DESIGN EXAMPLE

The following design example briefly illustrates some of the basic steps used in the allowable stress design of a reinforced concrete masonry cantilever retaining wall.

Example: Design the reinforced concrete masonry cantilever retaining wall shown in Figure 2. Assume level backfill, no surcharge or seismic loading, active earth pressure and masonry laid in running bond. The coefficient of friction between the footing and foundation soil, k_1, is 0.25, and the allowable soil bearing pressure is 2,000 psf (95.8 kPa) (ref. 7).

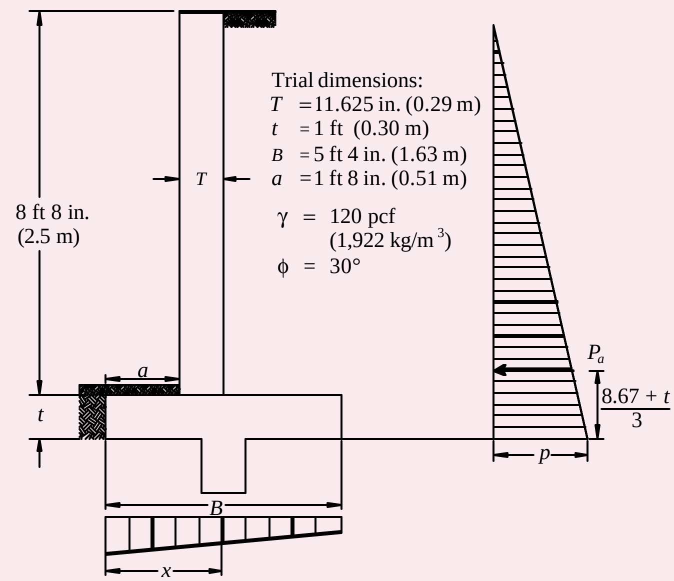

Figure 2—Reinforced Cantilever Retaining Wall Design Example

a. Design criteria:

Wall thickness = 12 in. (305 mm)

f'_m = 1,500 psi (10.3 MPa)

Assumed weights:

Reinforced masonry: 130 pcf (2,082 kg/m³) (solid grout to increase overturning and sliding resistance)

Reinforced concrete: 150 pcf (2,402 kg/m³)

Required factors of safety (ref. 7)

F.S. (overturning) = 1.5

F.S. (sliding) = 1.5

b. Rankine active earth pressure

$P_a = \frac{1}{2}\gamma (H + t)^2 K_a$

where $K_a = \tan^2 (45 - \phi/2) = \tan^2 (45 - 30/2)$
$= 0.33$

$P_a = \frac{1}{2} (120) (9.67)^2 (0.33)$ = 1,851 lb/ft (27 kN/m)

Overturning moment

$M = P_a$ (height/3)
= (1,851 lb/ft)(9.67 ft/3) = 5,966 ft-lb/ft (27 kN·m/m)

c. Resisting moment (about toe of footing)

Component weights:

masonry: (0.97)(8.67 ft)(130 pcf) = 1,093 lb/ft (16 kN/m)

earth: (2.69)(8.67 ft)(120 pcf) = 2,799 lb/ft (41 kN/m)

footing: (1.0)(5.33 ft)(150 pcf) = 800 lb/ft (12 kN/m)

	Weight (lb/ft)	x	Arm (ft) =	Moment (ft-lb/ft)
masonry:	1,093	x	2.67 =	2,918
earth:	2,799	x	3.98 =	11,140
footing:	800	x	2.67 =	2,136
	4,692			16,194

Total resisting moment 16,194 ft-lb/ft
Overturning moment - 5,966 ft-lb/ft
10,228 ft-lb/ft (45.5 kN·m/m)

d. Check factors of safety (F.S.)

F.S. (overturning)

= total resisting moment about toe/overturning moment
= 14,670/5,966
= 2.4 > 1.5 O.K.

$$F.S.(sliding) = \frac{(\Sigma W)k_1 + P_p}{P_a}$$

$P_p = \frac{1}{2} D$ (soil lateral bearing pressure)

set $D = t$ = 1.0 ft (0.30 m)

soil lateral bearing pressure = 150 psf/ft below grade (ref. 7)

$$F.S.(sliding) = \frac{(4{,}692\ lb/ft)(0.25) + \frac{1}{2}(1)(150\ psf/ft)}{1{,}851\ lb/ft}$$

= 1,248/1,851 = 0.67 < 1.5 N.G., need key

e. Pressure on footing

Location of resultant force,

x = (10,228 ft-lb/ft)/(4,692 lb/ft)
= 2.18 ft (0.6 m) (resultant falls in middle 1/3 of base)

e = (5.33 ft/2) - 2.18 = 0.48 ft (0.15 m)

$$p = \frac{W}{A} \pm \frac{Mc}{I} = \frac{W}{bd} \pm \frac{6We}{bd^2}$$

$$p = \frac{4{,}692\ lb/ft}{(1\ ft)(5.33\ ft)} \pm \frac{6(4{,}692\ lb/ft)(0.48\ ft)}{(1\ ft)(5.33\ ft)^2}$$

$p = 880 \pm 476$
= 404 psf (19.3 kPa) and 1,356 psf (64.9 kPa)
< 2,000 psf (95.8 kPa) O.K.

f. Determine size of key

Passive lateral soil resistance = 150 psf/ft of depth and may be increased 150 psf for each additional foot of depth to a maximum of 15 times the designated value (ref. 7). The average soil pressure under the footing is: ½(1,356 + 404) = 880 psf (42.1 kPa).

Equivalent soil depth: 880 psf/120 pcf = 7.33 ft (2.23 m)

P_p = (150 psf/ft)(7.33 ft) = 1,100 psf (52.7 kPa)

For F.S. (sliding) = 1.5, the required total passive soil resistance is: 1.5(1,851 lb/ft) = 2,776 lb/ft (41 kN/m)

The shear key must provide for this value minus the frictional resistance: 2,776 - 1,248 = 1,528 lb/ft (22 kN/m).

Depth of shear key = (1,528 lb/ft)/(1,100 psf) = 1.39 ft (0.42 m), try 1.33 ft (0.41 m).

At 1.33 ft, lateral resistance =

(1,100 psf) + (150 psf/ft)(1.33 ft) = 1,300 lb/ft (19 kN/m)

Depth = (1,528 lb/ft)/[1/2 (1,100 + 1,300)]

= 1.27 ft (0.39 m) < 1.33 ft (0.41 m) O.K.

g. Design of masonry

Tables 1 and 2 can be used to estimate the required reinforcing steel based on the equivalent fluid weight of soil, wall thickness, and wall height. For this example, the equivalent fluid weight = $(K_a)(\gamma)$ = 0.33 x 120 = 40 pcf (6.2 kN/m³).

Using allowable stress design (Table 1) and the conservative equivalent fluid weight of soil of 45 pcf (7.1 kN/m³), this wall requires No. 6 bars at 16 in. o.c. (M #19 at 406 mm o.c.). Using strength design (Table 2), this wall requires No. 5 bars at 16 in. o.c. (M #16 at 406 mm o.c.).

h. Design of footing

The design of the reinforced concrete footing and key should conform to American Concrete Institute requirements. For guidance, see ACI Standard 318 (ref. 2) or reinforced concrete design handbooks.

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GEOMETRY

CMU Stem Height	**8.67**	ft	
CMU Stem Thickness	**12.0**	in	
# of Rows of Blocks	**13**		
Footing Thickness	**12.0**	ft	
Toe Length	**1.67**	ft	
Heel Length	**2.67**	ft	
Soil Cover @ Toe	**0.00**	ft	
Backfill Height	**8.67**	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	0.30	
Seismic Force Pae-Pa	-0.2	k/ft

SOIL BEARING PRESSURES

Allow. Bearing Pressure ..	**2.0**	ksf	
Max. Pressure @ Toe	1.5	ksf	OK
Min. Pressure @ Heel	0.3	ksf	
Total Footing Length	5.34	ft	
Footing Length / 6	0.89	ft	
Resultant Eccentricity e ...	0.61	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

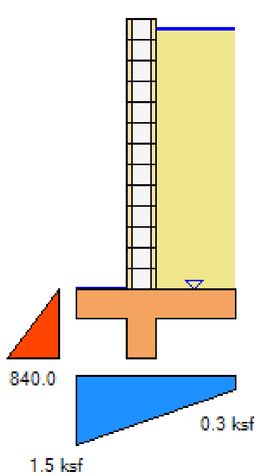
Backfill Density	**120.0**	pcf
Earth Pressure Theory	**Rankine Active**	
Internal Friction Angle	**30.0**	deg
Active Pressure Coeff. Ka	0.33	
Active Pressure @ Wall	40.0	psf/ft
Active Force @ Wall Pa	1.9	k/ft
Water Table Height	**0.00**	ft

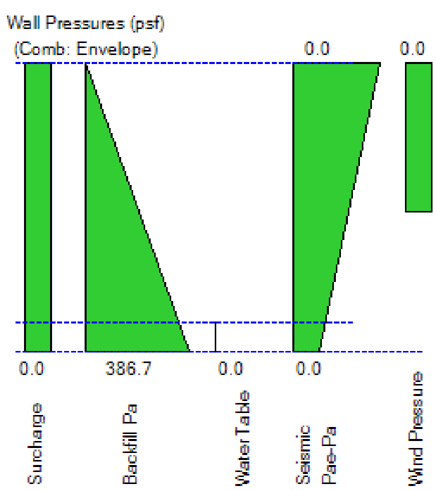
SHEAR KEY DESIGN

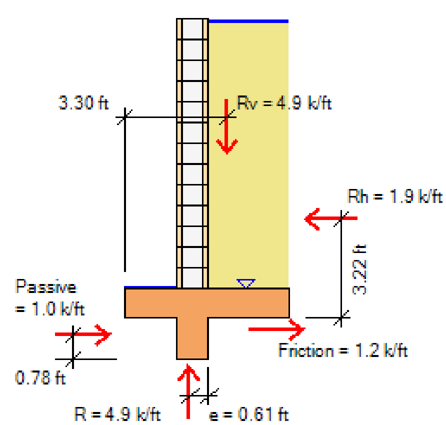
Shear Key Depth	**16.0**	in	
Shear Key Thickness	**12.0**	in	
Max. Shear Force @ Key ..	1.3	k/ft	
Shear Capacity Ratio	0.13		OK

Use vertical bars #4 @ 12 in Hooked at end

Moment Capacity Ratio	0.08		OK







OVERTURNING CALCULATIONS (Comb. D+H+W)

OVERTURNING	Force k/ft	Arm ft	Moment k-ft/ft
Backfill Pa	1.87	3.22	6.0
Water Table	0.00	0.33	0.0
Surcharge Hor	0.00	4.83	0.0
Strip Load Hor	0.00	4.33	0.0
Wind Load	0.00	7.17	0.0
Seismic Pae-Pa ...	0.00	5.80	0.0
Seismic Water	0.00	0.33	0.0
Seismic Selfweight	0.00	0.00	0.0
Rh =	1.87	OTM =	6.0

RESISTING	Force k/ft	Arm ft	Moment k-ft/ft
Stem Top	1.07	0.00	0.0
Stem Taper	0.00	0.00	0.0
CMU Stem at Top ..	0.00	0.00	0.0
Footing Weight	0.80	2.67	2.1
Shear Key	0.20	2.17	0.4
Soil Cover @ Toe .	0.00	0.84	0.0
Stem Wedge	0.00	0.00	0.0
Backfill Weight	2.78	4.01	11.1
Backfill Slope	0.00	4.45	0.0
Water Weight	0.00	4.01	0.0
Seismic Pae-Pa	0.00	5.34	0.0
Pa Vert @ Heel	0.00	5.34	0.0
Vertical Load	0.00	2.17	0.0
Surcharge Ver	0.00	4.01	0.0
Strip Load Ver	0.00	4.01	0.0
Rv =	4.85	RM =	16.0

Arm of Horizontal Resultant = $\frac{6.0}{1.87}$ = 3.22 ft

Arm of Vertical Resultant = $\frac{16.0}{4.85}$ = 3.30 ft

Overturning Safety Factor = $\frac{16.0}{6.0}$ = 2.66 > 1.5 OK

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

Height ft	d in	Mu k-ft/ft	ϕMn k-ft/ft	Ratio	
8.67	8.6	0.0	0.0	0.00	
7.80	8.6	0.0	3.8	0.00	
6.93	8.6	0.1	7.6	0.01	
6.07	8.6	0.2	8.5	0.02	
5.20	8.6	0.4	8.5	0.05	
4.33	8.6	0.9	8.5	0.10	
3.47	8.6	1.5	8.5	0.18	
2.60	8.6	2.4	8.5	0.28	
1.73	8.6	3.6	8.5	0.42	
0.87	8.6	5.1	8.5	0.59	
0.00	8.6	6.9	8.5	0.81	OK

Shear Force @ Crit. Height .. 2.2 k/ft OK

Resisting Shear ϕVc .... 10.0 k/ft

Use vertical bars #5 @ 16 in at backfill side

Do not cut off alternate bars. Solid grouted.

Vert. Bars Embed. Ldh Reqd .. 8.3 in OK

Vert. Bars Splice Length Ld .... 23.2 in

SLIDING CALCS (Comb. D+H+W)

Footing-Soil Friction Coeff. ..	0.25	
Friction Force at Base	1.2	k/ft
Passive Pressure Coeff. Kp .	3.00	
Depth to Neglect Passive	0.00	ft
Passive Pressure @ Wall	360.0	psf/ft
Passive Force @ Wall Pp	1.0	k/ft
Horiz. Resisting Force	2.2	k/ft
Horiz. Sliding Force	1.9	k/ft

Sliding Safety Factor = $\frac{2.2}{1.9}$ = 1.17 < 1.5 NG

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	0.89	0.0
Concrete Weight ..	0.4	1.34	0.5
Backfill Weight	2.5	1.34	3.3
Backfill Slope	0.0	1.78	0.0
Water Weight	0.0	1.34	0.0
Surcharge Ver.	0.0	1.34	0.0
Strip Load Ver.	0.0	0.67	0.0
	2.9	Mu =	5.9

Shear Force @ Crit. Sect. .. 4.4 k/ft OK
Resisting Shear ϕVc .... 11.0 k/ft
Use top bars #5 @ 16 in , Transv. #4 @ 12 in
Resisting Moment ϕMn ...... 10.0 k-ft/ft OK
Develop. Length Ratio at End .... 0.28 OK
Develop. Length Ratio at Toe .... 0.28 OK

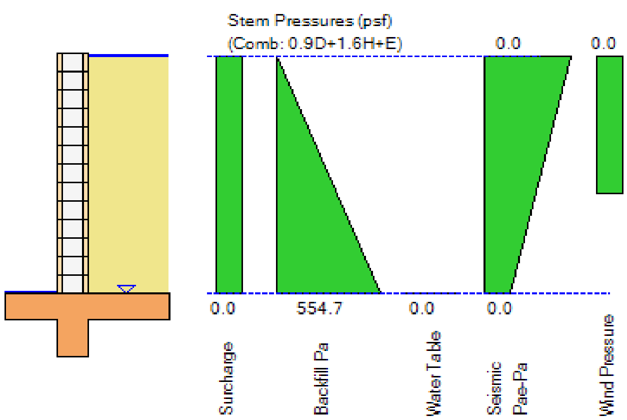
TOE DESIGN (Comb. 0.9D+1.6H+E)

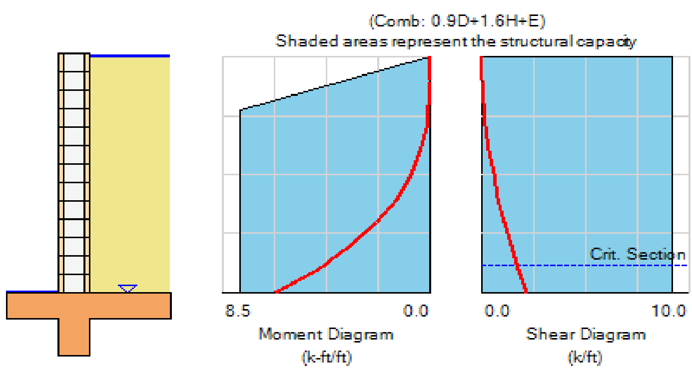
	Force k/ft	Arm ft	Moment k-ft/ft
Upward Presssure	3.7	0.89	3.3
Concrete Weight ..	-0.2	0.84	-0.2
Soil Cover	0.0	0.84	0.0
	3.5	Mu =	3.1

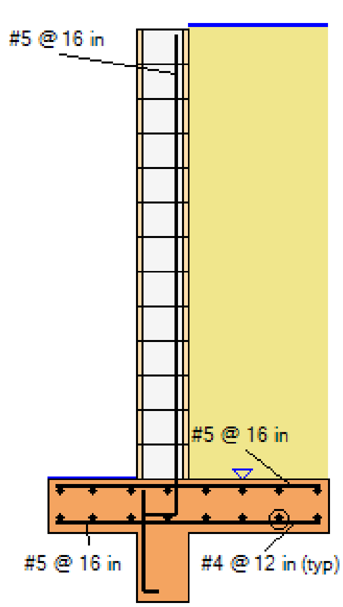
Shear Force @ Crit. Sect. .. 2.0 k/ft OK
Resisting Shear ϕVc .... 9.9 k/ft
Use bott. bars #5 @ 16 in , Transv. #4 @ 12 in
Resisting Moment ϕMn ...... 8.9 k-ft/ft OK
Develop. Length Ratio at End ...... 0.29 OK
Develop. Length Ratio at Stem .... 0.12 OK

MATERIALS

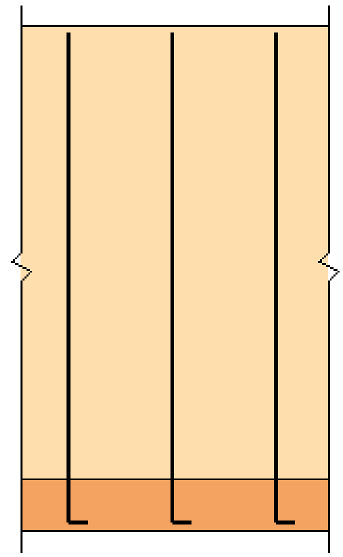
	Stem	Footing	
Concrete f'c	4.0	4.0	ksi
Rebars fy	60.0	60.0	ksi







SECTION


ELEVATION

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

CMU Stem Height	8.67	ft	
CMU Stem Thickness	12.0	in	
# of Rows of Blocks	13		
Footing Thickness	12.0	ft	
Toe Length	1.67	ft	
Heel Length	2.67	ft	
Soil Cover @ Toe	0.00	ft	
Backfill Height	8.67	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 α = 0.000 rad

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

Internal friction $\phi = Int.\ friction * \pi / 180$ = 30.0 * 3.14 / 180 = 0.524 rad

Wall-soil friction $\delta = \phi / 2$ = 0.524 / 2 = 0.262 rad

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

Footing length $ftg = toe + stem + heel$ = 1.67 + 12.0 / 12 + 2.67 = 5.34 ft

Height for Stability $Hs = wedge + backfill + footing$ = 0.00 + 8.67 + 12.0 / 12 = 9.67 ft

Earth pressure theory = Rankine Active   Moist density = 120 pcf   Saturated density = 130 pcf

$$\text{Active coefficient } ka = \frac{Cos\,\beta * [Cos\,\beta - (Cos^2\beta - Cos^2\phi)^{1/2}]^2}{Cos\,\beta + (Cos^2\beta - Cos^2\phi)^{1/2}} = 0.33$$

Active pressure $pa = ka * \gamma$ = 0.33 * 120.0 = 40.0 psf/ft of height

- For stability analysis (non-seismic)

Active force $Pa = ka * \gamma * Hs^2 / 2$ = 0.33 * 120.0 * 9.67² / 2 = 1.9 k/ft

$Pah = Pa * Cos\,\beta$ = 1.9 * Cos (0.000) = 1.9 k/ft , $Pav = Pa * Sin\,\beta$ = 1.9 * Sin (0.000) = 0.0 k/ft

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

Pw = (0.33 * (130.0 - 62.4 - 120.0) + 62.4) * (0.00 + 12.0 / 12)² / 2 = 0.0 k/ft

- For stem design (non-seismic)

Active force $Pa = ka * \gamma * H^2 / 2$ = 0.33 * 120.0 * 8.67² / 2 = 1.5 k/ft

$Pah = Pa * Cos\,\beta$ = 1.5 * Cos (0.000) = 1.5 k/ft , $Pav = Pa * Sin\,\beta$ = 1.5 * Sin (0.000) = 0.0 k/ft

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

Pw = (0.33 * (130.0 - 62.4 - 120.0) + 62.4) * 0.00² / 2 = 0.0 k/ft

Active seismic coeff. $kae = \dfrac{Cos^2(\phi - \alpha - \theta)}{Cos\theta * Cos^2\alpha * Cos(\delta + \alpha + \theta) * [1 + (\dfrac{Sin(\phi + \delta) * Sin(\phi - \beta - \theta)}{Cos(\delta + \alpha + \theta) * Cos(\beta - \alpha)})^{½}]^2}$ = 0.30

- For stability analysis (seismic)

Seismic force $Pae = kae * \gamma * Hs^2 / 2 * (1 - kv)$ = 0.30 * 120.0 * 9.67² / 2 * (1 - 0.0) = 1.7 k/ft

$Paeh = Pae * Cos(\delta + \alpha)$ = 1.7 * Cos (0.262 + 0.000) = 1.6 k/ft

$Paev = Pae * Sin(\delta + \alpha)$ = 1.7 * Sin (0.262 + 0.000) = 0.4 k/ft

Water force $Pwe = kh * (\gamma s - \gamma) * (water + footing)^2 / 2$

Pwe = 0.00 * (130.0 - 120.0) * (0.00 + 12.0 / 12)² / 2 = 0.0 k/ft

- For stem design (seismic)

Seismic force $Pae = kae * \gamma * H^2 / 2$ = 0.30 * 120.0 * 8.67² / 2 = 1.4 k/ft

$Paeh = Pae * Cos(\delta + \alpha)$ = 1.4 * Cos (0.262 + 0.000) = 1.3 k/ft

$Paev = Pae * Sin(\delta + \alpha)$ = 1.4 * Sin (0.262 + 0.000) = 0.4 k/ft

Water force $Pwe = kh * (\gamma s - \gamma) * (water\ table)^2 / 2$

Pwe = 0.00 * (130.0 - 120.0) * 0.00² / 2 = 0.0 k/ft

OVERTURNING CALCULATIONS (Comb. D+H+W)

- Overturning

Backfill = *Lat factor * Pah* = 1.0 * 1.9 = 1.9 k/ft

Arm = *Hs / 3* = 9.67 / 3 = 3.22 ft Moment = 1.9 * 3.22 = 6.0 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 * 0.33 * 0.0 * 9.67 = 0.0 k/ft

Arm = *Hs / 2* = 9.67 / 2 = 4.83 ft Moment = 0.0 * 4.83 = 0.0 k-ft/ft

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

Arm = 4.33 ft Moment = 0.0 * 4.33 = 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 + 8.67 - 5.00 / 2 = 7.17 ft

Moment = 0.0 * 7.17 = 0.0 k-ft/ft

Backfill seismic = *EQ factor * (Paeh - Pah)* = 0.0 * (1.6 - 1.6) = 0.0 k/ft

Arm = *0.6 * Hs* = 0.6 * 9.67 = 5.80 ft Moment = 0.0 * 5.80 = 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 + WFtg) * kh* = 0.0 * (1.0 + 0.8) * 0.00 = 0.0 k/ft

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

= 0.0 * (1.0 * (12.0 / 12 + 8.67 / 2) + 0.8 * 12.0 / 12 / 2) * 0.00 = 0.0 k-ft/ft

Hor. resultant Rh = 1.9 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 1.9 k/ft

Overturning moment OTM = 6.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 6.0 k-ft/ft

Arm of hor. resultant = *OTM / Rh* = 6.0 / 1.9 = 3.22 ft

- Resisting

Stem weight *WStem = DL factor * Height * γm =* 1.0 * 8.67 * 0.12 = 1.1 k/ft
Arm = *Toe + Thickness / 2 =* 1.67 + 12.0 / 12 / 2 = 2.17 ft Moment = 1.1 * 2.17 = 2.3 k-ft/ft
Stem taper *Wtaper = DL factor * ΔThick * Height / 2 * γm =* 1.0 * (12.0 - 12.0) / 12 * 8.67 / 2 * 0.12 = 0.0 k/ft
Arm = *Toe + Thickness / 2 =* 1.67 + 12.0 / 12 / 2 = 0.00 ft
Moment = 0.0 * 0.00 = 0.0 k-ft/ft
CMU stem at top = 0.0 k/ft
Arm = *Toe + Thickness / 2 =* 1.67 + 8.0 / 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 * 5.34 * 12.0 / 12 * 0.15 = 0.8 k/ft
Arm = *Length / 2 =* 5.34 / 2 = 2.67 ft Moment = 0.8 * 2.67 = 2.1 k-ft/ft
Key weight *WKey = DL factor * Depth * Thickness * γc =* 1.0 * 16.00 / 12 * 12.0 / 12 * 0.15 = 0.2 k/ft
Arm = *Toe + Thickness / 2 =* 1.67 + 12.0 / 12 / 2 = 2.17 ft Moment = 0.2 * 2.17 = 0.4 k-ft/ft
Soil cover = *DL factor * Toe * Soil cover * γ =* 1.0 * 1.67 * 0.00 * 120.0 = 0.0 k/ft
Arm = *Toe / 2 =* 1.67 / 2 = 0.84 ft Moment = 0.0 * 0.84 = 0.0 k-ft/ft
Stem wedge = *DL factor * ΔThick * Height / 2 * γ =* 1.0 * (20.0 - 12.0) / 12 * 8.67 / 2 * 120.0 = 0.0 k/ft
Arm = *Toe + Thick - ΔThick / 3 =* 1.67 + 20.0 / 12 - (20.0 - 12.0) / 12 / 3 = 0.00 ft
Moment = 0.0 * 0.00 = 0.0 k-ft/ft
Backfill weight = *DL factor * Heel * Height * γ =* 1.0 * 2.67 * 8.67 * 120.0 = 2.8 k/ft
Arm = *Ftg - Heel / 2 =* 5.34 - 2.67 / 2 = 4.01 ft Moment = 2.8 * 4.01 = 11.1 k-ft/ft
Backfill slope = *DL factor * Heel * Wedge / 2 * γ =*
= 1.0 * 2.7 * 0.00 / 2 * 120.0 = 0.0 k/ft
Arm = *ftg - Heel / 3 =* 5.34 - 2.67 / 3 = 4.45 ft
Moment = 0.0 * 4.45 = 0.0 k-ft/ft
Water = *DL factor * Heel * Water table * (γs - γ) =* 1.0 * 2.67 * 0.00 * (130.0 - 120.0) = 0.0 k/ft
Arm = *Ftg - Heel / 2 =* 5.34 - 2.67 / 2 = 4.01 ft Moment = 0.0 * 4.01 = 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 =* 5.34 ft Moment = 0.0 * 5.34 = 0.0 k-ft/ft
Backfill Pav = *Lat factor * Pav =* 1.0 * 0.4 = 0.0 k/ft
Arm = *Footing length =* 5.34 ft Moment = 0.0 * 5.34 = 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 =* 1.67 + (12.0 - 6.0) / 12 = 2.17 ft
Moment = 0.0 * 2.17 = 0.0 k-ft/ft

Surcharge = *Srch factor * Heel * Surcharge* = 1.0 * 2.7 * 0.0 = 0.0 k/ft

Arm = *ftg - Heel / 2* = 5.34 - 2.67 / 2 = 4.01 ft

Moment = 0.0 * 4.01 = 0.0 k-ft/ft

Strip = *Strip factor * Surcharge * Heel* = 1.0 * 0.0 * 2.67 = 0.0 k/ft

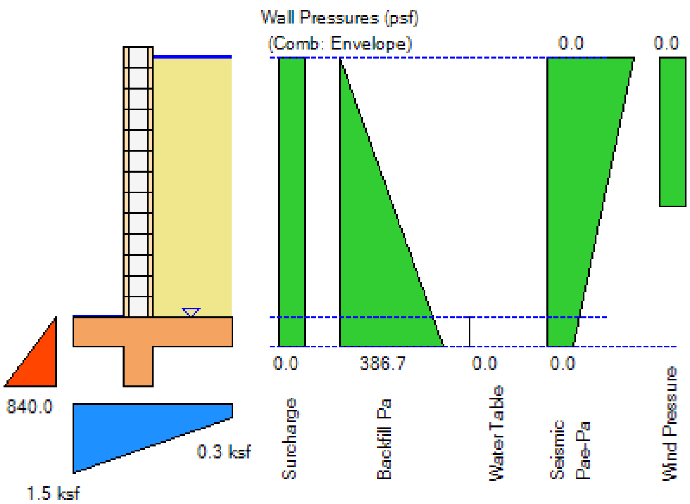
Arm = *Footing - Heel / 2* = 5.34 - 2.67 / 2 = 4.01 ft   Moment = 0.0 * 4.01 = 0.0 k-ft/ft

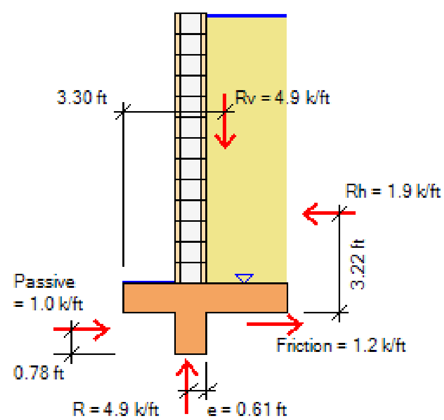
Ver. resultant Rv = *Σ Vertical forces* = 4.9 k/ft

Resisting moment RM = *Σ Moments* = 16.0 k-ft/ft

Arm of ver. resultant = *RM / Rv* = 16.0 / 4.9 = 3.30 ft

Overturning ratio = *RM / OTM* = 16.0 / 6.0 = 2.66 > 1.50 OK





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

Eccentricity = $\frac{Ftg}{2} - \frac{RM - OTM}{Rv} = \frac{5.34}{2} - \frac{16.0 - 6.0}{4.9}$ = 0.61 ft

Bearing length = *Min (Ftg , 3 * (Ftg / 2 - Ecc))* = Min (5.34, 3 * (5.34 / 2 - 0.61)) = 5.34 ft

Toe bearing = $\frac{Rv}{Ftg} + \frac{6 * Rv * Ecc}{Ftg^2} = \frac{4.9}{5.34} + \frac{6 * 4.9 * 0.61}{5.34^2}$ = 1.5 ksf < 2.0 ksf OK

Heel bearing = $\frac{Rv}{Ftg} - \frac{6 * Rv * Ecc}{Ftg^2} = \frac{4.9}{5.34} - \frac{6 * 4.9 * 0.61}{5.34^2}$ = 0.3 ksf

SLIDING CALCULATIONS (Comb. D+H+W)

Passive coefficient *kp = 1 / ka* = 1 / 0.33 = 3.00 ksf

Passive depth *Dp = Soil cover + Ftg + Key - Neglect depth* = 0.00 + (12.0 + 16.0) / 12 - 0.00 = 2.33 ft

Passive pressure top = *kp * γ * Neglect depth* = 3.00 * 120.0 * 0.00 = 0.00 ksf

Passive pressure bot = *kp * γ * (Dp + Neglect depth)* = 3.00 * 120.0 * (2.33 + 0.00) = 0.84 ksf

Passive force = *(Pressure top + Pressure bot) / 2 * Dp* = (0.00 + 0.84) / 2 * 2.33 = 1.0 k/ft

Friction force = *Max (0, Rv * Friction coeff.)* = Max (0, 4.9 * 0.25) = 1.2 k/ft

Sliding ratio = *(Passive + Friction) / Rh* = (1.0 + 1.2) / 1.9 = 1.17 < 1.50 NG

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

Backfill = *Lat factor * Pah* = 1.6 * 1.5 = 2.4 k/ft

Arm = *Hb / 3* = 8.67 / 3 = 2.89 ft Moment = 2.4 * 2.89 = 6.9 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 * 0.33 * 0.0 * 8.67 = 0.0 k/ft

Arm = *Hb / 2* = 8.67 / 2 = 4.33 ft Moment = 0.0 * 4.33 = 0.0 k-ft/ft

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

Arm = 4.33 ft Moment = 0.0 * 4.33 = 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* = 8.67 - 5.00 / 2 = 6.17 ft Moment = 0.0 * 6.17 = 0.0 k-ft/ft

Backfill seismic = *EQ factor * (Paeh - Pah)* = 1.0 * (1.3 - 1.3) = 0.0 k/ft

Arm = *0.6 * Hb* = 0.6 * 8.67 = 5.20 ft Moment = 0.0 * 5.20 = 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 = 2.4 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 2.4 k/ft

Shear at critical section = *Max shear - Max shear / Hb * d* = 2.4 - 2.4 / 8.67 * 8.6 / 12 = 2.2 k/ft

Max. moment = 6.9 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 + 0.0 = 6.9 k-ft/ft

M / V d = 6.9 / (2.4 * 12.0 / 12) = 2.89 *V factor* = 4.0 MSJC 3.3.4.1.2

Shear strength *φ Vn = φ * Min (V factor, 4.0 - 1.75 + M / V d) * Av * (f'm)½* MSJC Eq. (3-23)

φ Vn = 0.80 * Min (4.0, 4.0 - 1.75 + 2.89) * 144.0 * (1500)½ = 10.0 k/ft > 2.2 k/ft OK

Use #5 @ 16.0 in (Back edge) *a = As * fy / (0.8 * f'm * b)* = 0.31 * 60.0 / (0.8 * 1.5 * 16.0) = 1.0 in

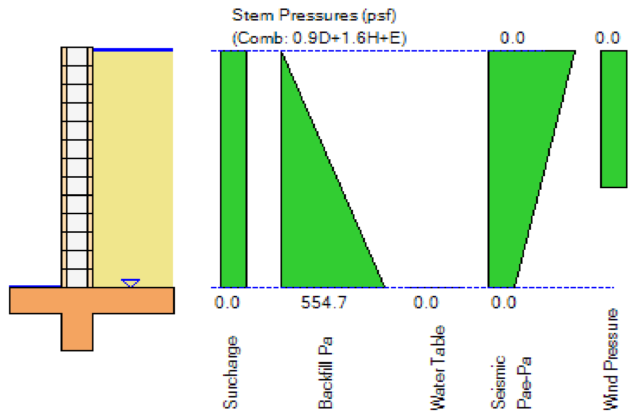
Neutral axis *c = a / 0.8* = 1.0 / 0.8 = 1.2 in < Shell tfs = 1.5 in (Solid grouted)

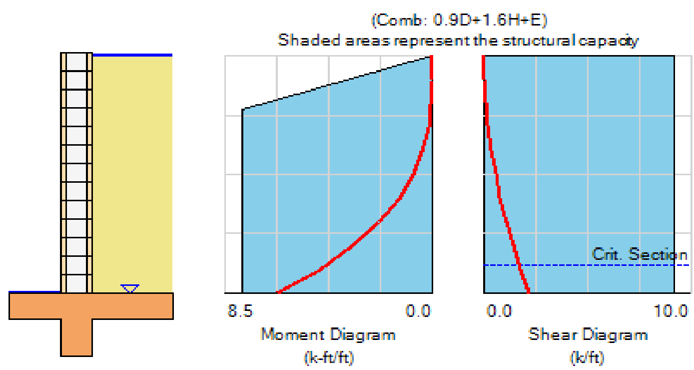
Bending strength *φ Mn = φ * As * fy * (d - a / 2)* MSJC 3.3.5.4

φ Mn = 0.90 * 0.31 * 60.0 * (8.6 - 1.0 / 2) / 16.0 = 8.5 k-ft/ft > 6.9 k-ft/ft OK

Hooked *Ldh = 0.02 * fy / (f'c)½ * db * 0.7* = 0.02 * 60.0 * 1000 / (4000)½ * 0.00 * 0.7 = 0.0 in ACI 12.5

Dev. length at footing = *Ftg - Cover* = 12.0 - 3.0 = 9.0 in > 0.0 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*

= (2.2 * 2.67² / 2 + (1.5 - 2.2) * 2.67² / 6) / 0.0 = 0.89 ft

Moment = 0.0 * 0.89 = 0.0 k-ft/ft

Concrete weight = *DL factor * Thick * Heel * γc* = 1.4 * 12.0 / 12 * 2.67 * 0.15 = 0.4 k/ft

Arm = *Heel / 2* = 2.67 / 2 = 1.34 ft Moment = 0.4 * 1.34 = 0.5 k-ft/ft

Backfill weight = *DL factor * Heel * Height * γ* = 1.4 * 2.67 * 8.67 * 120.0 = 2.5 k/ft

Arm = *Heel / 2* = 2.67 / 2 = 1.34 ft Moment = 2.5 * 1.34 = 3.3 k-ft/ft

Backfill slope = *DL factor * Heel * Wedge / 2 * γ* =

= 1.4 * 2.7 * 0.00 / 2 * 120.0 = 0.0 k/ft

Arm = *Heel * 2 / 3* = 2.67 * 2 / 3 = 1.78 ft Moment = 0.0 * 1.78 = 0.0 k-ft/ft

Water = *DL factor * Heel * Water table * (γs - γ)* = 1.4 * 2.67 * 0.00 * (130.0 - 120.0) = 0.0 k/ft

Arm = *Heel / 2* = 2.67 / 2 = 1.34 ft Moment = 0.0 * 1.34 = 0.0 k-ft/ft

Surcharge = *Srch factor * Heel * Surcharge* = 1.4 * 2.7 * 0.0 = 0.0 k/ft

Arm = *Heel / 2* = 2.67 / 2 = 1.34 ft Moment = 0.0 * 1.34 = 0.0 k-ft/ft

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

Arm = *Distance + Width / 2* = 3.00 + 4.00 / 2 = 0.67 ft

Moment = 0.0 * 0.67 = 0.0 k-ft/ft

Max. Shear Vu = -0.0 + 0.4 + 2.5 + 0.0 + 0.0 + 0.0 + 0.0 = 4.4 k/ft

Max. Moment Mu = -0.0 + 0.5 + 3.3 + 0.0 + 0.0 + 0.0 + 0.0 = 5.9 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 = 4.4 k/ft OK

Use #5 @ 16.0 in As = 0.23 in²/ft *ρ = As / b d* = 0.23 / (12 * 9.7) = 0.0020

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 * 0.030 * (1 - 0.59 * 0.030) = 10.0 k-ft/ft > Mu = 5.9 k-ft/ft OK

Cover factor = *Min (2.5, (Cover + db /2, Spacing / 2) / db)* = Min (2.5, (2.0 + 0.63 / 2, 16.0 / 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* = (5.34 - 2.67) / 12 - 2.0 = 30.0 in > 14.2 in OK

Dev. length at heel side = *Heel - Cover* = 2.67 / 12 - 2.0 = 30.0 in > 14.2 in OK

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

Bearing force = *(Bearing1 + Bearing2) / 2 * Toe* = (2.7 + 1.8) / 2 * 1.67 = 3.7 k/ft

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

= (1.8 * 1.67² / 2 + (2.7 - 1.8) * 1.67² / 3) / 3.7 = 0.89 ft

Moment = 3.7 * 0.89 = 3.3 k-ft/ft

Concrete weight = *DL factor * Thick * Toe * γc* = 0.9 * 12.0 / 12 * 1.67 * 0.15 = 0.2 k/ft

Arm = *Toe / 2* = 1.67 / 2 = 0.84 ft Moment = 0.2 * 0.84 = 0.2 k-ft/ft

Soil cover = *DL factor * Toe * Height * γ* = 0.9 * 1.67 * 0.00 * 120.0 = 0.0 k/ft

Arm = *Toe / 2* = 1.67 / 2 = 0.84 ft Moment = 0.0 * 0.84 = 0.0 k-ft/ft

Max. Shear Vu = 3.7 - 0.2 - 0.0 = 3.5 k/ft

Shear at crit. section Vu = *Max shear * (Toe - d) / Toe* = 3.5 * (1.67 - 8.7 / 12) / 1.67 = 2.0 k/ft

Max. Moment Mu = 3.3 - 0.2 - 0.0 = 3.1 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 = 2.0 k/ft OK

Use #5 @ 16.0 in As = 0.23 in²/ft *ρ = As / b d* = 0.23 / (12 * 8.7) = 0.0022

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 * 0.033 * (1 - 0.59 * 0.033) = 8.9 k-ft/ft > Mu = 3.1 k-ft/ft OK

Cover factor = *Min (2.5, (Cover + db /2, Spacing / 2) / db)* = Min (2.5, (3.0 + 0.63 / 2, 16.0 / 2) / 0.63) = 2.5

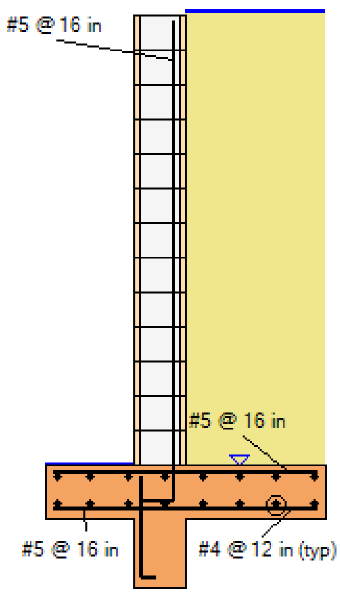
Straight *Ld = 3 / 40 * fy / (f'c)½ * Size * Location / Cover * db* ACI Eq. (12-1)

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

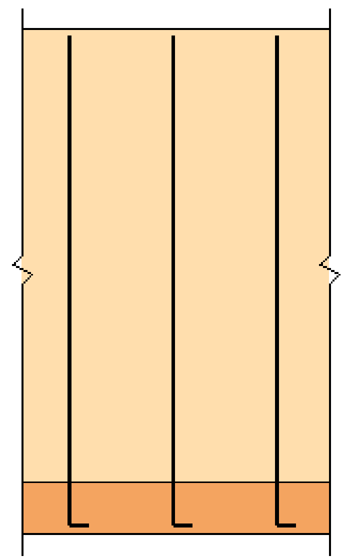
Hooked *Ldh = 0.02 * fy / (f'c)½ * db * 0.7* = 0.02 * 60.0 * 1000 / (4000)½ * 0.63 * 0.7 = 8.3 in ACI 12.5

Dev. length at toe side = *Ftg - Toe - Cover* = (5.34 - 1.67) / 12 - 3.0 = 41.0 in > 14.2 in OK

Dev. length at toe side = *Toe - Cover* = 1.67 / 12 - 3.0 = 17.0 in > 14.2 in OK



SECTION



ELEVATION

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

Shear key depth = 16.0 in Shear key thickness = 12.0 in

Passive force = *Lat factor * (Passive1 + Passive2) / 2 * Key* = 1.6 * (0.8 + 0.4) / 2 * 16.0 / 12 = 1.3 k/ft

Shear at crit. section Vu = *Max shear * (Key - d) / Key* = 1.3 * (16.0 - 8.8) / 16.0 = 0.6 k/ft

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

= (0.4 * 16.00² / 2 + (0.8 - 0.4) * 16.00² / 3) / 1.3 = 0.47 ft

Max. moment Mu = 1.3 * 0.47 = 0.6 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 * 8.8 = 10.0 k/ft > Vu = 0.6 k/ft OK

Use #4 @ 12.0 in As = 0.20 in²/ft *ρ = As / b d* = 0.20 / (12 * 8.8) = 0.0019

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

φ Mn = 0.90 * 8.8² * 4.0 * 0.029 * (1 - 0.59 * 0.029) = 7.7 k-ft/ft > Mu = 0.6 k-ft/ft OK