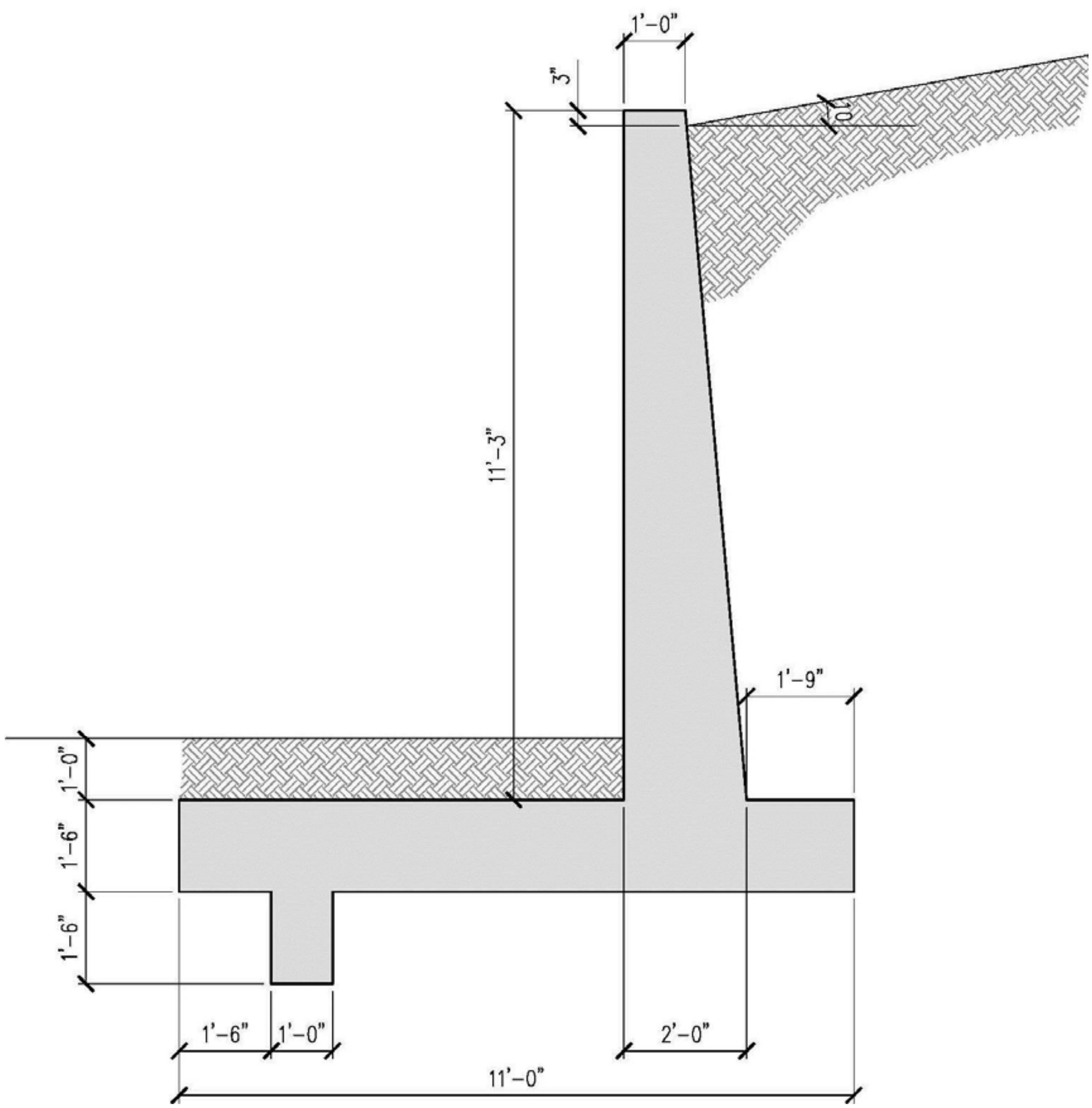
EXAMPLE:

Design of a retaining wall based on AASHTO LRFD Design Standards and the following information

1) **Design Data:**

a) **Wall Dimensions:**



b) Soil Data:

Pp = Passive Soil Pressure = 400 pcf

qua= Strength Limit Bearing Pressure = 4500 pcf

γ = Soil Density = 120 pcf

fr = Foundation Friction Factor = 0.4

Pa = Active Soil Pressure = 30 PCf

Kh= Horizontal Seismic Acceleration Co. = 0.15

que = Extreme Event Bearing Pressure = 9000 psf

Eq= Seismic Pressure = 10 PCf

Surcharge = 1 ft

c) Material Data:

f'c= 4000 psi

fy = 60000 psi

Es= 29000 ksi

Ec = 3600 ksi

d) Loads

1. Active Soil Pressure:

   Ha = 30 pcf x $(1.5\ ft + 11\ ft + 1.75 \times TAN\ 10)^2$ x ½ = 2,460.89 lbs

2. Passive Soil Pressure:

$Hp = 400$ pcf x (1ft + 1.5 ft + 1.5 ft) ^{2} x ½ = 3,200 lbs

3. Surcharge

H_{seur} = (30 Pcf/120 pcf) x 120 Pcf x 1 ft x (11 ft + 1.5 ft + TAN 10 x 1.75 ft) = 384.25 lbs

4. wall weight

W1 = 11.25 ft x (1 ft +2 ft) x 1/2 x 150 pcf = 2531.25 lbs

5. foundation weight

W2 = 11 ft x 1.5 ft x 150 pcf =2475lbs

6. soil weight

W3= (1.75 ft x11 ft +1.75ft x TAN 10 x 1.75 x 1/2) x 120 pcf

w3= 2342.40 lbs

7. key weight

W4 = (1.5 ft x1.0 ft) x 150 pcf =225 lbs

8. surcharge weight

Wsur= 1 ft x 1.75 ft x 120 pcf = 210 lbs

9. seismic loads

Heq = 10 pcf x (11 ft + 1.5 ft + 1.75 ft x TAN10)^2 +0.15 x 2531.25 +0.15 x 2342.40

Heq= 1640.60 lbs +379.70 lbs + 351.36 lbs =2371.66 lbs

e) Un-factored Loads

vertical loads:

- Wall = 2531.25 lbs
- Foundation= 2475 lbs
- Soil =2342.4 lbs
- Key= 225 lbs
- Wsur= 210 lbs
- MR1 = (11 ft -1.75 ft -(1 ft +2 ft) x 1/2 x1/2) x 2531.25 lbs

  MR1 = 21515.63 lbs_ft
- MR2= (11 ft x 1/2) x 2475 lbs = 13612.5 lbs_ft
- MR3= [(11 ft-1.75 ft x1/2) + 1.75 ft x TAN10 x 2/3] x 2342.4 lbs

  MR3= =24198.67 lbs-ft
- MR4 = 2 ft x 225 lbs = 450 lbs_ft
- MR5= 210 lbs x (11 ft -1.75 ft /2)= 2126.25 lbs_ft

Horizontal loads:

- Active Pressure = 2460.89 lbs
- Surcharge Pressure = 384.26 lbs
- Seismic Pressure = 2371.66 lbs
- M_{D1}= (11 ft +1.75 ft x TAN 10 + 1.5 ft) x 1/3 x 2460.89 lbs

  MD1= 10506.83 lbs_ft
- M_{D2} = (11 ft +1.75 ft x TAN 10 + 1.5 ft) x 1/2 x 384.26 lbs = 2460.8 lbs_ft

- M_{D3}= 1640.60 lbs x (11 fb + 1.75 ft x TAN 10 x 1.5 ft) x 1/2 + 379.40 lbs x (11.25 ft/2 +1.5 ft) +351.36 lbs x (11 ft +1.75 ft x TAN 10 +1.5 ft) x 1/2

  M_{D3}= 15462.31 lbs_ft

f) **Strength Limit I:**

1.25 DL + 1.75 LL +1.35 Ev +1.50 EH

V = 1.25 x (2531.25 lbs + 2475 lbs +225lbs) +1.75 x 210 lbs +1.35 x (2342.4 lbs)

V = 10,068.81

M_{UR} = 1.25 x (21515.62 lbs _ft + 13612.5 lbs_ft + 450 lbs_ft) + 1.35 x 24198.67 lbs_ft + 1.75 x 2126.5 lbs_ft

M_{UR}= 80862.23 lbs_ft

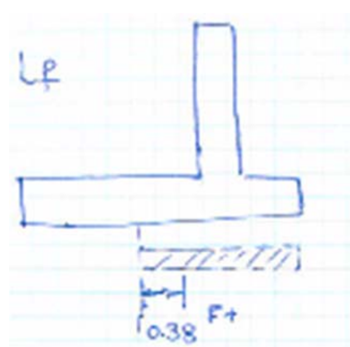
H_U = 1.5 x (2460.89 lbs) + 1.75 x 384.26 lbs = 4363.79 lbs

M_{UH} = 1.5 x 10506.84 lbs_ft + 1.75 x 2460.89 lbs_ft = 20066.82 lbs

Stability Checks:

Eccentricity Checks:

e_{ec} = 0.5 x Lf – (M_{uR} – M_{uLL} – M_{UH}) / (V_U–V_{LL})



e_{ec} =0.5x 11 ft –(80862.23-1.75x2126.5-20066.82)/(10068.81-1.75x210)

e_{ec} = -0.38 ft < emax = 3.66 ft

Bearing Check:

e_b = 0.5 x 11 ft – (80862.23 -20066.82) / (10068.81) = -0.54 ft

q_b = V / (L_f – 2 x e_b) = 10068.8 lbs/ (11 ft – 2x 0.54) = 1015.00 psf

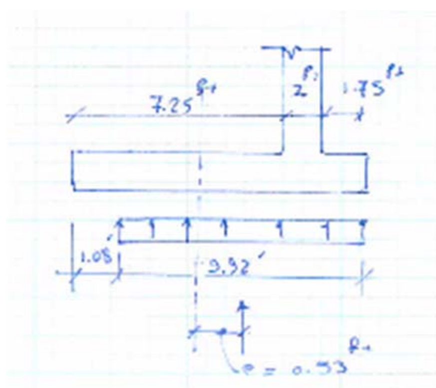
R= qa / qb = 4500 /1015 = 4.44

Sliding Check:

H_R = (10068.8 lbs – 1.75 x 210 lbs) x 0.4 + 0.5 x 3200 lbs = 5480.52 lbs

H_U = 4363.79 lbs

R = HR/ HU = 5480.52 lbs/4363.79 lbs = 1.26



Foundation Force Calculation:

L` = L_f – 2 x e_b

L` = 11 ft – 2 x 0.54 ft

L` = 9.92 ft

q_{u1} = 1015.00 psf

M_{qu1}= 1015.00 psf x (7.25 ft – 1.08 ft)^2 x 1/2 = 19320 lbs_ft

M_{W1} = -1.25 x 1.5 ft x 7.25 ft x 150 pcf x 1/2 x 7.25 ft = – 7391.60 lb_ft

M_{U1} = 11928.40 lbs-ft reinforcing at bottom V_{U1} = 4220.89 lbs

q_{u2} = 1015 psf

M_{qU2} = 1015 x (1.75 ft)^2 x1/2 = 1554.22 lbs_ft

M_{W2} = -1.25 x 1.75 ft x 1.5 ft x 150 pcf x 1.75 ft x 1/2 = - 430.66 lbs_ft

M_{W3} = -1.35 x 2342.4 lbs x 1/2 x 1.75 ft = - 2766.96

M_{W4} = - 1.75 x 210 lbs x 1/2 x 1.75 ft = -321.56

M_{U2} = -1965.00 reinforcing at top V_{U2} = -2222.11 lbs

g) Strength Limit Ia:

0.9 DL + 1/75 LL + 1.00 Ev + 1.50 EH

V_u = 0.9 x (2531.25 lbs + 2475 lbs + 225 lbs) + 1.75 x 210 lbs + 1.00 x 2342.4 lbs

V_u = 7418.03 lbs

M_{uR} = 0.9 x (21515.62 lbs-ft + 13612.5 lbs-ft +450 lbs-ft) + 1.00 x 24198.67 lbs-ft +1.75 x 2126.5 lbs-ft

M_{uR} = 59940.35 lbs-ft

H_U = 4363.79 lbs

M_{UH} = 20066.82 lbs-ft

<u>Eccentricity Check:</u>

e_{ec} = 0.5 x L_f - (M_{UR} - M_{ULL} - M_{UH}) / (V_U - V_{ULL})

e_{ec}= 0.5 x 11 ft - (59940.35 lbs-ft - 1.75 x 2126.5 lbs-ft - 20066.82 lbs-ft) / (7418.02 lbs - 1.75x210 lbs)

e_{ec} = 0.372< emax = 3.66 ft

Bearing Check:

e_b = 0.5 x 11 ft – (59940.35 lbs-ft – 20066.82 lbs-ft)/7418.02 lbs

e_b = 0.125 ft

$q_b = V_u/(L_f - 2 \times e_b)$ = 7418.02 lbs / (11 ft – 2 x 0.125 ft) = 690.05 lb/ft^2

R= qa / qb = 4500 /690.05 = 6.52

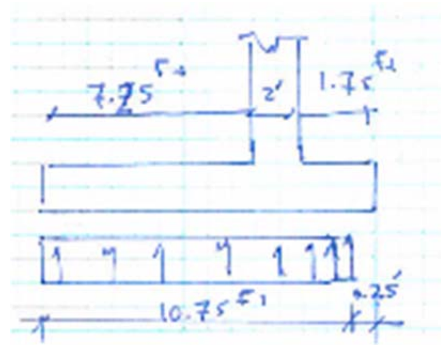
Sliding Check:

H_R = (7418.02 lbs – 1.75 x 210 lbs) x 0.4 – 0.5 x 3200 lbs = 4420.21 lbs

H_U = 4363.79 lbs

R= H_R/H_U = 4420.21 lbs/4363.79 lbs = 1.01

Force at Foundation:



L` = $L_f - 2 \times e_b$ = 11 ft – 2 x 0.125 ft = 10.75 ft

q_{U1} = 690.05 psf

M_{qu1} = 690.05 psf x (7.25 ft)^2 x 1/2 = 18135.38 lbs-ft

M_{w1}= -0.9 x 1.5 ft x 7.25 ft x 150 pcf x 1/2 x 7.25 ft = – 5321.95 lbs-ft

M_{u1}= 12813.42 lbs-ft reinforcing at bottom V_{u1} = 3534.74 lbs

q_{u2}= 690.05 psf

M_{qu2} = 690.05 psf x (1.5 ft)^2 x 1/2 = 776.30 lbs-ft

M_{w2} = -0.9 x 1.75 ft x 1.5 ft x 150 pcf x 1.75 ft x 1/2 = -310.08 lbs-ft

M_{W3} = -1.0 x 2342.4 lbs x 1/2 x 1.75 ft = - 2049.6

M_{w4} = - 1.75 x 210 lbs x1/2 x 1.75 ft = -321.56 lbs-ft

M_{u2} = -1904.94 lbs-ft

V_{u2} = 2019.10 lbs

h) *Strength limit III:*

0.9 DL + 1.00 EV + 1.50 EH +1.40 WL

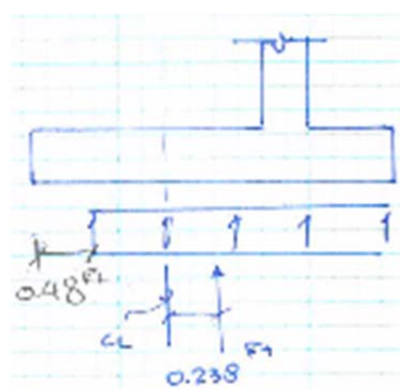
V_u= 0.9 x (2531.25 lbs +2475 lbs + 225 lbs) +1.00 x 2342.4 lbs = 7050.52 lbs

M_{uR} = 0.9 x (21515.62 lbs-ft + 13612.5 lbs-ft + 450 lbs-ft) +1.0 x 24198.67 lbs-ft

M_{uR} = 56218.98 lbs-ft

H_u = 1.5 x (2460.89 lbs) = 3691.34 lbs

M_{uH} = 1.5 x 10506.84 lbs-ft = 15760.26 lbs-ft



Eccentricity Check:

e_{ec}= 0.5 x L_f – (M_{uR} – M_{uH}) /V_u

e_{ec}= 0.50 x 11 ft – (56218.98 lbs-ft – 15760.26 lbs-ft) / (7050.52 lbs)

e_{ec}= -0.238 ft < emax = 3.66 ft

Bearing Check:

$eec = -0.238$ ft$=eb$

$q_b = V_u / (L_f - 2 \times e_b)$ = 7050.52 lbs/ (11 ft - 2 x 0.238 ft)

q_b = 670.20 lb/ft^2

R= qa / qb = 4500 /670.20 = 6.71

Sliding:

H_R = 7050.52 lbs x 0.4 +0.5 x 3200 lbs =4420.21 lbs

H_u = 3691.34 lbs

R= H_R/ H_U = 4420.21 lbs / 3691.34 lbs = 1.20

Forces at Foundation

L` = L_f - 2 x e_b = 11 ft - 2 x 0.238 ft = 10.52 ft

q_{u1}= 670.20 PSF

M_{qu1} = 670.20 PSF x (7.25 ft - 0.48 ft)^2 x 1/2 = 15358.60

M_{w1}= - 0.9 x 1.5 ft x 7.25 ft x 150 pcf x 1/2 x 7.25 ft = -5321.95 lbs-ft

M_{u1} = 10036.67 lbs-ft reinforcing at botom V_{u1} = 306778 lbs

q_{u2} = 670.20 PSF

M_{qu2} = 670.20 PSF x (1.75 ft)^2 x 1/2 = 1026.25 lbs-ft

M_{w2} = -310.08 lbs-ft

M_{w3}= - 2049.6lbs-ft

M_{u2} = -1333.43 lbs-ft V_{u2}= -1524.9 lbs

i) **Strength Limit IV:**

1.5 DL +1.35 EV +1.50 EH

V_u = 1.5 x (2531.25 lbs + 2475 +225 lbs) +1.35 x 2342.4 lbs = 11009.115 lbs

M_{uR} = 1.5 x (21515.62 lbs-ft + 13612.5 lbs-ft +450 lbs-ft) + 1.35 x 24198.67 lbs-ft = 86035.38

H_R = 3691.34 lbs

M_{UH}= 15760.26 lbs-ft

Eccentricity Check:

e_{ec} = 0.5 x L_f - (M_{uR} - M_{uH}) / V_u

e_{ec} = 0.5 x 11 ft - (86035.38 - 15760.26 lbs) / 11009.115 lbs

e_{ec}= -0.883 ft < emax = 3.66 ft

Bearing Check:

e_{ec} = - 0.883 = eb

q_b = Vu /(Lf - 2 x eb) = 11009.115 lbs / (11 ft - 2 x 0.883 ft)

q_b = 1192.24 psf

$R = qa / qb = 4500 / 1192.24 = 3.77$

Sliding Check:

$H_R = 11009.115$ lbs x 0.4 + 0.5 x 3200 lbs = 6003.65 lbs

$H_U = 3691.34$ lbs

$R = H_R/H_U = 6003.65$ lbs / 3691.34 lbs = 1.63

Forces at Foundation:

$L` = L_f - 2 \times e_b = 11$ ft - 2 x 0.883 ft = 9.234 ft

$q_{u1} = 1192.24$ psf

$M_{qu1} = 1192.24$ psf x (7.25 ft - 1.76 ft)^2 x 1/2 = 17967.116 lbs-ft

$M_{w1} = -1.5$ x 1.5 ft x 7.25 ft x 150 pcf x 1/2 x 7.25 ft = - 8869.92 lbs-ft

$M_{u1} = 9097.20$ lbs-ft reinforcing at bottom $V_{u1} = 4098.52$ lbs

$q_{u2} = 1192.24$ psf

$M_{qu2} = 1192.24$ psf x (1.75 ft)^2 x 1/2 = 1825.62 lbs-ft

$M_{w2} = -1.5$ x 1.75 ft x 1.5 ft x 150 pcf x 1.75 ft x 1/2 = -516.80 lbs-ft

$M_{w3} = -1.35$ x 2342.4 lbs x 1/2 x 1.75 ft = -2766.96 las-ft

$M_{u2} = -1458.14$ lbs-ft reinforcing at top $V_{u2} = 1666.45$ lbs

j) Extreme Event I:

0.9 DL + 1.00 EV + 1.00 EH +1.00 EQ

$V_u = 7050.52$ lbs

M_{uR} = 56218.98 lbs-ft

Hu= 1.0 x 2460.89 lbs +1.0 x 2368.94 lbs = 4828.94 lbs

M_{uH} = 10506.84 lbs-ft + 15462.36 lbs-ft = 25969.2 lbs-ft

Eccentricity Check:

e_{ec} = 0.5 x Lf - (MuR - MuH) / Vu

e_{ec} = 0.5 x 11 ft - (56218.98 lbs-ft - 25969.2 lbs-ft) / 7050.52 lbs

e_{ec}= 1.20 ft < emax = 3.66 ft

Bearing Check:

e_{ec} = 1.21 ft = eb

q_b= V_u /(Lf - 2 x e_{ec})= 7050.52 lbs /(11 ft - 2 x 1.21 ft) = 821.74 psf

R= qa / qb = 9000 /821.74 = 10.95

Sliding Check:

HR = 7050.52 lbs x 0.45 +1.0 x 3200 lbs = 6372.47 lbs

Hu = 4828.94 lbs

R= H_R/ H_U = 6372.47 lbs / 4828.94 lbs = 1.32

Force Foundation:

$L` = L_f - 2 \times e_f = 11$ ft $- 2 \times 1.21$ ft $= 8.58$ ft

$q_{u1} = 821.74$ PSF

$M_{qu1} = 821.74$ psf x (7.25 ft)^2 x 1/2 = 21596.35

$M_{w1} = - 0.9 \times 1.5$ ft x 7.25 ft x 1/2 = -5321.95 lbs-ft

M_{u1} =16274.40 reinforcement at bottom $V_{u1} = 4489.49$ lbs

$q_{u2} = 821.74$ PSF

$M_{w2} = - 0.9 \times 1.75$ ft x 1.5 ft x 150 pcf x 1.75 ft x 1/2 = -310.08 lbs-ft

$M_{w3} = -1.0 \times 2342.4$ lbs x 1/2 x 1.75 ft = - 2049.60 lbs-ft

$M_{u2} = -2359.68$ lbs-ft top reinforcing $V_{u2} = 2696.78$ lbs

k) Extreme Event Ia:

1.25 DL + 1.35 EV 1.00 EH + 1.00 EQ

$V_u = 1.25 \times (2531.25$ k + 2475 lbs +225 lbs) +1.35 x 2342.4 lbs

$V_u = 9701.30$

$M_{uR} = 1.25 \times (21515.62$ lbs-ft +13612.5 lbs-ft +450 lbs-ft) +1.35 x 24198.67 lbs-ft

$M_{uR} = 77140.85$ lbs

$M_{uH} = 25969.2$ lbs-ft

<u>Eccentricity Check:</u>

$e_{ec} = 0.5 \times L_f - (M_{UR} - M_{uH}) / V_u$

e_{ec} = 0.5 x 11 ft – (77140.85 lbs-ft – 25969.2 lbs-ft) / 9701.30 lbs

eec= 0.225 ft < emax = 3.66 ft

Bearing Check:

e_{ec} = 0.225 = eb

$q_b = V_u$ / (Lf – 2 x e_{ec})= 9701.30 lbs / (11 – 2 x 0.225)

q_b = 919.50 psf

R= qa / qb = 9000 /919.50 = 9.79

Sliding:

HR = 9701.30 lbs x 0.45 + 1.0 x 3200 lbs = 7565.59 lbs

H_u= 4828.94 lbs

R = H_R /H_u = 75659.59 lbs / 4828.94 lbs = 1.57

Foundation Forces:

L` = L_f – 2 x e_f = 11 ft – 2 x 0.225 ft = 10.55 ft

q_{u1} = 919.50 psf

M_{qu1} = 919.50 psf x (7.25 ft) ^2 x 1/2 = 24165.61 lbs-ft

M_{w1} = -5321.95 x 1.25/0.9 = -7391.60 lbs-ft

M_{u1} = 16774. 01 lbs-ft reinforcement at bottom

V_{u1} = 4627.31 lbs

q_{u2}= 919.50 psf

M_{qu2} = 919.50 psf x (1.30 ft)^2 / 2 = 776.98 lbs-ft

M_{w1} = -1.25 x 1.5 ft x 1.75 ft x 150 pcf x 1.75 ft /2 = -430.66 lbs-ft

M_{w3} = -1.35 x 2342-4 x 1/2 x 1.75 ft = -2766.96 lbs-ft

M_{u2} = -2420.64 lbs-ft reinforcement at top Vu2 = -2413.10 lbs

l) Service Loads:

D +L +EV +EH

V_s = (2531.25 lbs +2475 lbs +225 lbs) +210 lbs +2342.4 lbs

V_s = 7, 783.65 lbs

M_{sR} = (21515.62 lbs-ft + 13612.5 lbs-ft +450 lbs-ft) + 24198.67 lbs-ft +2126.5 lbs-ft = 61,903.29

e_s = 0.5 x 11 - (61,903.29 lbs-ft - 12,967.73 lbs-ft) / 7,783.65 lbs

e_s = - 0.787 ft < 0

L` = L_f - 2 x e_s = 11 ft - 2 x 0.787 ft = 9.426 ft

q_s = 7783.65 lbs / 9.426 ft = 825.76 PSF

M_{u1s} = 825.76 psf x (7.25 ft - 1.574 ft)^2 x 1/2 - 1.5 ft x 7.25 ft x 150 pcf x 7.25 ft x 1/2

M_{u1s} = 7388.46 lbs-ft

M_{u2s} = -825.76 psf x (1.75)^2 x 1/2 + 1.75 ft x 150 pcf x 1.5 ft x 1.75 ft /2 + 2342.4 k x 1.75 ft x 1/2

M_{u2s} = 1129.69 lbs-ft

Toe Reinforcing

M_{umax}= 16776.71 lbs-ft

V_{umax}= 4627.31 lbs

fr= 024 x (4ksi) $^{1/2}$ x1000 = 480 psi

Ig = 12 x (1.5 ft x 12) ^3 / 12 = 5832 in^4

M_{cr} = 2 x fr x Ig / tf = [2 x 480 psi x 5832 in^4 / (1.5 ft * 12)] / 12

M_{cr} = 25920.00 lbs-ft

1.6 x 0.67 x Mcr = 1.6 x 0.67 x 25920.00 lbs-ft = 27,786 lbs-ft > 1.33 Mumax = 22,313.02 lbs-ft

use min (1.6 x 0.67 x Mcr ε 1.33 Mumax) = 22,313.02 lbs-ft

fy = 60000 psi

d = 1.5 ft x 12 in - 3 in - 1/2 x 0.5 in = 14.75 in

f'c = 4000 psi

A_s= 0.342 in^2

ϕM_n = ϕAsfy (d - a/2) = 0.9 x 0.342 in^2 x 60,000 (14.75 in – 0.5* [(0.342 in^2 x 60000)/(0.85 x 4000 x 12 in)]) x 1/12

ϕM_n= 22,313 lbs-f >= Mu = 22,313 lbs-ft

A_{ssh} ≥ 1.3 bh / 2 (b +h) fy

A_{ssh} = 1.3 x [(11 ft x 1.5 ft x 144)/ ((11+15) x 2 x 12 x 60000/1000)]

A_{ssh} =0.1716 in^2

0.11 ≤ A_{ssh} = 0.176 in^2 ≤ 0.6 in^2 ok

As = 0.342 in^2 > A_{ssh} = 0.176 in^2

Spacing = 0.2 in^2 /0.342 in^2 x 12 in = 7.018 in Say 7 in

Spacing < 18 in and < 1.5 X12 x 1.5 = 27 in

Crack Control:

$S <= 700 \gamma_e / (\beta_s * f_{ss}) - 2 dc$

Dc= 1.5 ft*12 -14.75 in = 3.25 in

$\beta_s = 1 + dc / (0.7 * (h-dc))$

β_s = 1 + 3.25 in / (0.7 * (1.5 ft *12-3.25 in))

β_s =1.31

γ_e = 1.00 Mus1 = 7388.46 lbs-ft

$fss = Mus1 / (\rho * j * b * d^2)$

$j= 1 - k/3$

$k= ((n\rho)^2 + 2 * n\rho)^{0.5} - n\rho)$

n = Es / Ec = 29000/3600 = 8.06

ρ = As / (b*d) = 0.342 in^2 / (12 in * 14.75 in) = 0.00193

$k = ((8.06 * 0.00193)^2 + 2 * 8.06 * 0.00193)^{0.5} - 8.06 * 0.00193$

k = 0.1615

$j = 1 - 0.1615/3 = 0.946$

$fss = 7388.46$ lbs-ft $* 12 /(0.00193*0.946 * 12 * (14.75)^2)$

$fss = 18600.36$ psi $< 0.6 * fy = 0.6 * 60000 = 36\ 000$ psi

$S <= 700 * 1 / (1.31* 18600.36/1000) - 2 * 3.25 = 22.5$ in

Spacing = 7 in < S = 22.5 in

Heel Reinforcing

Mumax = 2359.68 lbs-ft   Mus2 = 1129.68 lbs-ft

$1.6 * 0.67 * Mcr = 29001.9$ lbs-ft > 1.33 Mumax $= 1.33 \times 2359.68 = 3138.37$ lbs-ft

Use min (1.6 * 0.67 * Mcr & 1.33 * Mumax) = 3138.37 lbs-ft

$As = 0.1716\ in^2$

$f'c = 4000$ psi $fy=60000$ psi $d=14.75$ in

$\phi Mn = \phi As * fy (d - a/ 2)$

$\phi Mn = 0.9 * 0.1716\ in^2 * 60000\ psi * (14.75\ in - 0.1716\ in^2 * 60\ ksi / (0.85 * 4\ ksi * 12 * 2)) * 1 /12$

$\phi Mn = 11292.51$ lbs-ft $>$ Mu $= 1129.68$ lbs-ft

Spacing = 0.2 / 0.1716 * 12 = 13.98 in

Say Spacing = 13 in < 18 in and < 12 * 1.5 ft * 12

Crack Control:

$S <= 700\ \gamma_e / (\beta_s * f_{ss}) - 2\ dc$

Dc= 1.5 ft*12 -14.75 in = 3.25 in

$\beta s = 1 + dc / (0.7 * (h-dc))$

$\beta s = 1 + 3.25\ in / (0.7 * (1.5\ ft *12-3.25\ in))$

$\beta s = 1.31$

$\gamma e = 1.00$ Mus2 = 1129.68 lbs-ft

$fss = Mus2 / (\rho * j * b * d\ 2)$

$j= 1 - k/3$

$k= ((n\rho)^2 + 2 * n\rho)^{0.5} - n\rho)$

$n = Es / Ec = 29000/3600 = 8.06$

$\rho = As / (b*d) = 0.1716\ in^2 / (12\ in * 14.75\ in) = 0.00097$

$k = ((8.06 * 0.00097)^2 + 2 * 8.06 * 0.00097)^{0.5} - 8.06 * 0.00097$

$k = 0.1175$

$j = 1 - 0.1175/3 = 0.960$

$fss = 1129.68\ lbs\text{-}ft * 12 /(0.00097*0.96 * 12 * (14.75)^2)$

$fss = 5576.072\ psi < 0.6 * fy = 0.6 * 60000 = 36\ 000\ psi$

$S <= 700 * 1 / (1.31 * 5576.07/1000) - 2 * 3.25 = 89\ in$

Spacing = 18in < S = 89 in

Toe Shear

$Vu = 4627.31$ lbs $Mu1=16776.71$ lbs-ft

$Vn = Vc + Vs$

$\beta = (4.8 / (1+ 750\, \varepsilon_s)) * (51 / (39 + S_{xe}))$

$\varepsilon_s = (Mu / dv + Vu) / (Es * As)$

$12 \text{ in} <= S_{xe} = S_x * 1.38 / (a_g+0.63) <= 80 \text{ in}$ $a_g = 1$ in

$dv = d - a/2 = 14.75 \text{ in} - (0.342 \text{ in2} * 60 \text{ ksi})/(0.85 * 4 \text{ ksi} * 12 \text{ in} * 2)$

$dv = 14.499$ in

$dv * Vu = 14.499 \text{ in} * 4627.31 \text{ lbs} = 67{,}089 \text{ lbs-in} < Mu = 16776.71 \text{ lbs-ft} * 12 = 201320.52 \text{ lbs-in}$

$\varepsilon_s = (16776.71 * 12 / 14.499 + 4627.31) / (29000* 0.342*1000)$

$\varepsilon_s = 1.867 E-3$

$Sx = dv = 14.499$ in

$S_{xe} = S_x * 1.38 / (a_g+0.63) = 14.499 * 1.38 /(1.0+0.63) = 12.26 \text{ in} > 12 \text{ in}$ and < 80 in

$\beta = (4.8 / (1+ 750* 1.867 E-3)) * (51 / (39 + 12.26)) = 1.98$

$Vc1 = 0.9 * b * (f'c) ^ 0.5 * \beta * dv = 0.9 * 12 \text{ in} * (4000 \text{ psi}) ^0.5 *1.98* 14.499 \text{ in}$

$Vc1 = 19609.07$ lbs

Heel Shear

V_u = 2696.78 lbs   Mu2=2359.68 lbs-ft

Vn = Vc+ Vs

$\beta = (4.8 / (1+ 750\ \varepsilon_s)) * (51 / (39 + S_{xe}))$

$\varepsilon_s = (Mu / dv + Vu) / (Es * As)$

$12\ in <= S_{xe} = S_x * 1.38 / (a_g+0.63) <= 80\ in$ $a_g = 1\ in$

dv = d – a/2 = 14.75 in – (0.1716 in2 * 60 ksi)/(0.85 * 4 ksi * 12 in * 2)

dv = 14.62 in

dv * Vu = 14.62in * 2696.78 lbs = 39426.9 lbs-in > Mu = 2359.68 lbs-ft * 12 = 28316.16 lbs-in

ε_s = (39426.9 / 14.62 + 2696.78) / (29000* 0.1716*1000)

ε_s =1.084 E-3

Sx = dv = 14.62 in

$S_{xe} = S_x * 1.38 / (a_g+0.63)$ = 14.62 * 1.38 /(1.0+0.63) = 12.37 in > 12 in and < 80 in

β = (4.8 / (1+ 750* 1.084 E-3)) * (51 / (39 + 12.37)) = 2.63

Vc2 = 0.9 * b * (f'c) ^ 0.5 * β * dv = 0.9 * 12 in * (4000 psi) ^0.5 *2.63* 14.620 in

Vc2 = 26263.76 lbs

Wall Reinforcement

1) Wall un-factored loads:

Ha1 = (11 ft/ 3 +0.31 ft)^2 x 30 PCF x ½ = 237.21 lbs

Hsur1= 0.25 * 1 x 120 pcf x (11ft/3 +0.31ft) = 119.3 lbs

Heq1 = Heq / (11 ft + 0.31 ft + 1.5 ft) * (11 ft /3 + 0.31 ft)

Heq1 = = 509.34 lbs

Ha2 = (11 ft*2 / 3 +0.31 ft)^2 x 30 PCF x ½ = 876.31 lbs

Hsur2= 0.25 * 1 x 120 pcf x (11ft*2 /3 +0.31ft) = 229.3 lbs

Heq2 = Heq / (11 ft + 0.31 ft + 1.5 ft) * (11 ft *2 /3 + 0.31 ft)

Heq2 = = 978.90 lbs

Ha3 = (11 ft+0.31 ft)^2 x 30 PCF x ½ = 1918.74 lbs

Hsur3= 0.25 * 1 x 120 pcf x (11ft+0.31ft) = 339.3 lbs

Heq3 = Heq / (11 ft + 0.31 ft + 1.5 ft) * (11 ft + 0.31 ft)

Heq3 = = 1448.76 lbs

Ma1 = (11 ft/ 3 +0.31 ft) x 1/3 x 237.21 lbs= 314.42 lbs-ft

Msur1= 119.3 lbs x (11ft/3 +0.31ft) x ½ = 237.21 lbs-ft

Meq1 = 509.34 lbs x (11 ft /3 + 0.31 ft) x ½ = 1012.73 lbs -ft

Ma2 = (2* 11 ft/ 3 +0.31 ft) x 1/3 x 876.31 lbs= 2232.42 lbs-ft

Msur2= 229.3 lbs x (2* 11ft/3 +0.31ft) x ½ = 876.31 lbs-ft

Meq2 = 978.90 lbs x (2* 11 ft /3 + 0.31 ft) x ½ = 3741.03 lbs –ft

Ma3 = (11 ft+0.31 ft) x 1/3 x 1918.74 lbs= 7233.65 lbs-ft

Msur3= 339.3 lbs x (11ft+0.31ft) x ½ = 1918.46 lbs-ft

Meq3 = 1448.76 lbs x (11 ft + 0.31 ft) x ½ = 8192.74 lbs –ft

2) Wall factored loads:

Strength I and Strength Ia

1.5 EH + 1.75 LL

Mu1 = 1.75 x 237.21 lbs-ft + 1.5 * 314.42 lbs-ft = 886.75 lbs-ft

Mu2 = 1.75 x 876.31 lbs-ft + 1.5 * 2232.46 lbs-ft = 4882.23 lbs-ft

Mu3 = 1.75 x 1918.46 lbs-ft + 1.5 * 7233.65 lbs-ft = 14207.78 lbs-ft

Strength IV

1.5 EH

Extreme I and Ia :

1:00 EH + 1.00 EQ

Mu1 = 314.42+1012.73 = 1327.16 lbs-ft

Mu2 = 2232.46+3741.03 = 5973.50 lbs-ft

Mu3 = 7233.65+8192.74 = 15426.39 lbs-ft

3) Wall governing loads:

Section	Mu (lbs-ft)	Ms (lbs-ft)
One	1327.16	314.42+237.21 = 551.63 lbs-ft
Two	5973.50	2232.46 +876.31 =3108.77 lbs-ft
Three	15426.36	7233.65+1918.46 =9152.11 lbs-ft

Shear at base

Vu = 1.5 * 1918.74 lbs + 1.75 * 339.3 lbs = 3471.89 lbs

4) Wall Design Section One:

Mu = 1327.16 lbs-ft

Mus = 551.63 lbs-ft

fr= 0.24 x (4ksi) $^{1/2}$ x1000 = 480 psi

t= (1 ft + (2 ft + 1 ft) x 1/3) x 12 = 16 in

d = 16 in – 2 in – 0.5 in x ½ = 13.75 in

$Ig = 12 \times (16\ in)^3 / 12 = 4096\ in^4$

$M_{cr} = 2 \times fr \times Ig / tf = [2 \times 480\ psi \times 4096 in^4 / (16\ in)] / 12$

$M_{cr} = 20480\ lbs\text{-}ft$

$1.6 \times 0.67 \times Mcr = 1.6 \times 0.67 \times 20480\ lbs\text{-}ft = 21954.56\ lbs\text{-}ft > 1.33\ Mu = 1765.13\ lbs\text{-}ft$

use min $(1.6 \times 0.6 \times Mcr\ \varepsilon\ 1.33\ Mu) = 1765.13\ lbs\text{-}ft$

$fy = 60000\ psi$

$f'c = 4000\ psi$

$A_s = 0.155\ in^2$

$\phi\ Mn = \phi\ As * fy\ (d - a/2)$

$\phi\ Mn = 0.9 * 0.155\ in^2 * 60000\ psi * (13.75\ in - 0.155\ in^2 * 60\ ksi / (0.85 * 4\ ksi * 12 * 2)) * 1/12$

$\phi\ Mn = 9511.13\ lbs\text{-}ft > Mu = 1765.13\ lbs\text{-}ft$

$Ash = 1.3 \times b \times h / (2 \times (b+h) \times fy)$

$Ash = 1.3 \times 16\ in/12 \times 11.25\ ft / (2 \times (16\ in/12 + 11.25\ ft) \times 60\ ksi) \times 12$

$Ash = 0.155\ in^2 > 0.11$ and < 0.6

$Spacing = 0.2\ in^2 / 0.155\ in^2 * 12 = 15.5\ in$

Say $Spacing = 15.0\ in$ and $< 12 * 16$ and $< 18\ in$

Crack Control:

$S \leq 700\ \gamma e / (\beta s\ (* fss - 2\ dc))$

Dc= 2.25 in

$\beta s = 1 + dc / (0.7 * (h - dc))$

$\beta s = 1 + 2.25\ in / (0.7 * (13.75\ in))$

$\beta s = 1.23$

$\gamma e = 1.00$ Mus = 551.63 lbs-ft

$fss = Mus / (\rho * j * b * d\ 2)$

$j = 1 - k/3$

$k = ((n\rho)^2 + 2 * n\rho)^{0.5} - n\rho)$

n = Es / Ec = 29000/3600 = 8.06

$\rho = As / (b*d) = 0.155\ in^2 / (12\ in * 13.75\ in) = 0.00094$

$k = ((8.06 * 0.00094)^2 + 2 * 8.06 * 0.00094)^{0.5} - 8.06 * 0.00094$

k = 0.116

j = 1 – 0.116/3 = 0.961

$fss = 551.63\ lbs\text{-}ft * 12 / (0.00094*0.961 * 12 * (13.75)^2)$

fss = 3232 psi < 0.6 * fy = 0.6 * 60000 = 36 000 psi

S <= 700 * 1 / (1.23* 3232/1000) – 2 * 2.25 = 171.58 in

Spacing max = 18in < S = 171.58 in

Use S = 15.5 in

5) Wall Design Section two:

$Mu = 5973.5$ lbs-ft $Mus = 3108.77$ lbs-ft

$fr = 0.24 \times (4ksi)^{1/2} \times 1000 = 480$ psi

$t = (1 \text{ ft} + (2 \text{ ft } 0 \text{ } 1 \text{ ft}) \times 2/3) \times 12 = 20$ in

$d = 20 \text{ in} - 2 \text{ in} - 0.5 \text{ in} \times ½ = 17.75$ in

$Ig = 12 \times (20 \text{ in})^3 / 12 = 8000 \text{ in}^4$

$M_{cr} = 2 \times fr \times Ig / tf = [2 \times 480 \text{ psi} \times 8000 \text{ in}^4 / (16 \text{ in})] / 12$

$M_{cr} = 32000$ lbs-ft

$1.6 \times 0.67 \times Mcr = 1.6 \times 0.67 \times 32000$ lbs-ft $= 34304$ lbs-ft $> 1.33 Mu = 7944.76$ lbs-ft

use min $(1.6 \times 0.6 \times Mcr \; \varepsilon \; 1.33 Mu) = 7944.76$ lbs-ft

$fy = 60000$ psi

$f'c = 4000$ psi

$A_s = 0.19 \text{ in}^2$

$\phi Mn = \phi As * fy (d - a/2)$

$\phi Mn = 0.9 * 0.19 \text{ in}^2 * 60000 \text{ psi} * (17.75 \text{ in} - 0.19 \text{ in}^2 * 60 \text{ ksi} / (0.85 * 4 \text{ ksi} * 12 * 2)) * 1/12$

$\phi Mn = 15049.3$ lbs-ft $> Mu = 7944.76$ lbs-ft

$Ash = 1.3 \times b \times h / (2 \times (b+h) \times fy)$

$Ash = 1.3 \times 20 \text{ in} /12 \times 11.25 \text{ ft} / (2 \times (20 \text{ in} /12 + 11.25 \text{ ft}) \times 60 \text{ ksi})$

$Ash = 0.19 \text{ in}^2 > 0.11$ and < 0.6

Spacing $= 0.2 / 0.19 * 12 = 12.63$ in

Say Spacing = 12.63 in and < 12 * 16 and < 18 in

Crack Control:

$S <= 700 \gamma e / (\beta s (* fss - 2 dc))$

Dc= 2.25 in

$\beta s = 1 + dc / (0.7 * (h-dc))$

$\beta s = 1 + 2.25 in / (0.7 * (20in - 2.25 in))$

$\beta s = 1.18$

$\gamma e = 1.00$ Mus = 3108.73 lbs-ft

$fss = Mus / (\rho * j * b * d^2)$

$j = 1 - k/3$

$k = ((n\rho)^2 + 2 * n\rho)^{0.5} - n\rho)$

n = Es / Ec = 29000/3600 = 8.06

$\rho = As / (b*d) = 0.19 in^2 / (12 in * 17.75 in) = 0.00089$

$k = ((8.06 * 0.00089)^2 + 2 * 8.06 * 0.00089)^{0.5} - 8.06 * 0.00089$

k = 0.113

j = 1 – 0.113/3 = 0.962

$fss = 3108.73 lbs\text{-}ft * 12 /(0.00089*0.962 * 12 * (17.75)^2)$

fss = 11717.64 psi < 0.6 * fy = 0.6 * 60000 = 36 000 psi

S <= 700 * 1 / (1.18* 11717.64/1000) – 2 * 2.25 = 46.12 in

Spacing max = 18in < S = 46.12 in

Use S = 12.63 in

6) Wall Design Section three:

M_u = 15426.36 lbs-ft M_{us} = 9152.11 lbs-ft

fr= 0.24 x (4ksi) $^{1/2}$ x1000 = 480 psi

t= 24 in

d = 24 in – 2 in – 0.5 in x ½ = 21.75 in

Ig = 12 x (24 in) ^3 / 12 = 13824 in^4

M_{cr} = 2 x fr x Ig / tf = [2 x 480 psi x 13824 in^4 / (16 in)] / 12

M_{cr} = 46080 lbs-ft

1.6 x 0.67 x Mcr = 1.6 x 0.67 x 46080 lbs-ft = 49397.76 lbs-ft >1.33 Mu

Mu= 20517.06 lbs-ft

use min (1.6 x 0.6 x Mcr ε 1.33 Mu) = 20517.06 lbs-ft

fy = 60000 psi

f'c = 4000 psi

A_s= 0.22 in^2

ϕ Mn = ϕ As * fy (d – a/ 2)

ϕ Mn = 0.9 * 0.22 in^2 * 60000 psi * (21.75 in – 0.22 in ^{2} * 60 ksi / (0.85 * 4 ksi * 12 * 2)) * 1 /12

ϕ Mn = 21374.1 lbs-ft > Mu = 20517.06 lbs-ft

Ash = 1.3 x b x h / (2 x (b+h) x fy)

Ash = 1.3 x 24 in /12 x 11.25 ft / (2 x (24 in /12 + 11.25 ft) x 60 ksi)

Ash = 0.22 in^2 > 0.11 and < 0.6

Spacing = 0.2 / 0.22 * 12 = 10.91 in

Say Spacing = 10.91 in and < 12 * 16 and < 18 in

Crack Control:

S <= 700 γe / (βs (* fss – 2 dc))
Dc= 2.25 in
βs = 1 + dc / (0.7 * (h-dc))

βs = 1 + 2.25 in / (0.7 * (24in – 2.25 in))

βs =1.16

γe = 1.00 Mus = 9457.76 lbs-ft

fss = Mus / (ρ * j * b * d 2)

j= 1 – k/3

k= $((n\rho)^2 + 2 * n\rho)^{0.5} - n\rho)$

n = Es / Ec = 29000/3600 = 8.06

ρ = As / (b*d) = 0.22 in^2 / (12 in * 21.75 in) = 0.00084

k = $((8.06 * 0.00084)^2 + 2 * 8.06 * 0.00084)^{0.5} - 8.06 * 0.00084$

k = 0.11

j = 1 – 0.11/3 = 0.963

fss = 9457.76 lbs-ft * 12 /(0.00084* 0.963 * 12 * $(21.75)^2$)

fss = 24629.82 psi < 0.6 * fy = 0.6 * 60000 = 36 000 psi

S <= 700 * 1 / (1.16* 24629.82/1000) – 2 * 2.25 = 20 in

Spacing max = 18in < S = 20 in

Use S = 10.91 in

Wall Shear

Vu = 3471.89 lbs   Mu=15426.36 lbs-ft

Vn = Vc+ Vs

β = (4.8 / (1+ 750 ε_s)) * (51 / (39 + S_{xe}))

ε_s = (Mu / dv + Vu) / (Es * As)

12 in < = S_{xe} = S_x * 1.38 / (a_g+0.63) <= 80 in a_g = 1 in

dv = d – a/2 = 21.75 in – 0.32 in /2

dv = 21.59 in

dv * Vu = 21.59 in * 3471.89 lbs / 12= 6246.51 lbs-ft < Mu = 15426.36 lbs-ft

ε_s = (15426.36 x 12 / 21.59 + 3471.89) / (29000* 0.22*1000)

ε_s =188 E-3

Sx = dv = 21.59 in

S_{xe} = S_x * 1.38 / (a_g+0.63) = 21.59 * 1.38 /(1.0+0.63) = 18.28 in > 12 in and < 80 in

β = (4.8 / (1+ 750* 1.88 E-3)) * (51 / (39 + 18.28)) = 1.77

Vc = 0.9 * b * (f'c) ^ 0.5 * β * dv

Vc = 0.9 * 12 in * (4000 psi) ^0.5 *1.77* 21.59 in

$V_c = 26151.57$ lbs $> V_u$