip \cdot ft}{ft}$$

Factored resisting forces:

$$W_{R\_minEQ} := \gamma_{pDCmin} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmin} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$$

$$W_{R\_minEQ} = 20.28 \frac{kip}{ft}$$

Factored resisting moment:

$$M_{R\_minEQ} := \gamma_{pDCmin} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmin} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_minEQ} = 129.62 \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_EQ} := \frac{(M_{R\_minEQ} - M_{oEQ})}{W_{R\_minEQ}} \qquad e_{A\_EQ} = 1.87\ ft$$

Distance to resultant from Point B:

$$e_{B\_EQ} := \frac{B}{2} - e_{A\_EQ} \qquad e_{B\_EQ} = 2.75\ ft$$

Check location of resultant:

$$Check_{Resultant\_EQ} := \text{if } \frac{-B}{3} \le e_{B\_EQ} \le \frac{B}{3} \;\; \text{“OK”} \;\; \text{else} \;\; \text{“NG”}$$

$$Check_{Resultant\_EQ} = \text{“OK”}$$

Factored sliding forces: $P_{slidingEQ} := \gamma_{pEHmax} \cdot R_{EH} \cdot \cos(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \cos(\delta_s)$

$P_{slidingEQ} = 12.73 \ \frac{kip}{ft}$

Vertical stress: $\sigma_{vEQ} := \left(\frac{W_{R\_minEQ}}{B - 2 \cdot e_{B\_EQ}}\right)$

$\sigma_{vEQ} = 5.42 \ ksf$

Bearing Width for seismic calculation: $BRG_{EQ} := B - 2 \cdot e_{B\_EQ}$

$BRG_{EQ} = 3.74 \ ft$

Sliding resistance - friction: Resistance is apportioned based upon uniform bearing pressure applied to discrete contact surface(s)

$$P_{Fric\_EQ} := \begin{cases} \text{if } L > (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_{vEQ} \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) \\ \text{also if } L < (BRG_{EQ}) \wedge H_k > 0 \ ft \\ \quad \mu_{s\_s} \cdot (\sigma_v \cdot (BRG_{EQ}) + \gamma_{pEVmin} \cdot W_6) + \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ} - L) \\ \text{else} \\ \quad \mu_{s\_c} \cdot \sigma_{vEQ} \cdot (BRG_{EQ}) \end{cases}$$

$P_{Fric\_EQ} = 12.17 \ \frac{kip}{ft}$

Total sliding resistance: $P_{resist\_EQ} := \phi_{EQ} \cdot (P_{Fric\_EQ} + P_{pass})$

$P_{resist\_EQ} = 12.73 \ \frac{kip}{ft}$

Compare sliding demand vs. calculated capacity: $Sliding_{check\_EQ} := check_{dc}(P_{slidingEQ}, P_{resist\_EQ})$

$Sliding_{check\_EQ} = \text{“OK”}$

BEARING PRESSURE - SEISMIC:

Factored resisting forces: $W_{R\_maxEQ} := \gamma_{pDCmax} \cdot (W_1 + W_2 + W_3 + W_4 + W_{10}) + \gamma_{pEVmax} \cdot (W_5 + W_7 + W_8 + W_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot \sin(\delta_s)$

$W_{R\_maxEQ} = 25.73 \ \frac{kip}{ft}$

Factored resisting moment:

$$M_{R\_maxEQ} := \gamma_{pDCmax} \cdot (M_1 + M_2 + M_3 + M_4 + M_{10}) + \gamma_{pEVmax} \cdot (M_5 + M_7 + M_8 + M_9) + \gamma_{pEHmax} \cdot R_{EH} \cdot B \cdot \sin(\delta_s) + \gamma_{EQ} \cdot \Delta E_{ae} \cdot B \cdot \sin(\delta_s)$$

$$M_{R\_maxEQ} = 158.86 \ \frac{kip \cdot ft}{ft}$$

Distance to resultant from Point A:

$$e_{A\_BR\_EQ} := \frac{(M_{R\_maxEQ} - M_{oEQ})}{W_{R\_maxEQ}} \qquad e_{A\_BR\_EQ} = 2.61 \ ft$$

Distance to resultant from Point B:

$$e_{B\_BR\_EQ} := \frac{B}{2} - e_{A\_BR\_EQ} \qquad e_{B\_BR\_EQ} = 2.01 \ ft$$

Maximum bearing pressure (uniform bearing pressure - Reference 1, Figure 11.6.3.2-1):

$$\sigma_{BR\_EQ} := \left(\frac{W_{R\_maxEQ}}{B - 2 \cdot e_{B\_BR\_EQ}}\right) \qquad \sigma_{BR\_EQ} = 4.92 \ ksf$$

Bearing pressure check:

$$Check_{Bearing\_EQ} := \text{if } \sigma_{BR\_EQ} \le \phi_{EQ} \cdot Q_n \ \| \ \text{"OK"} \ \text{else} \ \| \ \text{"NG"}$$

$$Check_{Bearing\_EQ} = \text{"OK"}$$

MAIN REINFORCING DESIGN - STEM, TOE, HEEL

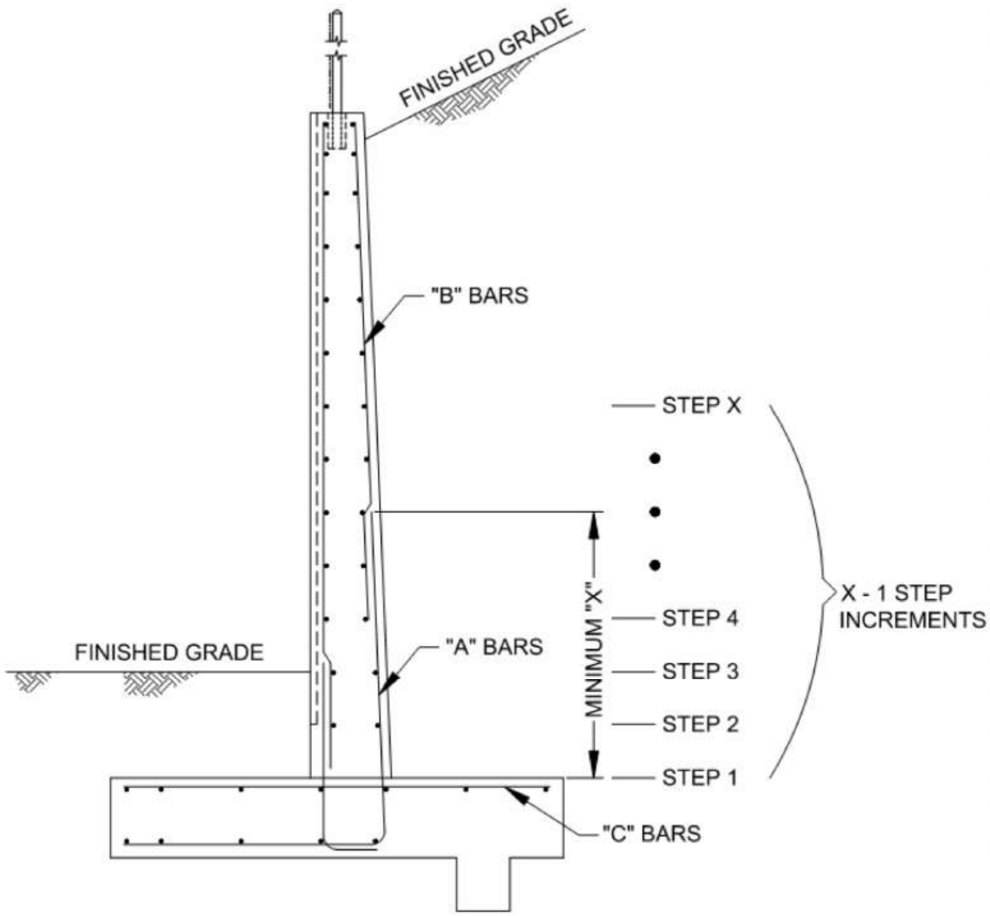


FIGURE 3 - Main Wall Reinforcing Sketch

Stem design height increment: $z := 1.00\ ft$ — user selected variable to determine the increment size which leads to the total number of moment and reinforcing outputs for the stem

Number of increments for matrix: $step := \text{round}\left(\frac{H}{z}\right) - 1$ $\quad step = 11.00$

Heights along stem wall (first entry in each matrix is located at the base of the wall)

$$H_{st} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} H_{st_i} \leftarrow H - (i) \cdot z \\ H_{st} \end{array} \right.$$

$$H_{st}^{T} = [12.0\ \ 11.0\ \ 10.0\ \ 9.0\ \ 8.0\ \ 7.0\ \ 6.0\ \ 5.0\ \ 4.0\ \ 3.0\ \ 2.0\ \ 1.0]\ ft$$

Horizontal earth pressure resultant:

$$R_{EH\_s} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} R_{EH\_s_i} \leftarrow \frac{1}{2} \cdot \gamma_s \cdot k_{af} \cdot \left(H_{st_i} + H_{bs}\right)^2 \cdot \cos\left(\delta_s\right) \\ R_{EH\_s} \end{array} \right.$$

$$R_{EH\_s}^{\mathrm{T}} = [4.57 \;\; 3.98 \;\; 3.43 \;\; 2.92 \;\; 2.45 \;\; 2.02 \;\; 1.63 \;\; 1.29 \;\; 0.98 \;\; 0.72 \;\; 0.50 \;\; 0.31] \; \frac{kip}{ft}$$

Shear:
Factored shear - Strength I:

$$V_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} V_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} + \gamma_{WSstr3} \cdot R_{WS} \\ V_{str} \end{array} \right.$$

$$V_{str}^{\mathrm{T}} = [7.01 \;\; 6.12 \;\; 5.29 \;\; 4.52 \;\; 3.82 \;\; 3.18 \;\; 2.60 \;\; 2.08 \;\; 1.62 \;\; 1.23 \;\; 0.89 \;\; 0.62] \; \frac{kip}{ft}$$

Flexure:
Factored bending moment - Strength I:

$$M_{str} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{str_i} \leftarrow \gamma_{pEHmax} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSstr3} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + \left(h - H_{bs}\right)\right) \\ M_{str} \end{array} \right.$$

$$M_{str}^{\mathrm{T}} = [36.14 \;\; 29.58 \;\; 23.88 \;\; 18.98 \;\; 14.81 \;\; 11.32 \;\; 8.43 \;\; 6.10 \;\; 4.25 \;\; 2.83 \;\; 1.78 \;\; 1.03] \; \frac{kip \cdot ft}{ft}$$

Factored bending moment - Service:

$$M_{svc} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} h \leftarrow H_{st_i} + H_{bs} \\ M_{svc_i} \leftarrow \gamma_{EHsvc} \cdot R_{EH\_s_i} \cdot \frac{h}{3} + \gamma_{WSsvc1} \cdot R_{WS} \cdot \left(\frac{H_{fe}}{2} + t_{w\_ext} + \left(h - H_{bs}\right)\right) \\ M_{svc} \end{array} \right.$$

$$M_{svc}^{\mathrm{T}} = [23.36 \;\; 19.05 \;\; 15.30 \;\; 12.09 \;\; 9.36 \;\; 7.09 \;\; 5.22 \;\; 3.72 \;\; 2.54 \;\; 1.65 \;\; 1.00 \;\; 0.56] \; \frac{kip \cdot ft}{ft}$$

Values for Design:

Thickness of structural portion of wall:

$$t_w := \text{for } i \in 0..step \quad \left\| \begin{array}{l} t_{w_i} \leftarrow t_{w\_bot} - t_{arch} - \left(\dfrac{H}{step+1}\right) \cdot \left(\dfrac{i}{s_{bf\_vert}}\right) \\ t_w \end{array} \right.$$

$$t_w^T = [11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00\ 11.00]\ in$$

Section modulus:

$$S_s := \text{for } i \in 0..step \quad \left\| \begin{array}{l} S_{s_i} \leftarrow \dfrac{t_{w_i}^{\ 2}}{6} \\ S_s \end{array} \right.$$

$$S_s^T = [242\ 242\ 242\ 242\ 242\ 242\ 242\ 242\ 242\ 242\ 242\ 242]\ \frac{in^3}{ft}$$

Flexural cracking variability factor: $\gamma_1 := 1.6$

Section 5.6.3.3 for all other concrete structures

Ratio of specified minimum yield strength to ultimate tensile strength of nonprestressed reinforcement: $\gamma_3 := 0.67$

Section 5.6.3.3 for ASTM A615, Grade 60

Cracking moment: $M_{cr} := \gamma_3 \cdot \left(\left(\gamma_1 \cdot f_r\right) \cdot S_s\right)$

$$M_{cr}^T = [10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4\ 10.4]\ \frac{kip \cdot ft}{ft}$$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Stem wall design moments (Minimum design moment per Section 5.6.3.3):

$$M_{sD} := \text{for } i \in 0..step \quad \left\| \begin{array}{l} M_{sD_{i,0}} \leftarrow min\left(M_{cr_{i,0}}, 1.33 \cdot M_{str_{i,0}}\right) \\ M_{sD} \end{array} \right.$$

$$M_{sD}^T = [10.38\ 10.38\ 10.38\ 10.38\ 10.38\ 10.38\ 10.38\ 8.11\ 5.66\ 3.77\ 2.36\ 1.36]\ \frac{kip \cdot ft}{ft}$$

WALL STEM - Base of Wall Location:

Main stem reinforcing bar size and spacing: $B_A := 11$ $s_A := 6\ in$

Bar area per Reference workbook function: $A_{s\_A} := \frac{A_b(B_A)}{s_A}$ $A_b(B_A) = 1.56\ in^2$

$A_{s\_A} = 3.12\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_A := 0$ $xa := Steps_A$ $xa = 0.00$

Depth of reinforcing in the stem wall: $d_{s\_1} := t_{w_{xa}} - CLR_{stem} - \frac{d_b(B_A)}{2}$ $d_{s\_1} = 8.80\ in$

Factored moment resistance: $\phi M_{n\_A} := \phi M_n\left(A_{s\_A}, f_y, \frac{12\ in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A} = 76.08\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

Reinforcing Ratio $\rho_1 := \frac{A_{s\_A}}{12\ \frac{in}{ft} \cdot d_{s\_1}}$ $\rho_1 = 0.0296$

Neutral axis depth factor: $k_1 := \sqrt{2 \cdot (\rho_1 \cdot n_{mod}) + (\rho_1 \cdot n_{mod})^2} - (\rho_1 \cdot n_{mod})$ $k_1 = 0.44$

Maximum reinforcing stress due to service load: $f_{s\_1} := \frac{M_{svc_{xa}}}{A_{s\_A} \cdot d_{s\_1} \cdot \left(1 - \frac{k_1}{3}\right)}$ $f_{s\_1} = 12\ ksi$

Concrete exposure category: $\gamma_e := 1.00$ Section 5.6.7, Class 1

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_1} := CLR_{stem} + \frac{d_b(B_A)}{2}$ $d_{c\_1} = 2.21\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_1} := 1 + \frac{d_{c\_1}}{0.7 \cdot \left(t_{w_{xa}} - d_{c\_1}\right)}$$

Equation 5.6.7-2

$\beta_{s\_1} = 1.36$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_1} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_1} \cdot f_{s\_1}} - 2 \cdot d_{c\_1}$$

Equation 5.6.7-1

$s_{max\_1} = 38.58\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_1} := min\left(s_{max\_1}, 18\ in, 1.5 \cdot t_{w_{xa}}\right)$$

Section 5.6.7 and 5.10.3.2

$s'_{max\_1} = 16.50\ in$

Check reinforcing spacing:

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

Section 5.7.2.8 and Equation 5.7.2.8-2.

$$d_{v\_1} := \max\left(\frac{M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)}{A_{s\_A} \cdot f_y}, 0.9 \cdot d_{s\_1}, 0.72 \cdot t_{w_{xa}}\right)$$

$d_{v\_1} = 7.92\ in$

Factored shear resistance (assumes Av equal to #4 bar and set s_v equal to 12 in):

$$\phi V_{n\_1} := \phi V_n\left(A_b(4), 12\ in, f_y, 12\ in, d_{v\_1}, f'_c\right) \cdot \frac{1}{ft}$$

Reference workbook function

$\phi V_{n\_1} = 17.9\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - Base of Wall Location - SEISMIC Check:

Check the base of wall location for the full Mononobe-Okabe active static and seismic force.

Demand moment for check:

$$M_{sD\_EQ} := \gamma_{EQ} \cdot \Delta E_{ae} \cdot z_{\Delta Eae} \cdot \cos\left(\delta_s\right) + M_{str_{xa}}$$

$M_{sD\_EQ} = 75.72\ \frac{kip \cdot ft}{ft}$

Factored moment resistance: $\phi M_{n\_A\_EQ} := \phi M_n\left(A_{s\_A}, f_y, 12\ \frac{in}{ft}, d_{s\_1}, f'_c\right)$

Reference workbook function

$\phi M_{n\_A\_EQ} = 76.08\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

Reference workbook function

Factored shear resistance: $\phi V_{n\_EQ} := \phi V_{n\_1}$ $\phi V_{n\_EQ} = 17.9\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

Reference workbook function

WALL STEM - "B" Bar Transition Location:

Main stem reinforcing bar size and spacing: $B_B := 6$ $s_B := 12\ in$

Bar area per reference workbook function $A_{s\_B} := \frac{A_b\left(B_B\right)}{s_B}$ $A_{s\_B} = 0.44\ \frac{in^2}{ft}$

Define number of design height increments up from the top of footing to define analysis location: $Steps_B := 4$ $xb := Steps_B$ $xb = 4.00$

Depth of reinforcing in the stem wall: $d_{s\_2} := t_{w_{xb}} - CLR_{stem} - \frac{d_b\left(B_B\right)}{2}$ $d_{s\_2} = 9.13\ in$

Factored moment resistance: $\phi M_{n\_B} := \phi M_n\left(A_{s\_B}, f_y, \frac{12\ in}{ft}, d_{s\_2}, f'_c\right)$

Reference workbook function $\phi M_{n\_B} = 17.43\ \frac{kip \cdot ft}{ft}$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

Reference workbook function

Reinforcing Ratio $\rho_2 := \frac{A_{s\_B}}{12 \frac{in}{ft} \cdot d_{s\_2}}$ $\rho_2 = 0.004$

Neutral axis depth factor: $k_2 := \sqrt{2 \cdot (\rho_2 \cdot n_{mod}) + (\rho_2 \cdot n_{mod})^2} - (\rho_2 \cdot n_{mod})$ $k_2 = 0.2$

Maximum reinforcing stress due to service load: $f_{s\_2} := \frac{M_{svc_{xb}}}{A_{s\_B} \cdot d_{s\_2} \cdot \left(1 - \frac{k_2}{3}\right)}$ $f_{s\_2} = 30\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_2} := CLR_{stem} + \frac{d_b(B_B)}{2}$ $d_{c\_2} = 1.88\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_2} := 1 + \frac{d_{c\_2}}{0.7 \cdot \left(t_{w_{xb}} - d_{c\_2}\right)}$ Equation 5.6.7-2

$\beta_{s\_2} = 1.29$

Limiting spacing for reinforcement based on service level stress: $s_{max\_2} := \frac{700 \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_2} \cdot f_{s\_2}} - 2 \cdot d_{c\_2}$ Equation 5.6.7-1

$s_{max\_2} = 14.32\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_2} := min\left(s_{max\_2}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$ Section 5.6.7 and 5.10.3.2

$s'_{max\_2} = 14.32\ in$

Check reinforcing spacing: $check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth: Reference workbook function and equation C5.7.2.8-1

$$d_{v\_2} := \max\left(\frac{M_n\left(A_{s\_B}, f_y, 12 \frac{in}{ft}, d_{s\_2}, f'_c\right)}{A_{s\_B} \cdot f_y}, 0.9 \cdot d_{s\_2}, 0.72 \cdot t_{w_{xb}}\right)$$

$d_{v\_2} = 8.80\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_2} := \phi V_n \left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_2}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_2} = 12.0\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$$

Minimum cut-off distance for "B" Bar measured from the top of footing (See figure 3):

$$Min_X := Steps_B \cdot z \qquad Min_X = 4.00\ ft$$

WALL FOOTING - Heel Location:

Conservatively design the heel reinforcing for the full weight of the backfill and the weight of the cantilevered portion of the footing with no counteracting force.

Length of the heel extension from back of stem to back of footing:

$$Heel := B - W_t - t_{w\_bot} \qquad Heel = 6.25\ ft$$

Heel factored demand shear at back face of stem:

$$V_{D\_heel} := \gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot Heel \cdot t_f + W_4\right) + \gamma_{pEVmax} \cdot W_7 + W_8 + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right)$$

$$V_{D\_heel} = 19.52\ \frac{kip}{ft}$$

Heel factored demand moment at back face of stem:

$$M_{D\_heel\_1} := \left(\gamma_{pDCmax} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(\left(L_4 - \left(B - Heel\right)\right)\right)\right) + \gamma_{pEVmax} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{pEHmax} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_heel\_1} = 72.71\ kip \cdot ft$$

Heel service demand moment at back face of stem:

$$M_{D\_svc} := \left(\gamma_{DCsvc} \cdot \left(\gamma_{conc} \cdot \frac{Heel^2}{2} \cdot t_f + W_4 \cdot \left(L_4 - \left(B - Heel\right)\right)\right) + \gamma_{EVsvc} \cdot W_7 \cdot \left(L_7 - W_t - t_{w\_bot}\right) + W_8 \cdot \left(L_8 - W_t - t_{w\_bot}\right) + \gamma_{EHsvc} \cdot R_{EH} \cdot \sin\left(\delta_s\right) \cdot Heel\right) \cdot 1.00\ ft$$

$$M_{D\_svc} = 53.92\ kip \cdot ft$$

Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads: $S_{c\_heel} := \frac{1.00\ ft \cdot t_f^2}{6}$ $S_{c\_heel} = 648.00\ in^3$

Heel cracking moment: $M_{cr\_heel} := \gamma_3 \cdot ((\gamma_1 \cdot f_r) \cdot S_{c\_heel})$ $M_{cr\_heel} = 27.79\ kip \cdot ft$

Equation 5.6.3.3-1 with prestress components omitted. This includes the Mdnc term since the result of Sc over Snc minus 1 is zero.

Controlling heel demand moment (minimum design moment per Section 5.6.3.3) $M_{D\_heel} := min(M_{cr\_heel}, 1.33 \cdot M_{D\_heel\_1})$

$M_{D\_heel} = 27.79\ kip \cdot ft$

Heel reinforcing bar size and spacing: $B_C := 6$ $s_C := 6\ in$

$A_{s\_C} := \frac{A_b(B_C)}{s_C}$ $A_{s\_C} = 0.88\ \frac{in^2}{ft}$

Reference workbook function

Depth of reinforcing $d_{s\_heel} := t_f - CLR_{top} - \frac{d_b(B_C)}{2}$ $d_{s\_heel} = 15.63\ in$

Factored moment resistance: $\phi M_{n\_heel} := \phi M_n\left(A_{s\_C}, f_y, \frac{12\ in}{ft}, d_{s\_heel}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function $\phi M_{n\_heel} = 59.31\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}(M_{D\_heel}, \phi M_{n\_heel}) = \text{"OK"}$

Reinforcing Ratio $\rho_h := \frac{A_{s\_C}}{12\ \frac{in}{ft} \cdot d_{s\_heel}}$ $\rho_h = 0.0047$

Neutral axis depth factor: $k_h := \sqrt{2 \cdot (\rho_h \cdot n_{mod}) + (\rho_h \cdot n_{mod})^2} - (\rho_h \cdot n_{mod})$ $k_h = 0.21$

Maximum reinforcing stress due to service load: $f_{s\_h} := \frac{M_{D\_svc}}{A_{s\_C} \cdot d_{s\_heel} \cdot \left(1 - \frac{k_h}{3}\right) \cdot 1.00\ ft}$ $f_{s\_h} = 50.62\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement:

$$d_{c\_h} := CLR_{top} + \frac{d_b(B_C)}{2}$$

$d_{c\_h} = 2.38\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain:

$$\beta_{s\_h} := 1 + \frac{d_{c\_h}}{0.7 \cdot (t_f - d_{c\_h})}$$

Equation 5.6.7-2

$\beta_{s\_h} = 1.22$

Limiting spacing for reinforcement based on service level stress:

$$s_{max\_h} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_h} \cdot f_{s\_h}} - 2 \cdot d_{c\_h}$$

Equation 5.6.7 -1

$s_{max\_h} = 6.61\ in$

Over all limiting spacing for stem reinforcement:

$$s'_{max\_h} := min\left(s_{max\_h}, 18\ in, 1.5 \cdot t_{w_{xb}}\right)$$

Section 5.10.3.2

$s'_{max\_h} = 6.61\ in$

Check reinforcing spacing: $check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_heel} := \max\left(\frac{M_n\left(A_{s\_C}, f_y, 12\ \frac{in}{ft}, d_{s\_heel}, f'_c\right)}{A_{s\_C} \cdot f_y}, 0.9 \cdot d_{s\_heel}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_heel} = 14.98\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_heel} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_heel}, f'_c\right) \cdot \frac{1}{ft}$$

$\phi V_{n\_heel} = 20.45\ \frac{kip}{ft}$

Compare the shear demand to the shear capacity: $check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

WALL FOOTING - Toe Location:

The demand moment for the toe is simply the moment produced by the largest bearing pressure acting on the toe, treating the footing toe as a cantilevered beam supported at the face of the stem wall. The weight of the cantilevered portion of the footing is subtracted from the calculated demand loads. Note that the bearing pressures have been calculated using factored loads, so the demand moments resulting from these pressure are already factored. Bearing pressure distribution is assumed to be uniform per AASHTO Figure 11.6.3.2-1.

Toe factored demand shear at face of stem:

$$V_{D\_toe} := W_t \cdot \left(\max\left(\sigma_{BR}, \sigma_{BR\_EQ}\right) - \gamma_{conc} \cdot \gamma_{pDCmin} \cdot t_f\right)$$

$$V_{D\_toe} = 9.43\ \frac{kip}{ft}$$

Toe factored demand moment at face of stem:

$$M_{D\_toe\_1} := V_{D\_toe} \cdot \frac{W_t}{2} \cdot 1.00\ ft \qquad M_{D\_toe\_1} = 9.43\ kip \cdot ft$$

Toe service demand moment at face of stem:

$$M_{D\_svc\_t} := W_t \cdot \left(\sigma_{v\_svc} - \gamma_{conc} \cdot \gamma_{DCsvc} \cdot t_f\right) \cdot 1.00\ ft$$

$$M_{D\_svc\_t} = 3.86\ \frac{kip \cdot ft}{ft}$$

Toe cracking moment:

$$M_{cr\_toe} := M_{cr\_heel} \qquad M_{cr\_toe} = 27.79\ kip \cdot ft$$

Controlling toe demand moment (Minimum design moment per AASHTO Sec. 5.6.3.3):

$$M_{D\_toe} := min\left(M_{cr\_toe}, 1.33 \cdot M_{D\_toe\_1}\right)$$

$$M_{D\_toe} = 12.54\ kip\ ft$$

Toe reinforcing bar size and spacing:

$$B_{toe} := B_A \qquad B_{toe} = 11.00$$

$$s_{toe} := s_A \qquad s_{toe} = 6.00\ in$$

Entered to reflect extension of main stem bars to the front of the footing

Bar area per Reference workbook function:

$$A_{s\_toe} := \frac{A_b\left(B_{toe}\right)}{s_{toe}} \qquad A_{s\_toe} = 3.12\ \frac{in^2}{ft}$$

Depth of reinforcing:

$$d_{s\_toe} := t_f - CLR_{bot} - \frac{d_b\left(B_{toe}\right)}{2} \qquad d_{s\_toe} = 14.3\ in$$

Factored moment resistance: $\phi M_{n\_toe} := \phi M_n\left(A_{s\_toe}, f_y, \frac{12\ in}{ft}, d_{s\_toe}, f'_c\right) \cdot 1.00\ ft$

Reference workbook function

$\phi M_{n\_toe} = 61.89\ kip \cdot ft$

Compare the moment demand to the moment capacity: $check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

Reinforcing Ratio: $\rho_t := \frac{A_{s\_toe}}{12\ \frac{in}{ft} \cdot d_{s\_toe}}$ $\rho_t = 0.0182$

Neutral axis depth factor: $k_t := \sqrt{2 \cdot (\rho_t \cdot n_{mod}) + (\rho_t \cdot n_{mod})^2} - (\rho_t \cdot n_{mod})$ $k_t = 0.37$

Maximum reinforcing stress due to service load: $f_{s\_t} := \frac{M_{D\_svc\_t}}{A_{s\_toe} \cdot d_{s\_toe} \cdot \left(1 - \frac{k_t}{3}\right)}$ $f_{s\_t} = 1\ ksi$

Concrete thickness from extreme tension fiber to center of flexural reinforcement: $d_{c\_t} := CLR_{bot} + \frac{d_b\left(B_{toe}\right)}{2}$ $d_{c\_t} = 3.71\ in$

Ratio of flexural strain at extreme tension fiber reinforcing strain: $\beta_{s\_t} := 1 + \frac{d_{c\_t}}{0.7 \cdot \left(t_f - d_{c\_t}\right)}$

Equation 5.6.7-2

$\beta_{s\_t} = 1.37$

Limiting spacing for reinforcement based on service level stress: $s_{max\_t} := \frac{700\ \frac{kip}{in} \cdot \gamma_e}{\beta_{s\_t} \cdot f_{s\_t}} - 2 \cdot d_{c\_t}$

Equation 5.6.7-1

$s_{max\_t} = 424.25\ in$

Over all limiting spacing for stem reinforcement: $s'_{max\_t} := min\left(s_{max\_t}, 18\ in, 1.5 \cdot t_f\right)$

Sections 5.6.7 and 5.10.3.2

$s'_{max\_t} = 18.00\ in$

Check reinforcing spacing: $check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

Using reference workbook function $check(demand, capacity)$. Due to the nature of the comparison, the provided spacing is entered first in order to be compared to the limiting calculated value.

Effective shear depth:

$$d_{v\_toe} := \max\left(\frac{M_n\left(A_{s\_toe}, f_y, 12\,\frac{in}{ft}, d_{s\_toe}, f'_c\right)}{A_{s\_toe} \cdot f_y}, 0.9 \cdot d_{s\_toe}, 0.72 \cdot t_f\right)$$

Section 5.7.2.8 and Equation C5.8.2.8-1. Using reference book function.

$d_{v\_toe} = 12.96\ in$

Factored shear resistance (assumes Av equal to zero and set s_v equal to 1000in):

$$\phi V_{n\_toe} := \phi V_n\left(0\ in^2, 1000\ in, f_y, 12\ in, d_{v\_toe}, f'_c\right) \cdot \frac{1}{ft}$$

$$\phi V_{n\_toe} = 17.7\ \frac{kip}{ft}$$

Compare the shear demand to the shear capacity:

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

WALL STEM - Temperature Reinforcing (horizontal orientation):

Provided temperature reinforcing:

$B_{temp\_stem} := 4$

$s_{temp\_stem} := 18\ in$

Listed bars provided each face

$$A_{s\_temp\_p1} := \frac{\left|A_b\left(B_{temp\_stem}\right)\right| \cdot 2}{s_{temp\_stem}}$$

$$A_{s\_temp\_p1} = 0.27\ \frac{in^2}{ft}$$

Minimum temperature reinforcing for EACH FACE (Conservatively uses base of wall portion):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_1} := \begin{array}{|l} A_{temp} \leftarrow \frac{1.3 \cdot \left(H + t_{w\_ext}\right) \cdot t_{w\_bot}}{2 \cdot \left(H + t_{w\_ext} + t_{w\_bot}\right) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad \left| A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \right. \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad \left| A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \right. \\ \text{return } A_{temp} \end{array}$$

$$A_{s\_temp\_1} = 0.12\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_1} := \begin{cases} \text{if } t_{w\_bot} > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_{w\_bot}, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_1} = 18.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_1}, A_{s\_temp\_p1}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_stem}, s_{max\_temp\_1}) = \text{"OK"}$$

WALL FOOTING- Temperature Reinforcing:

Bar number and total number of provided temperature reinforcing:

$B_{temp\_ftg} := 4$ $\quad N_{temp\_ftg} := 19$

For entire footing based on 18" max spacing where footing reinforcement is provided to support temperature bars.

$$A_{s\_temp\_p2} := \frac{|A_b(B_{temp\_ftg})| \cdot N_{temp\_ftg}}{B}$$

$$A_{s\_temp\_p2} = 0.41\ \frac{in^2}{ft}$$

Approximate maximum spacing for temperature reinforcing:

$$s_{temp\_ftg} := \frac{(B - 2 \cdot CLR_{side}) \cdot 2.0}{N_{temp\_ftg} - 1}$$

$$s_{temp\_ftg} = 11.89\ in$$

Minimum temperature reinforcing for EACH FACE (neglects key area):

Equations 5.10.6-1 and 5.10.6-2

$$A_{s\_temp\_2} := \begin{cases} A_{temp} \leftarrow \frac{1.3 \cdot t_f \cdot B}{2 \cdot (t_f + B) \cdot f_y} \cdot \frac{ksi}{12} \\ \text{if } A_{temp} < 0.11\ \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.11 \cdot \frac{in^2}{ft} \\ \text{else if } A_{temp} > 0.60 \cdot \frac{in^2}{ft} \\ \quad A_{temp} \leftarrow 0.60\ \frac{in^2}{ft} \\ \text{return } A_{temp} \end{cases}$$

$$A_{s\_temp\_2} = 0.17\ \frac{in^2}{ft}$$

Maximum temperature reinforcement spacing:

Section 5.10.6

$$s_{max\_temp\_2} := \begin{cases} \text{if } t_f > 18.00\ in \\ \quad 12\ in \\ \text{else} \\ \quad min(3.0 \cdot t_f, 18.0\ in) \end{cases}$$

$$s_{max\_temp\_2} = 12.00\ in$$

Check provided temperature reinforcing quantity and spacing:

$$check_{dc}(A_{s\_temp\_2}, A_{s\_temp\_p2}) = \text{"OK"}$$

$$check_{dc}(s_{temp\_ftg}, s_{max\_temp\_2}) = \text{"OK"}$$

ADDITIONAL DESIGN CHECKS - STEM INTERFACE

Stem Shear Interface Check

Determine the adequacy of provided reinforcing and specified surface condition for the interface between the wall stem and the wall footing. Conservatively design for the full sliding force for the Strength I or Extreme Event I load combination as calculated above.

Concrete shear area: $A_{cv} := (t_{w\_bot} - t_{arch}) \cdot 12\ in$ $\quad A_{cv} = 132.02\ in^2$

Cohesion factor: $c_v := 0.075\ ksi$

Friction factor: $\mu := 0.6$

$K_1 := 0.2$

$K_2 := 0.8\ ksi$

Section 5.7.4.4 for concrete placed against a clean concrete surface, free of laitance, but not intentionally roughened.

Area of interface shear reinforcement:

$$A_{vf\_min} := \frac{0.05 \cdot A_{cv}}{f_y} \cdot ksi \qquad A_{vf\_min} = 0.110\ in^2$$

$$A_{vf} := \left| \frac{A_b(B_A) \cdot 12\ in}{s_A} \right| \qquad A_{vf} = 3.12\ in^2$$

$$check_{dc}(A_{vf\_min}, A_{vf}) = \text{"OK"}$$

The above interface shear reinforcing calculations neglect the front face dowels to show that they are not required to satisfy the code requirements and have been provided for constructability purposes only.

Permanent compressive force acting on stem: $P_c := 0$

Compressive component neglected here since code intend is for this term to apply for prestressing induced compression.

Nominal concrete shear capacities:

$V_{ni\_1} := c_v \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ 5.7.4.3-3

$V_{ni\_2} := K_1 \cdot f'_c \cdot A_{cv}$ 5.7.4.3-4

$V_{ni\_3} := K_2 \cdot A_{cv}$ 5.7.4.3-5

$V_{ni\_1} = 122.22\ kip$ $V_{ni\_2} = 105.61\ kip$

$V_{ni\_3} = 105.61\ kip$

Controlling nominal concrete shear capacity:

$V_{niMax} :=$ if $min(V_{ni\_2}, V_{ni\_3}) < V_{ni\_1}$
  $min(V_{ni\_2}, V_{ni\_3})$
else
  V_{ni_1}

$V_{niMax} = 105.61\ kip$

Actual interface shear capacities for Strength I and Extreme Event I:

$V_{ri} := 0.90 \cdot V_{niMax}$ $V_{ri} = 95.05\ kip$

$InterfaceCheck_{stem} :=$ if $V_{ri} > \max(P_{sliding}, P_{slidingEQ}) \cdot 1\ ft$
  "OK"
else
  "NG"

$InterfaceCheck_{stem} =$ "OK"

SUMMARY OF DESIGN CHECKS

$Check_{Resultant\_str} = \text{"OK"}$

$Sliding_{check\_str} = \text{"OK"}$

$Bearing_{check\_str} = \text{"OK"}$

$OT_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_svc} = \text{"OK"}$

$Sliding_{check\_ser} = \text{"OK"}$

$Check_{Resultant\_EQ} = \text{"OK"}$

$Sliding_{check\_EQ} = \text{"OK"}$

$Check_{Bearing\_EQ} = \text{"OK"}$

$check_{dc}\left(M_{sD_{xa}}, \phi M_{n\_A}\right) = \text{"OK"}$

$check_{dc}\left(s_A, s'_{max\_1}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xa}}, \phi V_{n\_1}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD\_EQ}, \phi M_{n\_A\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(P_{slidingEQ}, \phi V_{n\_EQ}\right) = \text{"OK"}$

$check_{dc}\left(M_{sD_{xb}}, \phi M_{n\_B}\right) = \text{"OK"}$

$check_{dc}\left(s_B, s'_{max\_2}\right) = \text{"OK"}$

$check_{dc}\left(V_{str_{xb}}, \phi V_{n\_2}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_heel}, \phi M_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(s_C, s'_{max\_h}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_heel}, \phi V_{n\_heel}\right) = \text{"OK"}$

$check_{dc}\left(M_{D\_toe}, \phi M_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(s_{toe}, s'_{max\_t}\right) = \text{"OK"}$

$check_{dc}\left(V_{D\_toe}, \phi V_{n\_toe}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_1}, A_{s\_temp\_p1}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_stem}, s_{max\_temp\_1}\right) = \text{"OK"}$

$check_{dc}\left(A_{s\_temp\_2}, A_{s\_temp\_p2}\right) = \text{"OK"}$

$check_{dc}\left(s_{temp\_ftg}, s_{max\_temp\_2}\right) = \text{"OK"}$

$check_{dc}\left(A_{vf\_min}, A_{vf}\right) = \text{"OK"}$

$InterfaceCheck_{stem} = \text{"OK"}$

SUMMARY OF WALL GEOMETRY

Design height:	$H=12.00\ ft$
Footing width:	$B=9.25\ ft$
Footing depth:	$t_f=1.50\ ft$
Wall setback:	$W_t=2.00\ ft$
Key location:	$L=0.00\ ft$
Key depth:	$H_k=0.00\ ft$
Key width:	$W_k=0.00\ ft$

SUMMARY OF REINFORCING

Main stem reinforcing:	$B_A=11.00$	$s_A=6.00\ in$	
Main stem reinforcing	$B_B=6.00$	$s_B=12.00\ in$	
Heel reinforcing:	$B_C=6.00$	$s_C=6.00\ in$	
Minimum cut-off distance for "B" bar measured from top of footing (see Figure 3):	$Min_X=4.00\ ft$		
Temperature reinforcing - stem:	$B_{temp\_stem}=4.00$	$s_{temp\_stem}=18.00\ in$	listed bars provided each face
Temperature reinforcing - footing:	$B_{temp\_ftg}=4.00$	$N_{temp\_ftg}=19.00$	total number of bars for footing
Shear reinforcing -stem:	#4@12" $Min_X=4.00\ ft$ from top of footing		
Shear reinforcing -heel:	no shear reinforcement		
Shear reinforcing -toe:	no shear reinforcement		

END OF WORKBOOK

MONONABE-OKABE SEISMIC ACTIVE EARTH PRESSURE

Determine the active earth pressure coefficient using the Mononobe-Okabe solution described in Appendix A11 of reference 1 listed below. It is up to the designer to determine if the total active static and seismic earth force is to be used for the design or if the separate components off the active static and seismic earth forces are to be used.

Currently, the choice has been made to use only the increase in earth forces caused by the seismic loading since the active static component has been calculated in the main calculation workbook.

Legend

Variable (to be input by user) | Internal result (for reference) | Final result of interest

Commentary / instructions to the user | Unique modification by the user

References

1. AASHTO LRFD Bridge Specifications, 9th Edition

All section, table, equation and figure references are to reference 1 unless otherwise noted.

Standard user defined units: $kcf := \frac{kip}{ft^3}$

Inputs

Horizontal earthquake acceleration (g): $k_h := \frac{1}{2} \cdot 0.34$ $k_h = 0.17$

1/2 of the Design PGA per the project geotechnical report

Vertical earthquake acceleration (g): $k_v := 0 \cdot k_h$ $k_v = 0$

Effective soil friction angle (from main calculation workbook): $\phi := 36.0\ deg$

Backfill slope angle (from main calculation workbook): $\alpha := 25\ deg$

Friction angle between fill and wall (from main calculation workbook): $\delta := 22\ deg$ Table 3.11.5.3-1

Angle of wall backslope (from main calculation workbook): $\beta' := 0.00\ deg$

This variable is used in Appendix A11 equations. The prime has been added for these calculations to differentiate from the β value used in the main calculation workbook.

Active static pressure coefficient (from main calculation workbook): $K_a := 0.38$

Unit weight of soil: $\gamma_s := 0.130\ kcf$

From project geotechnical report

Wall batter from horizontal: $\theta_{MO} := \operatorname{atan}\left(\frac{k_h}{1-k_v}\right)$ $\theta_{MO} = 9.65\ deg$

Section A11.3.1

Seismic active pressure coefficient:

$$K_{ae} := \frac{\cos(\phi - \theta_{MO} - \beta')^2}{\cos(\theta_{MO}) \cdot \cos(\beta')^2 \cdot \cos(\delta + \theta_{MO} + \beta')} \cdot \left(1 + \sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi - \theta_{MO} - \alpha)}{\cos(\delta + \theta_{MO} + \beta') \cdot \cos(\alpha - \beta')}}\right)^{-2}$$

Equation A11.3.1-1 $K_{ae} = 0.710$

Design Calculations 8 ft. Wall

Height of soil face at back of footing: $H_1 := 8.00\ ft + (6.25\ ft - 2.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 9.52\ ft$

Active static earth pressure resultant: $P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot K_a$ $P_a = 2.24\ \frac{kip}{ft}$

Total active static and seismic earth force: $E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot (1 - k_v) \cdot K_{ae}$ $E_{ae} = 4.18\ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := E_{ae} - P_a$ $\Delta E_{ae} = 1.94\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 0.6 \cdot H_1$ $z_{\Delta Eae} = 5.71\ ft$

Section A11.3.1

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 4.35\ ft$

Design Calculations 10 ft. Wall

Height of soil face at back of footing: $H_1 := 10.00\ ft + (7.50\ ft - 2.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 12.10\ ft$

Active static earth pressure resultant: $P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\,2} \cdot K_a$ $\quad P_a = 3.62\ \frac{kip}{ft}$

Total active static and seismic earth force: $E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\,2} \cdot (1 - k_v) \cdot K_{ae}$ $\quad E_{ae} = 6.75\ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := E_{ae} - P_a$ $\quad \Delta E_{ae} = 3.14\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 0.6 \cdot H_1$ $\quad z_{\Delta Eae} = 7.26\ ft$

Section A11.3.1

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 5.53\ ft$

Design Calculations 12 ft. Wall

Height of soil face at back of footing: $H_1 := 12.00\ ft + (9.25\ ft - 2.00\ ft - 1.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Footing Width - Set back from toe to face of wall - total wall thickness at the top) * tan(backfill slope angle)

$H_1 = 14.91\ ft$

Active static earth pressure resultant:	$P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot K_a$	$P_a = 5.49\ \frac{kip}{ft}$
Total active static and seismic earth force:	$E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^{\ 2} \cdot (1 - k_v) \cdot K_{ae}$	$E_{ae} = 10.26\ \frac{kip}{ft}$
Active seismic earth force resultant (separated from active static component):	$\Delta E_{ae} := E_{ae} - P_a$	$\Delta E_{ae} = 4.77\ \frac{kip}{ft}$
Point of application for active seismic earth force (from top of footing):	$z_{\Delta Eae} := 0.6 \cdot H_1$ Section A11.3.1	$z_{\Delta Eae} = 8.95\ ft$
Point of application for active static and seismic earth force (from top of footing):	$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$	$z_{bar} = 6.82\ ft$

END OF WORKBOOK

CALCULATION WORKBOOK MAIN HEADER

This calculation is for the soldier pile wall (Wall 2). This calculation includes the steel pile and the deadman tieback.

Legend

Variable (to be input by user) Internal result (for reference) Final result of interest

Commentary / instructions to the user Unique modification by the user

References

1. AASHTO LRFD Bridge Design Specifications, 9th Edition
2. Geotechnical Report
3. AISC Steel Construction Manual, 15th Edition
4. WSDOT Bridge Design Manual, M23-50.20, September 2020
5. WSDOT Geotechnical Design Manual, M 46-03.13, December 2020

MathCAD external reference files used:

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Results_Check.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Rect_Concrete_Beam_Mn.mcdx

Include << L:\Projects\71000\71486\71486-000\Structural\Calculations\Mathcad\PBS_Ref_Bar_Reinf.mcdx

Standard user defined units:

$$kcf := \frac{kip}{ft^3}$$

Inputs

Unit weight of concrete:	$\gamma_{conc} := 0.155\ kcf$	
Specified compressive strength of concrete:	$f'_c := 4.000\ ksi$	
Correction factor for source of aggregate:	$K_1 := 1.0$	Reference 1, Section 5.4.2.4 - Taken to be 1.0 unless determined by physical test
Minimum yield strength of reinforcing bars:	$f_y := 60\ ksi$	Reference 1, Section 5.5.3.2
Reinforcement modulus of elasticity:	$E_s := 29000\ ksi$	Reference 1, Section 5.4.3.2 for yield strengths up to 100 ksi

Concrete modulus of elasticity: $E_c := 120000 \cdot K_1 \cdot \left(\frac{\gamma_{conc}}{kcf}\right)^{2.0} \cdot \left(\frac{f'_c}{ksi}\right)^{0.33} \cdot ksi$

Reference 1, Equation 5.4.2.4-1

$E_c = 4555\ ksi$

Modular ratios: $n_{mod} := \text{round}\left(\frac{E_s}{E_c}\right)$

Reference 1, Section 5.6.1

$n_{mod} = 6.00$

Modulus of rupture: $\lambda := 1.0$

Reference 1, Section 5.4.2.8 for normal weight concrete

$f_r := 0.24 \cdot \lambda \cdot \sqrt{\frac{f'_c}{ksi}} \cdot ksi$

$f_r = 0.48\ ksi$

Reference 1, Section 5.4.2.6 for normal weight concrete with f'c up to 15.0 ksi

Yield strength of steel piles: $f_{yw} := 50\ ksi$

Modulus of elasticity of steel piles: $E_s := 29000\ ksi$

Backfill soil unit weight: $\gamma_s := 130\ pcf$ — Reference

Native soil unit weight: $\gamma_{sn} := 115\ pcf$ — Reference

Backfill active soil coefficient: $K_a := 0.26$ — Reference

Backfill at rest soil coefficient: $K_{ar} := 0.41$ — Reference

Soil passive coefficient: $K_{pb} := 6.8$ — Backfill

Soil passive coefficient: $K_{pn} := 1.1$ — Native soil

Backfill friction angle: $\phi_{sb} := 36\ deg$ — Backfill

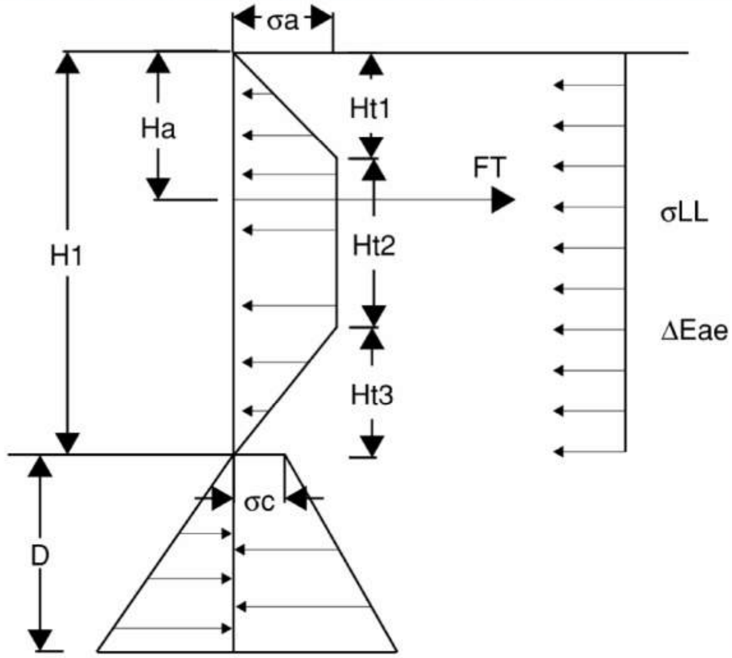
Wall height: $H1 := 17\ ft + 3\ ft$ — Wall height plus three feet of neglected passive pressure

Depth to tieback anchor: $Ha := 6\ ft$

Maximum angle of tieback anchor:	$\phi_{tb} := 10\ deg$	
Pile spacing:	$Sp := 8\ ft$	
Drilled pile diameter:	$dia_p := 3\ ft$	
Live load surcharge	$LL := 125\ psf$	
Ultimate strength of tieback anchors:	$f_{ta} := 270\ ksi$	Reference , Section
Tieback anchor diameter:	$dia_{ta} := 0.60\ in$	Reference , Section
Tension resistance factor:	$\phi_{ta} := 0.60$	Reference , Section

Moment and Shear in Soldier Pile

Soldier Pile Wall with Single Tieback:



Trapezoid loading dimensions

$H_{t1} := \frac{2}{3} \cdot Ha$ $H_{t1} = 4.00\ ft$

$H_{t2} := \frac{1}{3} \cdot H1$ $H_{t2} = 6.67\ ft$

$H_{t3} := \frac{2}{3} \cdot (H1 - Ha)$ $H_{t3} = 9.33\ ft$

Active pressure over one pile diameter $dia_{act} := dia_p$

Passive pressure over 3 pile diameters or the pile spacing $dia_{pas} := min(3 \cdot dia_p, Sp)$

$P := \frac{1}{2} \cdot \gamma_s \cdot H1^2 \cdot K_a$ $P = 6760.00\ \frac{lbf}{ft}$

$P_T := 1.3 \cdot P$ $P_T = 8788.00\ \frac{lbf}{ft}$

$\sigma_a := \frac{P_T}{\frac{2}{3} \cdot H1} \cdot ft$ $\sigma_a = 659.10 \frac{lbf}{ft}$ active stress in trapezoid per foot

$\sigma_c := \gamma_s \cdot H1 \cdot K_a \cdot dia_{act}$ $\sigma_c = 2028.00 \frac{lbf}{ft}$ active stress at base of wall over diameter of pile

$\sigma_{LL} := 0.5 \cdot LL \cdot Sp$ $\sigma_{LL} = 500.00 \frac{lbf}{ft}$ Ref. Geotech report 3.3.2.1 Lateral Earth Pressures

$\Delta E_{ae} := 1.60 \frac{kip}{ft} \cdot Sp$ Seismic load from M/O worksheet

$H_{eq} := 0.4 \cdot H1$ $H_{eq} = 8.00\ ft$ Distance from top of wall to seismic load

moment about tieback

Active pressures

$$f(D) := \sigma_a \cdot \frac{H_{t1}}{2} \cdot \left| Ha - \frac{2}{3} \cdot H_{t1} \right| - \sigma_a \cdot H_{t2} \cdot \left| Ha - \left(H_{t1} + \frac{H_{t2}}{2} \right) \right| - \sigma_a \cdot \frac{H_{t3}}{2} \cdot \left| H_{t1} + H_{t2} + \frac{1}{3} \cdot H_{t3} - Ha \right| - \sigma_c \cdot \left(H1 - Ha + \frac{D}{2} \right) \cdot D - \frac{1}{2} \cdot \gamma_s \cdot dia_{act} \cdot K_a \cdot \left(H1 - Ha + \frac{2}{3} \cdot D \right) \cdot D^2 - \sigma_{LL} \cdot H1 \cdot \left| \frac{H1}{2} - Ha \right| - \Delta E_{ae} \cdot \left| H_{eq} - Ha \right|$$

passive pressures

$$g(D) := K_{pn} \cdot \gamma_{sn} \cdot D \cdot \frac{1}{2} \cdot D \cdot \left(H1 - Ha + \frac{2}{3} \cdot D \right) \cdot dia_{pas}$$

$FS := 1.3$ Factor of Safety

$D := 10\ ft$ Initial guess

Solve for required depth $\mathbf{root}(FS \cdot f(D) + g(D), D) = 7.49\ ft$

$FS\ f(7.49\ ft) = -538.92\ ft \cdot kip$ $\sim=$ $g(7.49\ ft) = 539.16\ ft \cdot kip$

$D_{fs} := 7.49\ ft$

Solve for tieback force $\mathbf{root}(f(D) + g(D), D) = 6.04\ ft$

$f(6.04\ ft) = -332.81\ ft \cdot kip$ $\sim=$ $g(6.04\ ft) = 332.77\ ft \cdot kip$

$D_t := 6.04\ ft$

Sum the horizontal forces to find the tieback force

$$F_T := \left| \begin{array}{l} \left(-\left(\dfrac{H_{t1}}{2} + H_{t2} + \dfrac{H_{t3}}{2} \right) \cdot \sigma_a - \dfrac{1}{2} \cdot \gamma_s \cdot dia_{act} \cdot D_t^{\ 2} \cdot K_a - \sigma_c \cdot D_t + \dfrac{1}{2} \cdot \gamma_{sn} \cdot dia_{pas} \cdot D_t^{\ 2} \cdot K_{pn} \right. \\ \left. + K_{pn} \cdot \gamma_{sn} \cdot 3\ ft \cdot D_t \cdot dia_{pas} \right) \\ - \sigma_{LL} \cdot H1 - \Delta E_{ae} \end{array} \right|$$

$F_T = 8.89\ kip$

Force in tieback tendon at maximum angle: $F_{Ta} := \dfrac{F_T}{\cos(\phi_{tb})}$ $F_{Ta} = 9.03\ kip$

Shear at tieback

$$V_{top} := \frac{1}{2} \cdot \sigma_a \cdot H_{t1} + \sigma_a \cdot (Ha - H_{t1}) + \sigma_{LL} \cdot Ha + \frac{\Delta E_{ae}}{H1} \cdot Ha$$

$V_{top} = 9.48\ kip$

$$V_{bot} := \sigma_a \cdot (H_{t1} + H_{t2} - Ha) + \frac{1}{2} \cdot \sigma_a \cdot H_{t3} + \sigma_c \cdot D_t + \frac{1}{2} \cdot \gamma_s \cdot dia_{act} \cdot K_a \cdot D_t^{\ 2} - \frac{1}{2} \cdot \gamma_{sn} \cdot dia_{pas} \cdot K_{pn} \cdot D_t^{\ 2} + \sigma_{LL} \cdot (H1 - Ha) + \frac{\Delta E_{ae}}{H1} \cdot (H1 - Ha)$$

$V_{bot} = 17.75\ kip$

$V_{max} := \max(V_{top}, V_{bot})$ $V_{max} = 17.75\ kip$

Moment at tieback

$$M_{top} := \frac{1}{2} \cdot \sigma_a \cdot H_{t1} \cdot \left(Ha - \frac{2}{3} H_{t1} \right) + \sigma_a \cdot (Ha - H_{t1}) \cdot \left(\frac{Ha - H_{t1}}{2} \right) + \sigma_{LL} \cdot Ha \cdot \frac{Ha}{2} + \frac{\Delta E_{ae}}{H1} \cdot Ha \cdot \frac{Ha}{2}$$

$$M_{top} = 26.23\ ft \cdot kip$$

Find point of zero shear

Sum horizontal forces

$$h(y) := V_{bot} - \sigma_a \cdot (H_{t1} + H_{t2} - Ha) - \frac{1}{2} \cdot \sigma_a \cdot H_{t3} - \sigma_c \cdot y - \frac{1}{2} \cdot \gamma_s \cdot dia_{act} \cdot K_a \cdot y^2 + \frac{1}{2} \cdot \gamma_{sn} \cdot dia_{pas} \cdot K_{pn} \cdot y^2 - \left(\sigma_{LL} + \frac{\Delta E_{ae}}{H1} \right) \cdot (H1 - Ha)$$

$D_t = 6.04\ ft$ $\quad y := 1\ ft$

$$\mathbf{root}(h(y), y) = -1.59\ ft$$

negative or equal to Dt, point of zero shear above lower grade

$$\max(V_{top}, V_{bot}) - \left(\sigma_a + \sigma_{LL} + \frac{\Delta E_{ae}}{H1} \right) \cdot (H_{t1} + H_{t2} - Ha) = 9.35\ kip$$

greater than zero, point of zero shear is Ht3 region

$$i(y1) := \frac{1}{2} \cdot \left(\sigma_a + \left(\sigma_a - \frac{\sigma_a}{H_{t3}} \cdot y1 \right) \right) \cdot y1 - \max(V_{top}, V_{bot}) + \sigma_a \cdot (H_{t1} + H_{t2} - Ha) + \left(\sigma_{LL} + \frac{\Delta E_{ae}}{H1} \right) \cdot (H_{t1} + H_{t2} + y1 - Ha)$$

$y1 := 1\ ft$ $\quad \mathbf{root}(i(y1), y1) = 5.88\ ft$

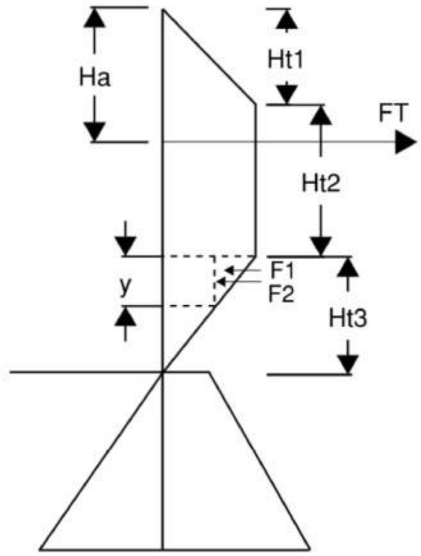
$y2 := 5.88\ ft$ point of zero shear
distance below top of Ht3

$$F1 := \frac{1}{2} \cdot \frac{\sigma_a}{H_{t3}} \cdot y2 \cdot y2$$

$$F1 = 1220.79\ lbf$$

$$F2 := \frac{\sigma_a}{H_{t3}} \cdot (H_{t3} - y2) \cdot y2$$

$$F2 = 1433.94\ lbf$$



Moment at zero shear

$$M_{zv} := V_{max} \cdot (H_{t1} + H_{t2} + y2 - Ha) - \sigma_a \cdot (H_{t1} + H_{t2} - Ha) \cdot \left(\frac{H_{t1} + H_{t2} - Ha}{2} + y2\right)$$
$$- F1 \cdot \frac{2}{3} \cdot y2 - F2 \cdot \frac{1}{2} \cdot y2 - M_{top}$$
$$- \left(\sigma_{LL} + \frac{\Delta E_{ae}}{H1}\right) \cdot (H_{t1} + H_{t2} + y2 - Ha) \cdot \frac{(H_{t1} + H_{t2} + y2 - Ha)}{2}$$

$$M_{zv} = 63.31\ ft \cdot kip$$

$$M_{max} := \max\left(\left|M_{top}\right|, \left|M_{zv}\right|\right) \qquad M_{max} = 63.31\ ft \cdot kip$$

Soldier Pile Checks

Shear and Moment in Steel Pile:

Section properties: W18x35

$d_w := 17.70\ in$ $bf_w := 6.00\ in$ $tw_w := 0.30\ in$

$Sx_w := 57.60\ in^3$ $Zx_w := 66.50\ in^3$

$Aw := d_w \cdot tw_w$ $Aw = 5.31\ in^2$

$htw := 53.5$ Reference 3, Table 1-1

Shear capacity:

$htw = 53.50$ < $2.24 \cdot \sqrt{\frac{E_s}{f_{yw}}} = 53.95$

$\Omega_V := 1.50$ Reference 3, Sect. G2.1(a)

$C_{v1} := 1.0$

$$Vn\Omega := \frac{0.6 \cdot f_{yw} \cdot Aw \cdot C_{v1}}{\Omega_V}$$

Allowable Shear
Reference 3, Eq. G2-1

$Vn\Omega = 106.20\ kip$

$\frac{V_{max}}{Vn\Omega} = 0.17$ $check_{dc}\left(V_{max}, Vn\Omega\right) = \text{"OK"}$

Moment capacity:

$\Omega_b := 1.67$ Allowable Moment
Reference 3, Sect. F1

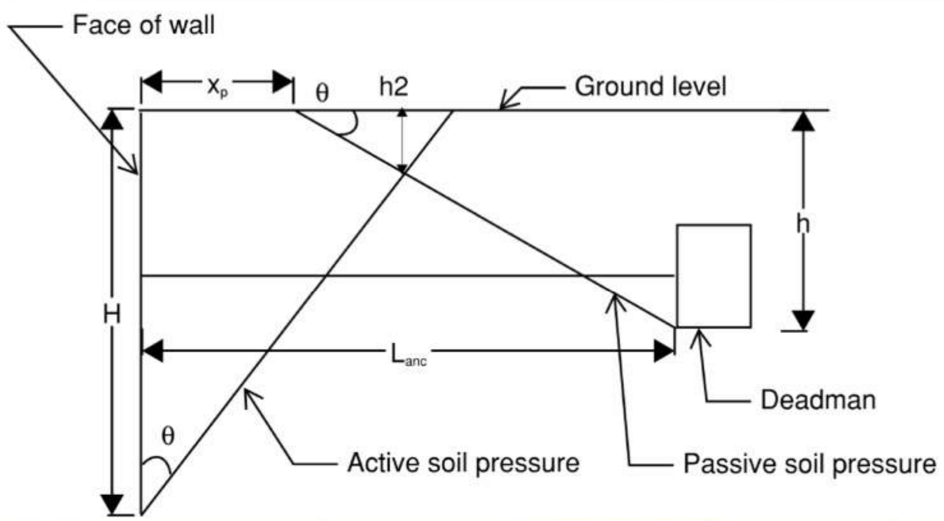
$$Mn\Omega := \frac{f_{yw} \cdot Zx_w}{\Omega_b}$$

$Mn\Omega = 165.92\ ft \cdot kip$

$\frac{M_{max}}{Mn\Omega} = 0.38$ $check_{dc}\left(M_{max}, Mn\Omega\right) = \text{"OK"}$

Deadman Checks

Passive pressure on deadman: Reference 5, Figure 15-4



Height of deadman: $h1_{dm} := 4.00\ ft$

Depth to deadman anchor: $Ha = 6.00\ ft$

Depth to bottom of deadman: $h_{dm} := Ha + \frac{h1_{dm}}{2}$ $h_{dm} = 8.00\ ft$

Length of deadman anchor: $L_{anc} := 16\ ft$

Angle of soil pressure plane: $\theta := 45\ deg - \frac{\phi_{sb}}{2}$ $\theta = 27.00\ deg$

$x_p := L_{anc} - \frac{h_{dm}}{\tan(\theta)}$ $x_p = 0.30\ ft$

Find the depth of the intersection of the two soil pressure planes by finding the intersection of the two lines.
Consider the coordinate origin at the top of the soldier pile wall (0, 0).

Active pressure line end points (0, -H) (tan(θ)H)
Passive pressure line end points (x_1, 0) (L_{anc}, -h)

Using the formula for a line $\dfrac{y-y_1}{x-x_1}=\dfrac{y_2-y_1}{x_2-x_1}$

Active pressure line: $\dfrac{y-(-H)}{x-0}=\dfrac{0-(-H)}{tan(\theta)\cdot H-0}$

Rearranged to Ax+By+C=0 form $-x+tan(\theta)\cdot y+tan(\theta)\cdot H=0$

Passive pressure line: $\dfrac{y-0}{x-x_p}=\dfrac{-h-0}{L_{anc}-x_p}$

Rearranged to Ax+By+C=0 form $hx+(L_{anc}-x_p)\cdot y-h\cdot x_p=0$

Using the formula for the y intersection point: $y=\dfrac{A1\cdot C2-A2\cdot C1}{A2\cdot B1-A1\cdot B2}$

Depth of intersection: $h_{2dm}:=\dfrac{(-1)\cdot(-h_{dm}\cdot x_p)-h_{dm}\cdot \tan(\theta)\cdot H1}{h_{dm}\cdot \tan(\theta)-(-1)\cdot(L_{anc}-x_p)}$

$h_{2dm}=-4.00\ ft$ negative value corresponds to distance below grade

$h1_{dm}=4.00\ ft$ > or = $|h_{2dm}|=4.00\ ft$

$P_p:=\dfrac{1}{2}\cdot K_{pb}\cdot\gamma_s\cdot h_{dm}^{\ 2}-\left(\dfrac{1}{2}\cdot K_{pb}\cdot\gamma_s\cdot|h_{2dm}|^2-\dfrac{1}{2}\cdot K_a\cdot\gamma_s\cdot|h_{2dm}|^2\right)$ Reference 5, Figure 15-4

$P_a:=\dfrac{1}{2}\cdot K_a\cdot\gamma_s\cdot h_{dm}^{\ 2}$

$P_p=21.48\ \dfrac{kip}{ft}$ $P_a=1.08\ \dfrac{kip}{ft}$

Width of deadman: $w_{dm} := 3\ ft$

$$Ap := \frac{w_{dm} \cdot (P_p - P_a)}{2}$$

$Ap = 30.60\ kip$

Anchor resistance with a safety factor of 2

$F_{Ta} = 9.03\ kip$

$check_{dc}(F_{Ta}, Ap) = \text{"OK"}$

Tension in tieback:

Number of strands per tieback: $N_s := 2$

Total tieback cross sectional area: $A_{ta} := N_s \cdot \pi \cdot \left(\frac{dia_{ta}}{2}\right)^2$

$A_{ta} = 0.57\ in^2$

Anchor capacity: $P_{ta} := \phi_{ta} \cdot A_{ta} \cdot f_{ta}$

Reference 1, Section

$P_{ta} = 91.61\ kip$

$check_{dc}(F_{Ta}, P_{ta}) = \text{"OK"}$

$0.80 \cdot A_{ta} \cdot f_{ta} = 122.15\ kip$ > $1.33 \cdot F_{Ta} = 12.01\ kip$

Anchor capacity exceeds proof load $check_{dc}(1.33 \cdot F_{Ta}, 0.80 \cdot A_{ta} \cdot f_{ta}) = \text{"OK"}$

Summary of Design Checks

All critical design checks within this workbook have been repeated below for reference.

Depth of Pile embedment: $\max(D_{fs}, 10\ ft) = 10.00\ ft$ Ref. 4, Section 8.1.5.B.2

Force in Tieback: $F_{Ta} = 9.03\ kip$

Steel Pile Section: W18x35 $check_{dc}(V_{max}, Vn\Omega) = \text{“OK”}$

$check_{dc}(M_{max}, Mn\Omega) = \text{“OK”}$

Deadman dimensions: $h1_{dm} = 4.00\ ft$

$w_{dm} = 3.00\ ft$ $check_{dc}(F_T, Ap) = \text{“OK”}$

Tieback: $N_s = 2.00$ Number of strands

$dia_{ta} = 0.60\ in$ diameter of strands

$check_{dc}(F_{Ta}, P_{ta}) = \text{“OK”}$ force check

$check_{dc}(1.33 \cdot F_{Ta}, 0.80 \cdot A_{ta} \cdot f_{ta}) = \text{“OK”}$ proof load

END OF WORKBOOK

MONONABE-OKABE SEISMIC ACTIVE EARTH PRESSURE

Determine the active earth pressure coefficient using the Mononobe-Okabe solution described in Appendix A11 of reference 1 listed below. It is up to the designer to determine if the total active static and seismic earth force is to be used for the design or if the separate components off the active static and seismic earth forces are to be used.

Currently, the choice has been made to use only the increase in earth forces caused by the seismic loading since the active static component has been calculated in the main calculation workbook.

Legend

Variable (to be input by user) Internal result (for reference) Final result of interest

Commentary / instructions to the user Unique modification by the user

References

1. AASHTO LRFD Bridge Specifications, 9th Edition

All section, table, equation and figure references are to reference 1 unless otherwise noted.

Standard user defined units: $kcf := \frac{kip}{ft^3}$

Inputs

Horizontal earthquake acceleration (g): $k_h := \frac{1}{2} \cdot 0.34$ $k_h = 0.17$

1/2 of the Design PGA per the project geotechnical report

Vertical earthquake acceleration (g): $k_v := 0 \cdot k_h$ $k_v = 0$

Effective soil friction angle (from main calculation workbook): $\phi := 36.0\ deg$

Backfill slope angle (from main calculation workbook): $\alpha := 0.00\ deg$

Friction angle between fill and wall (from main calculation workbook): $\delta := 22\ deg$ Table 3.11.5.3-1

Angle of wall backslope (from main calculation workbook): $\beta' := 0.00\ deg$

This variable is used in Appendix A11 equations. The prime has been added for these calculations to differentiate from the β value used in the main calculation workbook.

Active static pressure coefficient (from main calculation workbook): $K_a := 0.26$

Unit weight of soil: $\gamma_s := 0.130\ kcf$ From project geotechnical report

Wall batter from horizontal: $\theta_{MO} := \operatorname{atan}\left(\frac{k_h}{1-k_v}\right)$ $\theta_{MO} = 9.65\ deg$

Section A11.3.1

Seismic active pressure coefficient:

$$K_{ae} := \frac{\cos(\phi - \theta_{MO} - \beta')^2}{\cos(\theta_{MO}) \cdot \cos(\beta')^2 \cdot \cos(\delta + \theta_{MO} + \beta')} \cdot \left(1 + \sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi - \theta_{MO} - \alpha)}{\cos(\delta + \theta_{MO} + \beta') \cdot \cos(\alpha - \beta')}}\right)^{-2}$$

Equation A11.3.1-1 $K_{ae} = 0.345$

Design Calculations

Height of soil face at back of footing: $H_1 := 17.00\ ft + (13.00\ ft) \cdot \tan(\alpha)$

Excludes the footing thickness consistent with Reference 1 design methodology.

Wall Base Height + (Active Width) * tan(backfill slope angle)

$H_1 = 17.00\ ft$

Active static earth pressure resultant: $P_a := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot K_a$ $P_a = 4.88\ \frac{kip}{ft}$

Total active static and seismic earth force: $E_{ae} := \frac{1}{2} \cdot \gamma_s \cdot H_1^2 \cdot (1 - k_v) \cdot K_{ae}$ $E_{ae} = 6.48\ \frac{kip}{ft}$

Active seismic earth force resultant (separated from active static component): $\Delta E_{ae} := E_{ae} - P_a$ $\Delta E_{ae} = 1.60\ \frac{kip}{ft}$

Point of application for active seismic earth force (from top of footing): $z_{\Delta Eae} := 0.6 \cdot H_1$ $z_{\Delta Eae} = 10.20\ ft$

Section A11.3.1

Point of application for active static and seismic earth force (from top of footing):

$$z_{bar} := \frac{z_{\Delta Eae} \cdot \Delta E_{ae} + \frac{H_1}{3} \cdot P_a}{E_{ae}}$$

$z_{bar} = 6.78\ ft$

END OF WORKBOOK

PROBLEM STATEMENT

This workbook is intended to function as a reference sheet that can be called by other workbook files. It contains functions for automating bar diameter and area declarations based upon references to nominal bar size.

Legend

Variable (to be input by user) Internal result (for reference) Final result of interest

Commentary / instructions to the user Unique modification by the user

References

1. AASHTO LRFD Bridge Design Specifications, 9th Edition

Functions

Matrix declarations:

$$bar_{size} := \begin{bmatrix} 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 14 \\ 18 \end{bmatrix} \quad bar_{dia} := \begin{bmatrix} 0.375 \\ 0.500 \\ 0.625 \\ 0.750 \\ 0.875 \\ 1.000 \\ 1.128 \\ 1.270 \\ 1.410 \\ 1.693 \\ 2.257 \end{bmatrix} \quad bar_{area} := \begin{bmatrix} 0.11 \\ 0.20 \\ 0.31 \\ 0.44 \\ 0.60 \\ 0.79 \\ 1.00 \\ 1.27 \\ 1.56 \\ 2.25 \\ 4.00 \end{bmatrix}$$

Function for retrieving bar diameter:

$$d_b\left(size_{bar}\right) := \left|\text{lookup}\left(size_{bar}, bar_{size}, bar_{dia}\right)\right| \cdot in$$

Function for retrieving bar area:

$$A_b\left(size_{bar}\right) := \left|\text{lookup}\left(size_{bar}, bar_{size}, bar_{area}\right)\right| \cdot in^2$$

END OF WORKBOOK

PROBLEM STATEMENT

This workbook is intended to function as a reference sheet that can be called by other workbook files. It contains functions for solving for the flexural capacity (including the variable resistance factor) of a RECTANGULAR reinforced concrete section with a specified amount of reinforcing in accordance with AASHTO LRFD provisions (see reference 1 below). This workbook does not take into account the effects of compression reinforcement and should not be used for T-sections or other non-rectangular sections.

Legend

Variable (to be input by user) | Internal result (for reference) | Final result of interest

Commentary / instructions to the user | Unique modification by the user

References

1. AASHTO LRFD Bridge Design Specifications, 9th Edition

All section and figure references are to reference 1 unless otherwise noted.

Functions

Function for ratio of compression block depth to neutral axis depth:

Section 5.6.2.2

$$\beta_1(f'_c) := \begin{cases} \text{if } f'_c \le 4.00\ ksi & 0.85 \\ \text{also if } f'_c \ge 8.00\ ksi & 0.65 \\ \text{else} & \text{linterp}\left(\begin{bmatrix} 4.0 \\ 8.0 \end{bmatrix} \cdot ksi, \begin{bmatrix} 0.85 \\ 0.65 \end{bmatrix}, f'_c\right) \end{cases}$$

Function for depth of equivalent compression block:

$$a(A_{sc}, f_y, b'_w, f'_c) := \frac{A_{sc} \cdot f_y}{0.85 \cdot b'_w \cdot f'_c}$$

0.85 assumes f'c is less than or equal to 10 ksi

Section 5.6.2.2

Function for nominal moment capacity of section:

$$M_n(A_{sc}, f_y, b'_w, d_s, f'_c) := (A_{sc} \cdot f_y) \cdot \left(d_s - \frac{a(A_{sc}, f_y, b'_w, f'_c)}{2}\right)$$

Equation 5.6.3.2.2-1

Function for depth from extreme compression fiber to neutral axis:

$$c_n(A_{sc}, f_y, b'_w, f'_c) := \frac{a(A_{sc}, f_y, b'_w, f'_c)}{\beta_1(f'_c)}$$

Equation 5.6.3.1.2-4

Function for strain in tension reinforcement assuming concrete strain = 0.003 in/in:

$$\varepsilon_s(A_{sc}, f_y, b'_w, d_s, f'_c) := d_s \cdot \left(\frac{0.003}{c_n(A_{sc}, f_y, b'_w, f'_c)}\right) - 0.003$$

Function for flexural resistance factor (Section 5.6.2.1, Figure C5.5.4.2.1-1 and equation 5.5.4.2-2):

$$\phi_f\left(A_{sc}, f_y, b'_w, d_s, f'_c\right) := \begin{cases} \text{if } \varepsilon_s\left(A_{sc}, f_y, b'_w, d_s, f'_c\right) \le 0.002 \\ \quad 0.75 \\ \text{also if } \varepsilon_s\left(A_{sc}, f_y, b'_w, d_s, f'_c\right) \ge 0.005 \\ \quad 0.90 \\ \text{else} \\ \quad 0.75 + \dfrac{0.15 \cdot \varepsilon_s\left(A_{sc}, f_y, b'_w, d_s, f'_c\right) - 0.002}{0.005 - 0.002} \end{cases}$$

Function for the factored moment capacity of the section:

$$\phi M_n\left(A_{sc}, f_y, b'_w, d_s, f'_c\right) := \phi_f\left(A_{sc}, f_y, b'_w, d_s, f'_c\right) \cdot M_n\left(A_{sc}, f_y, b'_w, d_s, f'_c\right)$$

Function for factored shear capacity of normal weight concrete, with a non-prestressed section, β_v =2.0, θ_v = 45 degrees, α_v = 90 degrees (Section 5.7.3.4.1 and 5.7.3.3) and ϕ_v = 0.90 (Section 5.5.4.2):

$$\phi V_n\left(A_v, s_v, f_y, b_v, d_v, f'_c\right) := 0.90 \cdot \begin{cases} V_c \leftarrow 0.0316 \cdot 2.0 \cdot \sqrt{\dfrac{f'_c}{ksi}} \cdot ksi \cdot b_v \cdot d_v \\ V_s \leftarrow \dfrac{A_v \cdot f_y \cdot d_v \cdot \cot(45\ deg)}{s_v} \\ min\left(0.25 \cdot f'_c \cdot b_v \cdot d_v, V_c + V_s\right) \end{cases}$$

Equation 5.7.3.3-3

Equation 5.7.3.3-4

Equation 5.7.3.3-1 and 2

END OF WORKBOOK

PROBLEM STATEMENT

This workbook is intended to function as a reference sheet that can be called by other workbook files. It contains functions that takes two numerical variables and compares them. If the first variable ("demand" or "provided") is greater than the second ("capacity" or "upper_limit"), the function result is "NG". If the first variable is less than the second, the function result is "OK".

Legend

Variable (to be input by user) Internal result (for reference) Final result of interest

Commentary / instructions to the user Unique modification by the user

References

None.

Functions

$$check_{dc}(demand, capacity) := \textbf{if}(demand > capacity, \text{“NG”}, \text{“OK”})$$

Users are cautioned to note the syntax: demand is the first variable, capacity is the second variable.

$$check_{ulim}(provided, upper\_limit) := \textbf{if}(provided > upper\_limit, \text{“NG”}, \text{“OK”})$$

Users are cautioned to note the syntax: provided is the first variable, upper limit is the second variable.

END OF WORKBOOK