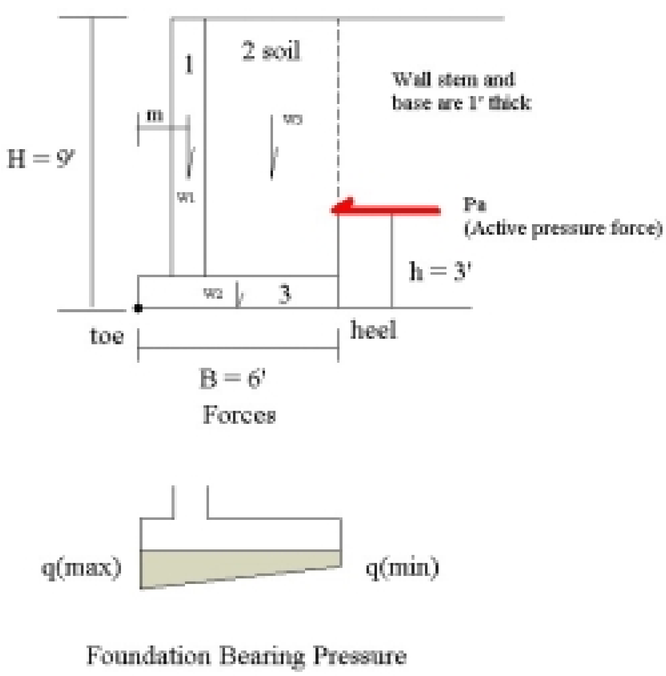
Example (2.0)

Using the Rankine method of analysis, calculate the factors of safety with respect to sliding, overturning and bearing capacity. Use the values presented in the following Table and refer to Figure 5. It is inferred that all calculations relate to a unit length of wall.

Friction angle of soil backfill (ϕ)	32 degrees
Soil Backfill Unit Weight (γ)	125 pcf
Friction angle of the foundation soil (ϕ_1)	33 degrees
Rankine active pressure coefficient (Ka)	0.307
Concrete Unit Weight (γ_c)	150 pcf
Dimensions of the concrete wall section 1	1-ft by 8-ft
Dimensions of the soil backfill section 2	4-ft by 8-ft
Dimensions of the concrete wall section 3	6-ft by 1-ft



Note:

Since Pa is horizontal, there is no vertical component of the force. If the backfill surface were sloping then Pa would slope at an angle parallel to the backfill slope. In this case there would be both a vertical and horizontal component of Pa. The lateral thrust would be the horizontal component and the vertical component would be an additional vertical force included in ΣV.

Figure 5

Solution

Calculate the values shown in the following Table. The dimensions for "Area" relate to each of the three sections identified in Figure 3. The unit weight (γ) is provided for the concrete wall and soil backfill over the base of the wall. W is the weight of each section and it acts at the centroid of the mass area as shown in Figure 3. The value "m" is the moment arm measured from the toe to the location of the individual W values. M is the resisting moment for each of the individual areas.

Section	Area (sf)	γ (pcf)	W (lbs)	m (ft)	M (ft-lb)
1	1 x 8	150	1200	1.5	1800
2	4 x 8	125	4000	4	16000
3	6 x 1	150	900	3	2700
			ΣV = **6100**		ΣMr = **20500**

$Pa = ½\ Ka\ \gamma\ H^2$ = (0.5) (0.307) (125) (81) = **1554.2 lbs**

ΣMo = Pa (h) = (1554.2) (3) = **4662.6 ft-lbs**

Overturning: Fs_o = ΣMr / ΣMo = 20500 / 4662.6 = **4.4** > 2 **OK**

Sliding: $FS_s = \Sigma V \tan(k\phi_1) / Pa_h$ = (6100) tan (22) / 1554.2 = **1.58** > 1.5 **OK**
Where k = 2/3

Bearing Capacity:

Assume that the ultimate bearing capacity of the foundation soil is 5000 psf.

e = (B / 2) - (ΣMr – ΣMo) / ΣV = (6 / 2) – (20500 – 4662.6) / 6100 = **0.4** (i.e. e < B / 6)

q_{max} = (ΣV / B) (1 + 6e / B) = (6100 / 6) (1 + 2.4 / 6) = (1016.6) (1.4) = **1423.4 psf**

q_{min} = (ΣV / B) (1 - 6e / B) = (6100 / 6) (1 - 2.4 / 6) = (1016.6) (.6) = **610 psf** (i.e. base of wall is in full soil contact)

$FS_{bc} = q_u / q_{max}$ = 5000 / 1423.4 = **3.5** > 3.0 **OK**

GEOMETRY

Conc. Stem Height	**8.00**	ft	
Stem Thickness Top	**12.0**	in	
Stem Thickness Bot	**12.0**	in	
Footing Thickness	**12.0**	ft	
Toe Length	**1.00**	ft	
Heel Length	**4.00**	ft	
Soil Cover @ Toe	**0.00**	ft	
Backfill Height	**8.00**	ft	OK
Backfill Slope Angle	**0.0**	deg	

SEISMIC EARTH FORCES

Hor. Seismic Coeff. kh	**0.00**	
Ver. Seismic Coeff kv	**0.00**	
Seismic Active Coeff. Kae	0.28	
Seismic Force Pae-Pa	-0.1	k/ft

SOIL BEARING PRESSURES

Allow. Bearing Pressure ..	**4.0**	ksf	
Max. Pressure @ Toe	1.4	ksf	OK
Min. Pressure @ Heel	0.6	ksf	
Total Footing Length	6.00	ft	
Footing Length / 6	1.00	ft	
Resultant Eccentricity e ...	0.40	ft	

Resultant is Within the Middle Third

APPLIED LOADS

Uniform Surcharge	**0.0**	psf
Strip Pressure	**0.0**	psf

Strip 2.0 ft deep, 4.0 ft wide @ 3.0 ft from Stem

Stem Vertical (Dead)	**0.0**	k/ft
Stem Vertical (Live)	**0.0**	k/ft
Vertical Load Eccentricity	**6.0**	in
Wind Load on Stem	**0.0**	psf

BACKFILL PROPERTIES

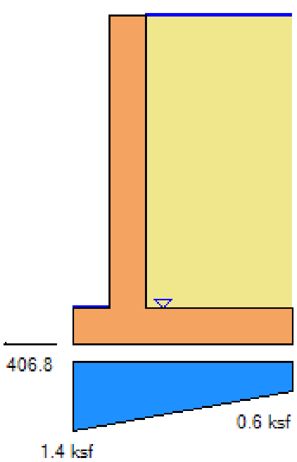
Backfill Density	**125.0**	pcf
Earth Pressure Theory	**Rankine Active**	
Internal Friction Angle	**32.0**	deg
Active Pressure Coeff. Ka	0.31	
Active Pressure @ Wall	38.4	psf/ft
Active Force @ Wall Pa	1.6	k/ft
Water Table Height	**0.00**	ft

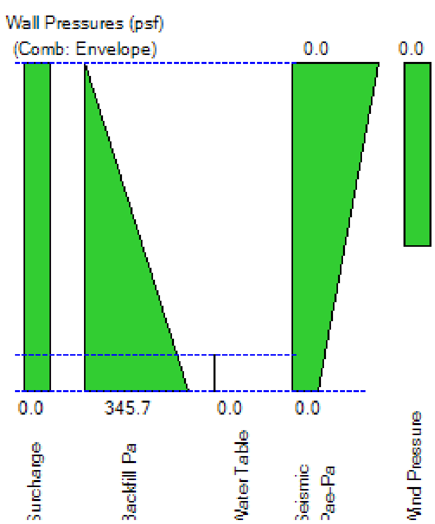
SHEAR KEY DESIGN

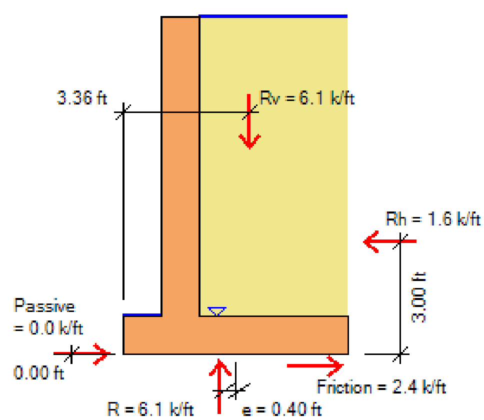
Shear Key Depth	**0.0**	in	
Shear Key Thickness	**0.0**	in	
Max. Shear Force @ Key ..	0.0	k/ft	
Shear Capacity Ratio	0.00		OK

No shear key has been specified

Moment Capacity Ratio	0.00	OK







CANTILEVER RETAINING WALL DESIGN

OVERTURNING CALCULATIONS (Comb. D+H+W)

OVERTURNING

	Force k/ft	Arm ft	Moment k-ft/ft
Backfill Pa	1.56	3.00	4.7
Water Table	0.00	0.33	0.0
Surcharge Hor	0.00	4.50	0.0
Strip Load Hor	0.00	4.00	0.0
Wind Load	0.00	6.50	0.0
Seismic Pae-Pa ...	0.00	5.40	0.0
Seismic Water	0.00	0.33	0.0
Seismic Selfweight	0.00	0.00	0.0
Rh =	1.56	OTM =	4.7

Arm of Horizontal Resultant = $\frac{4.7}{1.56}$ = 3.00 ft

Arm of Vertical Resultant = $\frac{20.5}{6.10}$ = 3.36 ft

Overturning Safety Factor = $\frac{20.5}{4.7}$ = 4.39 > 2 OK

RESISTING

	Force k/ft	Arm ft	Moment k-ft/ft
Stem Top	1.20	1.50	1.8
Stem Taper	0.00	2.00	0.0
CMU Stem at Top ..	0.00	0.00	0.0
Footing Weight	0.90	3.00	2.7
Shear Key	0.00	1.00	0.0
Soil Cover @ Toe .	0.00	0.50	0.0
Stem Wedge	0.00	2.00	0.0
Backfill Weight	4.00	4.00	16.0
Backfill Slope	0.00	4.67	0.0
Water Weight	0.00	4.00	0.0
Seismic Pae-Pa	0.00	6.00	0.0
Pa Vert @ Heel	0.00	6.00	0.0
Vertical Load	0.00	1.50	0.0
Surcharge Ver	0.00	4.00	0.0
Strip Load Ver	0.00	4.00	0.0
Rv =	6.10	RM =	20.5

STEM DESIGN (Comb. 0.9D+1.6H+E)

Height ft	d in	Mu k-ft/ft	ϕMn k-ft/ft	Ratio	
8.00	9.7	0.0	0.0	0.00	
7.20	9.7	0.0	8.9	0.00	
6.40	9.7	0.0	13.2	0.00	
5.60	9.7	0.1	13.2	0.01	
4.80	9.7	0.3	13.2	0.03	
4.00	9.7	0.7	13.2	0.05	
3.20	9.7	1.1	13.2	0.09	
2.40	9.7	1.8	13.2	0.14	
1.60	9.7	2.7	13.2	0.20	
0.80	9.7	3.8	13.2	0.29	
0.00	9.7	5.2	13.2	0.40	OK

Shear Force @ Crit. Height ..	1.8	k/ft	OK
Resisting Shear ϕVc	11.0	k/ft	

Use vertical bars #5 @ 12 in at backfill side

Do not cut off alternate vertical bars

Vert. Bars Embed. Ldh Reqd ..	8.3	in	OK
Vert. Bars Splice Length Ld	14.2	in	

SLIDING CALCS (Comb. D+H+W)

Footing-Soil Friction Coeff. ..	0.40	
Friction Force at Base	2.4	k/ft
Passive Pressure Coeff. Kp .	3.25	
Depth to Neglect Passive	1.00	ft
Passive Pressure @ Wall	Infinity	psf/ft
Passive Force @ Wall Pp	0.0	k/ft
Horiz. Resisting Force	2.4	k/ft
Horiz. Sliding Force	1.6	k/ft

Sliding Safety Factor = $\frac{2.4}{1.6}$ = 1.57 > 1.5 OK

LOAD COMBINATIONS (ASCE 7)

STABILITY	STRENGTH
① D+H+W	① 1.4D
② D+L+H+W	② 1.2D+1.6(L+H)
③ D+H+0.7E	③ 1.2D+0.8W
④ D+L+H+0.7E	④ 1.2D+L+1.6W
	⑤ 1.2D+L+E
	⑥ 0.9D+1.6H+1.6W
	⑦ 0.9D+1.6H+E

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HEEL DESIGN (Comb. 1.4D)

	Force k/ft	Arm ft	Moment k-ft/ft
Upward Pressure .	0.0	1.33	0.0
Concrete Weight ..	0.5	2.00	1.1
Backfill Weight	3.6	2.00	7.2
Backfill Slope	0.0	2.67	0.0
Water Weight	0.0	2.00	0.0
Surcharge Ver.	0.0	2.00	0.0
Strip Load Ver.	0.0	2.00	0.0
	4.1	Mu =	12.9

Shear Force @ Crit. Sect. .. 6.4 k/ft OK

Resisting Shear ϕVc .... 11.0 k/ft

Use top bars #5 @ 12 in , Transv. #4 @ 12 in

Resisting Moment ϕMn ...... 13.2 k-ft/ft OK

Develop. Length Ratio at End .... 0.30 OK

Develop. Length Ratio at Toe .... 0.63 OK

TOE DESIGN (Comb. 1.2D+1.6(L+H))

	Force k/ft	Arm ft	Moment k-ft/ft
Upward Presssure	1.9	0.51	1.0
Concrete Weight ..	-0.2	0.50	-0.1
Soil Cover	0.0	0.50	0.0
	1.7	Mu =	0.9

Shear Force @ Crit. Sect. .. 0.5 k/ft OK

Resisting Shear ϕVc .... 9.9 k/ft

Use bott. bars #5 @ 12 in , Transv. #4 @ 12 in

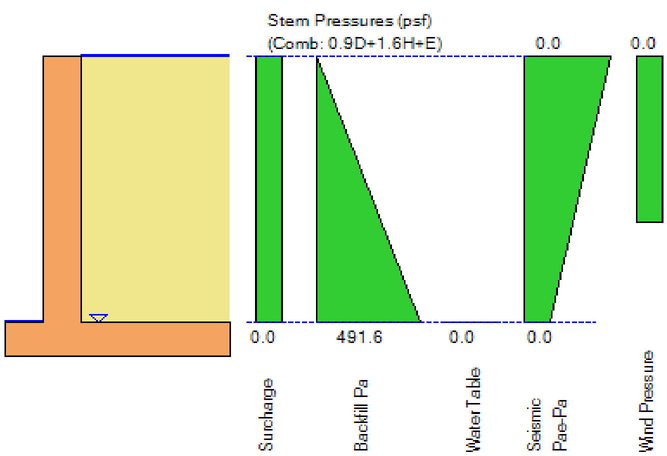
Resisting Moment ϕMn ...... 11.8 k-ft/ft OK

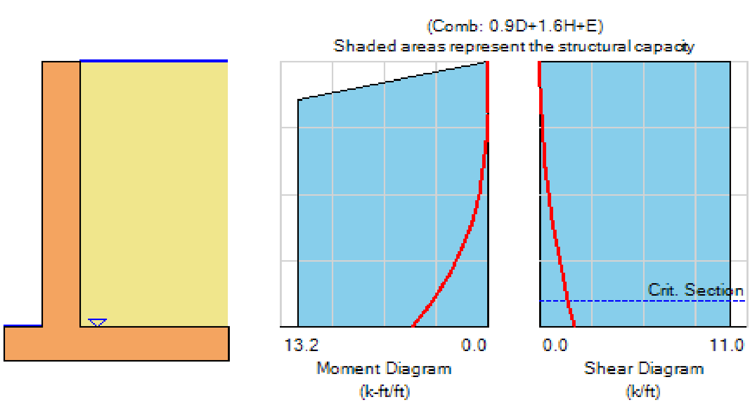
Develop. Length Ratio at End ...... 0.12 OK

Develop. Length Ratio at Stem .... 0.02 OK

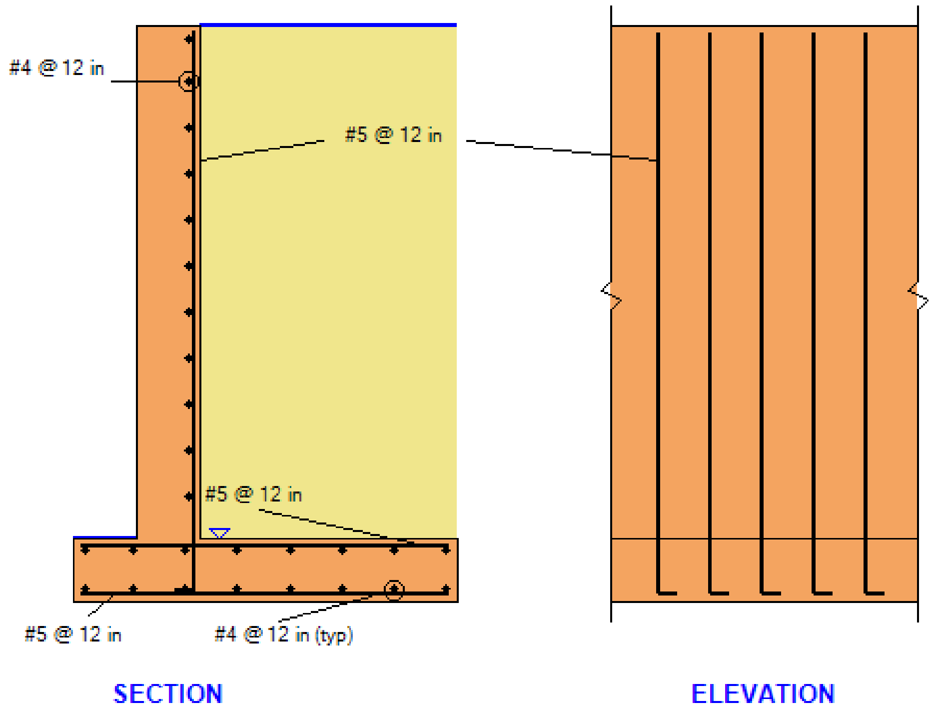
MATERIALS

	Stem	Footing	
Concrete f'c	4.0	4.0	ksi
Rebars fy	60.0	60.0	ksi





CANTILEVER RETAINING WALL DESIGN



DESIGN CODES

General Analysis	IBC-12
Concrete Design	ACI 318-11
Masonry Design	MSJC-11
Load Combinations	ASCE 7-05

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GEOMETRY

Conc. Stem Height	8.00	ft	
Stem Thickness Top	12.0	in	
Stem Thickness Bot	12.0	in	
Footing Thickness	12.0	ft	
Toe Length	1.00	ft	
Heel Length	4.00	ft	
Soil Cover @ Toe	0.00	ft	
Backfill Height	8.00	ft	OK
Backfill Slope Angle	0.0	deg	

APPLIED LOADS

Uniform Surcharge	0.0	psf
Strip Pressure	0.0	psf
Strip 2.0 ft deep, 4.0 ft wide @ 3.0 ft from Stem		
Stem Vertical (Dead)	0.0	k/ft
Stem Vertical (Live)	0.0	k/ft
Vertical Load Eccentricity	6.0	in
Wind Load on Stem	0.0	psf
Wind Height from Top	5.00	ft

BACKFILL PROPERTIES

Wall taper $\alpha = aTan\ (taper / H) =$ aTan ((12.0 - 12.0) / 12 / 8.00) = 0.000 rad

Backfill slope $\beta = slope * \pi / 180 =$ 0.0 * 3.14 / 180 = 0.000 rad

Internal friction $\phi = Int.\ friction * \pi / 180 =$ 32.0 * 3.14 / 180 = 0.559 rad

Wall-soil friction $\delta = \phi / 2 =$ 0.559 / 2 = 0.279 rad

Seismic angle $\theta = aTan\ (kh / (1 - kv)) =$ aTan (0 / (1 - 0)) = 0.000 rad

Footing length $ftg = toe + stem + heel =$ 1.00 + 12.0 / 12 + 4.00 = 6.00 ft

Height for Stability $Hs = wedge + backfill + footing =$ 0.00 + 8.00 + 12.0 / 12 = 9.00 ft

Earth pressure theory = Rankine Active   Moist density = 125 pcf   Saturated density = 130 pcf

Active coefficient $ka = \dfrac{Cos\ \beta * [Cos\ \beta - (Cos^2 \beta - Cos^2 \phi)^{½}]^2}{Cos\ \beta + (Cos^2 \beta - Cos^2 \phi)^{½}}$ = 0.31

Active pressure $pa = ka * \gamma =$ 0.31 * 125.0 = 38.4 psf/ft of height

- For stability analysis (non-seismic)

Active force $Pa = ka * \gamma * Hs^2 / 2 =$ 0.31 * 125.0 * 9.00² / 2 = 1.6 k/ft

$Pah = Pa * Cos\ \beta =$ 1.6 * Cos (0.000) = 1.6 k/ft , $Pav = Pa * Sin\ \beta =$ 1.6 * Sin (0.000) = 0.0 k/ft

Water force $Pw = (ka * (\gamma s - \gamma w - \gamma) + \gamma w) * (water + footing)^2 / 2$

Pw = (0.31 * (130.0 - 62.4 - 125.0) + 62.4) * (0.00 + 12.0 / 12)² / 2 = 0.0 k/ft

- For stem design (non-seismic)

Active force $Pa = ka * \gamma * H^2 / 2 =$ 0.31 * 125.0 * 8.00² / 2 = 1.2 k/ft

$Pah = Pa * Cos\ \beta =$ 1.2 * Cos (0.000) = 1.2 k/ft , $Pav = Pa * Sin\ \beta =$ 1.2 * Sin (0.000) = 0.0 k/ft

Water force $Pw = (ka * (\gamma s - \gamma w - \gamma) + \gamma w) * (water\ table)^2 / 2$

Pw = (0.31 * (130.0 - 62.4 - 125.0) + 62.4) * 0.00² / 2 = 0.0 k/ft

Active seismic coeff. $kae = \dfrac{Cos^2(\phi - \alpha - \theta)}{Cos\theta * Cos^2\alpha * Cos(\delta + \alpha + \theta) * [1 + (\dfrac{Sin(\phi + \delta) * Sin(\phi - \beta - \theta)}{Cos(\delta + \alpha + \theta) * Cos(\beta - \alpha)})^{½}]^2}$ = 0.28

- For stability analysis (seismic)

Seismic force *Pae = kae * γ * Hs² / 2 * (1 - kv)* = 0.28 * 125.0 * 9.00² / 2 * (1 - 0.0) = 1.4 k/ft

*Paeh = Pae * Cos (δ + α)* = 1.4 * Cos (0.279 + 0.000) = 1.4 k/ft

*Paev = Pae * Sin (δ + α)* = 1.4 * Sin (0.279 + 0.000) = 0.4 k/ft

Water force *Pwe = kh * (γs - γ) * (water + footing)² / 2*

Pwe = 0.00 * (130.0 - 125.0) * (0.00 + 12.0 / 12)² / 2 = 0.0 k/ft

- For stem design (seismic)

Seismic force *Pae = kae * γ * H² / 2* = 0.28 * 125.0 * 8.00² / 2 = 1.1 k/ft

*Paeh = Pae * Cos (δ + α)* = 1.1 * Cos (0.279 + 0.000) = 1.1 k/ft

*Paev = Pae * Sin (δ + α)* = 1.1 * Sin (0.279 + 0.000) = 0.3 k/ft

Water force *Pwe = kh * (γs - γ) * (water table)² / 2*

Pwe = 0.00 * (130.0 - 125.0) * 0.00² / 2 = 0.0 k/ft

OVERTURNING CALCULATIONS (Comb. D+H+W)

- Overturning

Backfill = *Lat factor * Pah* = 1.0 * 1.6 = 1.6 k/ft

Arm = *Hs / 3* = 9.00 / 3 = 3.00 ft Moment = 1.6 * 3.00 = 4.7 k-ft/ft

Water table = *Lat factor * Pw* = 1.0 * 0.0 = 0.0 k/ft

Arm = *(Water table + Ftg) / 3* = (0.00 + 12.0 / 12) / 3 = 0.33 ft Moment = 0.0 * 0.33 = 0.0 k-ft/ft

Surcharge = *Lat factor * ka * Surcharge * Hs* = 1.0 * 0.31 * 0.0 * 9.00 = 0.0 k/ft

Arm = *Hs / 2* = 9.00 / 2 = 4.50 ft Moment = 0.0 * 4.50 = 0.0 k-ft/ft

Strip load = *Σ Lat factor * 2 * Q / π * [β - Sin β * Cos (2α)]* = 0.0 k/ft

Arm = 4.00 ft Moment = 0.0 * 4.00 = 0.0 k-ft/ft

Wind load = *WL factor * Pressure * Wind height* = 1.0 * 0.0 * 5.00 = 0.0 k/ft

Arm = *Ftg + Stem - Wind height / 2* = 12.0 / 12 + 8.00 - 5.00 / 2 = 6.50 ft

Moment = 0.0 * 6.50 = 0.0 k-ft/ft

Backfill seismic = *EQ factor * (Paeh - Pah)* = 0.0 * (1.4 - 1.4) = 0.0 k/ft

Arm = *0.6 * Hs* = 0.6 * 9.00 = 5.40 ft Moment = 0.0 * 5.40 = 0.0 k-ft/ft

Water seismic = *EQ factor * Pwe* = 0.0 * 0.0 = 0.0 k/ft

Arm = *(Water table + Ftg) / 3* = (0.00 + 12.0 / 12) / 3 = 0.33 ft Moment = 0.0 * 0.33 = 0.0 k-ft/ft

Wall seismic = *EQ factor * (WStem + WTaper + WFtg) * kh* = 0.0 * (0.0 + 0.0 + 0.9) * 0.00 = 0.0 k/ft

Moment = *EQ factor * (WStem * (Ftg + Stem / 2) + WTaper * (Ftg + Stem / 3) + WFtg * Ftg / 2) * kh* =

= 0.0 * (0.0 * (12.0 / 12 + 8.00 / 2) + 0.0 * (12.0 / 12 + 8.00 / 3) + 0.9 * 12.0 / 12 / 2) * 0.00 = 0.0 k-ft/ft

Hor. resultant Rh = 1.6 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 1.6 k/ft

Overturning moment OTM = 4.7 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 4.7 k-ft/ft

Arm of hor. resultant = *OTM / Rh* = 4.7 / 1.6 = 3.00 ft

- Resisting

Stem weight *WStem = DL factor * Thickness * Height * γc =* 1.0 * 12.0 / 12 * 8.00 * 0.15 = 1.2 k/ft

Arm = *Toe + Thickness / 2 =* 1.00 + 12.0 / 12 / 2 = 1.50 ft Moment = 1.2 * 1.50 = 1.8 k-ft/ft

Stem taper *WTaper = DL factor * ΔThick * Height / 2 * γc =* 1.0 * (12.0 - 12.0) / 12 * 8.00 / 2 * 0.15 = 0.0 k/ft

Arm = *Toe + Thick + ΔThick / 3 =* 1.00 + 12.0 / 12 - (12.0 - 12.0) / 12 * 2 / 3 = 2.00 ft

Moment = 0.0 * 2.00 = 0.0 k-ft/ft

CMU stem at top = 0.0 k/ft

Arm = *Toe + Thickness / 2 =* 1.00 + 0.0 / 12 / 2 = 0.00 ft

Moment = 0.0 * 0.00 = 0.0 k-ft/ft

Ftg. weight *WFtg = DL factor * Length * Thickness * γc =* 1.0 * 6.00 * 12.0 / 12 * 0.15 = 0.9 k/ft

Arm = *Length / 2 =* 6.00 / 2 = 3.00 ft Moment = 0.9 * 3.00 = 2.7 k-ft/ft

Key weight *WKey = DL factor * Depth * Thickness * γc =* 1.0 * 0.00 / 12 * 0.0 / 12 * 0.15 = 0.0 k/ft

Arm = *Toe + Thickness / 2 =* 1.00 + 0.0 / 12 / 2 = 1.00 ft Moment = 0.0 * 1.00 = 0.0 k-ft/ft

Soil cover = *DL factor * Toe * Soil cover * γ =* 1.0 * 1.00 * 0.00 * 125.0 = 0.0 k/ft

Arm = *Toe / 2 =* 1.00 / 2 = 0.50 ft Moment = 0.0 * 0.50 = 0.0 k-ft/ft

Stem wedge = *DL factor * ΔThick * Height / 2 * γ =* 1.0 * (12.0 - 12.0) / 12 * 8.00 / 2 * 125.0 = 0.0 k/ft

Arm = *Toe + Thick - ΔThick / 3 =* 1.00 + 12.0 / 12 - (12.0 - 12.0) / 12 / 3 = 2.00 ft

Moment = 0.0 * 2.00 = 0.0 k-ft/ft

Backfill weight = *DL factor * Heel * Height * γ =* 1.0 * 4.00 * 8.00 * 125.0 = 4.0 k/ft

Arm = *Ftg - Heel / 2 =* 6.00 - 4.00 / 2 = 4.00 ft Moment = 4.0 * 4.00 = 16.0 k-ft/ft

Backfill slope = *DL factor * (Heel + ΔThick) * Wedge / 2 * γ =*

= 1.0 * (4.0 + (12.0 - 12.0) / 12) * 0.00 / 2 * 125.0 = 0.0 k/ft

Arm = *ftg - (Heel + ΔThick) / 3 =* 6.00 - (4.00 + (12.0 - 12.0) / 12) / 3 = 4.67 ft

Moment = 0.0 * 4.67 = 0.0 k-ft/ft

Water = *DL factor * Heel * Water table * (γs - γ) =* 1.0 * 4.00 * 0.00 * (130.0 - 125.0) = 0.0 k/ft

Arm = *Ftg - Heel / 2 =* 6.00 - 4.00 / 2 = 4.00 ft Moment = 0.0 * 4.00 = 0.0 k-ft/ft

Seismic Pae-Pa = *EQ factor * (Paev - Pav) =* 0.0 * (0.4 - 0.4) = 0.0 k/ft

Arm = *Footing length =* 6.00 ft Moment = 0.0 * 6.00 = 0.0 k-ft/ft

Backfill Pav = *Lat factor * Pav =* 1.0 * 0.4 = 0.0 k/ft

Arm = *Footing length =* 6.00 ft Moment = 0.0 * 6.00 = 0.0 k-ft/ft

Concentrated = *DL factor * Ver load + LL factor * Ver load =* 1.0 * 0.0 + 0.0 * 0.0 = 0.0 k/ft

Arm = *Toe + Stem - Ecc =* 1.00 + (12.0 - 6.0) / 12 = 1.50 ft

Moment = 0.0 * 1.50 = 0.0 k-ft/ft

Surcharge = *Srch factor * (Heel + ΔThick) * Surcharge* =1.0 * (4.0 + (12.0 - 12.0) / 12) * 0.0 = 0.0 k/ft

Arm = *ftg - (Heel + ΔThick) / 2* = 6.00 - (4.00 + (12.0 - 12.0) / 12) / 2 = 4.00 ft

Moment =0.0 * 4.00 = 0.0 k-ft/ft

Strip = *Strip factor * Surcharge * Heel* = 1.0 * 0.0 * 4.00 = 0.0 k/ft

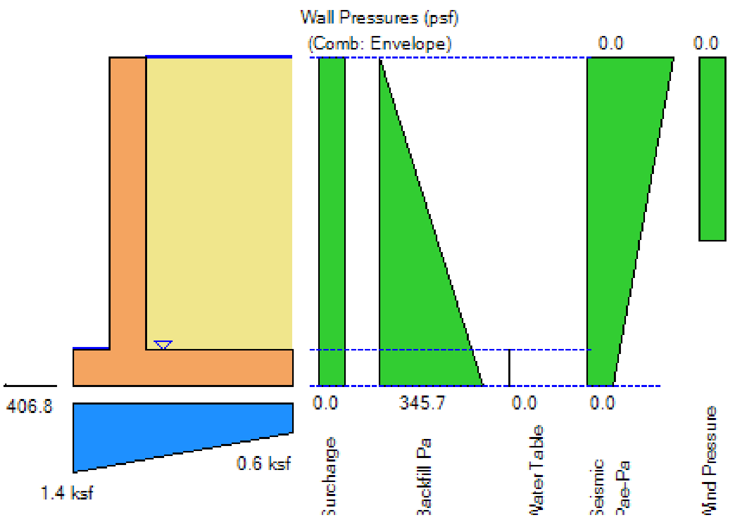
Arm = *Footing - Heel / 2* = 6.00 - 4.00 / 2 = 4.00 ft   Moment =0.0 * 4.00 = 0.0 k-ft/ft

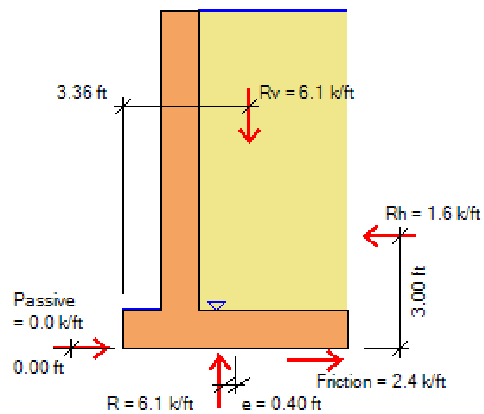
Ver. resultant Rv = *Σ Vertical forces* = 6.1 k/ft

Resisting moment RM = *Σ Moments* = 20.5 k-ft/ft

Arm of ver. resultant = *RM / Rv* = 20.5 / 6.1 = 3.36 ft

Overturning ratio = *RM / OTM* = 20.5 / 4.7 = 4.39 > 2.00 OK





SOIL BEARING PRESSURES (Comb. D+H+W)

$$\text{Eccentricity} = \frac{Ftg}{2} - \frac{RM - OTM}{Rv} = \frac{6.00}{2} - \frac{20.5 - 4.7}{6.1} = 0.40 \text{ ft}$$

Bearing length = *Min (Ftg , 3 * (Ftg / 2 - Ecc))* = Min (6.00, 3 * (6.00 / 2 - 0.40)) = 6.00 ft

$$\text{Toe bearing} = \frac{Rv}{Ftg} + \frac{6 * Rv * Ecc}{Ftg^2} = \frac{6.1}{6.00} + \frac{6 * 6.1 * 0.40}{6.00^2} = 1.4 \text{ ksf} < 4.0 \text{ ksf} \quad \text{OK}$$

$$\text{Heel bearing} = \frac{Rv}{Ftg} - \frac{6 * Rv * Ecc}{Ftg^2} = \frac{6.1}{6.00} - \frac{6 * 6.1 * 0.40}{6.00^2} = 0.6 \text{ ksf}$$

SLIDING CALCULATIONS (Comb. D+H+W)

Passive coefficient *kp = 1 / ka* = 1 / 0.31 = 3.25 ksf

Passive depth *Dp = Soil cover + Ftg + Key - Neglect depth* = 0.00 + (12.0 + 0.0) / 12 - 1.00 = 0.00 ft

Passive pressure top = *kp * γ * Neglect depth* = 3.25 * 125.0 * 1.00 = 0.41 ksf

Passive pressure bot = *kp * γ * (Dp + Neglect depth)* = 3.25 * 125.0 * (0.00 + 1.00) = 0.41 ksf

Passive force = *(Pressure top + Pressure bot) / 2 * Dp* = (0.41 + 0.41) / 2 * 0.00 = 0.0 k/ft

Friction force = *Max (0, Rv * Friction coeff.)* = Max (0, 6.1 * 0.40) = 2.4 k/ft

Sliding ratio = *(Passive + Friction) / Rh* = (0.0 + 2.4) / 1.6 = 1.57 > 1.50 OK

STEM DESIGN (Comb. 0.9D+1.6H+E)

Backfill = *Lat factor * Pah* = 1.6 * 1.2 = 2.0 k/ft

Arm = *Hb / 3* = 8.00 / 3 = 2.67 ft Moment = 2.0 * 2.67 = 5.2 k-ft/ft

Water table = *Lat factor * Pw* = 1.6 * 0.0 = 0.0 k/ft

Arm = *Water table / 3* = 0.00 / 3 = 0.00 ft Moment = 0.0 * 0.00 = 0.0 k-ft/ft

Surcharge = *Lat factor * ka * Surcharge * Hb* = 1.6 * 0.31 * 0.0 * 8.00 = 0.0 k/ft

Arm = *Hb / 2* = 8.00 / 2 = 4.00 ft Moment = 0.0 * 4.00 = 0.0 k-ft/ft

Strip load = *Σ Lat factor * 2 * Q / π * [β - Sin β * Cos (2α)]* = 0.0 k/ft

Arm = 4.00 ft Moment = 0.0 * 4.00 = 0.0 k-ft/ft

Wind load = *WL factor * Pressure * Wind height* = 0.0 * 0.0 * 5.00 = 0.0 k/ft

Arm = *Stem - Wind height / 2* = 8.00 - 5.00 / 2 = 5.50 ft Moment = 0.0 * 5.50 = 0.0 k-ft/ft

Backfill seismic = *EQ factor * (Paeh - Pah)* = 1.0 * (1.1 - 1.1) = 0.0 k/ft

Arm = *0.6 * Hb* = 0.6 * 8.00 = 4.80 ft Moment = 0.0 * 4.80 = 0.0 k-ft/ft

Water seismic = *EQ factor * Pwe* = 1.0 * 0.0 = 0.0 k/ft

Arm = *Water table / 3* = 0.00 / 3 = 0.00 ft Moment = 0.0 * 0.00 = 0.0 k-ft/ft

Max. shear = 2.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 2.0 k/ft

Shear at critical section = *Max shear - Max shear / Hb * d* = 2.0 - 2.0 / 8.00 * 9.7 / 12 = 1.8 k/ft

Max. moment = 5.2 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 5.2 k-ft/ft

Shear strength *φ Vn = φ * 2 * (f'c)½ * 12 * d* ACI Eq. (11-3)

φ Vn = 0.75 * 2 * (4000)½ * 12 * 9.7 = 11.0 k/ft > 1.8 k/ft OK

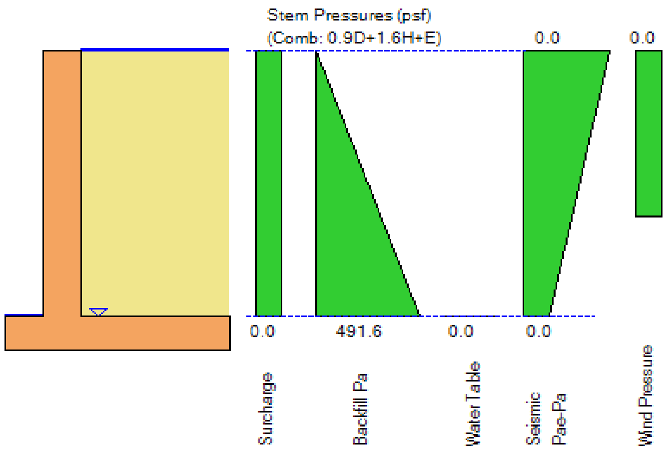
Use #5 @ 12.0 in As = 0.31 in²/ft *ρ = As / b d* = 0.31 / (12 * 9.7) = 0.0027

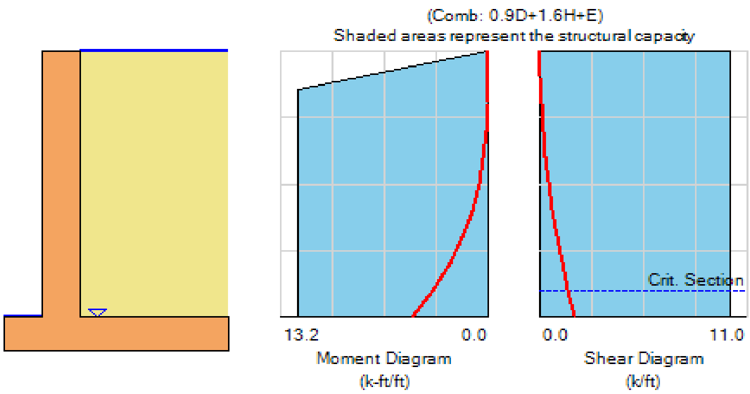
Bending strength *φ Mn = φ * d² * f'c * q * (1 - 0.59 * q)* ACI 10.2.7

φ Mn = 0.90 * 9.7² * 4.0 * 0.040 * (1 - 0.59 * 0.040) = 13.2 k-ft/ft > 5.2 k-ft/ft OK

Hooked *Ldh = 0.02 * fy / (f'c)½ * db * 0.7* = 0.02 * 60.0 * 1000 / (4000)½ * 0.63 * 0.7 = 8.3 in ACI 12.5

Dev. length at footing = *Ftg - Cover* = 12.0 - 3.0 = 9.0 in > 8.3 in OK





HEEL DESIGN (Comb. 1.4D)

Bearing force = 0.0 k/ft (Neglect bearing pressure for heel design)

Arm = *(Bearing1 * Heel² / 2 + (Bearing2 - Bearing1) * Heel² / 6) / Force*

= $(1.9 * 4.00^2 / 2 + (1.3 - 1.9) * 4.00^2 / 6) / 0.0 = 1.33$ ft

Moment = 0.0 * 1.33 = 0.0 k-ft/ft

Concrete weight = *DL factor * Thick * Heel * γc* = 1.4 * 12.0 / 12 * 4.00 * 0.15 = 0.5 k/ft

Arm = *Heel / 2* = 4.00 / 2 = 2.00 ft Moment = 0.5 * 2.00 = 1.1 k-ft/ft

Backfill weight = *DL factor * Heel * Height * γ* = 1.4 * 4.00 * 8.00 * 125.0 = 3.6 k/ft

Arm = *Heel / 2* = 4.00 / 2 = 2.00 ft Moment = 3.6 * 2.00 = 7.2 k-ft/ft

Backfill slope = *DL factor * (Heel + ΔThick) * Wedge / 2 * γ* =

= 1.4 * (4.0 + (12.0 - 12.0) / 12) * 0.00 / 2 * 125.0 = 0.0 k/ft

Arm = *Heel * 2 / 3* = 4.00 * 2 / 3 = 2.67 ft Moment = 0.0 * 2.67 = 0.0 k-ft/ft

Water = *DL factor * Heel * Water table * (γs - γ)* = 1.4 * 4.00 * 0.00 * (130.0 - 125.0) = 0.0 k/ft

Arm = *Heel / 2* = 4.00 / 2 = 2.00 ft Moment = 0.0 * 2.00 = 0.0 k-ft/ft

Surcharge = *Srch factor * (Heel + ΔThick) * Surcharge* =1.4 * (4.0 + (12.0 - 12.0) / 12) * 0.0 = 0.0 k/ft

Arm = *Heel / 2* = 4.00 / 2 = 2.00 ft Moment =0.0 * 2.00 = 0.0 k-ft/ft

Strip = *Strip factor * Surcharge * Width* =1.4 * 0.0 * 4.00 = 0.0 k/ft

Arm = *Distance - ΔStem + Width / 2* = 3.00 - (12.0 - 12.0) / 12 + 4.00 / 2 = 2.00 ft

Moment = 0.0 * 2.00 = 0.0 k-ft/ft

Max. Shear Vu = -0.0 + 0.5 + 3.6 + 0.0 + 0.0 + 0.0 + 0.0 = 6.4 k/ft

Max. Moment Mu = -0.0 + 1.1 + 7.2 + 0.0 + 0.0 + 0.0 + 0.0 = 12.9 k/ft

Shear strength *φ Vn = φ * 2 * (f'c)½ * 12 * d* ACI Eq. (11-3)

φ Vn = 0.75 * 2 * (4000)½ * 12 * 9.7 = 11.0 k/ft > Vu = 6.4 k/ft OK

Use #5 @ 12.0 in As = 0.31 in²/ft *ρ = As / b d* = 0.31 / (12 * 9.7) = 0.0027

Bending strength *φ Mn = φ * d² * f'c * q * (1 - 0.59 * q)* ACI 10.2.7

φ Mn = 0.90 * 9.7² * 4.0 * 0.040 * (1 - 0.59 * 0.040) = 13.2 k-ft/ft > Mu = 12.9 k-ft/ft OK

Cover factor = *Min (2.5, (Cover + db /2, Spacing / 2) / db)* = Min (2.5, (2.0 + 0.63 / 2, 12.0 / 2) / 0.63) = 2.5

Straight *Ld = 3 / 40 * fy / (f'c)½ * Size * Location / Cover * db* ACI Eq. (12-1)

= 3 / 40 * 60.0 * 1000 / (4000)½ * 0.8 * 1.0 / 2.5 * 0.63 = 14.2 in

Hooked *Ldh = 0.02 * fy / (f'c)½ * db * 0.7* =0.02 * 60.0 * 1000 / (4000)½ * 0.63 * 0.7 = 8.3 in ACI 12.5

Dev. length at toe side = *Ftg - Heel - Cover* = (6.00 - 4.00) / 12 - 2.0 = 22.0 in > 14.2 in OK

Dev. length at heel side = *Heel - Cover* = 4.00 / 12 - 2.0 = 46.0 in > 14.2 in OK

TOE DESIGN (Comb. 1.2D+1.6(L+H))

Bearing force = *(Bearing1 + Bearing2) / 2 * Toe* = (2.0 + 1.8) / 2 * 1.00 = 1.9 k/ft

Arm = *(Bearing1 * Toe² / 2 + (Bearing2 - Bearing1) * Toe² / 3) / Force*

= (1.8 * 1.00² / 2 + (2.0 - 1.8) * 1.00² / 3) / 1.9 = 0.51 ft

Moment = 1.9 * 0.51 = 1.0 k-ft/ft

Concrete weight = *DL factor * Thick * Toe * γc* = 1.2 * 12.0 / 12 * 1.00 * 0.15 = 0.2 k/ft

Arm = *Toe / 2* = 1.00 / 2 = 0.50 ft Moment =0.2 * 0.50 = 0.1 k-ft/ft

Soil cover = *DL factor * Toe * Height * γ* = 1.2 * 1.00 * 0.00 * 125.0 = 0.0 k/ft

Arm = *Toe / 2* = 1.00 / 2 = 0.50 ft Moment = 0.0 * 0.50 = 0.0 k-ft/ft

Max. Shear Vu = 1.9 - 0.2 - 0.0 = 1.7 k/ft

Shear at crit. section Vu = *Max shear * (Toe - d) / Toe* = 1.7 * (1.00 - 8.7 / 12) / 1.00 = 0.5 k/ft

Max. Moment Mu = 1.0 - 0.1 - 0.0 = 0.9 k/ft

Shear strength *φ Vn = φ * 2 * (f'c)½ * 12 * d* ACI Eq. (11-3)

φ Vn = 0.75 * 2 * (4000)½ * 12 * 8.7 = 9.9 k/ft > Vu = 0.5 k/ft OK

Use #5 @ 12.0 in As = 0.31 in²/ft *ρ = As / b d* = 0.31 / (12 * 8.7) = 0.0030

Bending strength *φ Mn = φ * d² * f'c * q * (1 - 0.59 * q)* ACI 10.2.7

φ Mn = 0.90 * 8.7² * 4.0 * 0.045 * (1 - 0.59 * 0.045) = 11.8 k-ft/ft > Mu = 0.9 k-ft/ft OK

Cover factor = *Min (2.5, (Cover + db /2, Spacing / 2) / db)* = Min (2.5, (3.0 + 0.63 / 2, 12.0 / 2) / 0.63) = 2.5

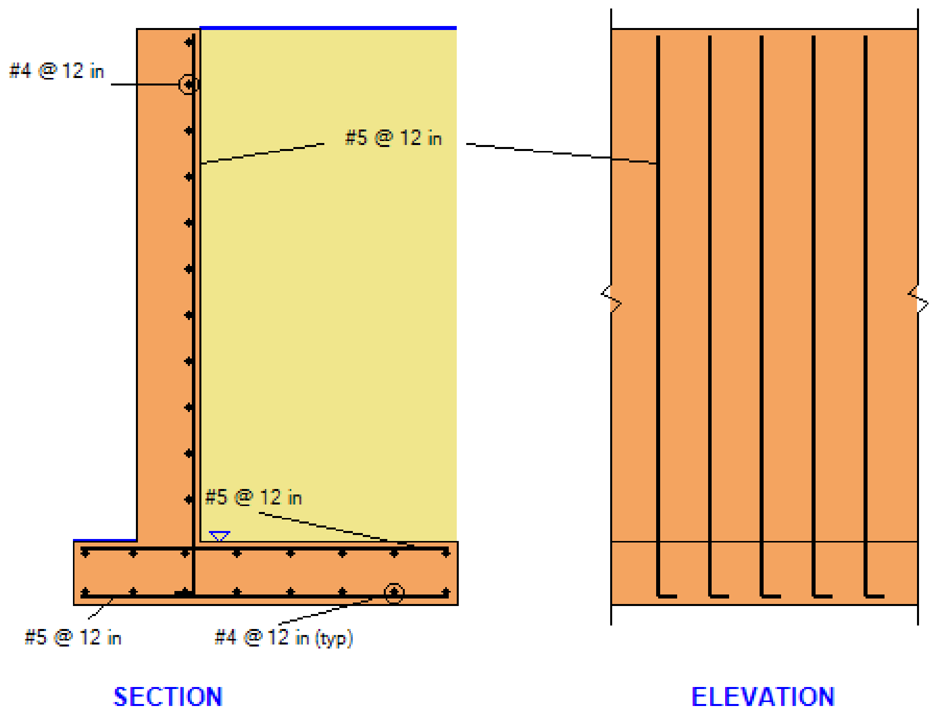
Straight *Ld = 3 / 40 * fy / (f'c)½ * Size * Location / Cover * db* ACI Eq. (12-1)

= 3 / 40 * 60.0 * 1000 / (4000)½ * 0.8 * 1.0 / 2.5 * 0.63 = 14.2 in

Hooked *Ldh = 0.02 * fy / (f'c)½ * db * 0.7* = 0.02 * 60.0 * 1000 / (4000)½ * 0.63 * 0.7 = 8.3 in ACI 12.5

Dev. length at toe side = *Ftg - Toe - Cover* = (6.00 - 1.00) / 12 - 3.0 = 57.0 in > 14.2 in OK

Dev. length at toe side = *Toe - Cover* = 1.00 / 12 - 3.0 = 9.0 in < 14.2 in NG



SHEAR KEY DESIGN (Comb. 0.9D+1.6H+E)

Shear key depth = 0.0 in Shear key thickness = 0.0 in

Passive force = *Lat factor * (Passive1 + Passive2) / 2 * Key* = 1.6 * (0.4 + 0.4) / 2 * 0.0 / 12 = 0.0 k/ft

Shear at crit. section Vu = *Max shear * (Key - d) / Key* = 0.0 * (0.0 - 0.1) / 0.0 = 0.0 k/ft

Arm = *(Passive1 * Key² / 2 + (Passive2 - Passive1) * Key² / 3) / Force*

= (0.4 * 0.00² / 2 + (0.4 - 0.4) * 0.00² / 3) / 0.0 = 0.00 ft

Max. moment Mu = 0.0 * 0.00 = 0.0 k-ft/ft

Shear strength *φ Vn = φ * 2 * (f'c)½ * 12 * d* ACI Eq. (11-3)

φ Vn = 0.75 * 2 * (4000)½ * 12 * 0.1 = 0.1 k/ft > Vu = 0.0 k/ft OK

Use #4 @ 12.0 in As = 0.20 in²/ft *ρ = As / b d* = 0.20 / (12 * 0.1) = 0.1667

Bending strength *φ Mn = φ * d² * f'c * q * (1 - 0.59 * q)* ACI 10.2.7

φ Mn = 0.90 * 0.1² * 4.0 * 2.500 * (1 - 0.59 * 2.500) = 0.1 k-ft/ft > Mu = 0.0 k-ft/ft OK