Washington State Department of Transportation

# SEG 2B WALLS
# NOISE WALL 6 ON SPREAD FOOTINGS

## I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT

## Design Calculations:

## *CIP NOISE WALL ON SPREAD FOOTINGS*


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Checked By: Mike Harding
Reviewed By: Chengyu Li


Wood Environment & Infrastructure, Inc.
01/10/2022
Date
DQAM Initials
RELEASED FOR CONSTRUCTION

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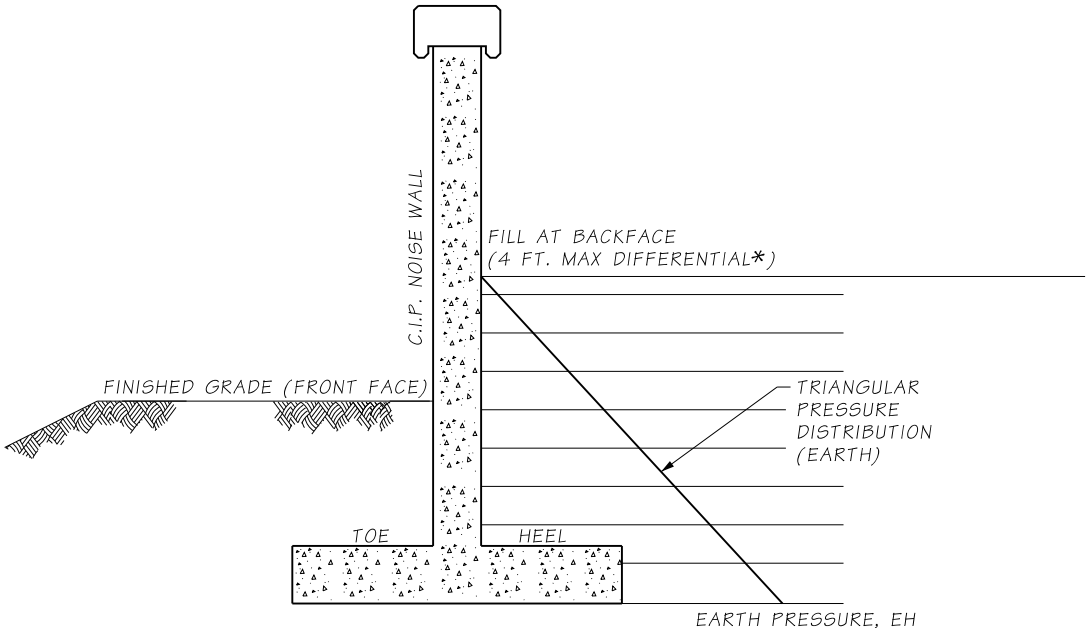
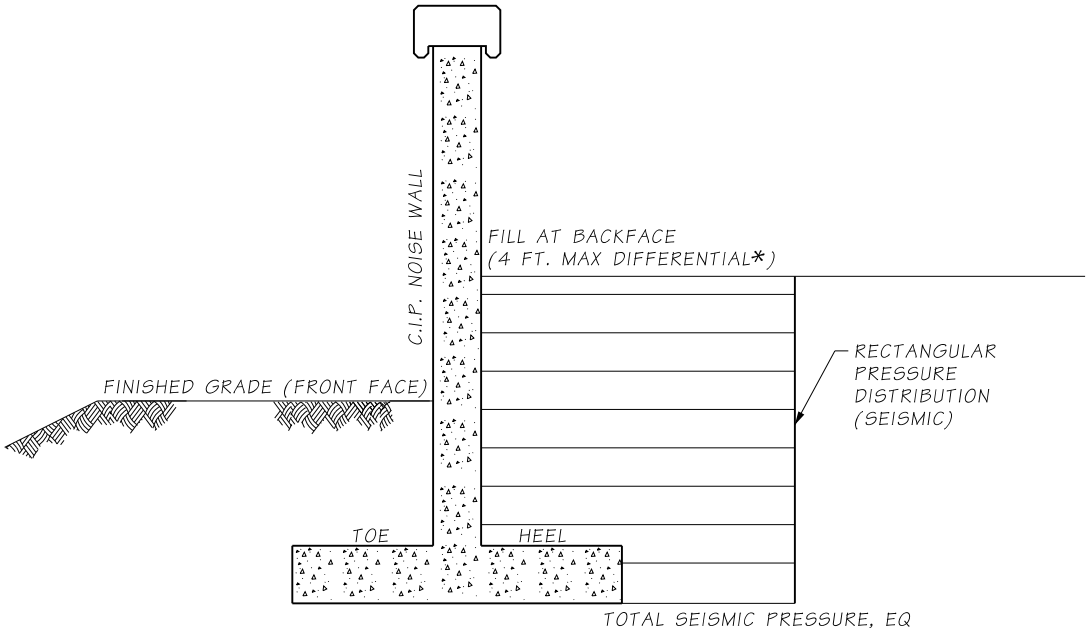



*DIFFERENTIAL = NET HEIGHT BETWEEN FINISHED GRADE AT FRONT FACE AT BACK FACE.

(A) STRENGTH LIMIT STATE EARTH PRESSURES




(B) EXTREME EVENT I LIMIT STATE EARTH PRESSURES

PRESENTATION OF LATERAL EARTH PRESSURES FOR NOISE WALL DESIGN

| | | | |
|---|---|---|---|
| JOB NO. | PS19203160 | SHEET | 1 of 5 |
| JOB NAME | I-405 - Renton to Bellevue Design-Build | | |
| Supervisor | WPM | TASK | CIP Noise Wall 6 |
| BY | RUK | DATE | 12/21/2021 |
| CHK'D. BY | MGH | DATE | 12/22/2021 |

**Preliminary Analysis for:**
**Cast-In-Place Concrete Noise Wall on Footing**
**Maximum Total Wall Height = 12.0' with Minimum Embedment**

DESIGN CRITERIA:
- WSDOT Bridge Design Manual, July 2019
- AASHTO LRFD 8th Edition
- Geotechnical Engineering Report: Soldier Pile Wall 10.35L and Noise Wall 6

DESIGN ASSUMPTIONS:
- Exposed Wall Height is maximum 10' front face and 8' back face.
- Noise Wall Wall is supporting 2' of fill.
- Seismic design is based on WSDOT BDM 8.2.2 and AASHTO LRFD 4.7.4.3.3.
- Noise Wall Dimensions are based on WSDOT Bridge Manual for Non-Standard Walls, page 8-23.
- Wind load is considered.
- Seismic soil forces are considered.
- Seismic internal wall forces are considered.
- Moment is positive with right hand rule at bottom center of footing. Right of center is positive, Left of center is negative.

Try:

| | | | |
|---|---|---|---|
| Footing Width = | 6.42 | ft | |
| Footing Thickness = | 1.00 | ft | |
| Wall Height = | 12.00 | ft | |
| Exposed Wall Height = | 10 | ft | |
| Wall Thickness = | 1.000 | ft | - Includes form liner on each face |
| Footing Toe Width = | 2.708 | ft | |
| Footing Heel Width = | 2.708 | ft | |

DEAD LOAD (DC):

Loads based on linear foot of wall

| Item | Density | Length | Thickness | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Noise Wall | 0.150 | 12 | 1.00 | 1 | 12.00 | 1.80 | 0.00 | 0.00 |
| Footing | 0.150 | 6.4 | 1.00 | 1 | 6.42 | 0.96 | 0.00 | 0.00 |
| | | | | | Totals = | 2.76 | | 0.00 |

| | | | |
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VERTICAL SOIL LOAD (EV):

Loads based on linear foot of wall

| Item | Density | Width | Height | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Toe | 0.130 | 2.71 | 2.00 | 1 | 5.42 | 0.70 | -1.85 | -1.31 |
| Heel | 0.130 | 2.71 | 4.00 | 1 | 10.83 | 1.41 | 1.85 | 2.61 |
| | | | | | Totals = | 2.11 | | 1.31 |

HORIZONTAL SOIL LOAD (EH): - Not required when seismic soil is being included. (AASHTO C11.6.5.1)

$EH = (1/2)*Ka*\Upsilon*H^2$

| | | | | | |
|---|---|---|---|---|---|
| EH = | 0.06 | klf | ϕ= | 38 | degrees |
| Moment Arm @ B/Footing = | 0.67 | ft | Ka = | 0.24 | |
| Moment = | 0.04 | k*ft | ϒ= | 0.13 | kcf |
| | | | H = | 2.00 | ft |

WIND LOAD (WS): (AASHTO 3.8.1.2.4)

$P_Z = 2.56X10^{-6}*V^2*K_Z*G*C_D$

| | | | |
|---|---|---|---|
| $V_{STR\ III}$= | 110 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{STR\ V}$= | 80 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{SERV\ I}$= | 70 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $K_{Z_STR}$= | 0.71 | | (AASHTO Table C3.8.1.2.1-1) |
| $K_{Z_SERV}$= | 1.0 | | (AASHTO 3.8.1.2.1) |
| G= | 0.85 | | (AASHTO Table 3.8.1.2.1-1) |
| $C_D$ = | 1.2 | | (AASHTO Table 3.8.1.2.1-2) |
| Z= | 8.00 | = Exposed Noise Wall Height at the Back Face | |

| | | |
|---|---|---|
| $P_{Z_STR\ III}$= | 0.022 | ksf |
| $P_{Z_STR\ V}$= | 0.012 | ksf |
| $P_{Z_SERV\ I}$= | 0.013 | ksf |

$P_W = P_Z*Z$ (AASHTO 3.8.1.2.4)

Moment Arm @ B/Footing = 9.4 ft

| | | | |
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| | Linear feet of Wall | |
|---|---|---|
| | $P_W$ | Moment |
| | klf | k*ft |
| STR III | 0.18 | 1.7 |
| STR V | 0.09 | 0.9 |
| SERV I | 0.10 | 1.0 |

- $P_W$ is a line load applied at 0.55*Z from the top of roadway. (AASHTO 3.8.1.2.4)
- Moment Arm is from the top of the retaining wall.
  = 0.55*(Noise Wall Height + Traffic Barrier Height) + Slab Thickness

SEISMIC ACTIVE EARTH PRESSURES ($EQ_{soil}$):

$P_{seis} = P_{AE}$ LRFD 11.6.5.1

$P_{seis}$ = 0.190 klf $P_{seis}$ is applied 1/3 height of soil.

$P_{AE}$ = 0.190 klf LRFD 11.6.5.3-2

$P_{AE} = 0.5*\Upsilon*K_{AE}*h^2$

- Monobe-Okabe Analysis LRFD A11.3.1

**Figure A11.3.1-1—Mononobe-Okabe Method Force Diagrams**

$$K_{AE} = \frac{\cos^2(\phi-\theta_{MO}-\beta)}{\cos\theta_{MO}\cos^2\beta\cos(\delta+\beta+\theta_{MO})}\times\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2} \quad \text{(A11.3.1-1)}$$

where:

$K_{AE}$ = seismic active earth pressure coefficient (dim)
$\gamma$ = unit weight of soil (kcf)
$H$ = height of wall (ft)
$h$ = height of wall at back of wall heel considering height of sloping surcharge, if present (ft)
$\phi_f$ = friction angle of soil (degrees)
$\theta_{MO}$ = arc tan $[k_h/(1-k_v)]$ (degrees)
$\delta$ = wall backfill interface friction angle (degrees)
$k_h$ = horizontal seismic acceleration coefficient (dim.)
$k_v$ = vertical seismic acceleration coefficient (dim.)
$i$ = backfill slope angle (degrees)
$\beta$ = slope of wall to the vertical, negative as shown (degrees)

$k_{AE}$ = 0.732

$\psi$ = 0.42

$$\psi = \left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2}$$

$\Upsilon_{soil}$ = 0.130 kcf

H = 2.0 ft Height of soil and footing

$\phi$ = 38.00 degrees

$\theta$ = 26.4 degrees

$\delta = 2/3*\phi$ = 25.3 degrees

$k_h = 1.0*k_{h0}$ = 0.497 Note: 0.5*kho=0.249, by using 1.0*kho this increased the Extreme Event Moment by 0% and the Lateral load by 10%. This small increase does not affect the outcome of the calc.

$k_{h0} = A_s$ = 0.497

$k_v$ = 0.0

i = 0.0 degrees

$\beta$ = 0.0 degrees

Moment Arm @ B/Footing = 0.67 ft

Moment = 0.1 k*ft

| | | | |
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SEISMIC FORCES ON WALL ($EQ_{wall}$): (See Attached Calc)

Shear at base of wall = 1.0 k
Moment on wall = 8.7 k*ft

LOAD SUMMARY

| Load | Force | | Moment |
|---|---|---|---|
| | Vertical | Lateral | |
| | $P_Y$ (kips) | $P_X$ (kips) | (kips) |
| DC | 2.8 | | 0.0 |
| EV | 2.1 | | 1.3 |
| EH | | 0.1 | 0.1 |
| $WS_{STR\ III}$ | | 0.18 | 1.7 |
| $WS_{STR\ V}$ | | 0.09 | 0.9 |
| $WS_{SERV\ I}$ | | 0.10 | 1.0 |
| $EQ_{soil}$ | | 0.2 | 0.1 |
| $EQ_{wall}$ | | 1.0 | 8.7 |

**Calculate Bearing Pressure**

Load Combinations (AASHTO Table 3.4.1-1)

| Load Combination | Force | | Moment | e | B' | $\sigma_v$ |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_Y$ (kips) | $P_X$ (kips) | (kips) | ft | ft | **ksf** |
| STRENGTH III: 1.25DC+1.5EH+1.0(EV+WS) | 5.6 | 0.3 | 3.1 | 0.6 | 5.3 | **1.05** |
| STRENGTH V: 1.25DC+1.5EH+1.0(EV+WS) | 5.6 | 0.3 | 2.3 | 0.4 | 5.6 | **1.00** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.9 | 1.2 | 10.1 | 2.1 | 2.3 | **2.16** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.9 | 0.2 | 2.3 | 0.5 | 5.5 | **0.89** |

Eccentricity = e =M/$P_y$

B = 6.42 ft B' = B - 2e

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\sum V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

| | | | |
|---|---|---|---|
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**Check Eccentricity Limits** (AASHTO 11.6.3.3)

- The location of the resultant is limited to the middle two-thirds of the width of the foundation.

emax = B/3 2.14 ft

| Load Combination | Force | | Moment | e | Middle | |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | Two-Thirds | |
| STRENGTH III: 0.9DC+1.5EH+1.00(EV+WS) | 4.6 | 0.3 | 3.1 | 0.6 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 4.6 | 0.3 | 2.3 | 0.4 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.9 | 1.2 | 10.1 | 2.1 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.9 | 0.2 | 2.3 | 0.5 | Yes | **OK** |

**Check Sliding** (AASHTO 10.6.3.4 and AASHTO 11.5.6)

| Load Combination | Force | | $\phi_T R\tau$ | Is $R\tau > Vx$? | |
|---|---|---|---|---|---|
| | Vertical | Lateral | | | |
| | $P_y$ (kips) | $P_X$ (kips) | kips | | |
| STRENGTH III: 0.90DC+1.5EH+1.00(EV+WS) | 4.6 | 0.3 | 2.9 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 4.6 | 0.3 | 2.9 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.9 | 1.2 | 3.0 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.9 | 0.2 | 3.0 | Yes | **OK** |

Sliding Resistance = $\phi_T R\tau = \phi_T C P_y \tan \phi_f$ (AASHTO 10.6.3.4-2)

$\phi_T$ = 0.8 (AASHTO Table 10.5.5.2.2-1)

C = 1.0

$\phi_f$ = 38 degrees

Coeffient of Friction = $\tan \phi_f$ = 0.78 (AASHTO C3.11.5.3)

| | | | |
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## SOUND BARRIER DESIGN FORCE

**NOISE BARRIER CIP WALL TYPE GEOMETRY**

| | | | |
|---|---|---|---|
| Wall Length | L = | 1 | ft |
| Wall/Wall Height | H = | 12 | ft |
| Wall Thickness | T = | 12 | in |

**MATERIALS**

| | | | |
|---|---|---|---|
| Wall Concrete | $f_c'$ = | 4 | ksi |
| | $\gamma_c$ = | 0.15 | kcf |
| | $E_c$ = | 4266 | ksi |
| Reinforcing Steel | $f_y$ = | 60 | ksi |
| | $E_s$ = | 29000 | ksi |

**DEAD LOAD**

Weight of Wall

| | | | |
|---|---|---|---|
| Vertical Dead Load | D = | 1.80 | kips |

**SEISMIC FORCE**

Seismic design shall be in accordance with AASHTO LRFD Article 3.10.2.1-General Procedure, considering site class D:

a. Modal analysis shall be performed for the first 4 periods. Elastic seismic response coefficient Csm shall be computed for each modal period in accordance with LRFD Article 3.10.4.2 and all 4 Csm coefficients shall be combined through the SRSS method.

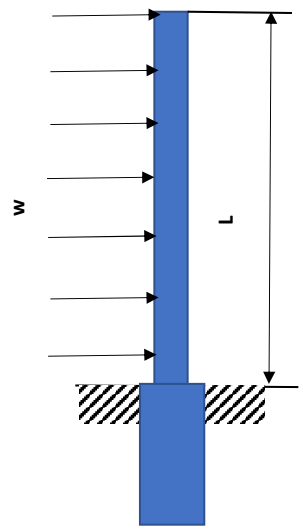
b. The resultant seismic force shall be considered to act at a height of 0.71H above the top of the shaft, where H is the total height measured from the top of the Wall to the top of the shaft.

**Structural Modeling**

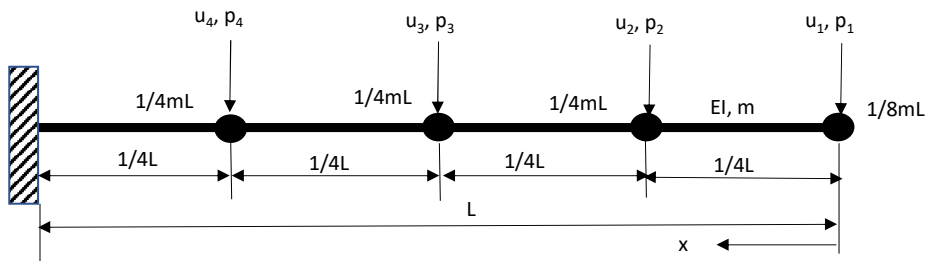
Modeling the column as a cantilever beam

The mass of column and ajacent panels is uniformly distributed along the column

| | | | |
|---|---|---|---|
| Uniform Weight | w = | 0.15 | kips/ft |
| Uniform Mass | m = | 0.0004 | |
| Column | I = | 1728 | $in^4$ |
| Modulus | E = | 4266 | ksi |
| Gravity | g = | 386 | $in/sec^2$ |



**Modal Analysis**




Flexibility Matrix

| | | |
|---|---|---|
| $p_1$ = | 1 | |
| | x | u |
| $u_1$ | 0.00 | 0.33333333 |
| $u_2$ | 0.25 | 0.21093750 |
| $u_3$ | 0.50 | 0.10416667 |
| $u_4$ | 0.75 | 0.02864583 |

| | | |
|---|---|---|
| $p_2$ = | 1 | |
| a = | 0.25 | |
| b = | 0.75 | |
| | x | u |
| $u_1$ | 0.00 | 0.2109375 |
| $u_2$ | 0.25 | 0.1406250 |
| $u_3$ | 0.50 | 0.0729167 |
| $u_4$ | 0.75 | 0.0208333 |

| | | |
|---|---|---|
| $p_3$ = | 1 | |
| a = | 0.5 | |
| b = | 0.5 | |
| | x | u |
| $u_1$ | 0 | 0.104166667 |
| $u_2$ | 0.25 | 0.072916667 |
| $u_3$ | 0.5 | 0.041666667 |
| $u_4$ | 0.75 | 0.013020833 |

| | | |
|---|---|---|
| $p_4$ = | 1 | |
| a = | 0.75 | |
| b = | 0.25 | |
| | x | u |
| $u_1$ | 0.00 | 0.028645833 |
| $u_2$ | 0.25 | 0.020833333 |
| $u_3$ | 0.50 | 0.013020833 |
| $u_4$ | 0.75 | 0.005208333 |

| | | | |
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Flexibility Matrix

| | $p_1 = 1$ | $p_2 = 1$ | $p_3 = 1$ | $p_4 = 1$ |
|---|---|---|---|---|
| $u_1 = L^3/EI^*$ | 0.3333 | 0.2109 | 0.1042 | 0.0286 |
| $u_2 = L^3/EI^*$ | 0.2109 | 0.1406 | 0.0729 | 0.0208 |
| $u_3 = L^3/EI^*$ | 0.1042 | 0.0729 | 0.0417 | 0.0130 |
| $u_4 = L^3/EI^*$ | 0.0286 | 0.0208 | 0.0130 | 0.0052 |

Stiffness Matrix K

| | | | | |
|---|---|---|---|---|
| $EI/L^3$ | 102.928 | -233.567 | 166.268 | -47.505 |
| $EI/L^3$ | -233.567 | 633.402 | -613.608 | 285.031 |
| $EI/L^3$ | 166.268 | -613.608 | 918.433 | -756.124 |
| $EI/L^3$ | -47.505 | 285.031 | -756.124 | 1203.464 |

K =

| | | | |
|---|---|---|---|
| 254.116 | -576.649 | 410.496 | -117.284 |
| -576.649 | 1563.793 | -1514.925 | 703.707 |
| 410.496 | -1514.925 | 2267.500 | -1866.778 |
| -117.284 | 703.707 | -1866.778 | 2971.207 |

Mass Matrix M

| | | | |
|---|---|---|---|
| 1/8mL | 0 | 0 | 0 |
| 0 | 1/4mL | 0 | 0 |
| 0 | 0 | 1/4mL | 0 |
| 0 | 0 | 0 | 1/4mL |

M =

| | | | |
|---|---|---|---|
| 0.000582902 | 0 | 0 | 0 |
| 0 | 0.001165803 | 0 | 0 |
| 0 | 0 | 0.001165803 | 0 |
| 0 | 0 | 0 | 0.001165803 |

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First Mode

| $w_1^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 6185.414 | 250.511 | -576.649 | 410.496 | -117.284 |
| | -576.649 | 1556.582 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 2260.289 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 2963.996 |

$Det(K-w_n^2*M)=0$ 0.00007 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_1$ = 78.647 rad/sec $T_1$ = 0.080 sec

Second Mode

| $w_2^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 213692.70 | 129.5545743 | -576.649 | 410.496 | -117.284 |
| | -576.649 | 1314.669 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 2018.376 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 2722.083 |

$Det(K-w_n^2*M)=0$ 0.000613373 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_2$ = 462.269 rad/sec $T_2$ = 0.014 sec

Third Mode

| $w_3^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 1498532.78 | -619.381 | -576.649 | 410.496 | -117.284 |
| | -576.649 | -183.201 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 520.506 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 1224.213 |

$Det(K-w_n^2*M)=0$ -0.000817904 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_3$ = 1224.146 rad/sec $T_3$ = 0.005 sec

Fourth Mode

| $w_4^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 4552573.24 | -2399.586 | -576.649 | 410.496 | -117.284 |
| | -576.649 | -3743.611 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | -3039.904 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | -2336.197 |

$Det(K-w_n^2*M)=0$ -0.079570 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_4$ = 2133.676 rad/sec $T_4$ = 0.003 sec

| | | | |
|---|---|---|---|
| wood. | JOB NO. PS19203160 | SHEET 5 of 10 | |
| | JOB NAME I-405 - Renton to Bellevue Design-Build | | |
| | Supervisor WPM | TASK CIP Noise Wall 6 | |
| | BY RUK | DATE 6/18/2021 | |
| | CHK'D. BY MGH | DATE 6/18/2021 | |

Summary

| Mode | ω (rad/sec) | T (sec) |
|---|---|---|
| 1 | 78.647 | 0.080 |
| 2 | 462.269 | 0.014 |
| 3 | 1224.146 | 0.005 |
| 4 | 2133.676 | 0.003 |

NATURAL PERIODS By Equation

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$T_n = 1/f_n$ $\omega_n = 2\pi/T_n$

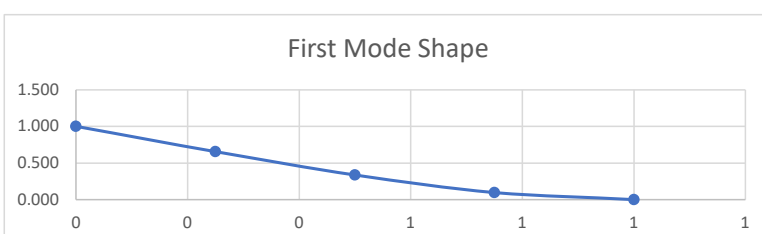
| | | |
|---|---|---|
| First Mode | $K_1$ = | 3.52 |
| Second Mode | $K_1$ = | 22.03 |
| Third Mode | $K_3$ = | 61.7 |
| Fourth Mode | $K_4$ = | 120.9 |
| | g = | 386 |

| Mode | Natural Frequency | Natural period | Natural Frequency |
|---|---|---|---|
| | $f_n$ (Hz) | $T_n$ (second) | $\omega_n$ (Rad/Sec) |
| 1 | 12.876 | 0.078 | 80.901 |
| 2 | 80.676 | 0.012 | 506.899 |
| 3 | 225.950 | 0.004 | 1419.687 |
| 4 | 442.745 | 0.002 | 2781.849 |

First Mode

| | | | | |
|---|---|---|---|---|
| $K-w_1^2M$ | 250.511 | -576.649 | 410.496 | -117.284 |
| | -576.649 | 1556.582 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 2260.289 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 2963.996 |
| | 0.0030259 | 0.0029901 | 0.0011648 | -577 |
| | 0.0029901 | 0.0038767 | 0.0017317 | 410 |
| | 0.0011648 | 0.0017317 | 0.0011515 | -117 |

| | | Mode Shape Plot | |
|---|---|---|---|
| $\phi_1$ = | 1 | 0 | 1.000 |
| | 0.654 | 0.250 | 0.654 |
| | 0.336 | 0.500 | 0.336 |
| | 0.096 | 0.750 | 0.096 |
| | | 1.000 | 0.000 |



| | | | |
|---|---|---|---|
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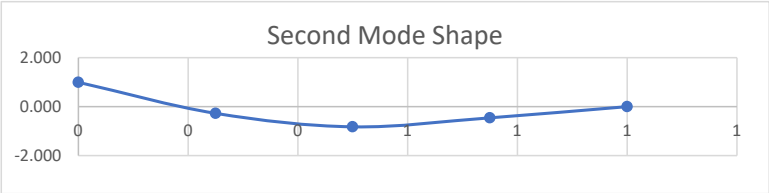
| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

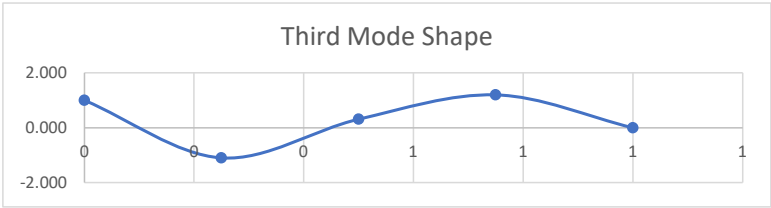
Secod Mode

| | | | | |
|---|---|---|---|---|
| $K-w_2^2M$ | 129.555 | -576.649 | 410.496 | -117.284 |
| | -576.649 | 1314.669 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 2018.376 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 2722.083 |
| | | | | |
| | -0.0032156 | -0.0044971 | -0.0022528 | -576.649 |
| | -0.0044971 | -0.0049345 | -0.0022215 | 410.496 |
| | -0.0022528 | -0.0022215 | -0.0005737 | -117.284 |
| | | | Mode Shape Plot | |
| $\phi_2$ = | 1 | | 0 | 1.000 |
| | -0.272 | | 0.250 | -0.272 |
| | -0.828 | | 0.500 | -0.828 |
| | -0.454 | | 0.750 | -0.454 |
| | | | 1.000 | 0.000 |




Third Mode

| | | | | |
|---|---|---|---|---|
| $K-w_3^2M$ | -619.381 | -576.649 | 410.496 | -117.284 |
| | -576.649 | -183.201 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 520.506 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 1224.213 |
| | | | | |
| | -0.0019850 | 0.0003771 | 0.0017160 | -576.649 |
| | 0.0003771 | -0.0005015 | -0.0009815 | 410.496 |
| | 0.0017160 | -0.0009815 | -0.0016662 | -117.284 |
| | | | Mode Shape Plot | |
| $\phi_3$ = | 1 | | 0 | 1.000 |
| | -1.098 | | 0.250 | -1.098 |
| | 0.308 | | 0.500 | 0.308 |
| | 1.197 | | 0.750 | 1.197 |
| | | | 1.000 | 0 |



| | | | |
|---|---|---|---|
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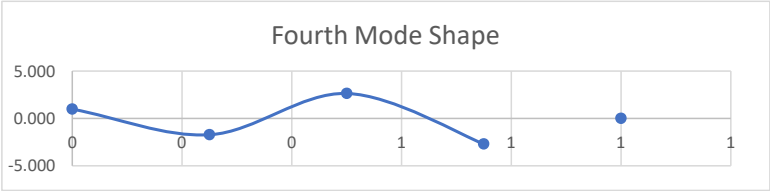
| Supervisor | WPM | TASK | CIP Noise Wall 6 |
| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

Fourth Mode

| | | | | |
|---|---|---|---|---|
| $K-w_4^2M$ | -2399.586 | -576.649 | 410.496 | -117.284 |
| | -576.649 | -3743.611 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | -3039.904 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | -2336.197 |
| | | | | |
| | -0.0013429 | 0.0018018 | -0.0018443 | -576.649 |
| | 0.0018018 | -0.0030633 | 0.0029906 | 410.496 |
| | -0.0018443 | 0.0029906 | -0.0033732 | -117.284 |
| | | | Mode Shape Plot | |
| $\phi_4$ = | 1 | | 0 | 1.000 |
| | -1.730 | | 0.250 | -1.730 |
| | 2.647 | | 0.500 | 2.647 |
| | -2.687 | | 0.750 | -2.687 |
| | | | | |
| | | | 1.000 | 0.000 |




| | | | | |
|---|---|---|---|---|
| Mode Shape Matrix | 1.000 | 1.000 | 1.000 | 1.000 |
| | 0.654 | -0.272 | -1.098 | -1.730 |
| | 0.336 | -0.828 | 0.308 | 2.647 |
| | 0.096 | -0.454 | 1.197 | -2.687 |
| | | | | |
| Transpose Mode Shape Matrix | 1.000 | 0.654 | 0.336 | 0.096 |
| | 1.000 | -0.272 | -0.828 | -0.454 |
| | 1.000 | -1.098 | 0.308 | 1.197 |
| | 1.000 | -1.730 | 2.647 | -2.687 |
| | | | | |
| Generalized Mass | 0.0006 | 0.0008 | 0.0004 | 0.0001 |
| | 0.0006 | -0.0003 | -0.0010 | -0.0005 |
| | 0.0006 | -0.0013 | 0.0004 | 0.0014 |
| | 0.0006 | -0.0020 | 0.0031 | -0.0031 |
| | | | | |
| $M_n$ = | 0.001 | 0.000 | 0.000 | 0.000 |
| | 0.000 | 0.002 | 0.000 | 0.000 |
| | 0.000 | 0.000 | 0.004 | 0.000 |
| | 0.000 | 0.000 | 0.000 | 0.021 |
| | | | | |
| Generalized Stiffness | 3.605 | 4.717 | 2.423 | 0.691 |
| | 124.562 | -67.874 | -206.318 | -113.210 |
| | 873.497 | -1918.505 | 538.408 | 2091.179 |
| | 2653.702 | -9183.569 | 14049.965 | -14259.577 |

$K_n$ =

| | | | |
|---|---|---|---|
| 7.571 | 0.000 | 0.000 | 0.000 |
| 0.000 | 365.368 | 0.000 | 0.000 |
| 0.000 | 0.000 | 5649.457 | 0.000 |
| 0.000 | 0.000 | 0.000 | 94049.609 |

Verify Natural Frequency

| Mode | ω | Eigen Value | Equation |
|---|---|---|---|
| 1 | 78.647 | 78.647 | 80.901 |
| 2 | 462.269 | 462.269 | 506.899 |
| 3 | 1224.146 | 1224.146 | 1419.687 |
| 4 | 2133.676 | 2133.676 | 2781.849 |

| | | | | |
|---|---|---|---|---|
| Generalized Force $P_n$ | 0.000582902 | 0.000762528 | 0.000391655 | 0.000111764 |
| | 0.000582902 | -0.000317626 | -0.000965489 | -0.000529781 |
| | 0.000582902 | -0.001280255 | 0.00035929 | 0.001395485 |
| | 0.000582902 | -0.002017226 | 0.003086159 | -0.003132202 |

| | | |
|---|---|---|
| Directional Vector | 1 | 0.001848849 |
| | 1 | -0.001229995 |
| | 1 | 0.001057421 |
| | 1 | -0.001480367 |

| | |
|---|---|
| $P_n$ | 1.5106 |
| | -0.7194 |
| | 0.2805 |
| | -0.0717 |

| | | | |
|---|---|---|---|
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| | BY RUK | DATE 6/18/2021 | |
| | CHK'D. BY MGH | DATE 6/18/2021 | |

**SEISMIC DESIGN PARAMETERS**

| | | | |
|---|---|---|---|
| Peak Ground Acceleration | PGA = | 0.422 | |
| Spectral Acceleration at 0.2 Second | $S_S$ = | 0.959 | g |
| Spectral Acceleration at 1 Second | $S_1$ = | 0.278 | g |
| Site Class | D | | |
| Site Factors: | $F_{pga}$ | 1.178 | |
| | $F_a$ = | 1.116 | |
| | $F_v$ = | 2.044 | |
| Response Spectrum | $S_{DS}$ = | 1.070 | g |
| | $S_{D1}$ = | 0.568 | g |
| | $T_S$ = | 0.531 | |
| | $T_o$ = | 0.106 | |
| | $A_S$ = | 0.497 | |

**ELASTIC SEISMIC RESPONSE COEFFICIENT $C_{sm}$**

AASHTO LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$
- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| Mode | ω (rad/sec) | T (sec) | $C_{sm}$ | $C_{Disp}$ |
|---|---|---|---|---|
| 1 | 78.647 | 0.080 | 0.928 | 0.08751 |
| 2 | 462.269 | 0.014 | 0.570 | -0.00074 |
| 3 | 1224.146 | 0.005 | 0.525 | 0.00004 |
| 4 | 2133.676 | 0.003 | 0.513 | 0.00000 |

| | | | |
|---|---|---|---|
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| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

**MODAL SPECTRUM ANALYSIS**

**Modal Displacements**

| Mode 1 | | Mode 2 | |
|---|---|---|---|
| $\phi_1$ = | u1 | $\phi_2$ = | u2 |
| 1.000 | 0.08751 | 1.000 | -0.00074 |
| 0.654 | 0.05724 | -0.272 | 0.00020 |
| 0.336 | 0.02940 | -0.828 | 0.00061 |
| 0.096 | 0.00839 | -0.454 | 0.00034 |
| Mode 3 | | Mode 4 | |
| $\phi_3$ = | u3 | $\phi_4$ = | u4 |
| 1.000 | 0.00004 | 1.000 | -0.000003 |
| -1.098 | -0.00004 | -1.730 | 0.000005 |
| 0.308 | 0.00001 | 2.647 | -0.000008 |
| 1.197 | 0.00005 | -2.687 | 0.000008 |

**Total Displacements**

| | | |
|---|---|---|
| $u_1$ = | 0.09 | in |
| $u_2$ = | 0.06 | in |
| $u_3$ = | 0.03 | in |
| $u_4$ = | 0.01 | in |

Modal Base Shear

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 |
|---|---|---|---|---|
| $V_1$ | 0.316 | -0.092 | 0.033 | -0.008 |
| $V_2$ | 0.413 | 0.050 | -0.073 | 0.029 |
| $V_3$ | 0.212 | 0.153 | 0.020 | -0.044 |
| $V_4$ | 0.060 | 0.084 | 0.079 | 0.044 |
| Total | 1.001 | 0.195 | 0.060 | 0.021 |

**Base Shear**

| | | |
|---|---|---|
| SRSS | **1.02** | kips |
| **Base Moment** | **8.70** | kips-ft |

| | | | |
|---|---|---|---|
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| Supervisor | WPM | TASK | CIP Noise Wall 6 |
| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | RUK | DATE | 6/18/2021 |

## Stem Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2 |
| Arch. Treatments = | 2 | in | |
| h = | 10.00 | in | |
| b = | 12 | in | |
| cover = | 2 | in | |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 12 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| Mu = | 10.08 | k-ft | Extreme Event |
| M(service) = | 2.31 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.00 | | |
| Rebar Area = | 0.79 | $in^2$ | |
| As= | 0.79 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 7.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.16 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.37 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 24.60 | k-ft | |
| **ΦMn > Mu ?** | **YES** | | |

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 200 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6* Mcr = | 20 | kips-ft |
| 1.33 * Mu = | 13 | kips-ft |
| **ΦMn > MIN(1.6*Mcr,1.33*Mu ?** | **YES** | |

| | | | |
|---|---|---|---|
| JOB NO. | PS19203160 | SHEET | 2 of 4 |
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| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | RUK | DATE | 6/18/2021 |

**Check Crack Control: (LRFD 5.6.7)**

| | | | |
|---|---|---|---|
| ρ = | As/(b*d) | | |
| ρ = | 0.00878 | | |
| ρ*n = | 0.07022 | | |
| k = | SQRT($\rho n^2$ + 2*ρn)-ρn | | |
| k = | 0.31106 | | |
| j = | 1-(k/3) | | |
| j = | 0.896 | | |
| fs = | M(service)/(As*j*d) | | |
| fs = | 5.22 | ksi | |
| 0.6*fy = | 36 | ksi | |
| **fs <=** | **0.6*fy** | | **OKAY** |

**Check if tension in cross-section exceeds 80% of modulus of rupture**

| | | | |
|---|---|---|---|
| fr = | 0.24*SQRT(f'c) | | |
| fr = | 0.48 | ksi | |
| 0.8*fr = | 0.38 | ksi | |
| fT = | M(service)/Sx | | |
| fT = | 0.14 | ksi | |
| fT > 0.8*fr | | | **DOES NOT EXCEED** |

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

| | | | |
|---|---|---|---|
| $A_s$ >= | 1.3*b*h/(2*(b+h)*$f_y$) | | |
| $As_{min}$ = | 0.11 | $in^2$ | |
| $S_{max}$ = | 15 | in | |
| Try Bar # = | 4 | | |
| $A_{bar}$ = | 0.20 | $in^2$ | |
| Spacing = | 15 | in | **OKAY** |
| As = | 0.16 | $in^2$/ft | **OKAY** |

| | | | |
|---|---|---|---|
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| CHK'D. BY | RUK | DATE | 6/18/2021 |

**Wall Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Vu = 1.12 kips

Shear Bar = 4
Area per Bar = 0.20 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.4 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 3.75 in

Vc= 2*SQRT(f'c)*b*d
Vc= 11.38 kips
Req'd Vn= Vu/$\phi_v$
Req'd Vn= 1.25 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 10 **OKAY**

**Development Length of Hooked Rebar in Stem and Grade Beam (LRFD 5.10.8.2.1a):**

$l_{db}$ = 2.4*$d_b$*$f_y$/SQRT(f'$_c$)
$l_{db}$ = 72 in
$\lambda$ = 1.0 for normal weight concrete
$\lambda$ = 1
$\lambda_{rl}$ = reinforcement location factor, 1.3 if more than 12" concrete below reinf.
$\lambda_{rl}$ = 1
$\lambda_{cf}$ = coating factor
$\lambda_{cf}$ = 1
$d_b$ = 1
$c_b$ = MIN(cover,bar spacing/2)
$c_b$ = 2
$k_{tr}$ = cross-sect area of transv reinf.
$k_{tr}$ = 0
$\lambda_{rc}$ = reinforcement confinement factor, $d_b/(c_b+k_{tr})$
$\lambda_{rc}$ = 0.5
$As_{required}$ = (Mu/$\phi$)/($f_y$*(d-a/2))
$As_{required}$ = 0.32 $in^2$
$\lambda_{er}$ = 1.0 for seismic-force-resisting systems
$\lambda_{er}$ = 1.00
$l_d$ = $l_{db}$ *($\lambda$rl*$\lambda_{cf}$*$\lambda_{rc}$*$\lambda_{er}$)/$\lambda$
$l_d$ = 36.00 in

| | | | |
|---|---|---|---|
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| CHK'D. BY | RUK | DATE | 6/18/2021 |

**Vertical Flexural Rebar to be Lapped with Hooked Rebar Design (AISC 14th Ed. Table 3-23-19):**

$M_{max}$ = $M_u$
$M_{max}$ = 10.08 kip-ft
L = Height of Noise Wall
L = 12.00 ft
w = $2*M_{max}/L^2$
w = 0.14 kip/ft

x = Height of Noise Wall -Development Length of Hooked Rebar
x = 9.00 ft
$M_{at\ x}$ = $w*x^2/2$
$M_{at\ x}$ = 5.67 kip-ft
Φ = 0.90

Try Rebar Size 6
Try Spacing 12.00 in
# of rebar = 1.00
Rebar Area = 0.44 $in^2$
As= 0.44 $in^2$

d = h-cover-(Rebar Diameter/2)
d = 7.50 in
$\beta_1$ = 0.85
a = (As*fy)/(0.85*fc*b)
a = 0.65 in
c = $a/\beta_1$
c = 0.76 in

ΦMn = Φ*As*fy*(d-a/2)
ΦMn = 14.21 k-ft
**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | RUK | DATE | 6/18/2021 |

## Footing Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| h = | 12 | in | |
| b = | 12 | in | |
| cover = | 3 | in | AASHTO 5.10.1 |
| Rebar # = | 6 | | |
| Rebar Diameter = | 0.75 | in | |
| Spacing = | 12 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| $q_{extr}$ = | 2.14 | ksf | Max bearing pressure applied |
| $q_{serv}$ = | 0.89 | ksf | Service Load bearing pressure |
| L = | 2.71 | ft | Heel of Footing Length |
| Mu = | $q*L^2/2$ | | |
| Mu = | 7.83 | k-ft | Extreme Event |
| M(service) = | 3.27 | k-ft | Service 1 |
| Φ = | 0.90 | | |
| # of rebar = | 1.00 | | |
| Rebar Area = | 0.44 | $in^2$/ per bar | |
| As= | 0.44 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 8.63 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 0.65 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 0.76 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 16.44 | k-ft | |
| | **ΦMn > Mu ?** | **YES** | |

| | | | |
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**Check Min. Reinforcement: (LRFD 5.6.3.3)**

fr = 0.37*SQRT(fc)
fr = 0.74 ksi
Sx = $b*h^2/6$
Sx = 288 $in^3$
1.6 * Mcr = 1.6*fr*Sx
1.6 * Mcr = 28.42 kips-ft
1.33 * Mu = 10 kips-ft
**ΦMn > MIN(1.6*Mcr,1.33*Mu) ? YES**

**Check Crack Control: (LRFD 5.6.7)**

ρ = As/(b*d)
ρ = 0.00425
ρ*n = 0.03401
k = SQRT($ρn^2$ + 2*ρn)-ρn
k = 0.22900
j = 1-(k/3)
j = 0.924
fs = M(service)/(As*j*d)
fs = 11.19 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.14 ksi
fT > 0.8*fr **DOES NOT EXCEED**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= $1.3*b*h/(2*(b+h)*f_y)$
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 18 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 18 in **OKAY**
As = 0.13 $in^2/ft$ **OKAY**

| | | | |
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**Footing Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Footing Width = 6.42 ft
Stem Width = 1.00 ft
Critical Section = Ls = (Footing Width -Stem Width)/2-d
Ls = 1.99 ft
Vu = q*Ls
Vu = 4.25 kips

Shear Bar = 5
Area per Bar = 0.44 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.88 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 4.31 in

Vc= $0.0316*\beta*\lambda*\sqrt{(f'_c)}*b*d_v$ LRFD 5.7.3.3-3
$\lambda$ = 1 LRFD 5.4.2.8
$\beta$ = 2 LRFD 5.7.3.4
$d_v$ = MAX(0.9*d,0.72*h)
$d_v$ = 8.64 in
Vc= 13.11 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 4.72 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 12 **OKAY**

| | | | |
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**Preliminary Analysis for:**
**Cast-In-Place Concrete Noise Wall on Footing**
**Maximum Total Wall Height = 12.0' with Maximum Embedment**

DESIGN CRITERIA:
- WSDOT Bridge Design Manual, July 2019
- AASHTO LRFD 8th Edition
- Geotechnical Engineering Report: Soldier Pile Wall 10.35L and Noise Wall 6

DESIGN ASSUMPTIONS:
- Exposed Wall Height is maximum 10' front face and 8' back face.
- Noise Wall Wall is supporting 2' of fill.
- Seismic design is based on WSDOT BDM 8.2.2 and AASHTO LRFD 4.7.4.3.3.
- Noise Wall Dimensions are based on WSDOT Bridge Manual for Non-Standard Walls, page 8-23.
- Wind load is considered.
- Seismic soil forces are considered.
- Seismic internal wall forces are considered.
- Moment is positive with right hand rule at bottom center of footing. Right of center is positive, Left of center is n

Try:

| | | | |
|---|---|---|---|
| Footing Width = | 6.42 | ft | |
| Footing Thickness = | 1.00 | ft | |
| Wall Height = | 12.00 | ft | |
| Exposed Wall Height = | 10 | ft | |
| Wall Thickness = | 1.000 | ft | - Includes form liner on each face |
| Footing Toe Width = | 2.708 | ft | |
| Footing Heel Width = | 2.708 | ft | |

DEAD LOAD (DC):

Loads based on linear foot of wall

| Item | Density | Length | Thickness | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Noise Wall | 0.150 | 12 | 1.00 | 1 | 12.00 | 1.80 | 0.00 | 0.00 |
| Footing | 0.150 | 6.4 | 1.00 | 1 | 6.42 | 0.96 | 0.00 | 0.00 |
| | | | | | Totals = | 2.76 | | 0.00 |

| | | | |
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VERTICAL SOIL LOAD (EV):

Loads based on linear foot of wall

| Item | Density | Width | Height | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Toe | 0.130 | 2.71 | 3.25 | 1 | 8.80 | 1.14 | -1.85 | -2.12 |
| Heel | 0.130 | 2.71 | 6.50 | 1 | 17.60 | 2.29 | 1.85 | 4.24 |
| | | | | | Totals = | 3.43 | | 2.12 |

HORIZONTAL SOIL LOAD (EH): - Not required when seismic soil is being included. (AASHTO C11.6.5.1)

$EH = (1/2)*Ka*\Upsilon*H^2$

| | | | | | |
|---|---|---|---|---|---|
| EH = | 0.16 | klf | ϕ= | 38 | degrees |
| Moment Arm @ B/Footing = | 1.08 | ft | Ka = | 0.24 | |
| Moment = | 0.2 | k*ft | ϒ= | 0.13 | kcf |
| | | | H = | 3.25 | ft |

WIND LOAD (WS): (AASHTO 3.8.1.2.4)

$P_Z = 2.56X10^{-6}*V^2*K_Z*G*C_D$

| | | | |
|---|---|---|---|
| $V_{STR\ III}$= | 110 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{STR\ V}$= | 80 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{SERV\ I}$= | 70 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $K_{Z_STR}$= | 0.71 | | (AASHTO Table C3.8.1.2.1-1) |
| $K_{Z_SERV}$= | 1.0 | | (AASHTO 3.8.1.2.1) |
| G= | 0.85 | | (AASHTO Table 3.8.1.2.1-1) |
| $C_D$ = | 1.2 | | (AASHTO Table 3.8.1.2.1-2) |
| Z= | 5.50 | = Exposed Noise Wall Height at the Back Face | |

| | | |
|---|---|---|
| $P_{Z_STR\ III}$= | 0.022 | ksf |
| $P_{Z_STR\ V}$= | 0.012 | ksf |
| $P_{Z_SERV\ I}$= | 0.013 | ksf |

$P_W = P_Z*Z$ (AASHTO 3.8.1.2.4)

Moment Arm @ B/Footing = 10.5 ft

| | | | |
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| | Linear feet of Wall | |
|---|---|---|
| | $P_W$ | Moment |
| | klf | k*ft |
| STR III | 0.12 | 1.3 |
| STR V | 0.07 | 0.7 |
| SERV I | 0.07 | 0.7 |

- $P_W$ is a line load applied at 0.55*Z from the top of roadway. (AASHTO 3.8.1.2.4)
- Moment Arm is from the top of the retaining wall.
  = 0.55*(Noise Wall Height + Traffic Barrier Height) + Slab Thickness

SEISMIC ACTIVE EARTH PRESSURES ($EQ_{soil}$):

$P_{seis} = P_{AE}$ LRFD 11.6.5.1

$P_{seis}$ = 0.503 klf $P_{seis}$ is applied 1/3 height of soil.

$P_{AE}$ = 0.503 klf LRFD 11.6.5.3-2

$P_{AE} = 0.5*\Upsilon*K_{AE}*h^2$

- Monobe-Okabe Analysis LRFD A11.3.1

**Figure A11.3.1-1—Mononobe-Okabe Method Force Diagrams**

$$K_{AE} = \frac{\cos^2(\phi - \theta_{MO} - \beta)}{\cos\theta_{MO}\cos^2\beta\cos(\delta+\beta+\theta_{MO})} \times \left[1 + \sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2} \quad \text{(A11.3.1-1)}$$

where:

$K_{AE}$ = seismic active earth pressure coefficient (dim)
$\gamma$ = unit weight of soil (kcf)
$H$ = height of wall (ft)
$h$ = height of wall at back of wall heel considering height of sloping surcharge, if present (ft)
$\phi_f$ = friction angle of soil (degrees)
$\theta_{MO}$ = arc tan $[k_h/(1 - k_v)]$ (degrees)
$\delta$ = wall backfill interface friction angle (degrees)
$k_h$ = horizontal seismic acceleration coefficient (dim.)
$k_v$ = vertical seismic acceleration coefficient (dim.)
$i$ = backfill slope angle (degrees)
$\beta$ = slope of wall to the vertical, negative as shown (degrees)

$k_{AE}$ = 0.732

$\psi$ = 0.42

$$\psi = \left[1 + \sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2}$$

$\Upsilon_{soil}$ = 0.130 kcf

H = 3.3 ft Height of soil and footing

$\phi$ = 38.00 degrees

$\theta$ = 26.4 degrees

$\delta = 2/3*\phi$ = 25.3 degrees

$k_h = 1.0*k_{h0}$ = 0.497

$k_{h0} = A_s$ = 0.497

Note: 0.5*kho=0.249, by using 1.0*kho this increased the Extreme Event Moment by 3% and the Lateral load by 15%. This small increase does not affect the outcome of the calc.

$k_v$ = 0.0

i = 0.0 degrees

$\beta$ = 0.0 degrees

Moment Arm @ B/Footing = 1.08 ft

Moment = 0.5 k*ft

| | | | |
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SEISMIC FORCES ON WALL ($EQ_{wall}$): (See Attached Calc)

Shear at base of wall = 1.0 k
Moment on wall = 8.7 k*ft

LOAD SUMMARY

| Load | Force | | Moment |
|---|---|---|---|
| | Vertical | Lateral | |
| | $P_Y$ (kips) | $P_X$ (kips) | (kips) |
| DC | 2.8 | | 0.0 |
| EV | 3.4 | | 2.1 |
| EH | | 0.17 | 0.18 |
| $WS_{STR\ III}$ | | 0.12 | 1.3 |
| $WS_{STR\ V}$ | | 0.07 | 0.7 |
| $WS_{SERV\ I}$ | | 0.07 | 0.7 |
| $EQ_{soil}$ | | 0.5 | 0.5 |
| $EQ_{wall}$ | | 1.0 | 8.7 |

**Calculate Bearing Pressure**

Load Combinations (AASHTO Table 3.4.1-1)

| Load Combination | Force | | Moment | e | B' | $\sigma_v$ |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_Y$ (kips) | $P_X$ (kips) | (kips) | ft | ft | **ksf** |
| STRENGTH III: 1.25DC+1.5EH+1.0(EV+WS) | 6.9 | 0.4 | 3.7 | 0.5 | 5.3 | **1.29** |
| STRENGTH V: 1.25DC+1.5EH+1.0(EV+WS) | 6.9 | 0.3 | 3.1 | 0.4 | 5.5 | **1.25** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 6.2 | 1.5 | 11.4 | 1.8 | 2.7 | **2.26** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 6.2 | 0.2 | 3.0 | 0.5 | 5.4 | **1.14** |

Eccentricity = e =M/$P_y$

B = 6.42 ft B' = B - 2e

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\sum V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

| | | | |
|---|---|---|---|
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**Check Eccentricity Limits** (AASHTO 11.6.3.3)

- The location of the resultant is limited to the middle two-thirds of the width of the foundation.

emax = B/3 2.14 ft

| Load Combination | Force | | Moment | e | Middle | |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | Two-Thirds | |
| STRENGTH III: 0.9DC+1.5EH+1.00(EV+WS) | 5.9 | 0.4 | 3.7 | 0.5 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 5.9 | 0.3 | 3.1 | 0.4 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 6.2 | 1.5 | 11.4 | 1.8 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 6.2 | 0.2 | 3.0 | 0.5 | Yes | **OK** |

**Check Sliding** (AASHTO 10.6.3.4 and AASHTO 11.5.6)

| Load Combination | Force | | $\phi_T R\tau$ | Is Rτ > Vx? | |
|---|---|---|---|---|---|
| | Vertical | Lateral | | | |
| | $P_y$ (kips) | $P_X$ (kips) | kips | | |
| STRENGTH III: 0.90DC+1.5EH+1.00(EV+WS) | 5.9 | 0.4 | 3.7 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 5.9 | 0.3 | 3.7 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 6.2 | 1.5 | 3.9 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 6.2 | 0.2 | 3.9 | Yes | **OK** |

Sliding Resistance = $\phi_T R\tau = \phi_T C P_y \tan \phi_f$ (AASHTO 10.6.3.4-2)

$\phi_T$ = 0.8 (AASHTO Table 10.5.5.2.2-1)

C = 1.0

$\phi_f$ = 38 degrees

Coeffient of Friction = $\tan \phi_f$ = 0.78 (AASHTO C3.11.5.3)

| | | | |
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## SOUND BARRIER DESIGN FORCE

**NOISE BARRIER CIP WALL TYPE GEOMETRY**

| | | | |
|---|---|---|---|
| Wall Length | L = | 1 | ft |
| Wall/Wall Height | H = | 12 | ft |
| Wall Thickness | T = | 12 | in |

**MATERIALS**

| | | | |
|---|---|---|---|
| Wall Concrete | $f_c'$ = | 4 | ksi |
| | $\gamma_c$ = | 0.15 | kcf |
| | $E_c$ = | 4266 | ksi |
| Reinforcing Steel | $f_y$ = | 60 | ksi |
| | $E_s$ = | 29000 | ksi |

**DEAD LOAD**

Weight of Wall

| | | | |
|---|---|---|---|
| Vertical Dead Load | D = | 1.80 | kips |

**SEISMIC FORCE**

Seismic design shall be in accordance with AASHTO LRFD Article 3.10.2.1-General Procedure, considering site class D:

a. Modal analysis shall be performed for the first 4 periods. Elastic seismic response coefficient Csm shall be computed for each modal period in accordance with LRFD Article 3.10.4.2 and all 4 Csm coefficients shall be combined through the SRSS method.

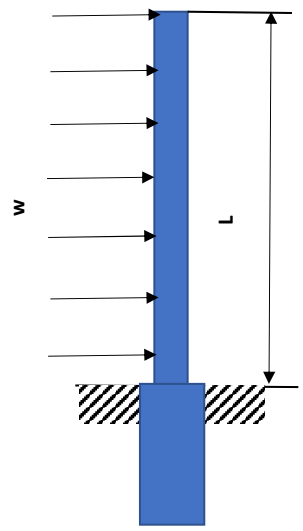
b. The resultant seismic force shall be considered to act at a height of 0.71H above the top of the shaft, where H is the total height measured from the top of the Wall to the top of the shaft.

**Structural Modeling**

Modeling the column as a cantilever beam

The mass of column and ajacent panels is uniformly distributed along the column

| | | | |
|---|---|---|---|
| Uniform Weight | w = | 0.15 | kips/ft |
| Uniform Mass | m = | 0.0004 | |
| Column | I = | 1728 | $in^4$ |
| Modulus | E = | 4266 | ksi |
| Gravity | g = | 386 | $in/sec^2$ |



| | | | |
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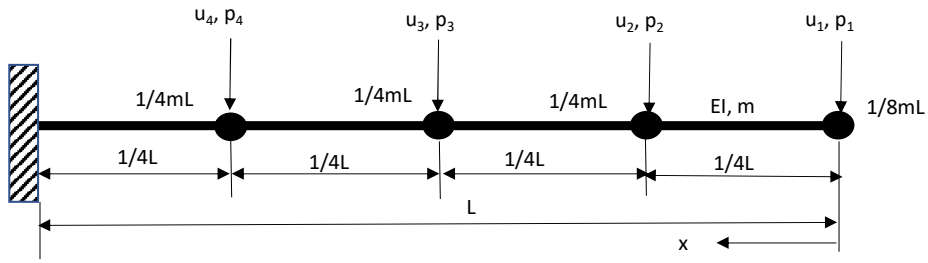
**Modal Analysis**




Flexibility Matrix

| | | |
|---|---|---|
| $p_1$ = | 1 | |
| | x | u |
| $u_1$ | 0.00 | 0.33333333 |
| $u_2$ | 0.25 | 0.21093750 |
| $u_3$ | 0.50 | 0.10416667 |
| $u_4$ | 0.75 | 0.02864583 |

| | | |
|---|---|---|
| $p_2$ = | 1 | |
| a = | 0.25 | |
| b = | 0.75 | |
| | x | u |
| $u_1$ | 0.00 | 0.2109375 |
| $u_2$ | 0.25 | 0.1406250 |
| $u_3$ | 0.50 | 0.0729167 |
| $u_4$ | 0.75 | 0.0208333 |

| | | |
|---|---|---|
| $p_3$ = | 1 | |
| a = | 0.5 | |
| b = | 0.5 | |
| | x | u |
| $u_1$ | 0 | 0.104166667 |
| $u_2$ | 0.25 | 0.072916667 |
| $u_3$ | 0.5 | 0.041666667 |
| $u_4$ | 0.75 | 0.013020833 |

| | | |
|---|---|---|
| $p_4$ = | 1 | |
| a = | 0.75 | |
| b = | 0.25 | |
| | x | u |
| $u_1$ | 0.00 | 0.028645833 |
| $u_2$ | 0.25 | 0.020833333 |
| $u_3$ | 0.50 | 0.013020833 |
| $u_4$ | 0.75 | 0.005208333 |

| | | | |
|---|---|---|---|
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Flexibility Matrix

| | $p_1 = 1$ | $p_2 = 1$ | $p_3 = 1$ | $p_4 = 1$ |
|---|---|---|---|---|
| $u_1 = L^3/EI^*$ | 0.3333 | 0.2109 | 0.1042 | 0.0286 |
| $u_2 = L^3/EI^*$ | 0.2109 | 0.1406 | 0.0729 | 0.0208 |
| $u_3 = L^3/EI^*$ | 0.1042 | 0.0729 | 0.0417 | 0.0130 |
| $u_4 = L^3/EI^*$ | 0.0286 | 0.0208 | 0.0130 | 0.0052 |

Stiffness Matrix K

| | | | | |
|---|---|---|---|---|
| $EI/L^3$ | 102.928 | -233.567 | 166.268 | -47.505 |
| $EI/L^3$ | -233.567 | 633.402 | -613.608 | 285.031 |
| $EI/L^3$ | 166.268 | -613.608 | 918.433 | -756.124 |
| $EI/L^3$ | -47.505 | 285.031 | -756.124 | 1203.464 |

K =

| | | | |
|---|---|---|---|
| 254.116 | -576.649 | 410.496 | -117.284 |
| -576.649 | 1563.793 | -1514.925 | 703.707 |
| 410.496 | -1514.925 | 2267.500 | -1866.778 |
| -117.284 | 703.707 | -1866.778 | 2971.207 |

Mass Matrix M

| | | | |
|---|---|---|---|
| 1/8mL | 0 | 0 | 0 |
| 0 | 1/4mL | 0 | 0 |
| 0 | 0 | 1/4mL | 0 |
| 0 | 0 | 0 | 1/4mL |

M =

| | | | |
|---|---|---|---|
| 0.000582902 | 0 | 0 | 0 |
| 0 | 0.001165803 | 0 | 0 |
| 0 | 0 | 0.001165803 | 0 |
| 0 | 0 | 0 | 0.001165803 |

| | | | |
|---|---|---|---|
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| | Supervisor | WPM | TASK CIP Noise Wall 6 |
| | BY | RUK | DATE 6/18/2021 |
| | CHK'D. BY | MGH | DATE 6/18/2021 |

First Mode

| $w_1^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 6185.414 | 250.511 | -576.649 | 410.496 | -117.284 |
| | -576.649 | 1556.582 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 2260.289 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 2963.996 |

$Det(K-w_n^2*M)=0$ 0.00007 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_1$ = 78.647 rad/sec $T_1$ = 0.080 sec

Second Mode

| $w_2^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 213692.70 | 129.5545743 | -576.649 | 410.496 | -117.284 |
| | -576.649 | 1314.669 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 2018.376 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 2722.083 |

$Det(K-w_n^2*M)=0$ 0.000613373 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_2$ = 462.269 rad/sec $T_2$ = 0.014 sec

Third Mode

| $w_3^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 1498532.78 | -619.381 | -576.649 | 410.496 | -117.284 |
| | -576.649 | -183.201 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 520.506 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 1224.213 |

$Det(K-w_n^2*M)=0$ -0.000817904 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_3$ = 1224.146 rad/sec $T_3$ = 0.005 sec

Fourth Mode

| $w_4^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 4552573.24 | -2399.586 | -576.649 | 410.496 | -117.284 |
| | -576.649 | -3743.611 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | -3039.904 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | -2336.197 |

$Det(K-w_n^2*M)=0$ -0.079570 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_4$ = 2133.676 rad/sec $T_4$ = 0.003 sec

| | | | |
|---|---|---|---|
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| | BY RUK | DATE 6/18/2021 | |
| | CHK'D. BY MGH | DATE 6/18/2021 | |

Summary

| Mode | ω (rad/sec) | T (sec) |
|---|---|---|
| 1 | 78.647 | 0.080 |
| 2 | 462.269 | 0.014 |
| 3 | 1224.146 | 0.005 |
| 4 | 2133.676 | 0.003 |

NATURAL PERIODS By Equation

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$T_n = 1/f_n$ $\omega_n = 2\pi/T_n$

| | | |
|---|---|---|
| First Mode | $K_1$ = | 3.52 |
| Second Mode | $K_1$ = | 22.03 |
| Third Mode | $K_3$ = | 61.7 |
| Fourth Mode | $K_4$ = | 120.9 |
| | g = | 386 |

| Mode | Natural Frequency | Natural period | Natural Frequency |
|---|---|---|---|
| | $f_n$ (Hz) | $T_n$ (second) | $\omega_n$ (Rad/Sec) |
| 1 | 12.876 | 0.078 | 80.901 |
| 2 | 80.676 | 0.012 | 506.899 |
| 3 | 225.950 | 0.004 | 1419.687 |
| 4 | 442.745 | 0.002 | 2781.849 |

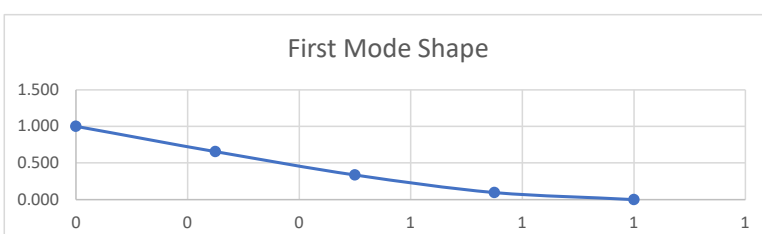
First Mode

$K-w_1^2M$

| | | | |
|---|---|---|---|
| 250.511 | -576.649 | 410.496 | -117.284 |
| -576.649 | 1556.582 | -1514.925 | 703.707 |
| 410.496 | -1514.925 | 2260.289 | -1866.778 |
| -117.284 | 703.707 | -1866.778 | 2963.996 |

| | | |
|---|---|---|
| 0.0030259 | 0.0029901 | 0.0011648 |
| 0.0029901 | 0.0038767 | 0.0017317 |
| 0.0011648 | 0.0017317 | 0.0011515 |

| | | | |
|---|---|---|---|
| | | Mode Shape Plot | |
| $\phi_1$ = | 1 | 0 | 1.000 |
| | 0.654 | 0.250 | 0.654 |
| | 0.336 | 0.500 | 0.336 |
| | 0.096 | 0.750 | 0.096 |
| | | 1.000 | 0.000 |



| | | | |
|---|---|---|---|
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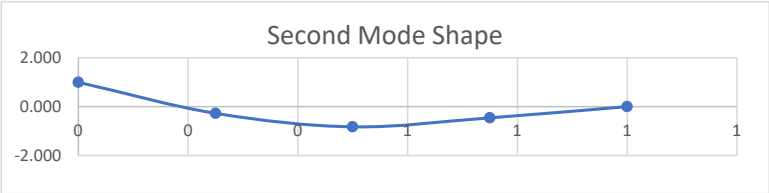
| CHK'D. BY | MGH | DATE | 6/18/2021 |

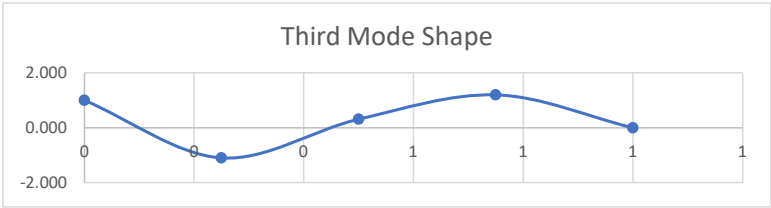
Secod Mode

| | | | | |
|---|---|---|---|---|
| $K-w_2^2M$ | 129.555 | -576.649 | 410.496 | -117.284 |
| | -576.649 | 1314.669 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 2018.376 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 2722.083 |
| | | | | |
| | -0.0032156 | -0.0044971 | -0.0022528 | -576.649 |
| | -0.0044971 | -0.0049345 | -0.0022215 | 410.496 |
| | -0.0022528 | -0.0022215 | -0.0005737 | -117.284 |
| | | | Mode Shape Plot | |
| $\phi_2$ = | 1 | | 0 | 1.000 |
| | -0.272 | | 0.250 | -0.272 |
| | -0.828 | | 0.500 | -0.828 |
| | -0.454 | | 0.750 | -0.454 |
| | | | 1.000 | 0.000 |




Third Mode

| | | | | |
|---|---|---|---|---|
| $K-w_3^2M$ | -619.381 | -576.649 | 410.496 | -117.284 |
| | -576.649 | -183.201 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | 520.506 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | 1224.213 |
| | | | | |
| | -0.0019850 | 0.0003771 | 0.0017160 | -576.649 |
| | 0.0003771 | -0.0005015 | -0.0009815 | 410.496 |
| | 0.0017160 | -0.0009815 | -0.0016662 | -117.284 |
| | | | Mode Shape Plot | |
| $\phi_3$ = | 1 | | 0 | 1.000 |
| | -1.098 | | 0.250 | -1.098 |
| | 0.308 | | 0.500 | 0.308 |
| | 1.197 | | 0.750 | 1.197 |
| | | | 1.000 | 0 |



| | | | |
|---|---|---|---|
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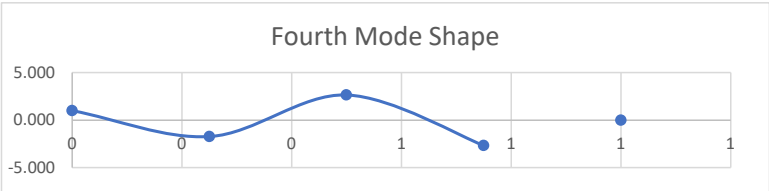
Fourth Mode

| | | | | |
|---|---|---|---|---|
| $K-w_4^2M$ | -2399.586 | -576.649 | 410.496 | -117.284 |
| | -576.649 | -3743.611 | -1514.925 | 703.707 |
| | 410.496 | -1514.925 | -3039.904 | -1866.778 |
| | -117.284 | 703.707 | -1866.778 | -2336.197 |
| | | | | |
| | -0.0013429 | 0.0018018 | -0.0018443 | -576.649 |
| | 0.0018018 | -0.0030633 | 0.0029906 | 410.496 |
| | -0.0018443 | 0.0029906 | -0.0033732 | -117.284 |
| | | | Mode Shape Plot | |
| $\phi_4$ = | 1 | | 0 | 1.000 |
| | -1.730 | | 0.250 | -1.730 |
| | 2.647 | | 0.500 | 2.647 |
| | -2.687 | | 0.750 | -2.687 |
| | | | | |
| | | | 1.000 | 0.000 |




| | | | | |
|---|---|---|---|---|
| Mode Shape Matrix | 1.000 | 1.000 | 1.000 | 1.000 |
| | 0.654 | -0.272 | -1.098 | -1.730 |
| | 0.336 | -0.828 | 0.308 | 2.647 |
| | 0.096 | -0.454 | 1.197 | -2.687 |
| | | | | |
| Transpose Mode Shape Matrix | 1.000 | 0.654 | 0.336 | 0.096 |
| | 1.000 | -0.272 | -0.828 | -0.454 |
| | 1.000 | -1.098 | 0.308 | 1.197 |
| | 1.000 | -1.730 | 2.647 | -2.687 |
| | | | | |
| Generalized Mass | 0.0006 | 0.0008 | 0.0004 | 0.0001 |
| | 0.0006 | -0.0003 | -0.0010 | -0.0005 |
| | 0.0006 | -0.0013 | 0.0004 | 0.0014 |
| | 0.0006 | -0.0020 | 0.0031 | -0.0031 |
| | | | | |
| $M_n$ = | 0.001 | 0.000 | 0.000 | 0.000 |
| | 0.000 | 0.002 | 0.000 | 0.000 |
| | 0.000 | 0.000 | 0.004 | 0.000 |
| | 0.000 | 0.000 | 0.000 | 0.021 |
| | | | | |
| Generalized Stiffness | 3.605 | 4.717 | 2.423 | 0.691 |
| | 124.562 | -67.874 | -206.318 | -113.210 |
| | 873.497 | -1918.505 | 538.408 | 2091.179 |
| | 2653.702 | -9183.569 | 14049.965 | -14259.577 |

| | | | |
|---|---|---|---|
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$K_n$ =

| | | | |
|---|---|---|---|
| 7.571 | 0.000 | 0.000 | 0.000 |
| 0.000 | 365.368 | 0.000 | 0.000 |
| 0.000 | 0.000 | 5649.457 | 0.000 |
| 0.000 | 0.000 | 0.000 | 94049.609 |

Verify Natural Frequency

| Mode | ω | Eigen Value | Equation |
|---|---|---|---|
| 1 | 78.647 | 78.647 | 80.901 |
| 2 | 462.269 | 462.269 | 506.899 |
| 3 | 1224.146 | 1224.146 | 1419.687 |
| 4 | 2133.676 | 2133.676 | 2781.849 |

Generalized Force $P_n$

| | | | |
|---|---|---|---|
| 0.000582902 | 0.000762528 | 0.000391655 | 0.000111764 |
| 0.000582902 | -0.000317626 | -0.000965489 | -0.000529781 |
| 0.000582902 | -0.001280255 | 0.00035929 | 0.001395485 |
| 0.000582902 | -0.002017226 | 0.003086159 | -0.003132202 |

Directional Vector

| | |
|---|---|
| 1 | 0.001848849 |
| 1 | -0.001229995 |
| 1 | 0.001057421 |
| 1 | -0.001480367 |

$P_n$

| |
|---|
| 1.5106 |
| -0.7194 |
| 0.2805 |
| -0.0717 |

| | | | |
|---|---|---|---|
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| | CHK'D. BY MGH | DATE 6/18/2021 | |

**SEISMIC DESIGN PARAMETERS**

| | | | |
|---|---|---|---|
| Peak Ground Acceleration | PGA = | 0.422 | |
| Spectral Acceleration at 0.2 Second | $S_S$ = | 0.959 | g |
| Spectral Acceleration at 1 Second | $S_1$ = | 0.278 | g |
| Site Class | D | | |
| Site Factors: | $F_{pga}$ | 1.178 | |
| | $F_a$ = | 1.116 | |
| | $F_v$ = | 2.044 | |
| Response Spectrum | $S_{DS}$ = | 1.070 | g |
| | $S_{D1}$ = | 0.568 | g |
| | $T_S$ = | 0.531 | |
| | $T_o$ = | 0.106 | |
| | $A_S$ = | 0.497 | |

**ELASTIC SEISMIC RESPONSE COEFFICIENT $C_{sm}$**

AASHTO LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$
- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| Mode | ω (rad/sec) | T (sec) | $C_{sm}$ | $C_{Disp}$ |
|---|---|---|---|---|
| 1 | 78.647 | 0.080 | 0.928 | 0.08751 |
| 2 | 462.269 | 0.014 | 0.570 | -0.00074 |
| 3 | 1224.146 | 0.005 | 0.525 | 0.00004 |
| 4 | 2133.676 | 0.003 | 0.513 | 0.00000 |

| | | | |
|---|---|---|---|
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**MODAL SPECTRUM ANALYSIS**

**Modal Displacements**

| Mode 1 | | Mode 2 | |
|---|---|---|---|
| $\phi_1$ = | u1 | $\phi_2$ = | u2 |
| 1.000 | 0.08751 | 1.000 | -0.00074 |
| 0.654 | 0.05724 | -0.272 | 0.00020 |
| 0.336 | 0.02940 | -0.828 | 0.00061 |
| 0.096 | 0.00839 | -0.454 | 0.00034 |
| Mode 3 | | Mode 4 | |
| $\phi_3$ = | u3 | $\phi_4$ = | u4 |
| 1.000 | 0.00004 | 1.000 | -0.000003 |
| -1.098 | -0.00004 | -1.730 | 0.000005 |
| 0.308 | 0.00001 | 2.647 | -0.000008 |
| 1.197 | 0.00005 | -2.687 | 0.000008 |

**Total Displacements**

| | | |
|---|---|---|
| $u_1$ = | 0.09 | in |
| $u_2$ = | 0.06 | in |
| $u_3$ = | 0.03 | in |
| $u_4$ = | 0.01 | in |

Modal Base Shear

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 |
|---|---|---|---|---|
| $V_1$ | 0.316 | -0.092 | 0.033 | -0.008 |
| $V_2$ | 0.413 | 0.050 | -0.073 | 0.029 |
| $V_3$ | 0.212 | 0.153 | 0.020 | -0.044 |
| $V_4$ | 0.060 | 0.084 | 0.079 | 0.044 |
| Total | 1.001 | 0.195 | 0.060 | 0.021 |

**Base Shear**

| | | |
|---|---|---|
| SRSS | **1.02** | kips |
| **Base Moment** | **8.70** | kips-ft |

| | | | |
|---|---|---|---|
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| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | RUK | DATE | 6/18/2021 |

## Stem Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2 |
| Arch. Treatments = | 2 | in | |
| h = | 10.00 | in | |
| b = | 12 | in | |
| cover = | 2 | in | |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 12 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| Mu = | 10.08 | k-ft | Extreme Event |
| M(service) = | 2.21 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.00 | | |
| Rebar Area = | 0.79 | $in^2$ | |
| As= | 0.79 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 7.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.16 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.37 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 24.60 | k-ft | |
| **ΦMn > Mu ?** | **YES** | | |

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 200 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6* Mcr = | 20 | kips-ft |
| 1.33 * Mu = | 13 | kips-ft |
| **ΦMn > MIN(1.6*Mcr,1.33*Mu ?** | **YES** | |

| | | | |
|---|---|---|---|
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| CHK'D. BY | RUK | DATE | 6/18/2021 |

**Check Crack Control: (LRFD 5.6.7)**

| | | | |
|---|---|---|---|
| ρ = | As/(b*d) | | |
| ρ = | 0.00878 | | |
| ρ*n = | 0.07022 | | |
| k = | SQRT(ρn$^2$ + 2*ρn)-ρn | | |
| k = | 0.31106 | | |
| j = | 1-(k/3) | | |
| j = | 0.896 | | |
| fs = | M(service)/(As*j*d) | | |
| fs = | 4.99 | ksi | |
| 0.6*fy = | 36 | ksi | |
| **fs <=** | **0.6*fy** | | **OKAY** |

**Check if tension in cross-section exceeds 80% of modulus of rupture**

| | | | |
|---|---|---|---|
| fr = | 0.24*SQRT(f'c) | | |
| fr = | 0.48 | ksi | |
| 0.8*fr = | 0.38 | ksi | |
| fT = | M(service)/Sx | | |
| fT = | 0.13 | ksi | |
| fT > 0.8*fr | | | **DOES NOT EXCEED** |

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

| | | | |
|---|---|---|---|
| $A_s$ >= | 1.3*b*h/(2*(b+h)*$f_y$) | | |
| $As_{min}$ = | 0.11 | in$^2$ | |
| $S_{max}$ = | 15 | in | |
| Try Bar # = | 4 | | |
| $A_{bar}$ = | 0.20 | in$^2$ | |
| Spacing = | 15 | in | **OKAY** |
| As = | 0.16 | in$^2$/ft | **OKAY** |

| | | | |
|---|---|---|---|
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**Wall Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Vu = 1.12 kips

Shear Bar = 4
Area per Bar = 0.20 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.4 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 3.75 in

Vc= 2*SQRT(f'c)*b*d
Vc= 11.38 kips
Req'd Vn= Vu/$\phi_v$
Req'd Vn= 1.25 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 10 **OKAY**

**Development Length of Hooked Rebar in Stem and Grade Beam (LRFD 5.10.8.2.1a):**

$l_{db}$ = 2.4*$d_b$*$f_y$/SQRT(f'$_c$)
$l_{db}$ = 72 in
$\lambda$ = 1.0 for normal weight concrete
$\lambda$ = 1
$\lambda_{rl}$ = reinforcement location factor, 1.3 if more than 12" concrete below reinf.
$\lambda_{rl}$ = 1
$\lambda_{cf}$ = coating factor
$\lambda_{cf}$ = 1
$d_b$ = 1
$c_b$ = MIN(cover,bar spacing/2)
$c_b$ = 2
$k_{tr}$ = cross-sect area of transv reinf.
$k_{tr}$ = 0
$\lambda_{rc}$ = reinforcement confinement factor, $d_b/(c_b+k_{tr})$
$\lambda_{rc}$ = 0.5
$As_{required}$ = (Mu/$\phi$)/($f_y$*(d-a/2))
$As_{required}$ = 0.32 $in^2$
$\lambda_{er}$ = 1.0 for seismic-force-resisting systems
$\lambda_{er}$ = 1.00
$l_d$ = $l_{db}$ *($\lambda$rl*$\lambda_{cf}$*$\lambda_{rc}$*$\lambda_{er}$)/$\lambda$
$l_d$ = 36.00 in

| | | | |
|---|---|---|---|
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| CHK'D. BY | RUK | DATE | 6/18/2021 |

**Vertical Flexural Rebar to be Lapped with Hooked Rebar Design (AISC 14th Ed. Table 3-23-19):**

$M_{max} = M_u$

$M_{max} =$ 10.08 kip-ft

L = Height of Noise Wall

L = 12.00 ft

$w = 2*M_{max}/L^2$

w = 0.14 kip/ft

x = Height of Noise Wall -Development Length of Hooked Rebar

x = 9.00 ft

$M_{at\ x} = w*x^2/2$

$M_{at\ x} =$ 5.67 kip-ft

$\Phi =$ 0.90

Try Rebar Size 6

Try Spacing 12.00 in

# of rebar = 1.00

Rebar Area = 0.44 $in^2$

As= 0.44 $in^2$

d = h-cover-(Rebar Diameter/2)

d = 7.50 in

$\beta_1 =$ 0.85

a = (As*fy)/(0.85*fc*b)

a = 0.65 in

$c = a/\beta_1$

c = 0.76 in

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

$\Phi Mn =$ 14.21 k-ft

**ΦMn > Mu ? YES**

| | | | |
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## Footing Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| h = | 12 | in | |
| b = | 12 | in | |
| cover = | 3 | in | AASHTO 5.10.1 |
| Rebar # = | 6 | | |
| Rebar Diameter = | 0.75 | in | |
| Spacing = | 12 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| $q_{extr}$ = | 1.97 | ksf | Max bearing pressure applied |
| $q_{serv}$ = | 1.02 | ksf | Service Load bearing pressure |
| L = | 2.71 | ft | Heel of Footing Length |
| Mu = | $q*L^2/2$ | | |
| Mu = | 7.24 | k-ft | Extreme Event |
| M(service) = | 3.74 | k-ft | Service 1 |
| Φ = | 0.90 | | |
| # of rebar = | 1.00 | | |
| Rebar Area = | 0.44 | $in^2$/ per bar | |
| As= | 0.44 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 8.63 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 0.65 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 0.76 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 16.44 | k-ft | |
| | **ΦMn > Mu ?** | **YES** | |

| | | | |
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**Check Min. Reinforcement: (LRFD 5.6.3.3)**

fr = 0.37*SQRT(fc)
fr = 0.74 ksi
Sx = $b*h^2/6$
Sx = 288 $in^3$
1.6 * Mcr = 1.6*fr*Sx
1.6 * Mcr = 28.42 kips-ft
1.33 * Mu = 10 kips-ft
**ΦMn > MIN(1.6*Mcr,1.33*Mu) ? YES**

**Check Crack Control: (LRFD 5.6.7)**

ρ = As/(b*d)
ρ = 0.00425
ρ*n = 0.03401
k = SQRT($ρn^2$ + 2*ρn)-ρn
k = 0.22900
j = 1-(k/3)
j = 0.924
fs = M(service)/(As*j*d)
fs = 12.79 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy** **OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.16 ksi
fT > 0.8*fr **DOES NOT EXCEED**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= 1.3*b*h/(2*(b+h)*$f_y$)
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 18 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 18 in **OKAY**
As = 0.13 $in^2$/ft **OKAY**

| | | | |
|---|---|---|---|
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**Footing Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Footing Width = 6.42 ft
Stem Width = 1.00 ft
Critical Section = Ls = (Footing Width -Stem Width)/2-d
Ls = 1.99 ft
Vu = q*Ls
Vu = 3.93 kips

Shear Bar = 5
Area per Bar = 0.44 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.88 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 4.31 in

Vc= $0.0316*\beta*\lambda*\sqrt{(f'_c)}*b*d_v$ LRFD 5.7.3.3-3
$\lambda$ = 1 LRFD 5.4.2.8
$\beta$ = 2 LRFD 5.7.3.4
$d_v$ = MAX(0.9*d,0.72*h)
$d_v$ = 8.64 in
Vc= 13.11 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 4.37 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 12 **OKAY**

| | | | |
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**Preliminary Analysis for:**
**Cast-In-Place Concrete Noise Wall on Footing**
**Maximum Total Wall Height = 17' with Minimum Embedment**

DESIGN CRITERIA:
- WSDOT Bridge Design Manual, July 2019
- AASHTO LRFD 8th Edition
- Geotechnical Engineering Report: Soldier Pile Wall 10.35L and Noise Wall 6

DESIGN ASSUMPTIONS:
- Exposed Wall Height is maximum 15' front face and 11' back face.
- Noise Wall is supporting 4' of fill.
- Seismic design is based on WSDOT BDM 8.2.2 and AASHTO LRFD 4.7.4.3.3.
- Noise Wall Dimensions are based on WSDOT Bridge Manual for Non-Standard Walls, page 8-23.
- Wind load is considered.
- Seismic soil forces are considered.
- Seismic internal wall forces are considered.
- Moment is positive with right hand rule at bottom center of footing. Right of center is positive, Left of center is n

Try:

| | | | |
|---|---|---|---|
| Footing Width = | 9.50 | ft | |
| Footing Thickness = | 1.00 | ft | |
| Wall Height = | 17.00 | ft | |
| Exposed Wall Height = | 15 | ft | |
| Wall Thickness = | 1.000 | ft | - Includes form liner on each face |
| Footing Toe Width = | 4.250 | ft | |
| Footing Heel Width = | 4.250 | ft | |

DEAD LOAD (DC):

Loads based on linear foot of wall

| Item | Density | Length | Thickness | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Noise Wall | 0.150 | 17 | 1.00 | 1 | 17.00 | 2.55 | 0.00 | 0.00 |
| Footing | 0.150 | 9.5 | 1.00 | 1 | 9.50 | 1.43 | 0.00 | 0.00 |
| | | | | | Totals = | 3.98 | | 0.00 |

| | | | |
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VERTICAL SOIL LOAD (EV):

Loads based on linear foot of wall

| Item | Density | Width | Height | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Toe | 0.130 | 4.25 | 2.00 | 1 | 8.50 | 1.11 | -2.63 | -2.90 |
| Heel | 0.130 | 4.25 | 6.00 | 1 | 25.50 | 3.32 | 2.63 | 8.70 |
| | | | | | Totals = | 4.42 | | 5.80 |

HORIZONTAL SOIL LOAD (EH): - Not required when seismic soil is being included. (AASHTO C11.6.5.1)

$EH = (1/2)*Ka*\Upsilon*H^2$

| | | | | | |
|---|---|---|---|---|---|
| EH = | 0.25 | klf | ϕ= | 38 | degrees |
| Moment Arm @ B/Footing = | 1.33 | ft | Ka = | 0.24 | |
| Moment = | 0.3 | k*ft | ϒ= | 0.13 | kcf |
| | | | H = | 4.00 | ft |

WIND LOAD (WS): (AASHTO 3.8.1.2.4)

$P_Z = 2.56X10^{-6}*V^2*K_Z*G*C_D$

| | | | |
|---|---|---|---|
| $V_{STR\ III}$= | 110 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{STR\ V}$= | 80 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{SERV\ I}$= | 70 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $K_{Z_STR}$= | 0.71 | | (AASHTO Table C3.8.1.2.1-1) |
| $K_{Z_SERV}$= | 1.0 | | (AASHTO 3.8.1.2.1) |
| G= | 0.85 | | (AASHTO Table 3.8.1.2.1-1) |
| $C_D$ = | 1.2 | | (AASHTO Table 3.8.1.2.1-2) |
| Z= | 11.00 | = Exposed Noise Wall Height at the Back Face | |

| | | |
|---|---|---|
| $P_{Z_STR\ III}$= | 0.022 | ksf |
| $P_{Z_STR\ V}$= | 0.012 | ksf |
| $P_{Z_SERV\ I}$= | 0.013 | ksf |

$P_W = P_Z*Z$ (AASHTO 3.8.1.2.4)

Moment Arm @ B/Footing = 13.1 ft

| | | | |
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| | Linear feet of Wall | |
|---|---|---|
| | $P_W$ | Moment |
| | klf | k*ft |
| STR III | 0.25 | 3.2 |
| STR V | 0.13 | 1.7 |
| SERV I | 0.14 | 1.8 |

- $P_W$ is a line load applied at 0.55*Z from the top of roadway. (AASHTO 3.8.1.2.4)
- Moment Arm is from the top of the retaining wall.
  = 0.55*(Noise Wall Height + Traffic Barrier Height) + Slab Thickness

SEISMIC ACTIVE EARTH PRESSURES ($EQ_{soil}$):

$P_{seis} = P_{AE}$ LRFD 11.6.5.1

$P_{seis}$ = 0.761 klf $P_{seis}$ is applied 1/3 height of soil.

$P_{AE}$ = 0.761 klf LRFD 11.6.5.3-2

$P_{AE} = 0.5*\Upsilon*K_{AE}*h^2$

- Monobe-Okabe Analysis LRFD A11.3.1

**Figure A11.3.1-1—Mononobe-Okabe Method Force Diagrams**

$$K_{AE} = \frac{\cos^2(\phi-\theta_{MO}-\beta)}{\cos\theta_{MO}\cos^2\beta\cos(\delta+\beta+\theta_{MO})}\times\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2} \quad \text{(A11.3.1-1)}$$

where:

$K_{AE}$ = seismic active earth pressure coefficient (dim)
$\gamma$ = unit weight of soil (kcf)
$H$ = height of wall (ft)
$h$ = height of wall at back of wall heel considering height of sloping surcharge, if present (ft)
$\phi_f$ = friction angle of soil (degrees)
$\theta_{MO}$ = arc tan $[k_h/(1-k_v)]$ (degrees)
$\delta$ = wall backfill interface friction angle (degrees)
$k_h$ = horizontal seismic acceleration coefficient (dim.)
$k_v$ = vertical seismic acceleration coefficient (dim.)
$i$ = backfill slope angle (degrees)
$\beta$ = slope of wall to the vertical, negative as shown (degrees)

$k_{AE}$ = 0.732

$\psi$ = 0.42

$$\psi = \left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2}$$

$\Upsilon_{soil}$ = 0.130 kcf

H = 4.0 ft Height of soil and footing

$\phi$ = 38.00 degrees

$\theta$ = 26.4 degrees

$\delta = 2/3*\phi$ = 25.3 degrees

$k_h = 1.0*k_{h0}$ = 0.497 Note: 0.5*kho=0.249, by using 1.0*kho this increased the Extreme Event Moment by 2% and the Lateral load by 16%. This small increase does not affect the outcome of the calc.

$k_{h0} = A_s$ = 0.497

$k_v$ = 0.0

i = 0.0 degrees

$\beta$ = 0.0 degrees

Moment Arm @ B/Footing = 1.33 ft

Moment = 1.0 k*ft

| | | | |
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SEISMIC FORCES ON WALL ($EQ_{wall}$): (See Attached Calc)

Shear at base of wall = 1.7 k
Moment on wall = 20.1 k*ft

LOAD SUMMARY

| Load | Force | | Moment |
|---|---|---|---|
| | Vertical | Lateral | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) |
| DC | 4.0 | | 0.0 |
| EV | 4.4 | | 5.8 |
| EH | | 0.3 | 0.4 |
| $WS_{STR\ III}$ | | 0.25 | 3.2 |
| $WS_{STR\ V}$ | | 0.13 | 1.7 |
| $WS_{SERV\ I}$ | | 0.14 | 1.8 |
| $EQ_{soil}$ | | 0.8 | 1.0 |
| $EQ_{wall}$ | | 1.7 | 20.1 |

**Calculate Bearing Pressure**

Load Combinations (AASHTO Table 3.4.1-1)

| Load Combination | Force | | Moment | e | B' | $\sigma_v$ |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | ft | **ksf** |
| STRENGTH III: 1.25DC+1.5EH+1.0(EV+WS) | 9.4 | 0.7 | 9.6 | 1.0 | 7.5 | **1.26** |
| STRENGTH V: 1.25DC+1.5EH+1.0(EV+WS) | 9.4 | 0.6 | 8.1 | 0.9 | 7.8 | **1.21** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 8.4 | 2.4 | 26.5 | 3.2 | 3.2 | **2.63** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 8.4 | 0.4 | 8.0 | 1.0 | 7.6 | **1.11** |

Eccentricity = e =M/$P_y$

B = 9.50 ft B' = B - 2e

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\sum V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

| | | | |
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**Check Eccentricity Limits** (AASHTO 11.6.3.3)

- The location of the resultant is limited to the middle two-thirds of the width of the foundation.

emax = B/3 3.17 ft

| Load Combination | Force | | Moment | e | Middle | |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | Two-Thirds | |
| STRENGTH III: 0.9DC+1.5EH+1.00(EV+WS) | 8.0 | 0.7 | 9.6 | 1.0 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 8.0 | 0.6 | 8.1 | 0.9 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 8.4 | 2.4 | 26.5 | 3.2 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 8.4 | 0.4 | 8.0 | 1.0 | Yes | **OK** |

**Check Sliding** (AASHTO 10.6.3.4 and AASHTO 11.5.6)

| Load Combination | Force | | $\phi_T R\tau$ | Is $R\tau > Vx$? | |
|---|---|---|---|---|---|
| | Vertical | Lateral | | | |
| | $P_y$ (kips) | $P_X$ (kips) | kips | | |
| STRENGTH III: 0.90DC+1.5EH+1.00(EV+WS) | 8.0 | 0.7 | 5.0 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 8.0 | 0.6 | 5.0 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 8.4 | 2.4 | 5.2 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 8.4 | 0.4 | 5.2 | Yes | **OK** |

Sliding Resistance = $\phi_T R\tau = \phi_T C P_y \tan \phi_f$ (AASHTO 10.6.3.4-2)

$\phi_T$ = 0.8 (AASHTO Table 10.5.5.2.2-1)

C = 1.0

$\phi_f$ = 38 degrees

Coeffient of Friction = $\tan \phi_f$ = 0.78 (AASHTO C3.11.5.3)

| | | | |
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## SOUND BARRIER DESIGN FORCE

**NOISE BARRIER CIP WALL TYPE GEOMETRY**

| | | | |
|---|---|---|---|
| Wall Length | L = | 1 | ft |
| Wall/Wall Height | H = | 17 | ft |
| Wall Thickness | T = | 12 | in |

**MATERIALS**

| | | | |
|---|---|---|---|
| Wall Concrete | $f_c'$ = | 4 | ksi |
| | $\gamma_c$ = | 0.15 | kcf |
| | $E_c$ = | 4266 | ksi |
| Reinforcing Steel | $f_y$ = | 60 | ksi |
| | $E_s$ = | 29000 | ksi |

**DEAD LOAD**

Weight of Wall

| | | | |
|---|---|---|---|
| Vertical Dead Load | D = | 2.55 | kips |

**SEISMIC FORCE**

Seismic design shall be in accordance with AASHTO LRFD Article 3.10.2.1-General Procedure, considering site class D:

a. Modal analysis shall be performed for the first four periods. The elastic seismic response coefficient Csm shall be computed for each modal period in accordance with AASHTO LRFD Article 3.10.4.2 and all four Csm coefficients shall be combined through the SRSS method

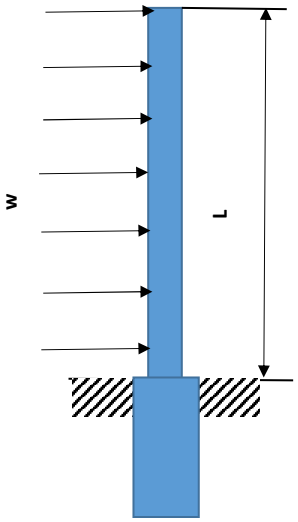
b. The resultant seismic force shall be considered to act at a height of 0.71H above the top of the shaft, where H is the total height measured from the top of the Wall to the top of the shaft.

**Structural Modeling**

Modeling the column as a cantilever beam

The mass of column and ajacent Walls is uniformly distributed along the column

| | | | |
|---|---|---|---|
| Uniform Weight | w = | 0.15 | kips/ft |
| Uniform Mass | m = | 0.0004 | |
| Column | I = | 1728 | $in^4$ |
| Modulus | E = | 4266 | ksi |
| Gravity | g = | 386 | $in/sec^2$ |



| | | | |
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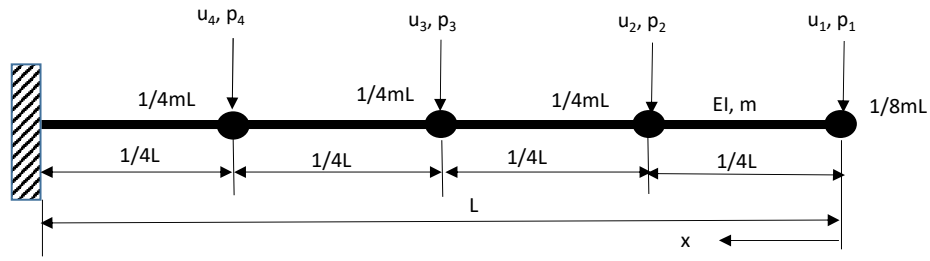
**Modal Analysis**




Flexibility Matrix

| | | |
|---|---|---|
| $p_1$ = | 1 | |
| | x | u |
| $u_1$ | 0.00 | 0.33333333 |
| $u_2$ | 0.25 | 0.21093750 |
| $u_3$ | 0.50 | 0.10416667 |
| $u_4$ | 0.75 | 0.02864583 |

| | | |
|---|---|---|
| $p_2$ = | 1 | |
| a = | 0.25 | |
| b = | 0.75 | |
| | x | u |
| $u_1$ | 0.00 | 0.2109375 |
| $u_2$ | 0.25 | 0.1406250 |
| $u_3$ | 0.50 | 0.0729167 |
| $u_4$ | 0.75 | 0.0208333 |

| | | |
|---|---|---|
| $p_3$ = | 1 | |
| a = | 0.5 | |
| b = | 0.5 | |
| | x | u |
| $u_1$ | 0 | 0.104166667 |
| $u_2$ | 0.25 | 0.072916667 |
| $u_3$ | 0.5 | 0.041666667 |
| $u_4$ | 0.75 | 0.013020833 |

| | | |
|---|---|---|
| $p_4$ = | 1 | |
| a = | 0.75 | |
| b = | 0.25 | |
| | x | u |
| $u_1$ | 0.00 | 0.028645833 |
| $u_2$ | 0.25 | 0.020833333 |
| $u_3$ | 0.50 | 0.013020833 |
| $u_4$ | 0.75 | 0.005208333 |

| | | | |
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Flexibility Matrix

| | $p_1 = 1$ | $p_2 = 1$ | $p_3 = 1$ | $p_4 = 1$ |
|---|---|---|---|---|
| $u_1 = L^3/EI^*$ | 0.3333 | 0.2109 | 0.1042 | 0.0286 |
| $u_2 = L^3/EI^*$ | 0.2109 | 0.1406 | 0.0729 | 0.0208 |
| $u_3 = L^3/EI^*$ | 0.1042 | 0.0729 | 0.0417 | 0.0130 |
| $u_4 = L^3/EI^*$ | 0.0286 | 0.0208 | 0.0130 | 0.0052 |

Stiffness Matrix K

| | | | | |
|---|---|---|---|---|
| $EI/L^3$ | 102.928 | -233.567 | 166.268 | -47.505 |
| $EI/L^3$ | -233.567 | 633.402 | -613.608 | 285.031 |
| $EI/L^3$ | 166.268 | -613.608 | 918.433 | -756.124 |
| $EI/L^3$ | -47.505 | 285.031 | -756.124 | 1203.464 |

K =

| | | | |
|---|---|---|---|
| 89.378 | -202.819 | 144.380 | -41.251 |
| -202.819 | 550.017 | -532.829 | 247.508 |
| 144.380 | -532.829 | 797.525 | -656.583 |
| -41.251 | 247.508 | -656.583 | 1045.033 |

Mass Matrix M

| | | | |
|---|---|---|---|
| 1/8mL | 0 | 0 | 0 |
| 0 | 1/4mL | 0 | 0 |
| 0 | 0 | 1/4mL | 0 |
| 0 | 0 | 0 | 1/4mL |

M =

| | | | |
|---|---|---|---|
| 0.000825777 | 0 | 0 | 0 |
| 0 | 0.001651554 | 0 | 0 |
| 0 | 0 | 0.001651554 | 0 |
| 0 | 0 | 0 | 0.001651554 |

First Mode

| $w_1^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 1535.670 | 88.110 | -202.819 | 144.380 | -41.251 |
| | -202.819 | 547.481 | -532.829 | 247.508 |
| | 144.380 | -532.829 | 794.989 | -656.583 |
| | -41.251 | 247.508 | -656.583 | 1042.496 |

$Det(K-w_n^2*M)=0$ 4.40822E-06 by using goal seek (Set cell: B154, To value: 0, By changing cell: A150)

$\omega_1 =$ 39.188 rad/sec $T_1 =$ 0.160 sec

Second Mode

| $w_2^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 53054.10 | 45.56692537 | -202.819 | 144.380 | -41.251 |
| | -202.819 | 462.395 | -532.829 | 247.508 |
| | 144.380 | -532.829 | 709.903 | -656.583 |
| | -41.251 | 247.508 | -656.583 | 957.411 |

$Det(K-w_n^2*M)=0$ 0.000257749 by using goal seek (Set cell: B163, To value: 0, By changing cell: A159)

$\omega_2 =$ 230.335 rad/sec $T_2 =$ 0.027 sec

| | | | |
|---|---|---|---|
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| | JOB NAME I-405 - Renton to Bellevue | | |
| | Supervisor WPM | TASK | CIP Noise Wall 6 |
| | BY RUK | DATE | 6/18/2021 |
| | CHK'D. BY MGH | DATE | 6/18/2021 |

Third Mode

| $w_3^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 372045.06 | -217.849 | -202.819 | 144.380 | -41.251 |
| | -202.819 | -64.435 | -532.829 | 247.508 |
| | 144.380 | -532.829 | 183.072 | -656.583 |
| | -41.251 | 247.508 | -656.583 | 430.580 |

Det($K-w_n^2*M$)=0 -2.54194E-06 by using goal seek (Set cell: B172, To value: 0, By changing cell: A168)

$\omega_3$ = 609.955 rad/sec $T_3$ = 0.010 sec

Fourth Mode

| $w_4^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 1130280.51 | -843.982 | -202.819 | 144.380 | -41.251 |
| | -202.819 | -1316.703 | -532.829 | 247.508 |
| | 144.380 | -532.829 | -1069.195 | -656.583 |
| | -41.251 | 247.508 | -656.583 | -821.687 |

Det($K-w_n^2*M$)=0 0.00028851 by using goal seek (Set cell: B181, To value: 0, By changing cell: A177)

$\omega_4$ = 1063.147 rad/sec $T_4$ = 0.006 sec

Summary

| Mode | ω (rad/sec) | T (sec) |
|---|---|---|
| 1 | 39.188 | 0.160 |
| 2 | 230.335 | 0.027 |
| 3 | 609.955 | 0.010 |
| 4 | 1063.147 | 0.006 |

NATURAL PERIODS By Equation

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$T_n = 1/f_n$ $\omega_n = 2\pi/T_n$

| | | |
|---|---|---|
| First Mode | $K_1$ = | 3.52 |
| Second Mode | $K_1$ = | 22.03 |
| Third Mode | $K_3$ = | 61.7 |
| Fourth Mode | $K_4$ = | 120.9 |
| | g = | 386 |

| Mode | Natural Frequency | Natural period | Natural Frequency |
|---|---|---|---|
| | $f_n$ (Hz) | $T_n$ (second) | $\omega_n$ (Rad/Sec) |
| 1 | 6.416 | 0.156 | 40.311 |
| 2 | 40.198 | 0.025 | 252.573 |
| 3 | 112.584 | 0.009 | 707.387 |
| 4 | 220.607 | 0.005 | 1386.112 |

| | | | |
|---|---|---|---|
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| Supervisor | WPM | TASK | CIP Noise Wall 6 |
| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

First Mode

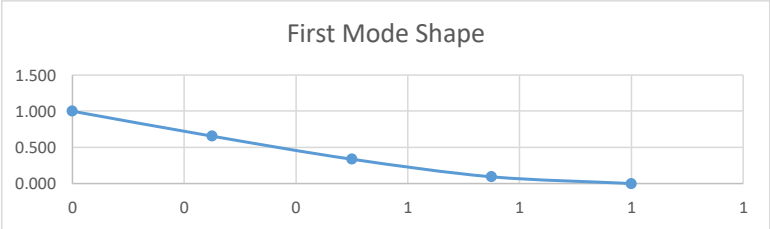
$K-w_1^2M$

| | | | |
|---|---|---|---|
| 88.110 | -202.819 | 144.380 | -41.251 |
| -202.819 | 547.481 | -532.829 | 247.508 |
| 144.380 | -532.829 | 794.989 | -656.583 |
| -41.251 | 247.508 | -656.583 | 1042.496 |

| | | | |
|---|---|---|---|
| 0.0086031 | 0.0085013 | 0.0033117 | -203 |
| 0.0085013 | 0.0110221 | 0.0049236 | 144 |
| 0.0033117 | 0.0049236 | 0.0032739 | -41 |

$\phi_1$ =

| | Mode Shape Plot | |
|---|---|---|
| 1 | 0 | 1.000 |
| 0.654 | 0.250 | 0.654 |
| 0.336 | 0.500 | 0.336 |
| 0.096 | 0.750 | 0.096 |
| | 1.000 | 0.000 |




Secod Mode

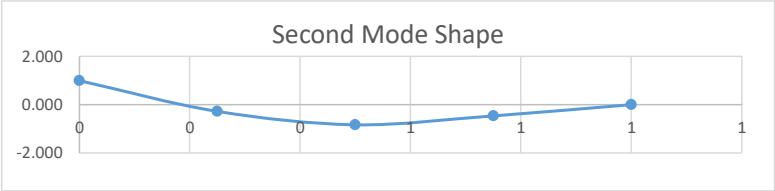
$K-w_2^2M$

| | | | |
|---|---|---|---|
| 45.567 | -202.819 | 144.380 | -41.251 |
| -202.819 | 462.395 | -532.829 | 247.508 |
| 144.380 | -532.829 | 709.903 | -656.583 |
| -41.251 | 247.508 | -656.583 | 957.411 |

| | | | |
|---|---|---|---|
| -0.0091425 | -0.0127859 | -0.0064050 | -202.819 |
| -0.0127859 | -0.0140297 | -0.0063160 | 144.380 |
| -0.0064050 | -0.0063160 | -0.0016312 | -41.251 |

$\phi_2$ =

| | Mode Shape Plot | |
|---|---|---|
| 1 | 0 | 1.000 |
| -0.272 | 0.250 | -0.272 |
| -0.828 | 0.500 | -0.828 |
| -0.454 | 0.750 | -0.454 |
| | 1.000 | 0.000 |



| | | | |
|---|---|---|---|
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| Supervisor | WPM | TASK | CIP Noise Wall 6 |
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| CHK'D. BY | MGH | DATE | 6/18/2021 |

Third Mode

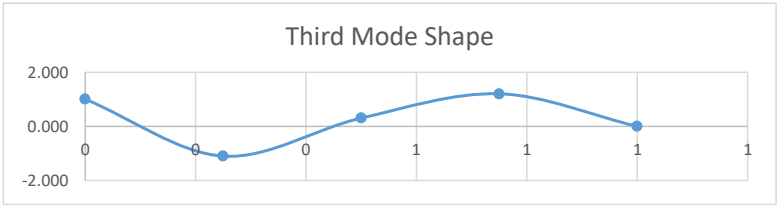
$K-w_3^2M$

| | | | |
|---|---|---|---|
| -217.849 | -202.819 | 144.380 | -41.251 |
| -202.819 | -64.435 | -532.829 | 247.508 |
| 144.380 | -532.829 | 183.072 | -656.583 |
| -41.251 | 247.508 | -656.583 | 430.580 |

| | | | |
|---|---|---|---|
| -0.0056437 | 0.0010721 | 0.0048789 | -202.819 |
| 0.0010721 | -0.0014259 | -0.0027906 | 144.380 |
| 0.0048789 | -0.0027906 | -0.0047374 | -41.251 |

$\phi_3$ =

| | | | |
|---|---|---|---|
| 1 | Mode Shape Plot | 0 | 1.000 |
| -1.098 | | 0.250 | -1.098 |
| 0.308 | | 0.500 | 0.308 |
| 1.197 | | 0.750 | 1.197 |
| | | 1.000 | 0 |




Fourth Mode

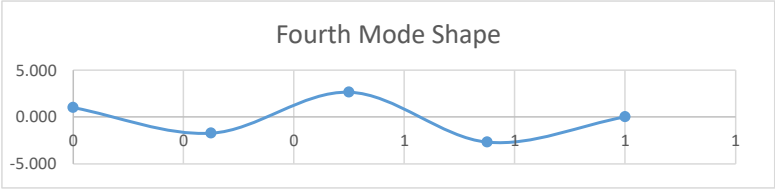
$K-w_4^2M$

| | | | |
|---|---|---|---|
| -843.982 | -202.819 | 144.380 | -41.251 |
| -202.819 | -1316.703 | -532.829 | 247.508 |
| 144.380 | -532.829 | -1069.195 | -656.583 |
| -41.251 | 247.508 | -656.583 | -821.687 |

| | | | |
|---|---|---|---|
| -0.0038182 | 0.0051228 | -0.0052436 | -202.819 |
| 0.0051228 | -0.0087096 | 0.0085027 | 144.380 |
| -0.0052436 | 0.0085027 | -0.0095907 | -41.251 |

$\phi_4$ =

| | | | |
|---|---|---|---|
| 1 | Mode Shape Plot | 0 | 1.000 |
| -1.730 | | 0.250 | -1.730 |
| 2.647 | | 0.500 | 2.647 |
| -2.687 | | 0.750 | -2.687 |
| | | 1.000 | 0.000 |




Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 1.000 | 1.000 | 1.000 |
| 0.654 | -0.272 | -1.098 | -1.730 |
| 0.336 | -0.828 | 0.308 | 2.647 |
| 0.096 | -0.454 | 1.197 | -2.687 |

| | | | |
|---|---|---|---|
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Transpose Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 0.654 | 0.336 | 0.096 |
| 1.000 | -0.272 | -0.828 | -0.454 |
| 1.000 | -1.098 | 0.308 | 1.197 |
| 1.000 | -1.730 | 2.647 | -2.687 |

Generalized Mass

| | | | |
|---|---|---|---|
| 0.0008 | 0.0011 | 0.0006 | 0.0002 |
| 0.0008 | -0.0004 | -0.0014 | -0.0008 |
| 0.0008 | -0.0018 | 0.0005 | 0.0020 |
| 0.0008 | -0.0029 | 0.0044 | -0.0044 |

$M_n$ =

| | | | |
|---|---|---|---|
| 0.002 | 0.000 | 0.000 | 0.000 |
| 0.000 | 0.002 | 0.000 | 0.000 |
| 0.000 | 0.000 | 0.005 | 0.000 |
| 0.000 | 0.000 | 0.000 | 0.029 |

Generalized Stiffness

| | | | |
|---|---|---|---|
| 1.268 | 1.659 | 0.852 | 0.243 |
| 43.811 | -23.873 | -72.566 | -39.818 |
| 307.226 | -674.776 | 189.369 | 735.509 |
| 933.360 | -3230.044 | 4941.653 | -5015.377 |

$K_n$ =

| | | | |
|---|---|---|---|
| 2.663 | 0.000 | 0.000 | 0.000 |
| 0.000 | 128.507 | 0.000 | 0.000 |
| 0.000 | 0.000 | 1987.027 | 0.000 |
| 0.000 | 0.000 | 0.000 | 33079.122 |

Verify Natural Frequency

| Mode | ω | Eigen Value | Equation |
|---|---|---|---|
| 1 | 39.188 | 39.188 | 40.311 |
| 2 | 230.335 | 230.335 | 252.573 |
| 3 | 609.955 | 609.955 | 707.387 |
| 4 | 1063.147 | 1063.147 | 1386.112 |

Generalized Force $P_n$

| | | | |
|---|---|---|---|
| 0.000825777 | 0.001080249 | 0.000554845 | 0.000158332 |
| 0.000825777 | -0.000449971 | -0.001367776 | -0.000750523 |
| 0.000825777 | -0.001813695 | 0.000508994 | 0.001976937 |
| 0.000825777 | -0.002857737 | 0.004372059 | -0.004437286 |

Directional Vector

| | |
|---|---|
| 1 | 0.002619203 |
| 1 | -0.001742492 |
| 1 | 0.001498013 |
| 1 | -0.002097186 |

$P_n$

| |
|---|
| 1.5106 |
| -0.7194 |
| 0.2805 |
| -0.0717 |

| | | | |
|---|---|---|---|
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**SEISMIC DESIGN PARAMETERS**

| | | | |
|---|---|---|---|
| Peak Ground Acceleration | PGA = | 0.422 | |
| Spectral Acceleration at 0.2 Second | $S_S$ = | 0.959 | g |
| Spectral Acceleration at 1 Second | $S_1$ = | 0.278 | g |
| Site Class | D | | |
| Site Factors: | $F_{pga}$ | 1.178 | |
| | $F_a$ = | 1.116 | |
| | $F_v$ = | 2.044 | |
| Response Spectrum | $S_{DS}$ = | 1.070 | g |
| | $S_{D1}$ = | 0.568 | g |
| | $T_S$ = | 0.531 | |
| | $T_o$ = | 0.106 | |
| | $A_S$ = | 0.497 | |

**ELASTIC SEISMIC RESPONSE COEFFICIENT $C_{sm}$**

AASHTO LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$
- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| Mode | ω (rad/sec) | T (sec) | $C_{sm}$ | $C_{Disp}$ |
|---|---|---|---|---|
| 1 | 39.188 | 0.160 | 1.070 | 0.40636 |
| 2 | 230.335 | 0.027 | 0.644 | -0.00337 |
| 3 | 609.955 | 0.010 | 0.553 | 0.00016 |
| 4 | 1063.147 | 0.006 | 0.529 | -0.00001 |

**MODAL SPECTRUM ANALYSIS**

**Modal Displacements**

| Mode 1 | | Mode 2 | |
|---|---|---|---|
| $\phi_1$ = | u1 | $\phi_2$ = | u2 |
| 1.000 | 0.40636 | 1.000 | -0.00337 |
| 0.654 | 0.26579 | -0.272 | 0.00092 |
| 0.336 | 0.13652 | -0.828 | 0.00279 |
| 0.096 | 0.03896 | -0.454 | 0.00153 |
| Mode 3 | | Mode 4 | |
| $\phi_3$ = | u3 | $\phi_4$ = | u4 |
| 1.000 | 0.00016 | 1.000 | -0.000013 |
| -1.098 | -0.00018 | -1.730 | 0.000022 |
| 0.308 | 0.00005 | 2.647 | -0.000034 |
| 1.197 | 0.00019 | -2.687 | 0.000035 |

| | | | |
|---|---|---|---|
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| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

**Total Displacements**

| | | |
|---|---|---|
| $u_1$ = | 0.41 | in |
| $u_2$ = | 0.27 | in |
| $u_3$ = | 0.14 | in |
| $u_4$ = | 0.04 | in |

Modal Base Shear

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 |
|---|---|---|---|---|
| $V_1$ | 0.515 | -0.148 | 0.049 | -0.012 |
| $V_2$ | 0.674 | 0.081 | -0.109 | 0.042 |
| $V_3$ | 0.346 | 0.245 | 0.030 | -0.064 |
| $V_4$ | 0.099 | 0.134 | 0.118 | 0.065 |
| Total | 1.634 | 0.312 | 0.090 | 0.031 |

**Base Shear**

| | | |
|---|---|---|
| SRSS | **1.67** | kips |
| **Base Moment** | **20.12** | kips-ft |

| | | | |
|---|---|---|---|
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| CHK'D. BY | MGH | DATE | 6/18/2021 |

## Stem Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2 |
| Arch. Treatments = | 2 | in | |
| h = | 10.00 | in | |
| b = | 12 | in | AASHTO 5.10.1 |
| cover = | 2 | in | |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 10 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| Mu = | 26.46 | k-ft | Extreme Event |
| M(service) = | 7.97 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.20 | | |
| Rebar Area = | 0.79 | $in^2$ | |
| As= | 0.95 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 7.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.39 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.64 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 29.02 | k-ft | |
| **ΦMn > Mu ?** | **YES** | | |

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 200 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6* Mcr = | 20 | kips-ft |
| 1.33 * Mu = | 35 | kips-ft |
| **ΦMn > MIN(1.6*Mcr,1.33*Mu ?** | **YES** | |

| | | | |
|---|---|---|---|
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| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

**Check Crack Control: (LRFD 5.6.7)**

$\rho$ = As/(b*d)
$\rho$ = 0.01053
$\rho$*n = 0.08427
k = SQRT($\rho n^2$ + 2*$\rho$n)-$\rho$n
k = 0.33482
j = 1-(k/3)
j = 0.888
fs = M(service)/(As*j*d)
fs = 15.14 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy** **OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.48 ksi
fT > 0.8*fr **EXCEEDS**

$d_c$ = cover + Rebar Diameter/2
$d_c$ = 2.5 in
$\beta_s$ = 1 + $d_c$/(0.7*(h-$d_c$)) LRFD 5.6.7.2
$\beta_s$ = 1.48
$\Upsilon_e$ = 0.75 for class 2 exposure condition
s <= (700*Ye / ($\beta$s*fs))-2*$d_c$
s <= 18.49 in
**Provided Spacing = 10 in** **OKAY**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= 1.3*b*h/(2*(b+h)*$f_y$)
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 15 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 15 in **OKAY**
As = 0.16 $in^2$/ft **OKAY**

| | | | |
|---|---|---|---|
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| Supervisor | WPM | TASK | CIP Noise Wall 6 |
| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

**Wall Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Vu = 2.08 kips

Shear Bar = 4
Area per Bar = 0.20 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.4 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 3.75 in

Vc= 2*SQRT(f'c)*b*d
Vc= 11.38 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 2.31 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 10 **OKAY**

**Development Length of Hooked Rebar in Stem and Grade Beam (LRFD 5.10.8.2.1a):**

$l_{db}$ = $2.4*d_b*f_y/SQRT(f'_c)$
$l_{db}$ = 72 in
$\lambda$ = 1.0 for normal weight concrete
$\lambda$ = 1
$\lambda_{rl}$ = reinforcement location factor, 1.3 if more than 12" concrete below reinf.
$\lambda_{rl}$ = 1
$\lambda_{cf}$ = coating factor
$\lambda_{cf}$ = 1
$d_b$ = 1
$c_b$ = MIN(cover,bar spacing/2)
$c_b$ = 2
$k_{tr}$ = cross-sect area of transv reinf.
$k_{tr}$ = 0
$\lambda_{rc}$ = reinforcement confinement factor, $d_b/(c_b+k_{tr})$
$\lambda_{rc}$ = 0.5
$As_{required}$ = $(Mu/\phi)/(f_y*(d-a/2))$
$As_{required}$ = 0.86 $in^2$
$\lambda_{er}$ = 1.0 for seismic-force-resisting systems
$\lambda_{er}$ = 1.00
$l_d$ = $l_{db}*(\lambda rl*\lambda_{cf}*\lambda_{rc}*\lambda_{er})/\lambda$
$l_d$ = 36.00 in

| | | | |
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**Vertical Flexural Rebar to be Lapped with Hooked Rebar Design (AISC 14th Ed. Table 3-23-19):**

$M_{max} = M_u$

$M_{max} =$ 26.46 kip-ft

L = Height of Noise Wall

L = 17.00 ft

$w = 2*M_{max}/L^2$

w = 0.18 kip/ft

x = Height of Noise Wall -Development Length of Hooked Rebar

x = 14.00 ft

$M_{at\ x} = w*x^2/2$

$M_{at\ x} =$ 17.95 kip-ft

$\Phi =$ 0.90

Try Rebar Size 7

Try Spacing 10.00 in

# of rebar = 1.20

Rebar Area = 0.60 $in^2$

As= 0.72 $in^2$

d = h-cover-(Rebar Diameter/2)

d = 7.50 in

$\beta_1 =$ 0.85

a = (As*fy)/(0.85*fc*b)

a = 1.06 in

$c = a/\beta_1$

c = 1.25 in

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

$\Phi Mn =$ 22.58 k-ft

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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## Footing Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| h = | 12 | in | |
| b = | 12 | in | |
| cover = | 3 | in | AASHTO 5.10.1 |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 10 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| $q_{extr}$ = | 2.63 | ksf | Max bearing pressure applied |
| $q_{serv}$ = | 1.10 | ksf | Service Load bearing pressure |
| L = | 4.25 | ft | Heel of Footing Length |
| Mu = | $q*L^2/2$ | | |
| Mu = | 23.73 | k-ft | Extreme Event |
| M(service) = | 9.97 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.20 | | |
| Rebar Area = | 0.79 | $in^2$/ per bar | |
| As= | 0.95 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 8.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.39 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.64 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 33.29 | k-ft | |

**ΦMn > Mu ? YES**

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 288 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6 * Mcr = | 28.42 | kips-ft |
| 1.33 * Mu = | 32 | kips-ft |

**ΦMn > MIN(1.6*Mcr,1.33*Mu) ? YES**

| | | | |
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**Check Crack Control: (LRFD 5.6.7)**

| | | | |
|---|---|---|---|
| ρ = | As/(b*d) | | |
| ρ = | 0.00929 | | |
| ρ*n = | 0.07435 | | |
| k = | SQRT(ρn$^2$ + 2*ρn)-ρn | | |
| k = | 0.31837 | | |
| j = | 1-(k/3) | | |
| j = | 0.894 | | |
| fs = | M(service)/(As*j*d) | | |
| fs = | 16.62 | ksi | |
| 0.6*fy = | 36 | ksi | |
| **fs <=** | **0.6*fy** | | **OKAY** |

**Check if tension in cross-section exceeds 80% of modulus of rupture**

| | | | |
|---|---|---|---|
| fr = | 0.24*SQRT(f'c) | | |
| fr = | 0.48 | ksi | |
| 0.8*fr = | 0.38 | ksi | |
| fT = | M(service)/Sx | | |
| fT = | 0.42 | ksi | |
| fT > | 0.8*fr | | **EXCEEDS** |
| $d_c$ = | cover + Rebar Diameter/2 | | |
| $d_c$ = | 3.5 | in | |
| $\beta_s$ = | 1 + $d_c$/(0.7*(h-$d_c$)) | | LRFD 5.6.7.2 |
| $\beta_s$ = | 1.59 | | |
| $\Upsilon_e$ = | 0.75 | for class 2 exposure condition | |
| s <= | (700*Ye / (βs*fs))-2*$d_c$ | | |
| s <= | 12.89 | in | |
| **Provided Spacing =** | **10** | **in** | **OKAY** |

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

| | | | |
|---|---|---|---|
| $A_s$ >= | 1.3*b*h/(2*(b+h)*$f_y$) | | |
| $As_{min}$ = | 0.11 | in$^2$ | |
| $S_{max}$ = | 18 | in | |
| Try Bar # = | 4 | | |
| $A_{bar}$ = | 0.20 | in$^2$ | |
| Spacing = | 18 | in | **OKAY** |
| As = | 0.13 | in$^2$/ft | **OKAY** |

| | | | |
|---|---|---|---|
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**Footing Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Footing Width = 9.50 ft
Stem Width = 1.00 ft
Critical Section = Ls = (Footing Width -Stem Width)/2-d
Ls = 3.54 ft
Vu = q*Ls
Vu = 9.30 kips

Shear Bar = 5
Area per Bar = 0.79 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 1.58 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 4.25 in

Vc= $0.0316*\beta*\lambda*\sqrt{(f'_c)}*b*d_v$ LRFD 5.7.3.3-3
$\lambda$ = 1 LRFD 5.4.2.8
$\beta$ = 2 LRFD 5.7.3.4
$d_v$ = MAX(0.9*d,0.72*h)
$d_v$ = 8.64 in
Vc= 13.11 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 10 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 12 **OKAY**

| | | | |
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**Preliminary Analysis for:**
**Cast-In-Place Concrete Noise Wall on Footing**
**Maximum Total Wall Height = 17' with Maximum Embedment**

DESIGN CRITERIA:
- WSDOT Bridge Design Manual, July 2019
- AASHTO LRFD 8th Edition
- Geotechnical Engineering Report: Soldier Pile Wall 10.35L and Noise Wall 6

DESIGN ASSUMPTIONS:
- Exposed Wall Height is maximum 15' front face and 11' back face.
- Noise Wall is supporting 4' of fill.
- Seismic design is based on WSDOT BDM 8.2.2 and AASHTO LRFD 4.7.4.3.3.
- Noise Wall Dimensions are based on WSDOT Bridge Manual for Non-Standard Walls, page 8-23.
- Wind load is considered.
- Seismic soil forces are considered.
- Seismic internal wall forces are considered.
- Moment is positive with right hand rule at bottom center of footing. Right of center is positive, Left of center is negative.

Try:

| | | | |
|---|---|---|---|
| Footing Width = | 9.50 | ft | |
| Footing Thickness = | 1.00 | ft | |
| Wall Height = | 17.00 | ft | |
| Exposed Wall Height = | 15 | ft | |
| Wall Thickness = | 1.000 | ft | - Includes form liner on each face |
| Footing Toe Width = | 4.250 | ft | |
| Footing Heel Width = | 4.250 | ft | |

DEAD LOAD (DC):

Loads based on linear foot of wall

| Item | Density | Length | Thickness | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Noise Wall | 0.150 | 17 | 1.00 | 1 | 17.00 | 2.55 | 0.00 | 0.00 |
| Footing | 0.150 | 9.5 | 1.00 | 1 | 9.50 | 1.43 | 0.00 | 0.00 |
| | | | | | Totals = | 3.98 | | 0.00 |

| | | | |
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VERTICAL SOIL LOAD (EV):

Loads based on linear foot of wall

| Item | Density | Width | Height | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Toe | 0.130 | 4.25 | 5.67 | 1 | 24.08 | 3.13 | -2.63 | -8.22 |
| Heel | 0.130 | 4.25 | 9.67 | 1 | 41.08 | 5.34 | 2.63 | 14.02 |
| | | | | | Totals = | 8.47 | | 5.80 |

HORIZONTAL SOIL LOAD (EH): - Not required when seismic soil is being included. (AASHTO C11.6.5.1)

$EH = (1/2)*Ka*\Upsilon*H^2$

| | | | | | |
|---|---|---|---|---|---|
| EH = | 0.25 | klf | ϕ= | 38 | degrees |
| Moment Arm @ B/Footing = | 1.33 | ft | Ka = | 0.24 | |
| Moment = | 0.3 | k*ft | ϒ= | 0.13 | kcf |
| | | | H = | 4.00 | ft |

WIND LOAD (WS): (AASHTO 3.8.1.2.4)

$P_Z = 2.56X10^{-6}*V^2*K_Z*G*C_D$

| | | | |
|---|---|---|---|
| $V_{STR\ III}$= | 110 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{STR\ V}$= | 80 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{SERV\ I}$= | 70 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $K_{Z_STR}$= | 0.71 | | (AASHTO Table C3.8.1.2.1-1) |
| $K_{Z_SERV}$= | 1.0 | | (AASHTO 3.8.1.2.1) |
| G= | 0.85 | | (AASHTO Table 3.8.1.2.1-1) |
| $C_D$ = | 1.2 | | (AASHTO Table 3.8.1.2.1-2) |
| Z= | 7.33 | = Exposed Noise Wall Height at the Back Face | |

| | | |
|---|---|---|
| $P_{Z_STR\ III}$= | 0.022 | ksf |
| $P_{Z_STR\ V}$= | 0.012 | ksf |
| $P_{Z_SERV\ I}$= | 0.013 | ksf |

$P_W = P_Z*Z$ (AASHTO 3.8.1.2.4)

Moment Arm @ B/Footing = 14.7 ft

| | Linear feet of Wall | |
|---|---|---|
| | $P_W$ | Moment |
| | klf | k*ft |
| STR III | 0.16 | 2.4 |
| STR V | 0.09 | 1.3 |
| SERV I | 0.09 | 1.4 |

- $P_W$ is a line load applied at 0.55*Z from the top of roadway. (AASHTO 3.8.1.2.4)
- Moment Arm is from the top of the retaining wall.
  = 0.55*(Noise Wall Height + Traffic Barrier Height) + Slab Thickness

| | | | |
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SEISMIC ACTIVE EARTH PRESSURES ($EQ_{soil}$):

$P_{seis} = P_{AE}$ LRFD 11.6.5.1

$P_{seis}$ = 0.761 klf $P_{seis}$ is applied 1/3 height of soil.

$P_{AE}$ = 0.761 klf LRFD 11.6.5.3-2

$P_{AE} = 0.5*\Upsilon*K_{AE}*h^2$

- Monobe-Okabe Analysis LRFD A11.3.1

**Figure A11.3.1-1—Mononobe-Okabe Method Force Diagrams**

$$K_{AE} = \frac{\cos^2(\phi-\theta_{MO}-\beta)}{\cos\theta_{MO}\cos^2\beta\cos(\delta+\beta+\theta_{MO})}\times\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2} \quad \text{(A11.3.1-1)}$$

where:

$K_{AE}$ = seismic active earth pressure coefficient (dim)
$\gamma$ = unit weight of soil (kcf)
$H$ = height of wall (ft)
$h$ = height of wall at back of wall heel considering height of sloping surcharge, if present (ft)
$\phi_f$ = friction angle of soil (degrees)
$\theta_{MO}$ = arc tan $[k_h/(1-k_v)]$ (degrees)
$\delta$ = wall backfill interface friction angle (degrees)
$k_h$ = horizontal seismic acceleration coefficient (dim.)
$k_v$ = vertical seismic acceleration coefficient (dim.)
$i$ = backfill slope angle (degrees)
$\beta$ = slope of wall to the vertical, negative as shown (degrees)

$k_{AE}$ = 0.732

$\psi$ = 0.42 $\psi = \left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2}$

$\Upsilon_{soil}$ = 0.130 kcf

H = 4.0 ft Height of soil and footing

$\phi$ = 38.00 degrees

$\theta$ = 26.4 degrees

$\delta = 2/3*\phi$ = 25.3 degrees

$k_h = 1.0*k_{h0}$ = 0.497 Note: 0.5*kho=0.249, by using 1.0*kho this increased the Extreme Event Moment by 2% and the Lateral load by 16%. This small increase does not affect the outcome of the calc.

$k_{h0} = A_s$ = 0.497

$k_v$ = 0.0

i = 0.0 degrees

$\beta$ = 0.0 degrees

Moment Arm @ B/Footing = 1.33 ft

Moment = 1.0 k*ft

| | | | |
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SEISMIC FORCES ON WALL ($EQ_{wall}$): (See Attached Calc)

Shear at base of wall = 1.7 k
Moment on wall = 20.1 k*ft

LOAD SUMMARY

| Load | Force | | Moment |
|---|---|---|---|
| | Vertical | Lateral | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) |
| DC | 4.0 | | 0.0 |
| EV | 8.5 | | 5.8 |
| EH | | 0.5 | 0.9 |
| $WS_{STR\ III}$ | | 0.16 | 2.4 |
| $WS_{STR\ V}$ | | 0.09 | 1.3 |
| $WS_{SERV\ I}$ | | 0.09 | 1.4 |
| $EQ_{soil}$ | | 0.8 | 1.0 |
| $EQ_{wall}$ | | 1.7 | 20.1 |

**Calculate Bearing Pressure**

Load Combinations (AASHTO Table 3.4.1-1)

| Load Combination | Force | | Moment | e | B' | $\sigma_v$ |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | ft | **ksf** |
| STRENGTH III: 1.25DC+1.5EH+1.0(EV+WS) | 13.4 | 1.0 | 9.6 | 0.7 | 8.1 | **1.66** |
| STRENGTH V: 1.25DC+1.5EH+1.0(EV+WS) | 13.4 | 0.9 | 8.4 | 0.6 | 8.2 | **1.63** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 12.4 | 2.4 | 26.9 | 2.2 | 5.2 | **2.41** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 12.4 | 0.6 | 8.1 | 0.7 | 8.2 | **1.52** |

| | | | |
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Eccentricity = e =M/$P_y$

B = 9.50 ft B' = B - 2e

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\Sigma V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

**Check Eccentricity Limits** (AASHTO 11.6.3.3)

- The location of the resultant is limited to the middle two-thirds of the width of the foundation.

emax = B/3 3.17 ft

| Load Combination | Force | | Moment | e | Middle | |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | Two-Thirds | |
| STRENGTH III: 0.9DC+1.5EH+1.00(EV+WS) | 12.0 | 1.0 | 9.6 | 0.7 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 12.0 | 0.9 | 8.4 | 0.6 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 12.4 | 2.4 | 26.9 | 2.2 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 12.4 | 0.6 | 8.1 | 0.7 | Yes | **OK** |

**Check Sliding** (AASHTO 10.6.3.4 and AASHTO 11.5.6)

| Load Combination | Force | | $\phi_T R\tau$ | Is Rτ > Vx? | |
|---|---|---|---|---|---|
| | Vertical | Lateral | | | |
| | $P_y$ (kips) | $P_X$ (kips) | kips | | |
| STRENGTH III: 0.90DC+1.5EH+1.00(EV+WS) | 12.0 | 1.0 | 7.5 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 12.0 | 0.9 | 7.5 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 12.4 | 2.4 | 7.8 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 12.4 | 0.6 | 7.8 | Yes | **OK** |

Sliding Resistance = $\phi_T R\tau = \phi_T C P_y \tan \phi_f$ (AASHTO 10.6.3.4-2)

$\phi_T$ = 0.8 (AASHTO Table 10.5.5.2.2-1)

C = 1.0

$\phi_f$ = 38 degrees

Coeffient of Friction = tan $\phi_f$ = 0.78 (AASHTO C3.11.5.3)

| | | | |
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## SOUND BARRIER DESIGN FORCE

**NOISE BARRIER CIP WALL TYPE GEOMETRY**

| | | | |
|---|---|---|---|
| Wall Length | L = | 1 | ft |
| Wall/Wall Height | H = | 17 | ft |
| Wall Thickness | T = | 12 | in |

**MATERIALS**

| | | | |
|---|---|---|---|
| Wall Concrete | $f_c'$ = | 4 | ksi |
| | $\gamma_c$ = | 0.15 | kcf |
| | $E_c$ = | 4266 | ksi |
| Reinforcing Steel | $f_y$ = | 60 | ksi |
| | $E_s$ = | 29000 | ksi |

**DEAD LOAD**

Weight of Wall

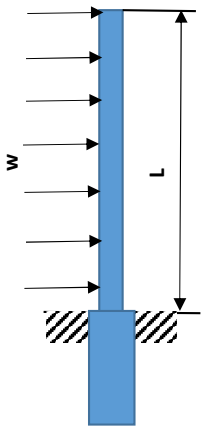
| | | | |
|---|---|---|---|
| Vertical Dead Load | D = | 2.55 | kips |

**SEISMIC FORCE**

Seismic design shall be in accordance with AASHTO LRFD Article 3.10.2.1-General Procedure, considering site class D:

a. Modal analysis shall be performed for the first 4 periods. Elastic seismic response coefficient Csm shall be computed for eacl modal period in accordance with LRFD Article 3.10.4.2 and all 4 Csm coefficients shall be combined through the SRSS method

b. The resultant seismic force shall be considered to act at a height of 0.71H above the top of the shaft, where H is the total height measured from the top of the Wall to the top of the shaft.




**Structural Modeling**

Modeling the column as a cantilever beam

The mass of column and ajacent Walls is uniformly distributed along the column

| | | | |
|---|---|---|---|
| Uniform Weight | w = | 0.15 | kips/ft |
| Uniform Mass | m = | 0.0004 | |
| Column | I = | 1728 | $in^4$ |
| Modulus | E = | 4266 | ksi |
| Gravity | g = | 386 | $in/sec^2$ |

| | | | |
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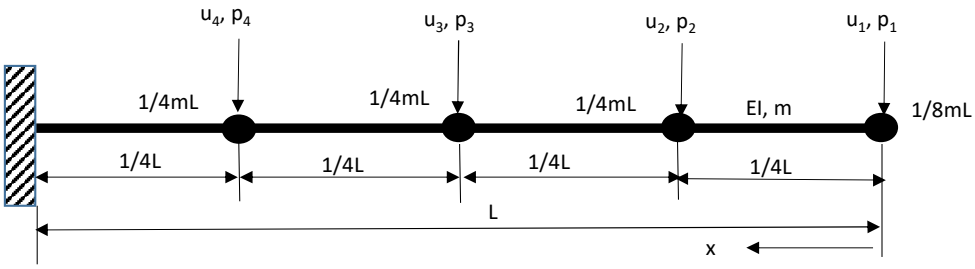
| | CHK'D. BY MGH | DATE | 6/18/2021 |

**Modal Analysis**




Flexibility Matrix

| | | |
|---|---|---|
| $p_1$ = | 1 | |
| | x | u |
| $u_1$ | 0.00 | 0.33333333 |
| $u_2$ | 0.25 | 0.21093750 |
| $u_3$ | 0.50 | 0.10416667 |
| $u_4$ | 0.75 | 0.02864583 |

| | | |
|---|---|---|
| $p_2$ = | 1 | |
| a = | 0.25 | |
| b = | 0.75 | |
| | x | u |
| $u_1$ | 0.00 | 0.2109375 |
| $u_2$ | 0.25 | 0.1406250 |
| $u_3$ | 0.50 | 0.0729167 |
| $u_4$ | 0.75 | 0.0208333 |

| | | |
|---|---|---|
| $p_3$ = | 1 | |
| a = | 0.5 | |
| b = | 0.5 | |
| | x | u |
| $u_1$ | 0 | 0.104166667 |
| $u_2$ | 0.25 | 0.072916667 |
| $u_3$ | 0.5 | 0.041666667 |
| $u_4$ | 0.75 | 0.013020833 |

| | | |
|---|---|---|
| $p_4$ = | 1 | |
| a = | 0.75 | |
| b = | 0.25 | |
| | x | u |
| $u_1$ | 0.00 | 0.028645833 |
| $u_2$ | 0.25 | 0.020833333 |
| $u_3$ | 0.50 | 0.013020833 |
| $u_4$ | 0.75 | 0.005208333 |

Flexibility Matrix

| | $p_1 = 1$ | $p_2 = 1$ | $p_3 = 1$ | $p_4 = 1$ |
|---|---|---|---|---|
| $u_1 = L^3/EI^*$ | 0.3333 | 0.2109 | 0.1042 | 0.0286 |
| $u_2 = L^3/EI^*$ | 0.2109 | 0.1406 | 0.0729 | 0.0208 |
| $u_3 = L^3/EI^*$ | 0.1042 | 0.0729 | 0.0417 | 0.0130 |
| $u_4 = L^3/EI^*$ | 0.0286 | 0.0208 | 0.0130 | 0.0052 |

Stiffness Matrix K

| | | | | |
|---|---|---|---|---|
| $EI/L^3$ | 102.928 | -233.567 | 166.268 | -47.505 |
| $EI/L^3$ | -233.567 | 633.402 | -613.608 | 285.031 |
| $EI/L^3$ | 166.268 | -613.608 | 918.433 | -756.124 |
| $EI/L^3$ | -47.505 | 285.031 | -756.124 | 1203.464 |

| | | | | |
|---|---|---|---|---|
| K = | 89.378 | -202.819 | 144.380 | -41.251 |
| | -202.819 | 550.017 | -532.829 | 247.508 |
| | 144.380 | -532.829 | 797.525 | -656.583 |
| | -41.251 | 247.508 | -656.583 | 1045.033 |

Mass Matrix M

| | | | | |
|---|---|---|---|---|
| | 1/8mL | 0 | 0 | 0 |
| | 0 | 1/4mL | 0 | 0 |
| | 0 | 0 | 1/4mL | 0 |
| | 0 | 0 | 0 | 1/4mL |

| | | | | |
|---|---|---|---|---|
| M = | 0.000825777 | 0 | 0 | 0 |
| | 0 | 0.001651554 | 0 | 0 |
| | 0 | 0 | 0.001651554 | 0 |
| | 0 | 0 | 0 | 0.001651554 |

| | | | |
|---|---|---|---|
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| Supervisor | WPM | TASK | CIP Noise Wall 6 |
| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

First Mode

| $w_1^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 1535.670 | 88.110 | -202.819 | 144.380 | -41.251 |
| | -202.819 | 547.481 | -532.829 | 247.508 |
| | 144.380 | -532.829 | 794.989 | -656.583 |
| | -41.251 | 247.508 | -656.583 | 1042.496 |

$Det(K-w_n^2*M)=0$ 0.000003 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_1$ = 39.188 rad/sec $T_1$ = 0.160 sec

Second Mode

| $w_2^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 53054.10 | 45.56692537 | -202.819 | 144.380 | -41.251 |
| | -202.819 | 462.395 | -532.829 | 247.508 |
| | 144.380 | -532.829 | 709.903 | -656.583 |
| | -41.251 | 247.508 | -656.583 | 957.411 |

$Det(K-w_n^2*M)=0$ 0.000258 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_2$ = 230.335 rad/sec $T_2$ = 0.027 sec

Third Mode

| $w_3^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 372045.06 | -217.849 | -202.819 | 144.380 | -41.251 |
| | -202.819 | -64.435 | -532.829 | 247.508 |
| | 144.380 | -532.829 | 183.072 | -656.583 |
| | -41.251 | 247.508 | -656.583 | 430.580 |

$Det(K-w_n^2*M)=0$ -0.000003 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_3$ = 609.955 rad/sec $T_3$ = 0.010 sec

Fourth Mode

| $w_4^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 1130280.51 | -843.982 | -202.819 | 144.380 | -41.251 |
| | -202.819 | -1316.703 | -532.829 | 247.508 |
| | 144.380 | -532.829 | -1069.195 | -656.583 |
| | -41.251 | 247.508 | -656.583 | -821.687 |

$Det(K-w_n^2*M)=0$ 0.00028851 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_4$ = 1063.147 rad/sec $T_4$ = 0.006 sec

| | | | |
|---|---|---|---|
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| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

Summary

| Mode | ω (rad/sec) | T (sec) |
|---|---|---|
| 1 | 39.188 | 0.160 |
| 2 | 230.335 | 0.027 |
| 3 | 609.955 | 0.010 |
| 4 | 1063.147 | 0.006 |

NATURAL PERIODS By Equation

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

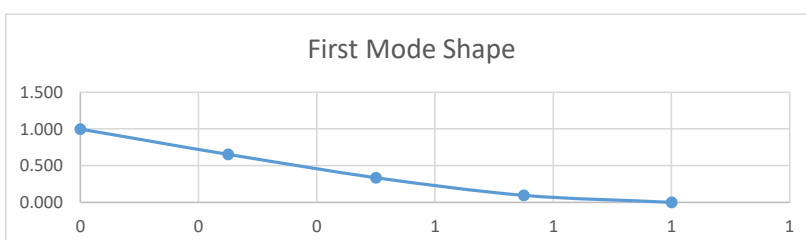
$T_n = 1/f_n$ $\omega_n = 2\pi/T_n$

| | | |
|---|---|---|
| First Mode | $K_1$ = | 3.52 |
| Second Mode | $K_1$ = | 22.03 |
| Third Mode | $K_3$ = | 61.7 |
| Fourth Mode | $K_4$ = | 120.9 |
| | g = | 386 |

| Mode | Natural Frequency $f_n$ (Hz) | Natural period $T_n$ (second) | Natural Frequency $\omega_n$ (Rad/Sec) |
|---|---|---|---|
| 1 | 6.416 | 0.156 | 40.311 |
| 2 | 40.198 | 0.025 | 252.573 |
| 3 | 112.584 | 0.009 | 707.387 |
| 4 | 220.607 | 0.005 | 1386.112 |

First Mode

| | | | | |
|---|---|---|---|---|
| $K-w_1^2M$ | 88.110 | -202.819 | 144.380 | -41.251 |
| | -202.819 | 547.481 | -532.829 | 247.508 |
| | 144.380 | -532.829 | 794.989 | -656.583 |
| | -41.251 | 247.508 | -656.583 | 1042.496 |
| | | | | |
| | 0.0086031 | 0.0085013 | 0.0033117 | -203 |
| | 0.0085013 | 0.0110221 | 0.0049236 | 144 |
| | 0.0033117 | 0.0049236 | 0.0032739 | -41 |
| | | | Mode Shape Plot | |
| $\phi_1$ = | 1 | | 0 | 1.000 |
| | 0.654 | | 0.250 | 0.654 |
| | 0.336 | | 0.500 | 0.336 |
| | 0.096 | | 0.750 | 0.096 |
| | | | 1.000 | 0.000 |



| | | | |
|---|---|---|---|
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| CHK'D. BY | MGH | DATE | 6/18/2021 |

Secod Mode

$K-w_2^2M$

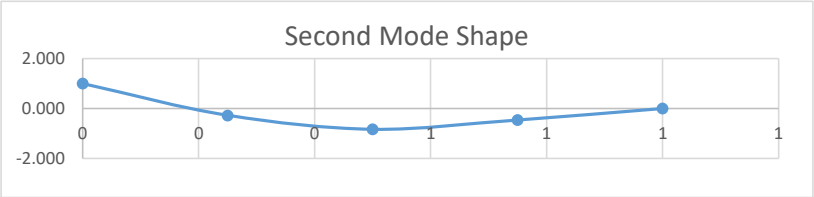
| | | | |
|---|---|---|---|
| 45.567 | -202.819 | 144.380 | -41.251 |
| -202.819 | 462.395 | -532.829 | 247.508 |
| 144.380 | -532.829 | 709.903 | -656.583 |
| -41.251 | 247.508 | -656.583 | 957.411 |

| | | | |
|---|---|---|---|
| -0.0091425 | -0.0127859 | -0.0064050 | -202.819 |
| -0.0127859 | -0.0140297 | -0.0063160 | 144.380 |
| -0.0064050 | -0.0063160 | -0.0016312 | -41.251 |

$\phi_2$ =

| | | | |
|---|---|---|---|
| 1 | | 0 | 1.000 |
| -0.272 | | 0.250 | -0.272 |
| -0.828 | | 0.500 | -0.828 |
| -0.454 | | 0.750 | -0.454 |
| | | 1.000 | 0.000 |

Mode Shape Plot




Third Mode

$K-w_3^2M$

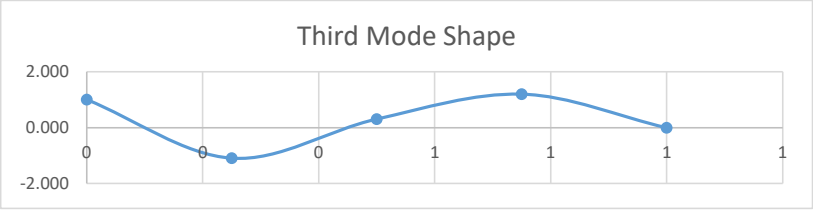
| | | | |
|---|---|---|---|
| -217.849 | -202.819 | 144.380 | -41.251 |
| -202.819 | -64.435 | -532.829 | 247.508 |
| 144.380 | -532.829 | 183.072 | -656.583 |
| -41.251 | 247.508 | -656.583 | 430.580 |

| | | | |
|---|---|---|---|
| -0.0056437 | 0.0010721 | 0.0048789 | -202.819 |
| 0.0010721 | -0.0014259 | -0.0027906 | 144.380 |
| 0.0048789 | -0.0027906 | -0.0047374 | -41.251 |

$\phi_3$ =

| | | | |
|---|---|---|---|
| 1 | | 0 | 1.000 |
| -1.098 | | 0.250 | -1.098 |
| 0.308 | | 0.500 | 0.308 |
| 1.197 | | 0.750 | 1.197 |
| | | 1.000 | 0 |

Mode Shape Plot



| | | | |
|---|---|---|---|
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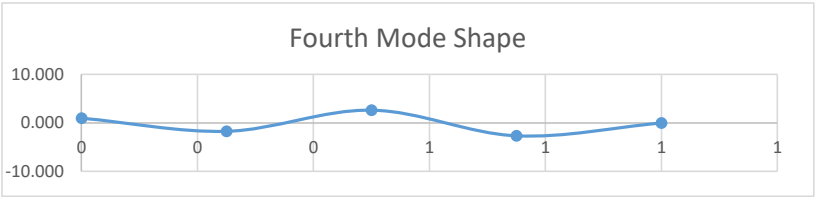
| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

Fourth Mode

| | | | | |
|---|---|---|---|---|
| $K-w_4^2M$ | -843.982 | -202.819 | 144.380 | -41.251 |
| | -202.819 | -1316.703 | -532.829 | 247.508 |
| | 144.380 | -532.829 | -1069.195 | -656.583 |
| | -41.251 | 247.508 | -656.583 | -821.687 |
| | | | | |
| | -0.0038182 | 0.0051228 | -0.0052436 | -202.819 |
| | 0.0051228 | -0.0087096 | 0.0085027 | 144.380 |
| | -0.0052436 | 0.0085027 | -0.0095907 | -41.251 |

| | | Mode Shape Plot | |
|---|---|---|---|
| $\phi_4$ = | 1 | 0 | 1.000 |
| | -1.730 | 0.250 | -1.730 |
| | 2.647 | 0.500 | 2.647 |
| | -2.687 | 0.750 | -2.687 |
| | | 1.000 | 0.000 |




Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 1.000 | 1.000 | 1.000 |
| 0.654 | -0.272 | -1.098 | -1.730 |
| 0.336 | -0.828 | 0.308 | 2.647 |
| 0.096 | -0.454 | 1.197 | -2.687 |

Transpose Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 0.654 | 0.336 | 0.096 |
| 1.000 | -0.272 | -0.828 | -0.454 |
| 1.000 | -1.098 | 0.308 | 1.197 |
| 1.000 | -1.730 | 2.647 | -2.687 |

| | | | |
|---|---|---|---|
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| | | | | |
|---|---|---|---|---|
| Generalized Mass | 0.0008 | 0.0011 | 0.0006 | 0.0002 |
| | 0.0008 | -0.0004 | -0.0014 | -0.0008 |
| | 0.0008 | -0.0018 | 0.0005 | 0.0020 |
| | 0.0008 | -0.0029 | 0.0044 | -0.0044 |
| $M_n$ = | 0.002 | 0.000 | 0.000 | 0.000 |
| | 0.000 | 0.002 | 0.000 | 0.000 |
| | 0.000 | 0.000 | 0.005 | 0.000 |
| | 0.000 | 0.000 | 0.000 | 0.029 |
| Generalized Stiffness | 1.268 | 1.659 | 0.852 | 0.243 |
| | 43.811 | -23.873 | -72.566 | -39.818 |
| | 307.226 | -674.776 | 189.369 | 735.509 |
| | 933.360 | -3230.044 | 4941.653 | -5015.377 |
| $K_n$ = | 2.663 | 0.000 | 0.000 | 0.000 |
| | 0.000 | 128.507 | 0.000 | 0.000 |
| | 0.000 | 0.000 | 1987.027 | 0.000 |
| | 0.000 | 0.000 | 0.000 | 33079.122 |

Verify Natural Frequency

| Mode | $\omega$ | Eigen Value | Equation |
|---|---|---|---|
| 1 | 39.188 | 39.188 | 40.311 |
| 2 | 230.335 | 230.335 | 252.573 |
| 3 | 609.955 | 609.955 | 707.387 |
| 4 | 1063.147 | 1063.147 | 1386.112 |

| | | | | |
|---|---|---|---|---|
| Generalized Force $P_n$ | 0.000825777 | 0.001080249 | 0.000554845 | 0.000158332 |
| | 0.000825777 | -0.000449971 | -0.001367776 | -0.000750523 |
| | 0.000825777 | -0.001813695 | 0.000508994 | 0.001976937 |
| | 0.000825777 | -0.002857737 | 0.004372059 | -0.004437286 |
| Directional Vector | 1 | | 0.002619203 | |
| | 1 | | -0.001742492 | |
| | 1 | | 0.001498013 | |
| | 1 | | -0.002097186 | |
| $P_n$ | 1.5106 | | | |
| | -0.7194 | | | |
| | 0.2805 | | | |
| | -0.0717 | | | |

**SEISMIC DESIGN PARAMETERS**

| | | | |
|---|---|---|---|
| Peak Ground Acceleration | PGA = | 0.422 | |
| Spectral Acceleration at 0.2 Second | $S_S$ = | 0.959 | g |
| Spectral Acceleration at 1 Second | $S_1$ = | 0.278 | g |
| Site Class | D | | |
| Site Factors: | $F_{pga}$ | 1.178 | |
| | $F_a$ = | 1.116 | |
| | $F_v$ = | 2.044 | |
| Response Spectrum | $S_{DS}$ = | 1.070 | g |
| | $S_{D1}$ = | 0.568 | g |
| | $T_S$ = | 0.531 | |
| | $T_o$ = | 0.106 | |
| | $A_S$ = | 0.497 | |

**ELASTIC SEISMIC RESPONSE COEFFICIENT $C_{sm}$**

AASHTO LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$
- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| Mode | ω (rad/sec) | T (sec) | $C_{sm}$ | $C_{Disp}$ |
|---|---|---|---|---|
| 1 | 39.188 | 0.160 | 1.070 | 0.40636 |
| 2 | 230.335 | 0.027 | 0.644 | -0.00337 |
| 3 | 609.955 | 0.010 | 0.553 | 0.00016 |
| 4 | 1063.147 | 0.006 | 0.529 | -0.00001 |

**MODAL SPECTRUM ANALYSIS**

**Modal Displacements**

| Mode 1 | | Mode 2 | |
|---|---|---|---|
| $\phi_1$ = | u1 | $\phi_2$ = | u2 |
| 1.000 | 0.40636 | 1.000 | -0.00337 |
| 0.654 | 0.26579 | -0.272 | 0.00092 |
| 0.336 | 0.13652 | -0.828 | 0.00279 |
| 0.096 | 0.03896 | -0.454 | 0.00153 |
| Mode 3 | | Mode 4 | |
| $\phi_3$ = | u3 | $\phi_4$ = | u4 |
| 1.000 | 0.00016 | 1.000 | -0.000013 |
| -1.098 | -0.00018 | -1.730 | 0.000022 |
| 0.308 | 0.00005 | 2.647 | -0.000034 |
| 1.197 | 0.00019 | -2.687 | 0.000035 |

| | | | |
|---|---|---|---|
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| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

**Total Displacements**

| | | |
|---|---|---|
| $u_1$ = | 0.41 | in |
| $u_2$ = | 0.27 | in |
| $u_3$ = | 0.14 | in |
| $u_4$ = | 0.04 | in |

Modal Base Shear

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 |
|---|---|---|---|---|
| $V_1$ | 0.515 | -0.148 | 0.049 | -0.012 |
| $V_2$ | 0.674 | 0.081 | -0.109 | 0.042 |
| $V_3$ | 0.346 | 0.245 | 0.030 | -0.064 |
| $V_4$ | 0.099 | 0.134 | 0.118 | 0.065 |
| Total | 1.634 | 0.312 | 0.090 | 0.031 |

**Base Shear**

| | | |
|---|---|---|
| SRSS | **1.67** | kips |
| **Base Moment** | **20.12** | kips-ft |

| | | | |
|---|---|---|---|
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| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | RUK | DATE | 6/18/2021 |

## Stem Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2 |
| Arch. Treatments = | 2 | in | |
| h = | 10.00 | in | |
| b = | 12 | in | AASHTO 5.10.1 |
| cover = | 2 | in | |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 10 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| Mu = | 26.16 | k-ft | Extreme Event |
| M(service) = | 7.21 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.20 | | |
| Rebar Area = | 0.79 | $in^2$ | |
| As= | 0.95 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 7.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.39 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.64 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 29.02 | k-ft | |
| **ΦMn > Mu ?** | **YES** | | |

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 200 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6* Mcr = | 20 | kips-ft |
| 1.33 * Mu = | 35 | kips-ft |
| **ΦMn > MIN(1.6*Mcr,1.33*Mu ?** | **YES** | |

| | | | |
|---|---|---|---|
| JOB NO. | PS19203160 | SHEET | 2 of 4 |
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| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | RUK | DATE | 6/18/2021 |

**Check Crack Control: (LRFD 5.6.7)**

| | | | |
|---|---|---|---|
| ρ = | As/(b*d) | | |
| ρ = | 0.01053 | | |
| ρ*n = | 0.08427 | | |
| k = | SQRT($\rho n^2$ + 2*ρn)-ρn | | |
| k = | 0.33482 | | |
| j = | 1-(k/3) | | |
| j = | 0.888 | | |
| fs = | M(service)/(As*j*d) | | |
| fs = | 13.69 | ksi | |
| 0.6*fy = | 36 | ksi | |
| **fs <=** | **0.6*fy** | | **OKAY** |

**Check if tension in cross-section exceeds 80% of modulus of rupture**

| | | | |
|---|---|---|---|
| fr = | 0.24*SQRT(f'c) | | |
| fr = | 0.48 | ksi | |
| 0.8*fr = | 0.38 | ksi | |
| fT = | M(service)/Sx | | |
| fT = | 0.43 | ksi | |
| fT > | 0.8*fr | | **EXCEEDS** |
| | | | |
| $d_c$ = | cover + Rebar Diameter/2 | | |
| $d_c$ = | 2.5 | in | |
| $\beta_s$ = | 1 + $d_c$/(0.7*(h-$d_c$)) | | LRFD 5.6.7.2 |
| $\beta_s$ = | 1.48 | | |
| $\Upsilon_e$ = | 0.75 | for class 2 exposure condition | |
| s <= | (700*$\Upsilon$e / (βs*fs))-2*$d_c$ | | |
| s <= | 20.98 | in | |
| **Provided Spacing =** | **10** | **in** | **OKAY** |

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

| | | | |
|---|---|---|---|
| $A_s$ >= | 1.3*b*h/(2*(b+h)*$f_y$) | | |
| $As_{min}$ = | 0.11 | $in^2$ | |
| $S_{max}$ = | 15 | in | |
| Try Bar # = | 4 | | |
| $A_{bar}$ = | 0.20 | $in^2$ | |
| Spacing = | 15 | in | **OKAY** |
| As = | 0.16 | $in^2$/ft | **OKAY** |

| | | | |
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**Wall Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Vu = 2.08 kips

Shear Bar = 4
Area per Bar = 0.20 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.4 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 3.75 in

Vc= 2*SQRT(f'c)*b*d
Vc= 11.38 kips
Req'd Vn= Vu/$\phi_v$
Req'd Vn= 2.31 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 10 **OKAY**

**Development Length of Hooked Rebar in Stem and Grade Beam (LRFD 5.10.8.2.1a):**

$l_{db}$ = 2.4*$d_b$*$f_y$/SQRT(f'$_c$)
$l_{db}$ = 72 in
$\lambda$ = 1.0 for normal weight concrete
$\lambda$ = 1
$\lambda_{rl}$ = reinforcement location factor, 1.3 if more than 12" concrete below reinf.
$\lambda_{rl}$ = 1
$\lambda_{cf}$ = coating factor
$\lambda_{cf}$ = 1
$d_b$ = 1
$c_b$ = MIN(cover,bar spacing/2)
$c_b$ = 2
$k_{tr}$ = cross-sect area of transv reinf.
$k_{tr}$ = 0
$\lambda_{rc}$ = reinforcement confinement factor, $d_b/(c_b+k_{tr})$
$\lambda_{rc}$ = 0.5
$As_{required}$ = (Mu/$\phi$)/($f_y$*(d-a/2))
$As_{required}$ = 0.85 $in^2$
$\lambda_{er}$ = 1.0 for seismic-force-resisting systems
$\lambda_{er}$ = 1.00
$l_d$ = $l_{db}$ *($\lambda$rl*$\lambda_{cf}$*$\lambda_{rc}$*$\lambda_{er}$)/$\lambda$
$l_d$ = 36.00 in

| | | | |
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**Vertical Flexural Rebar to be Lapped with Hooked Rebar Design (AISC 14th Ed. Table 3-23-19):**

$M_{max} = M_u$

$M_{max} =$ 26.16 kip-ft

L = Height of Noise Wall

L = 17.00 ft

$w = 2*M_{max}/L^2$

w = 0.18 kip/ft

x = Height of Noise Wall -Development Length of Hooked Rebar

x = 14.00 ft

$M_{at\ x} = w*x^2/2$

$M_{at\ x} =$ 17.74 kip-ft

$\Phi =$ 0.90

Try Rebar Size 7

Try Spacing 10.00 in

# of rebar = 1.20

Rebar Area = 0.60 $in^2$

As= 0.72 $in^2$

d = h-cover-(Rebar Diameter/2)

d = 7.50 in

$\beta_1 =$ 0.85

a = (As*fy)/(0.85*fc*b)

a = 1.06 in

$c = a/\beta_1$

c = 1.25 in

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

$\Phi Mn =$ 22.58 k-ft

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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## Footing Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| h = | 12 | in | |
| b = | 12 | in | |
| cover = | 3 | in | AASHTO 5.10.1 |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 10 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| $q_{extr}$ = | 2.37 | ksf | Max bearing pressure applied |
| $q_{serv}$ = | 1.50 | ksf | Service Load bearing pressure |
| L = | 4.25 | ft | Heel of Footing Length |
| Mu = | $q*L^2/2$ | | |
| Mu = | 21.42 | k-ft | Extreme Event |
| M(service) = | 13.55 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.20 | | |
| Rebar Area = | 0.79 | $in^2$/ per bar | |
| As= | 0.95 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 8.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.39 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.64 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 33.29 | k-ft | |

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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**Check Min. Reinforcement: (LRFD 5.6.3.3)**

fr = 0.37*SQRT(fc)
fr = 0.74 ksi
Sx = $b*h^2/6$
Sx = 288 $in^3$
1.6 * Mcr = 1.6*fr*Sx
1.6 * Mcr = 28.42 kips-ft
1.33 * Mu = 28.49 kips-ft
**ΦMn > MIN(1.6*Mcr,1.33*Mu) ? YES**

**Check Crack Control: (LRFD 5.6.7)**

ρ = As/(b*d)
ρ = 0.00929
ρ*n = 0.07435
k = SQRT($ρn^2$ + 2*ρn)-ρn
k = 0.31837
j = 1-(k/3)
j = 0.894
fs = M(service)/(As*j*d)
fs = 22.58 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.56 ksi
fT > 0.8*fr **EXCEEDS**

$d_c$ = cover + Rebar Diameter/2
$d_c$ = 3.5 in
$\beta_s$ = 1 + $d_c$/(0.7*(h-$d_c$)) LRFD 5.6.7.2
$\beta_s$ = 1.59
$\Upsilon_e$ = 1.00 for class 1 exposure condition
s <= (700*ϒe / (βs*fs))-2*$d_c$
s <= 12.52 in
**Provided Spa. = 10 in OKAY**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= 1.3*b*h/(2*(b+h)*$f_y$)
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 18 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 18 in **OKAY**
As = 0.13 $in^2$/ft **OKAY**

| | | | |
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**Footing Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Footing Width = 9.50 ft
Stem Width = 1.00 ft
Critical Section = Ls = (Footing Width -Stem Width)/2-d
Ls = 3.54 ft
Vu = q*Ls
Vu = 8.40 kips

Shear Bar = 5
Area per Bar = 0.79 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 1.58 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 4.25 in

Vc= $0.0316*\beta*\lambda*\sqrt{(f'_c)}*b*d_v$ LRFD 5.7.3.3-3
$\lambda$ = 1 LRFD 5.4.2.8
$\beta$ = 2 LRFD 5.7.3.4
$d_v$ = MAX(0.9*d,0.72*h)
$d_v$ = 8.64 in
Vc= 13.11 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 9 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 12 **OKAY**

| | | | |
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**Preliminary Analysis for:**
**Cast-In-Place Concrete Noise Wall on Footing**
**Maximum Total Wall Height = 18' with Minimum Embedment**

DESIGN CRITERIA:
- WSDOT Bridge Design Manual, July 2019
- AASHTO LRFD 8th Edition
- Geotechnical Engineering Report: Soldier Pile Wall 10.35L and Noise Wall 6

DESIGN ASSUMPTIONS:
- Exposed Wall Height is maximum 14'-4" front face and 10'-9" back face.
- Noise Wall is supporting 4' of fill.
- Seismic design is based on WSDOT BDM 8.2.2 and AASHTO LRFD 4.7.4.3.3.
- Noise Wall Dimensions are based on WSDOT Bridge Manual for Non-Standard Walls, page 8-23.
- Wind load is considered.
- Seismic soil forces are considered.
- Seismic internal wall forces are considered.
- Moment is positive with right hand rule at bottom center of footing. Right of center is positive, Left of center is negative.
- Wall section applies rom STA 5+42.01 to STA 5+54.01

Try:

| | | | |
|---|---|---|---|
| Footing Width = | 9.50 | ft | |
| Footing Thickness = | 1.00 | ft | |
| Wall Height = | 18.0 | ft | |
| Exposed Wall Height = | 14.4 | ft | |
| Wall Thickness = | 1.000 | ft | - Includes form liner on each face |
| Footing Toe Width = | 4.250 | ft | |
| Footing Heel Width = | 4.250 | ft | |

DEAD LOAD (DC):

Loads based on linear foot of wall

| Item | Density | Length | Thickness | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Noise Wall | 0.150 | 18 | 1.00 | 1 | 18.00 | 2.70 | 0.00 | 0.00 |
| Footing | 0.150 | 9.5 | 1.00 | 1 | 9.50 | 1.43 | 0.00 | 0.00 |
| | | | | | Totals = | 4.13 | | 0.00 |

| | | | |
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VERTICAL SOIL LOAD (EV):

Loads based on linear foot of wall

| Item | Density | Width | Height | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Toe | 0.130 | 4.25 | 3.50 | 1 | 14.88 | 1.93 | -2.63 | -5.08 |
| Heel | 0.130 | 4.25 | 7.08 | 1 | 30.08 | 3.91 | 2.63 | 10.27 |
| | | | | | Totals = | 5.84 | | 5.19 |

HORIZONTAL SOIL LOAD (EH): - Not required when seismic soil is being included. (AASHTO C11.6.5.1)

$EH = (1/2)*Ka*\Upsilon*H^2$

| | | | | | |
|---|---|---|---|---|---|
| EH = | 0.20 | klf | ϕ= | 38 | degrees |
| Moment Arm @ B/Footing = | 1.19 | ft | Ka = | 0.24 | |
| Moment = | 0.2 | k*ft | ϒ= | 0.13 | kcf |
| | | | H = | 3.58 | ft |

WIND LOAD (WS): (AASHTO 3.8.1.2.4)

$P_Z = 2.56X10^{-6}*V^2*K_Z*G*C_D$

| | | | |
|---|---|---|---|
| $V_{STR\ III}$= | 110 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{STR\ V}$= | 80 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{SERV\ I}$= | 70 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $K_{Z_STR}$= | 0.71 | | (AASHTO Table C3.8.1.2.1-1) |
| $K_{Z_SERV}$= | 1.0 | | (AASHTO 3.8.1.2.1) |
| G= | 0.85 | | (AASHTO Table 3.8.1.2.1-1) |
| $C_D$ = | 1.2 | | (AASHTO Table 3.8.1.2.1-2) |
| Z= | 10.92 | = Exposed Noise Wall Height at the Back Face | |

| | | |
|---|---|---|
| $P_{Z_STR\ III}$= | 0.022 | ksf |
| $P_{Z_STR\ V}$= | 0.012 | ksf |
| $P_{Z_SERV\ I}$= | 0.013 | ksf |

$P_W = P_Z*Z$ (AASHTO 3.8.1.2.4)

Moment Arm @ B/Footing = 14.1 ft

| | | | |
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| | Linear feet of Wall | |
|---|---|---|
| | $P_W$ | Moment |
| | klf | k*ft |
| STR III | 0.25 | 3.5 |
| STR V | 0.13 | 1.8 |
| SERV I | 0.14 | 2.0 |

- $P_W$ is a line load applied at 0.55*Z from the top of roadway. (AASHTO 3.8.1.2.4)
- Moment Arm is from the top of the retaining wall.
  = 0.55*(Noise Wall Height + Traffic Barrier Height) + Slab Thickness

SEISMIC ACTIVE EARTH PRESSURES ($EQ_{soil}$):

$P_{seis} = P_{AE}$ LRFD 11.6.5.1

$P_{seis}$ = 0.609 klf $P_{seis}$ is applied 1/3 height of soil.

$P_{AE}$ = 0.609 klf LRFD 11.6.5.3-2

$P_{AE} = 0.5*\Upsilon*K_{AE}*h^2$

- Monobe-Okabe Analysis LRFD A11.3.1

**Figure A11.3.1-1—Mononobe-Okabe Method Force Diagrams**

$$K_{AE} = \frac{\cos^2(\phi-\theta_{MO}-\beta)}{\cos\theta_{MO}\cos^2\beta\cos(\delta+\beta+\theta_{MO})}\times\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2} \quad \text{(A11.3.1-1)}$$

where:

$K_{AE}$ = seismic active earth pressure coefficient (dim)
$\gamma$ = unit weight of soil (kcf)
$H$ = height of wall (ft)
$h$ = height of wall at back of wall heel considering height of sloping surcharge, if present (ft)
$\phi_f$ = friction angle of soil (degrees)
$\theta_{MO}$ = arc tan $[k_h/(1-k_v)]$ (degrees)
$\delta$ = wall backfill interface friction angle (degrees)
$k_h$ = horizontal seismic acceleration coefficient (dim.)
$k_v$ = vertical seismic acceleration coefficient (dim.)
$i$ = backfill slope angle (degrees)
$\beta$ = slope of wall to the vertical, negative as shown (degrees)

$k_{AE}$ = 0.732

$\psi$ = 0.42

$$\psi = \left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta_{MO}-i)}{\cos(\delta+\beta+\theta_{MO})\cos(i-\beta)}}\right]^{-2}$$

$\Upsilon_{soil}$ = 0.130 kcf

H = 3.6 ft Height of soil and footing

$\phi$ = 38.00 degrees

$\theta$ = 26.4 degrees

$\delta = 2/3*\phi$ = 25.3 degrees

$k_h = 1.0*k_{h0}$ = 0.497 Note: 0.5*kho=0.249, by using 1.0*kho this increased the Extreme Event Moment by 1% and the Lateral load by 13%. This small increase does not affect the outcome of the calc.

$k_{h0} = A_s$ = 0.497

$k_v$ = 0.0

i = 0.0 degrees

$\beta$ = 0.0 degrees

Moment Arm @ B/Footing = 1.19 ft

Moment = 0.7 k*ft

| | | | |
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SEISMIC FORCES ON WALL ($EQ_{wall}$): (See Attached Calc)

Shear at base of wall = 1.8 k
Moment on wall = 22.6 k*ft

LOAD SUMMARY

| Load | Force | | Moment |
|---|---|---|---|
| | Vertical | Lateral | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) |
| DC | 4.1 | | 0.0 |
| EV | 5.8 | | 5.2 |
| EH | | 0.3 | 0.4 |
| $WS_{STR\ III}$ | | 0.25 | 3.5 |
| $WS_{STR\ V}$ | | 0.13 | 1.8 |
| $WS_{SERV\ I}$ | | 0.14 | 2.0 |
| $EQ_{soil}$ | | 0.6 | 0.7 |
| $EQ_{wall}$ | | 1.8 | 22.6 |

**Calculate Bearing Pressure**

Load Combinations (AASHTO Table 3.4.1-1)

| Load Combination | Force | | Moment | e | B' | $\sigma_v$ |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | ft | **ksf** |
| STRENGTH III: 1.25DC+1.5EH+1.0(EV+WS) | 11.0 | 0.7 | 9.2 | 0.8 | 7.8 | **1.41** |
| STRENGTH V: 1.25DC+1.5EH+1.0(EV+WS) | 11.0 | 0.6 | 7.6 | 0.7 | 8.1 | **1.36** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 10.0 | 2.4 | 28.5 | 2.9 | 3.8 | **2.63** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 10.0 | 0.5 | 7.6 | 0.8 | 8.0 | **1.25** |

Eccentricity = e =M/$P_y$

B = 9.50 ft B' = B - 2e

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\sum V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

| | | | |
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**Check Eccentricity Limits** (AASHTO 11.6.3.3)

- The location of the resultant is limited to the middle two-thirds of the width of the foundation.

emax = B/3 3.17 ft

| Load Combination | Force | | Moment | e | Middle | |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | Two-Thirds | |
| STRENGTH III: 0.9DC+1.5EH+1.00(EV+WS) | 9.6 | 0.7 | 9.2 | 0.8 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 9.6 | 0.6 | 7.6 | 0.7 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 10.0 | 2.4 | 28.5 | 2.9 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 10.0 | 0.5 | 7.6 | 0.8 | Yes | **OK** |

**Check Sliding** (AASHTO 10.6.3.4 and AASHTO 11.5.6)

| Load Combination | Force | | $\phi_T R\tau$ | Is $R\tau > Px$? | |
|---|---|---|---|---|---|
| | Vertical | Lateral | | | |
| | $P_y$ (kips) | $P_X$ (kips) | kips | | |
| STRENGTH III: 0.90DC+1.5EH+1.00(EV+WS) | 9.6 | 0.7 | 6.0 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 9.6 | 0.6 | 6.0 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 10.0 | 2.4 | 6.2 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 10.0 | 0.5 | 6.2 | Yes | **OK** |

Sliding Resistance = $\phi_T R\tau = \phi_T C P_y \tan \phi_f$ (AASHTO 10.6.3.4-2)

$\phi_T$ = 0.8 (AASHTO Table 10.5.5.2.2-1)

C = 1.0

$\phi_f$ = 38 degrees

Coeffient of Friction = $\tan \phi_f$ = 0.78 (AASHTO C3.11.5.3)

| | | | |
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## SOUND BARRIER DESIGN FORCE

**NOISE BARRIER CIP WALL TYPE GEOMETRY**

| | | | |
|---|---|---|---|
| Wall Length | L = | 1 | ft |
| Wall/Wall Height | H = | 18 | ft |
| Wall Thickness | T = | 12 | in |

**MATERIALS**

| | | | |
|---|---|---|---|
| Wall Concrete | $f_c'$ = | 4 | ksi |
| | $\gamma_c$ = | 0.15 | kcf |
| | $E_c$ = | 4266 | ksi |
| Reinforcing Steel | $f_y$ = | 60 | ksi |
| | $E_s$ = | 29000 | ksi |

**DEAD LOAD**

Weight of Wall

| | | | |
|---|---|---|---|
| Vertical Dead Load | D = | 2.70 | kips |

**SEISMIC FORCE**

Seismic design shall be in accordance with AASHTO LRFD Article 3.10.2.1-General Procedure, considering site class D:

a. Modal analysis shall be performed for the first four periods. The elastic seismic response coefficient Csm shall be computed for each modal period in accordance with AASHTO LRFD Article 3.10.4.2 and all four Csm coefficients shall be combined through the SRSS method

b. The resultant seismic force shall be considered to act at a height of 0.71H above the top of the shaft,

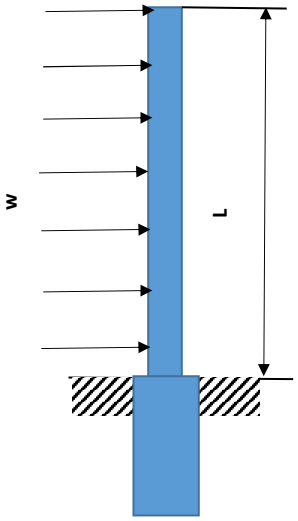
where H is the total height measured from the top of the Wall to the top of the shaft.

**Structural Modeling**

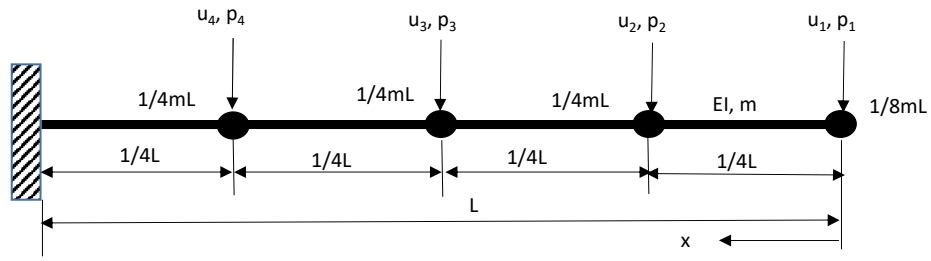
Modeling the column as a cantilever beam

The mass of column and ajacent Walls is uniformly distributed along the column

| | | | |
|---|---|---|---|
| Uniform Weight | w = | 0.15 | kips/ft |
| Uniform Mass | m = | 0.0004 | |
| Column | I = | 1728 | $in^4$ |
| Modulus | E = | 4266 | ksi |
| Gravity | g = | 386 | $in/sec^2$ |



**Modal Analysis**




Flexibility Matrix

| | | |
|---|---|---|
| $p_1$ = | 1 | |
| | x | u |
| $u_1$ | 0.00 | 0.33333333 |
| $u_2$ | 0.25 | 0.21093750 |
| $u_3$ | 0.50 | 0.10416667 |
| $u_4$ | 0.75 | 0.02864583 |

| | | |
|---|---|---|
| $p_2$ = | 1 | |
| a = | 0.25 | |
| b = | 0.75 | |
| | x | u |
| $u_1$ | 0.00 | 0.2109375 |
| $u_2$ | 0.25 | 0.1406250 |
| $u_3$ | 0.50 | 0.0729167 |
| $u_4$ | 0.75 | 0.0208333 |

| | | |
|---|---|---|
| $p_3$ = | 1 | |
| a = | 0.5 | |
| b = | 0.5 | |
| | x | u |
| $u_1$ | 0 | 0.104166667 |
| $u_2$ | 0.25 | 0.072916667 |
| $u_3$ | 0.5 | 0.041666667 |
| $u_4$ | 0.75 | 0.013020833 |

| | | |
|---|---|---|
| $p_4$ = | 1 | |
| a = | 0.75 | |
| b = | 0.25 | |
| | x | u |
| $u_1$ | 0.00 | 0.028645833 |
| $u_2$ | 0.25 | 0.020833333 |
| $u_3$ | 0.50 | 0.013020833 |
| $u_4$ | 0.75 | 0.005208333 |

| | | | |
|---|---|---|---|
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| BY | MGH | DATE | 6/18/2021 |
| CHK'D. BY | BJD | DATE | 6/18/2021 |

Flexibility Matrix

| | $p_1 = 1$ | $p_2 = 1$ | $p_3 = 1$ | $p_4 = 1$ |
|---|---|---|---|---|
| $u_1 = L^3/EI^*$ | 0.3333 | 0.2109 | 0.1042 | 0.0286 |
| $u_2 = L^3/EI^*$ | 0.2109 | 0.1406 | 0.0729 | 0.0208 |
| $u_3 = L^3/EI^*$ | 0.1042 | 0.0729 | 0.0417 | 0.0130 |
| $u_4 = L^3/EI^*$ | 0.0286 | 0.0208 | 0.0130 | 0.0052 |

Stiffness Matrix K

| | | | | |
|---|---|---|---|---|
| $EI/L^3$ | 102.928 | -233.567 | 166.268 | -47.505 |
| $EI/L^3$ | -233.567 | 633.402 | -613.608 | 285.031 |
| $EI/L^3$ | 166.268 | -613.608 | 918.433 | -756.124 |
| $EI/L^3$ | -47.505 | 285.031 | -756.124 | 1203.464 |

K =

| | | | |
|---|---|---|---|
| 75.294 | -170.859 | 121.628 | -34.751 |
| -170.859 | 463.346 | -448.867 | 208.506 |
| 121.628 | -448.867 | 671.852 | -553.119 |
| -34.751 | 208.506 | -553.119 | 880.358 |

Mass Matrix M

| | | | |
|---|---|---|---|
| 1/8mL | 0 | 0 | 0 |
| 0 | 1/4mL | 0 | 0 |
| 0 | 0 | 1/4mL | 0 |
| 0 | 0 | 0 | 1/4mL |

M =

| | | | |
|---|---|---|---|
| 0.000874352 | 0 | 0 | 0 |
| 0 | 0.001748705 | 0 | 0 |
| 0 | 0 | 0.001748705 | 0 |
| 0 | 0 | 0 | 0.001748705 |

First Mode

| $w_1^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 1221.810 | 74.225 | -170.859 | 121.628 | -34.751 |
| | -170.859 | 461.210 | -448.867 | 208.506 |
| | 121.628 | -448.867 | 669.715 | -553.119 |
| | -34.751 | 208.506 | -553.119 | 878.221 |

$Det(K-w_n^2*M)=0$ -3.49947E-05 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_1 =$ 34.954 rad/sec $T_1 =$ 0.180 sec

Second Mode

| $w_2^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 42210.90 | 38.38654052 | -170.859 | 121.628 | -34.751 |
| | -170.859 | 389.532 | -448.867 | 208.506 |
| | 121.628 | -448.867 | 598.037 | -553.119 |
| | -34.751 | 208.506 | -553.119 | 806.543 |

$Det(K-w_n^2*M)=0$ 4.61862E-06 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_2 =$ 205.453 rad/sec $T_2 =$ 0.031 sec

| | | | |
|---|---|---|---|
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Third Mode

| $w_3^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 296006.48 | -183.520 | -170.859 | 121.628 | -34.751 |
| | -170.859 | -54.282 | -448.867 | 208.506 |
| | 121.628 | -448.867 | 154.224 | -553.119 |
| | -34.751 | 208.506 | -553.119 | 362.730 |

$Det(K-w_n^2*M)=0$ -6.07873E-06 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_3$ = 544.065 rad/sec $T_3$ = 0.012 sec

Fourth Mode

| $w_4^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 899273.73 | -710.988 | -170.859 | 121.628 | -34.751 |
| | -170.859 | -1109.218 | -448.867 | 208.506 |
| | 121.628 | -448.867 | -900.712 | -553.119 |
| | -34.751 | 208.506 | -553.119 | -692.207 |

$Det(K-w_n^2*M)=0$ 0.000172484 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_4$ = 948.300 rad/sec $T_4$ = 0.007 sec

Summary

| Mode | ω (rad/sec) | T (sec) |
|---|---|---|
| 1 | 34.954 | 0.180 |
| 2 | 205.453 | 0.031 |
| 3 | 544.065 | 0.012 |
| 4 | 948.300 | 0.007 |

NATURAL PERIODS By Equation

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$T_n = 1/f_n$ $\omega_n = 2\pi/T_n$

| | | |
|---|---|---|
| First Mode | $K_1$ = | 3.52 |
| Second Mode | $K_1$ = | 22.03 |
| Third Mode | $K_3$ = | 61.7 |
| Fourth Mode | $K_4$ = | 120.9 |
| | g = | 386 |

| Mode | Natural Frequency | Natural period | Natural Frequency |
|---|---|---|---|
| | $f_n$ (Hz) | $T_n$ (second) | $\omega_n$ (Rad/Sec) |
| 1 | 5.723 | 0.175 | 35.956 |
| 2 | 35.856 | 0.028 | 225.289 |
| 3 | 100.422 | 0.010 | 630.972 |
| 4 | 196.776 | 0.005 | 1236.378 |

| | | | |
|---|---|---|---|
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| CHK'D. BY | BJD | DATE | 6/18/2021 |

First Mode

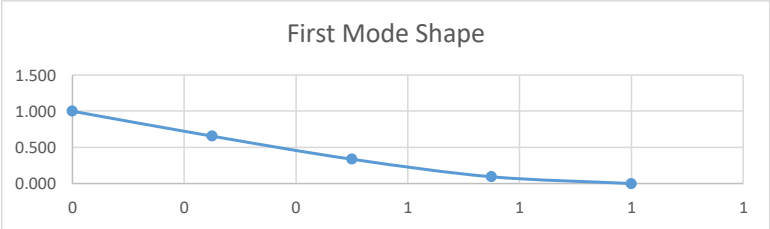
$K-w_1^2M$

| | | | |
|---|---|---|---|
| 74.225 | -170.859 | 121.628 | -34.751 |
| -170.859 | 461.210 | -448.867 | 208.506 |
| 121.628 | -448.867 | 669.715 | -553.119 |
| -34.751 | 208.506 | -553.119 | 878.221 |

| | | | |
|---|---|---|---|
| 0.0102124 | 0.0100915 | 0.0039312 | -171 |
| 0.0100915 | 0.0130838 | 0.0058445 | 122 |
| 0.0039312 | 0.0058445 | 0.0038863 | -35 |

$\phi_1$ =

| | | | |
|---|---|---|---|
| 1 | Mode Shape Plot | 0 | 1.000 |
| 0.654 | | 0.250 | 0.654 |
| 0.336 | | 0.500 | 0.336 |
| 0.096 | | 0.750 | 0.096 |
| | | 1.000 | 0.000 |




Secod Mode

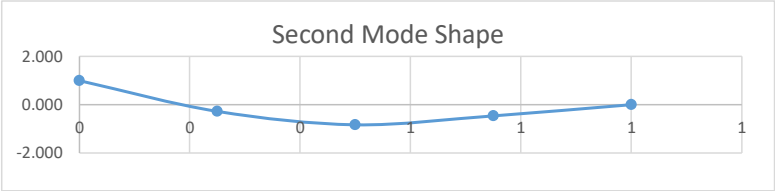
$K-w_2^2M$

| | | | |
|---|---|---|---|
| 38.387 | -170.859 | 121.628 | -34.751 |
| -170.859 | 389.532 | -448.867 | 208.506 |
| 121.628 | -448.867 | 598.037 | -553.119 |
| -34.751 | 208.506 | -553.119 | 806.543 |

| | | | |
|---|---|---|---|
| -0.0108526 | -0.0151776 | -0.0076031 | -170.859 |
| -0.0151776 | -0.0166540 | -0.0074975 | 121.628 |
| -0.0076031 | -0.0074975 | -0.0019363 | -34.751 |

$\phi_2$ =

| | | | |
|---|---|---|---|
| 1 | Mode Shape Plot | 0 | 1.000 |
| -0.272 | | 0.250 | -0.272 |
| -0.828 | | 0.500 | -0.828 |
| -0.454 | | 0.750 | -0.454 |
| | | 1.000 | 0.000 |



| | | | |
|---|---|---|---|
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Third Mode

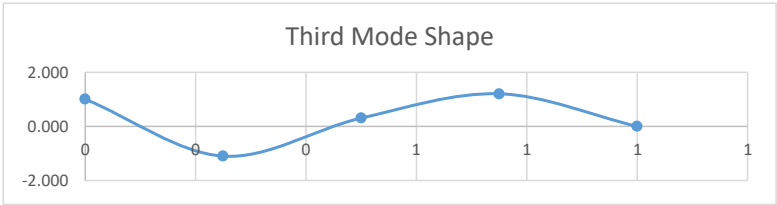
$K-w_3^2M$

| | | | |
|---|---|---|---|
| -183.520 | -170.859 | 121.628 | -34.751 |
| -170.859 | -54.282 | -448.867 | 208.506 |
| 121.628 | -448.867 | 154.224 | -553.119 |
| -34.751 | 208.506 | -553.119 | 362.730 |

| | | | |
|---|---|---|---|
| -0.0066994 | 0.0012726 | 0.0057915 | -170.859 |
| 0.0012726 | -0.0016927 | -0.0033126 | 121.628 |
| 0.0057915 | -0.0033126 | -0.0056236 | -34.751 |

$\phi_3$ =

| | | | |
|---|---|---|---|
| 1 | Mode Shape Plot | 0 | 1.000 |
| -1.098 | | 0.250 | -1.098 |
| 0.308 | | 0.500 | 0.308 |
| 1.197 | | 0.750 | 1.197 |
| | | 1.000 | 0 |




Fourth Mode

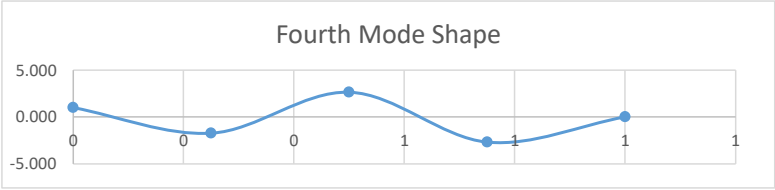
$K-w_4^2M$

| | | | |
|---|---|---|---|
| -710.988 | -170.859 | 121.628 | -34.751 |
| -170.859 | -1109.218 | -448.867 | 208.506 |
| 121.628 | -448.867 | -900.712 | -553.119 |
| -34.751 | 208.506 | -553.119 | -692.207 |

| | | | |
|---|---|---|---|
| -0.0045324 | 0.0060811 | -0.0062244 | -170.859 |
| 0.0060811 | -0.0103388 | 0.0100931 | 121.628 |
| -0.0062244 | 0.0100931 | -0.0113846 | -34.751 |

$\phi_4$ =

| | | | |
|---|---|---|---|
| 1 | Mode Shape Plot | 0 | 1.000 |
| -1.730 | | 0.250 | -1.730 |
| 2.647 | | 0.500 | 2.647 |
| -2.687 | | 0.750 | -2.687 |
| | | 1.000 | 0.000 |




Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 1.000 | 1.000 | 1.000 |
| 0.654 | -0.272 | -1.098 | -1.730 |
| 0.336 | -0.828 | 0.308 | 2.647 |
| 0.096 | -0.454 | 1.197 | -2.687 |

| | | | |
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Transpose Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 0.654 | 0.336 | 0.096 |
| 1.000 | -0.272 | -0.828 | -0.454 |
| 1.000 | -1.098 | 0.308 | 1.197 |
| 1.000 | -1.730 | 2.647 | -2.687 |

Generalized Mass

| | | | |
|---|---|---|---|
| 0.0009 | 0.0011 | 0.0006 | 0.0002 |
| 0.0009 | -0.0005 | -0.0014 | -0.0008 |
| 0.0009 | -0.0019 | 0.0005 | 0.0021 |
| 0.0009 | -0.0030 | 0.0046 | -0.0047 |

$M_n$ =

| | | | |
|---|---|---|---|
| 0.002 | 0.000 | 0.000 | 0.000 |
| 0.000 | 0.003 | 0.000 | 0.000 |
| 0.000 | 0.000 | 0.006 | 0.000 |
| 0.000 | 0.000 | 0.000 | 0.031 |

Generalized Stiffness

| | | | |
|---|---|---|---|
| 1.068 | 1.397 | 0.718 | 0.205 |
| 36.907 | -20.111 | -61.131 | -33.544 |
| 258.814 | -568.446 | 159.528 | 619.609 |
| 786.282 | -2721.057 | 4162.953 | -4225.060 |

$K_n$ =

| | | | |
|---|---|---|---|
| 2.243 | 0.000 | 0.000 | 0.000 |
| 0.000 | 108.257 | 0.000 | 0.000 |
| 0.000 | 0.000 | 1673.913 | 0.000 |
| 0.000 | 0.000 | 0.000 | 27866.551 |

Verify Natural Frequency

| Mode | ω | Eigen Value | Equation |
|---|---|---|---|
| 1 | 34.954 | 34.954 | 35.956 |
| 2 | 205.453 | 205.453 | 225.289 |
| 3 | 544.065 | 544.065 | 630.972 |
| 4 | 948.300 | 948.300 | 1236.378 |

Generalized Force $P_n$

| | | | |
|---|---|---|---|
| 0.000874352 | 0.001143793 | 0.000587483 | 0.000167646 |
| 0.000874352 | -0.00047644 | -0.001448233 | -0.000794671 |
| 0.000874352 | -0.001920383 | 0.000538935 | 0.002093227 |
| 0.000874352 | -0.003025839 | 0.004629239 | -0.004698302 |

Directional Vector

| | |
|---|---|
| 1 | 0.002773274 |
| 1 | -0.001844992 |
| 1 | 0.001586131 |
| 1 | -0.00222055 |

$P_n$

| |
|---|
| 1.5106 |
| -0.7194 |
| 0.2805 |
| -0.0717 |

| | | | |
|---|---|---|---|
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**SEISMIC DESIGN PARAMETERS**

| | | | |
|---|---|---|---|
| Peak Ground Acceleration | PGA = | 0.422 | |
| Spectral Acceleration at 0.2 Second | $S_S$ = | 0.959 | g |
| Spectral Acceleration at 1 Second | $S_1$ = | 0.278 | g |
| Site Class | D | | |
| Site Factors: | $F_{pga}$ | 1.178 | |
| | $F_a$ = | 1.116 | |
| | $F_v$ = | 2.044 | |
| Response Spectrum | $S_{DS}$ = | 1.070 | g |
| | $S_{D1}$ = | 0.568 | g |
| | $T_S$ = | 0.531 | |
| | $T_o$ = | 0.106 | |
| | $A_S$ = | 0.497 | |

**ELASTIC SEISMIC RESPONSE COEFFICIENT $C_{sm}$**

AASHTO LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$
- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| Mode | ω (rad/sec) | T (sec) | $C_{sm}$ | $C_{Disp}$ |
|---|---|---|---|---|
| 1 | 34.954 | 0.180 | 1.070 | 0.51075 |
| 2 | 205.453 | 0.031 | 0.662 | -0.00436 |
| 3 | 544.065 | 0.012 | 0.559 | 0.00020 |
| 4 | 948.300 | 0.007 | 0.533 | -0.00002 |

**MODAL SPECTRUM ANALYSIS**

**Modal Displacements**

| Mode 1 | | Mode 2 | |
|---|---|---|---|
| $\phi_1$ = | u1 | $\phi_2$ = | u2 |
| 1.000 | 0.51075 | 1.000 | -0.00436 |
| 0.654 | 0.33407 | -0.272 | 0.00119 |
| 0.336 | 0.17159 | -0.828 | 0.00361 |
| 0.096 | 0.04896 | -0.454 | 0.00198 |
| Mode 3 | | Mode 4 | |
| $\phi_3$ = | u3 | $\phi_4$ = | u4 |
| 1.000 | 0.00020 | 1.000 | -0.000016 |
| -1.098 | -0.00022 | -1.730 | 0.000028 |
| 0.308 | 0.00006 | 2.647 | -0.000043 |
| 1.197 | 0.00024 | -2.687 | 0.000044 |

| | | | |
|---|---|---|---|
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**Total Displacements**

| | | |
|---|---|---|
| $u_1$ = | 0.51 | in |
| $u_2$ = | 0.33 | in |
| $u_3$ = | 0.17 | in |
| $u_4$ = | 0.05 | in |

Modal Base Shear

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 |
|---|---|---|---|---|
| $V_1$ | 0.546 | -0.161 | 0.053 | -0.013 |
| $V_2$ | 0.714 | 0.088 | -0.116 | 0.045 |
| $V_3$ | 0.367 | 0.266 | 0.033 | -0.068 |
| $V_4$ | 0.105 | 0.146 | 0.127 | 0.069 |
| Total | 1.731 | 0.339 | 0.096 | 0.033 |

**Base Shear**

| | | |
|---|---|---|
| SRSS | **1.77** | kips |
| **Base Moment** | **22.58** | kips-ft |

| | | | |
|---|---|---|---|
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| CHK'D. BY | MGH | DATE | 6/18/2021 |

## Stem Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2 |
| Arch. Treatments = | 2 | in | |
| h = | 10.00 | in | |
| b = | 12 | in | AASHTO 5.10.1 |
| cover = | 2 | in | |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 10 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| Mu = | 28.16 | k-ft | Extreme Event |
| M(service) = | 7.39 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.20 | | |
| Rebar Area = | 0.79 | $in^2$ | |
| As= | 0.95 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 7.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.39 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.64 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 29.02 | k-ft | |
| **ΦMn > Mu ?** | **YES** | | |

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 200 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6* Mcr = | 20 | kips-ft |
| 1.33 * Mu = | 37 | kips-ft |
| **ΦMn > MIN(1.6*Mcr,1.33*Mu ?** | **YES** | |

| | | | |
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**Check Crack Control: (LRFD 5.6.7)**

| | | | |
|---|---|---|---|
| ρ = | As/(b*d) | | |
| ρ = | 0.01053 | | |
| ρ*n = | 0.08427 | | |
| k = | SQRT($\rho n^2$ + 2*ρn)-ρn | | |
| k = | 0.33482 | | |
| j = | 1-(k/3) | | |
| j = | 0.888 | | |
| fs = | M(service)/(As*j*d) | | |
| fs = | 14.05 | ksi | |
| 0.6*fy = | 36 | ksi | |
| **fs <=** | **0.6*fy** | | **OKAY** |

**Check if tension in cross-section exceeds 80% of modulus of rupture**

| | | | |
|---|---|---|---|
| fr = | 0.24*SQRT(f'c) | | |
| fr = | 0.48 | ksi | |
| 0.8*fr = | 0.38 | ksi | |
| fT = | M(service)/Sx | | |
| fT = | 0.44 | ksi | |
| fT > | 0.8*fr | | **EXCEEDS** |
| | | | |
| $d_c$ = | cover + Rebar Diameter/2 | | |
| $d_c$ = | 2.5 | in | |
| $\beta_s$ = | 1 + $d_c$/(0.7*(h-$d_c$)) | | LRFD 5.6.7.2 |
| $\beta_s$ = | 1.48 | | |
| $\Upsilon_e$ = | 0.75 | for class 2 exposure condition | |
| s <= | (700*Ye / (βs*fs))-2*$d_c$ | | |
| s <= | 20.32 | in | |
| **Provided Spacing =** | **10** | **in** | **OKAY** |

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

| | | | |
|---|---|---|---|
| $A_s$ >= | 1.3*b*h/(2*(b+h)*$f_y$) | | |
| $As_{min}$ = | 0.11 | $in^2$ | |
| $S_{max}$ = | 15 | in | |
| Try Bar # = | 4 | | |
| $A_{bar}$ = | 0.20 | $in^2$ | |
| Spacing = | 15 | in | **OKAY** |
| As = | 0.16 | $in^2$/ft | **OKAY** |

| | | | |
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**Wall Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Vu = 2.09 kips

Shear Bar = 4
Area per Bar = 0.20 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.4 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 3.75 in

Vc= 2*SQRT(f'c)*b*d
Vc= 11.38 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 2.33 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 10 **OKAY**

**Development Length of Hooked Rebar in Stem and Grade Beam (LRFD 5.10.8.2.1a):**

$l_{db}$ = $2.4*d_b*f_y/SQRT(f'_c)$
$l_{db}$ = 72 in
$\lambda$ = 1.0 for normal weight concrete
$\lambda$ = 1
$\lambda_{rl}$ = reinforcement location factor, 1.3 if more than 12" concrete below reinf.
$\lambda_{rl}$ = 1
$\lambda_{cf}$ = coating factor
$\lambda_{cf}$ = 1
$d_b$ = 1
$c_b$ = MIN(cover,bar spacing/2)
$c_b$ = 2
$k_{tr}$ = cross-sect area of transv reinf.
$k_{tr}$ = 0
$\lambda_{rc}$ = reinforcement confinement factor, $d_b/(c_b+k_{tr})$
$\lambda_{rc}$ = 0.5
$As_{required}$ = $(Mu/\phi)/(f_y*(d-a/2))$
$As_{required}$ = 0.92 $in^2$
$\lambda_{er}$ = 1.0 for seismic-force-resisting systems
$\lambda_{er}$ = 1.00
$l_d$ = $l_{db}*(\lambda rl*\lambda_{cf}*\lambda_{rc}*\lambda_{er})/\lambda$
$l_d$ = 36.00 in

| | | | |
|---|---|---|---|
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**Vertical Flexural Rebar to be Lapped with Hooked Rebar Design (AISC 14th Ed. Table 3-23-19):**

$M_{max}$ = $M_u$

$M_{max}$ = 28.16 kip-ft

L = Height of Noise Wall

L = 18.00 ft

w = $2*M_{max}/L^2$

w = 0.17 kip/ft

x = Height of Noise Wall -Development Length of Hooked Rebar

x = 15.00 ft

$M_{at\ x}$ = $w*x^2/2$

$M_{at\ x}$ = 19.55 kip-ft

Φ = 0.90

Try Rebar Size 7

Try Spacing 10.00 in

# of rebar = 1.20

Rebar Area = 0.60 $in^2$

As= 0.72 $in^2$

d = h-cover-(Rebar Diameter/2)

d = 7.50 in

$\beta_1$ = 0.85

a = (As*fy)/(0.85*fc*b)

a = 1.06 in

c = $a/\beta_1$

c = 1.25 in

ΦMn = Φ*As*fy*(d-a/2)

ΦMn = 22.58 k-ft

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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## Footing Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| h = | 12 | in | |
| b = | 12 | in | |
| cover = | 3 | in | AASHTO 5.10.1 |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 10 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| $q_{extr}$ = | 2.59 | ksf | Max bearing pressure applied |
| $q_{serv}$ = | 1.24 | ksf | Service Load bearing pressure |
| L = | 4.25 | ft | Heel of Footing Length |
| Mu = | $q*L^2/2$ | | |
| Mu = | 23.38 | k-ft | Extreme Event |
| M(service) = | 11.23 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.20 | | |
| Rebar Area = | 0.79 | $in^2$/ per bar | |
| As= | 0.95 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 8.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.39 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.64 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 33.29 | k-ft | |

**ΦMn > Mu ? YES**

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 288 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6 * Mcr = | 28.42 | kips-ft |
| 1.33 * Mu = | 31 | kips-ft |

**ΦMn > MIN(1.6*Mcr,1.33*Mu) ? YES**

| | | | |
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**Check Crack Control: (LRFD 5.6.7)**

| | | | |
|---|---|---|---|
| ρ = | As/(b*d) | | |
| ρ = | 0.00929 | | |
| ρ*n = | 0.07435 | | |
| k = | SQRT(ρn$^2$ + 2*ρn)-ρn | | |
| k = | 0.31837 | | |
| j = | 1-(k/3) | | |
| j = | 0.894 | | |
| fs = | M(service)/(As*j*d) | | |
| fs = | 18.71 | ksi | |
| 0.6*fy = | 36 | ksi | |
| **fs <=** | **0.6*fy** | | **OKAY** |

**Check if tension in cross-section exceeds 80% of modulus of rupture**

| | | | |
|---|---|---|---|
| fr = | 0.24*SQRT(f'c) | | |
| fr = | 0.48 | ksi | |
| 0.8*fr = | 0.38 | ksi | |
| fT = | M(service)/Sx | | |
| fT = | 0.47 | ksi | |
| fT > | 0.8*fr | | **EXCEEDS** |
| $d_c$ = | cover + Rebar Diameter/2 | | |
| $d_c$ = | 3.5 | in | |
| $\beta_s$ = | 1 + $d_c$/(0.7*(h-$d_c$)) | | LRFD 5.6.7.2 |
| $\beta_s$ = | 1.59 | | |
| $\Upsilon_e$ = | 0.75 | for class 2 exposure condition | |
| s <= | (700*Ye / (βs*fs))-2*$d_c$ | | |
| s <= | 10.67 | in | |
| **Provided Spacing =** | **10** | **in** | **OKAY** |

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

| | | | |
|---|---|---|---|
| $A_s$ >= | 1.3*b*h/(2*(b+h)*$f_y$) | | |
| $As_{min}$ = | 0.11 | in$^2$ | |
| $S_{max}$ = | 18 | in | |
| Try Bar # = | 4 | | |
| $A_{bar}$ = | 0.20 | in$^2$ | |
| Spacing = | 18 | in | **OKAY** |
| As = | 0.13 | in$^2$/ft | **OKAY** |

| | | | |
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**Footing Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Footing Width = 9.50 ft
Stem Width = 1.00 ft
Critical Section = Ls = (Footing Width -Stem Width)/2-d
Ls = 3.54 ft
Vu = q*Ls
Vu = 9.17 kips

Shear Bar = 5
Area per Bar = 0.79 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 1.58 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 4.25 in

Vc= $0.0316*\beta*\lambda*\sqrt{(f'_c)}*b*d_v$ LRFD 5.7.3.3-3
$\lambda$ = 1 LRFD 5.4.2.8
$\beta$ = 2 LRFD 5.7.3.4
$d_v$ = MAX(0.9*d,0.72*h)
$d_v$ = 8.64 in
Vc= 13.11 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 10 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 12 **OKAY**

| | | | |
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**Preliminary Analysis for:**
**Cast-In-Place Concrete Noise Wall on Footing**
**Maximum Total Wall Height = 18' with Maximum Embedment**

DESIGN CRITERIA:
- WSDOT Bridge Design Manual, July 2019
- AASHTO LRFD 8th Edition
- Geotechnical Engineering Report: Soldier Pile Wall 10.35L and Noise Wall 6

DESIGN ASSUMPTIONS:
- Exposed Wall Height is maximum 14.4' front face and 11.4' back face.
- Noise Wall is supporting 4' of fill.
- Seismic design is based on WSDOT BDM 8.2.2 and AASHTO LRFD 4.7.4.3.3.
- Noise Wall Dimensions are based on WSDOT Bridge Manual for Non-Standard Walls, page 8-23.
- Wind load is considered.
- Seismic soil forces are considered.
- Seismic internal wall forces are considered.
- Moment is positive with right hand rule at bottom center of footing. Right of center is positive, Left of center is negative.
- Wall section applies rom STA 5+42.01 to STA 5+54.01

Try:

| | | | |
|---|---|---|---|
| Footing Width = | 9.50 | ft | |
| Footing Thickness = | 1.00 | ft | |
| Wall Height = | 18.0 | ft | |
| Exposed Wall Height = | 14.4 | ft | |
| Wall Thickness = | 1.000 | ft | - Includes form liner on each face |
| Footing Toe Width = | 4.250 | ft | |
| Footing Heel Width = | 4.250 | ft | |

DEAD LOAD (DC):

Loads based on linear foot of wall

| Item | Density | Length | Thickness | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Noise Wall | 0.150 | 18 | 1.00 | 1 | 18.00 | 2.70 | 0.00 | 0.00 |
| Footing | 0.150 | 9.5 | 1.00 | 1 | 9.50 | 1.43 | 0.00 | 0.00 |
| | | | | | Totals = | 4.13 | | 0.00 |

| | | | |
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VERTICAL SOIL LOAD (EV):

Loads based on linear foot of wall

| Item | Density | Width | Height | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Toe | 0.130 | 4.25 | 4.60 | 1 | 19.55 | 2.54 | -2.63 | -6.67 |
| Heel | 0.130 | 4.25 | 7.60 | 1 | 32.30 | 4.20 | 2.63 | 11.02 |
| | | | | | Totals = | 6.74 | | 4.35 |

HORIZONTAL SOIL LOAD (EH): - Not required when seismic soil is being included. (AASHTO C11.6.5.1)

$EH = (1/2)*Ka*\Upsilon*H^2$

| | | | | | |
|---|---|---|---|---|---|
| EH = | 0.14 | klf | ϕ= | 38 | degrees |
| Moment Arm @ B/Footing = | 1.00 | ft | Ka = | 0.24 | |
| Moment = | 0.1 | k*ft | ϒ= | 0.13 | kcf |
| | | | H = | 3.00 | ft |

WIND LOAD (WS): (AASHTO 3.8.1.2.4)

$P_Z = 2.56X10^{-6}*V^2*K_Z*G*C_D$

| | | | |
|---|---|---|---|
| $V_{STR\ III}$= | 110 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{STR\ V}$= | 80 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{SERV\ I}$= | 70 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $K_{Z_STR}$= | 0.71 | | (AASHTO Table C3.8.1.2.1-1) |
| $K_{Z_SERV}$= | 1.0 | | (AASHTO 3.8.1.2.1) |
| G= | 0.85 | | (AASHTO Table 3.8.1.2.1-1) |
| $C_D$ = | 1.2 | | (AASHTO Table 3.8.1.2.1-2) |
| Z= | 10.40 | = Exposed Noise Wall Height at the Back Face | |

| | | |
|---|---|---|
| $P_{Z_STR\ III}$= | 0.022 | ksf |
| $P_{Z_STR\ V}$= | 0.012 | ksf |
| $P_{Z_SERV\ I}$= | 0.013 | ksf |

$P_W = P_Z*Z$ (AASHTO 3.8.1.2.4)

Moment Arm @ B/Footing = 14.3 ft

| | Linear feet of Wall | |
|---|---|---|
| | $P_W$ | Moment |
| | klf | k*ft |
| STR III | 0.23 | 3.3 |
| STR V | 0.12 | 1.8 |
| SERV I | 0.13 | 1.9 |

- $P_W$ is a line load applied at 0.55*Z from the top of roadway. (AASHTO 3.8.1.2.4)
- Moment Arm is from the top of the retaining wall.
  = 0.55*(Noise Wall Height + Traffic Barrier Height) + Slab Thickness

| | | | |
|---|---|---|---|
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SEISMIC ACTIVE EARTH PRESSURES ($EQ_{soil}$):

$P_{seis} = P_{AE}$ LRFD 11.6.5.1

$P_{seis} =$ 0.428 klf $P_{seis}$ is applied 1/3 height of soil.

$P_{AE} =$ 0.428 klf LRFD 11.6.5.3-2

$P_{AE} = 0.5*\Upsilon*K_{AE}*h^2$

- Monobe-Okabe Analysis LRFD A11.3.1

**Figure A11.3.1-1—Mononobe-Okabe Method Force Diagrams**

$$K_{AE} = \frac{\cos^2(\phi - \theta_{MO} - \beta)}{\cos\theta_{MO}\cos^2\beta\cos(\delta + \beta + \theta_{MO})} \times \left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \theta_{MO} - i)}{\cos(\delta + \beta + \theta_{MO})\cos(i - \beta)}}\right]^{-2} \quad \text{(A11.3.1-1)}$$

where:

$K_{AE}$ = seismic active earth pressure coefficient (dim)
$\gamma$ = unit weight of soil (kcf)
$H$ = height of wall (ft)
$h$ = height of wall at back of wall heel considering height of sloping surcharge, if present (ft)
$\phi_f$ = friction angle of soil (degrees)
$\theta_{MO}$ = arc tan $[k_h/(1 - k_v)]$ (degrees)
$\delta$ = wall backfill interface friction angle (degrees)
$k_h$ = horizontal seismic acceleration coefficient (dim.)
$k_v$ = vertical seismic acceleration coefficient (dim.)
$i$ = backfill slope angle (degrees)
$\beta$ = slope of wall to the vertical, negative as shown (degrees)

$k_{AE} =$ 0.732

$\psi =$ 0.42 $\psi = \left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \theta_{MO} - i)}{\cos(\delta + \beta + \theta_{MO})\cos(i - \beta)}}\right]^{-2}$

$\Upsilon_{soil} =$ 0.130 kcf

H = 3.0 ft Height of soil and footing

$\phi =$ 38.00 degrees

$\theta =$ 26.4 degrees

$\delta = 2/3*\phi =$ 25.3 degrees

$k_h = 1.0*k_{h0} =$ 0.497 Note: 0.5*kho=0.249, by using 1.0*kho this increased the Extreme Event Moment by 1% and the Lateral load by 10%. This small increase does not affect the outcome of the calc.

$k_{h0} = A_s =$ 0.497

$k_v =$ 0.0

i = 0.0 degrees

$\beta =$ 0.0 degrees

Moment Arm @ B/Footing = 1.00 ft

Moment = 0.4 k*ft

| | | | |
|---|---|---|---|
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SEISMIC FORCES ON WALL ($EQ_{wall}$): (See Attached Calc)

Shear at base of wall = 1.8 k
Moment on wall = 22.6 k*ft

LOAD SUMMARY

| Load | Force | | Moment |
|---|---|---|---|
| | Vertical | Lateral | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) |
| DC | 4.1 | | 0.0 |
| EV | 6.7 | | 4.4 |
| EH | | 0.3 | 0.5 |
| $WS_{STR\ III}$ | | 0.23 | 3.3 |
| $WS_{STR\ V}$ | | 0.12 | 1.8 |
| $WS_{SERV\ I}$ | | 0.13 | 1.9 |
| $EQ_{soil}$ | | 0.4 | 0.4 |
| $EQ_{wall}$ | | 1.8 | 22.6 |

**Calculate Bearing Pressure**

Load Combinations (AASHTO Table 3.4.1-1)

| Load Combination | Force | | Moment | e | B' | $\sigma_v$ |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | ft | **ksf** |
| STRENGTH III: 1.25DC+1.5EH+1.0(EV+WS) | 11.9 | 0.7 | 8.4 | 0.7 | 8.1 | **1.47** |
| STRENGTH V: 1.25DC+1.5EH+1.0(EV+WS) | 11.9 | 0.6 | 6.8 | 0.6 | 8.4 | **1.42** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 10.9 | 2.2 | 27.4 | 2.5 | 4.5 | **2.43** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 10.9 | 0.5 | 6.7 | 0.6 | 8.3 | **1.32** |

| | | | |
|---|---|---|---|
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Eccentricity = e =M/$P_y$

B = 9.50 ft B' = B - 2e

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\Sigma V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

**Check Eccentricity Limits** (AASHTO 11.6.3.3)

- The location of the resultant is limited to the middle two-thirds of the width of the foundation.

emax = B/3 3.17 ft

| Load Combination | Force | | Moment | e | Middle | |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | Two-Thirds | |
| STRENGTH III: 0.9DC+1.5EH+1.00(EV+WS) | 10.5 | 0.7 | 8.4 | 0.7 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 10.5 | 0.6 | 6.8 | 0.6 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 10.9 | 2.2 | 27.4 | 2.5 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 10.9 | 0.5 | 6.7 | 0.6 | Yes | **OK** |

**Check Sliding** (AASHTO 10.6.3.4 and AASHTO 11.5.6)

| Load Combination | Force | | $\phi_T R\tau$ | Is Rτ > Vx? | |
|---|---|---|---|---|---|
| | Vertical | Lateral | | | |
| | $P_y$ (kips) | $P_X$ (kips) | kips | | |
| STRENGTH III: 0.90DC+1.5EH+1.00(EV+WS) | 10.5 | 0.7 | 6.5 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 10.5 | 0.6 | 6.5 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 10.9 | 2.2 | 6.8 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 10.9 | 0.5 | 6.8 | Yes | **OK** |

Sliding Resistance = $\phi_T R\tau = \phi_T C P_y \tan \phi_f$ (AASHTO 10.6.3.4-2)

$\phi_T$ = 0.8 (AASHTO Table 10.5.5.2.2-1)

C = 1.0

$\phi_f$ = 38 degrees

Coeffient of Friction = tan $\phi_f$ = 0.78 (AASHTO C3.11.5.3)

| | | | |
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## SOUND BARRIER DESIGN FORCE

**NOISE BARRIER CIP WALL TYPE GEOMETRY**

| | | | |
|---|---|---|---|
| Wall Length | L = | 1 | ft |
| Wall/Wall Height | H = | 18 | ft |
| Wall Thickness | T = | 12 | in |

**MATERIALS**

| | | | |
|---|---|---|---|
| Wall Concrete | $f_c'$ = | 4 | ksi |
| | $\gamma_c$ = | 0.15 | kcf |
| | $E_c$ = | 4266 | ksi |
| Reinforcing Steel | $f_y$ = | 60 | ksi |
| | $E_s$ = | 29000 | ksi |

**DEAD LOAD**

Weight of Wall

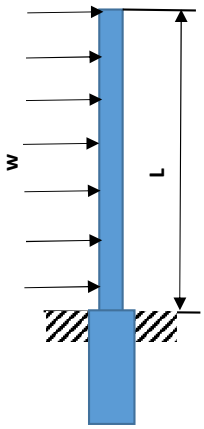
| | | | |
|---|---|---|---|
| Vertical Dead Load | D = | 2.70 | kips |

**SEISMIC FORCE**

Seismic design shall be in accordance with AASHTO LRFD Article 3.10.2.1-General Procedure, considering site class D:

a. Modal analysis shall be performed for the first 4 periods. Elastic seismic response coefficient Csm shall be computed for each modal period in accordance with LRFD Article 3.10.4.2 and all 4 Csm coefficients shall be combined through the SRSS method.

b. The resultant seismic force shall be considered to act at a height of 0.71H above the top of the shaft, where H is the total height measured from the top of the Wall to the top of the shaft.




**Structural Modeling**

Modeling the column as a cantilever beam

The mass of column and ajacent Walls is uniformly distributed along the column

| | | | |
|---|---|---|---|
| Uniform Weight | w = | 0.15 | kips/ft |
| Uniform Mass | m = | 0.0004 | |
| Column | I = | 1728 | $in^4$ |
| Modulus | E = | 4266 | ksi |
| Gravity | g = | 386 | $in/sec^2$ |

| | | | |
|---|---|---|---|
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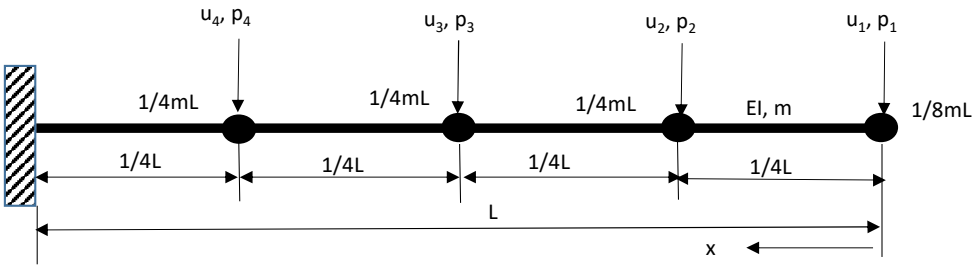
**Modal Analysis**




Flexibility Matrix

| | | |
|---|---|---|
| $p_1$ = | 1 | |
| | x | u |
| $u_1$ | 0.00 | 0.33333333 |
| $u_2$ | 0.25 | 0.21093750 |
| $u_3$ | 0.50 | 0.10416667 |
| $u_4$ | 0.75 | 0.02864583 |

| | | |
|---|---|---|
| $p_2$ = | 1 | |
| a = | 0.25 | |
| b = | 0.75 | |
| | x | u |
| $u_1$ | 0.00 | 0.2109375 |
| $u_2$ | 0.25 | 0.1406250 |
| $u_3$ | 0.50 | 0.0729167 |
| $u_4$ | 0.75 | 0.0208333 |

| | | |
|---|---|---|
| $p_3$ = | 1 | |
| a = | 0.5 | |
| b = | 0.5 | |
| | x | u |
| $u_1$ | 0 | 0.104166667 |
| $u_2$ | 0.25 | 0.072916667 |
| $u_3$ | 0.5 | 0.041666667 |
| $u_4$ | 0.75 | 0.013020833 |

| | | |
|---|---|---|
| $p_4$ = | 1 | |
| a = | 0.75 | |
| b = | 0.25 | |
| | x | u |
| $u_1$ | 0.00 | 0.028645833 |
| $u_2$ | 0.25 | 0.020833333 |
| $u_3$ | 0.50 | 0.013020833 |
| $u_4$ | 0.75 | 0.005208333 |

Flexibility Matrix

| | $p_1 = 1$ | $p_2 = 1$ | $p_3 = 1$ | $p_4 = 1$ |
|---|---|---|---|---|
| $u_1 = L^3/EI^*$ | 0.3333 | 0.2109 | 0.1042 | 0.0286 |
| $u_2 = L^3/EI^*$ | 0.2109 | 0.1406 | 0.0729 | 0.0208 |
| $u_3 = L^3/EI^*$ | 0.1042 | 0.0729 | 0.0417 | 0.0130 |
| $u_4 = L^3/EI^*$ | 0.0286 | 0.0208 | 0.0130 | 0.0052 |

Stiffness Matrix K

| | | | | |
|---|---|---|---|---|
| $EI/L^3$ | 102.928 | -233.567 | 166.268 | -47.505 |
| $EI/L^3$ | -233.567 | 633.402 | -613.608 | 285.031 |
| $EI/L^3$ | 166.268 | -613.608 | 918.433 | -756.124 |
| $EI/L^3$ | -47.505 | 285.031 | -756.124 | 1203.464 |

| | | | | |
|---|---|---|---|---|
| K = | 75.294 | -170.859 | 121.628 | -34.751 |
| | -170.859 | 463.346 | -448.867 | 208.506 |
| | 121.628 | -448.867 | 671.852 | -553.119 |
| | -34.751 | 208.506 | -553.119 | 880.358 |

Mass Matrix M

| | | | | |
|---|---|---|---|---|
| | 1/8mL | 0 | 0 | 0 |
| | 0 | 1/4mL | 0 | 0 |
| | 0 | 0 | 1/4mL | 0 |
| | 0 | 0 | 0 | 1/4mL |

| | | | | |
|---|---|---|---|---|
| M = | 0.000874352 | 0 | 0 | 0 |
| | 0 | 0.001748705 | 0 | 0 |
| | 0 | 0 | 0.001748705 | 0 |
| | 0 | 0 | 0 | 0.001748705 |

| | | | |
|---|---|---|---|
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First Mode

| $w_1^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 1221.810 | 74.225 | -170.859 | 121.628 | -34.751 |
| | -170.859 | 461.210 | -448.867 | 208.506 |
| | 121.628 | -448.867 | 669.715 | -553.119 |
| | -34.751 | 208.506 | -553.119 | 878.221 |

$Det(K-w_n^2*M)=0$ -0.000035 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_1$ = 34.954 rad/sec $T_1$ = 0.180 sec

Second Mode

| $w_2^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 42210.90 | 38.38654052 | -170.859 | 121.628 | -34.751 |
| | -170.859 | 389.532 | -448.867 | 208.506 |
| | 121.628 | -448.867 | 598.037 | -553.119 |
| | -34.751 | 208.506 | -553.119 | 806.543 |

$Det(K-w_n^2*M)=0$ 0.000005 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_2$ = 205.453 rad/sec $T_2$ = 0.031 sec

Third Mode

| $w_3^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 296006.48 | -183.520 | -170.859 | 121.628 | -34.751 |
| | -170.859 | -54.282 | -448.867 | 208.506 |
| | 121.628 | -448.867 | 154.224 | -553.119 |
| | -34.751 | 208.506 | -553.119 | 362.730 |

$Det(K-w_n^2*M)=0$ -0.000006 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_3$ = 544.065 rad/sec $T_3$ = 0.012 sec

Fourth Mode

| $w_4^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 899273.73 | -710.988 | -170.859 | 121.628 | -34.751 |
| | -170.859 | -1109.218 | -448.867 | 208.506 |
| | 121.628 | -448.867 | -900.712 | -553.119 |
| | -34.751 | 208.506 | -553.119 | -692.207 |

$Det(K-w_n^2*M)=0$ 0.000172484 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_4$ = 948.300 rad/sec $T_4$ = 0.007 sec

| | | | |
|---|---|---|---|
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Summary

| Mode | ω (rad/sec) | T (sec) |
|---|---|---|
| 1 | 34.954 | 0.180 |
| 2 | 205.453 | 0.031 |
| 3 | 544.065 | 0.012 |
| 4 | 948.300 | 0.007 |

NATURAL PERIODS By Equation

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

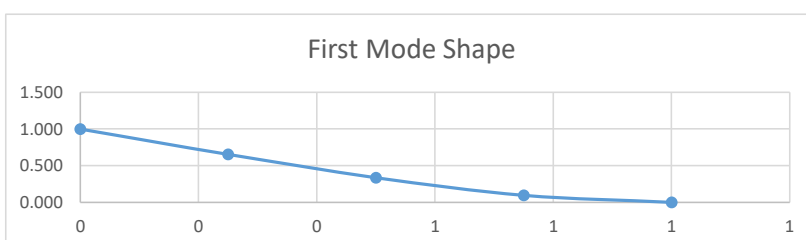
$T_n = 1/f_n$ $\omega_n = 2\pi/T_n$

| | | |
|---|---|---|
| First Mode | $K_1$ = | 3.52 |
| Second Mode | $K_1$ = | 22.03 |
| Third Mode | $K_3$ = | 61.7 |
| Fourth Mode | $K_4$ = | 120.9 |
| | g = | 386 |

| Mode | Natural Frequency $f_n$ (Hz) | Natural period $T_n$ (second) | Natural Frequency $\omega_n$ (Rad/Sec) |
|---|---|---|---|
| 1 | 5.723 | 0.175 | 35.956 |
| 2 | 35.856 | 0.028 | 225.289 |
| 3 | 100.422 | 0.010 | 630.972 |
| 4 | 196.776 | 0.005 | 1236.378 |

First Mode

| | | | | |
|---|---|---|---|---|
| $K-w_1^2M$ | 74.225 | -170.859 | 121.628 | -34.751 |
| | -170.859 | 461.210 | -448.867 | 208.506 |
| | 121.628 | -448.867 | 669.715 | -553.119 |
| | -34.751 | 208.506 | -553.119 | 878.221 |
| | | | | |
| | 0.0102124 | 0.0100915 | 0.0039312 | -171 |
| | 0.0100915 | 0.0130838 | 0.0058445 | 122 |
| | 0.0039312 | 0.0058445 | 0.0038863 | -35 |
| | | | Mode Shape Plot | |
| $\phi_1$ = | 1 | | 0 | 1.000 |
| | 0.654 | | 0.250 | 0.654 |
| | 0.336 | | 0.500 | 0.336 |
| | 0.096 | | 0.750 | 0.096 |
| | | | 1.000 | 0.000 |



| | | | |
|---|---|---|---|
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| CHK'D. BY | BJD | DATE | 6/18/2021 |

Secod Mode

$K-w_2^2M$

| | | | |
|---|---|---|---|
| 38.387 | -170.859 | 121.628 | -34.751 |
| -170.859 | 389.532 | -448.867 | 208.506 |
| 121.628 | -448.867 | 598.037 | -553.119 |
| -34.751 | 208.506 | -553.119 | 806.543 |

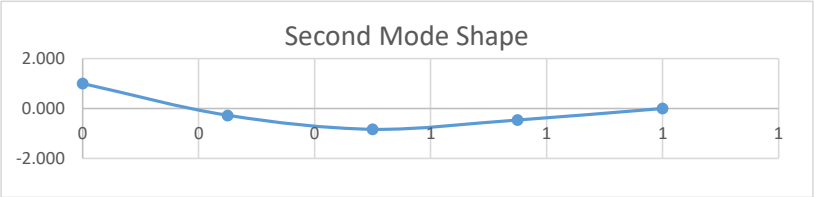
| | | | |
|---|---|---|---|
| -0.0108526 | -0.0151776 | -0.0076031 | -170.859 |
| -0.0151776 | -0.0166540 | -0.0074975 | 121.628 |
| -0.0076031 | -0.0074975 | -0.0019363 | -34.751 |

$\phi_2$ =

| |
|---|
| 1 |
| -0.272 |
| -0.828 |
| -0.454 |

Mode Shape Plot

| | |
|---|---|
| 0 | 1.000 |
| 0.250 | -0.272 |
| 0.500 | -0.828 |
| 0.750 | -0.454 |
| 1.000 | 0.000 |




Third Mode

$K-w_3^2M$

| | | | |
|---|---|---|---|
| -183.520 | -170.859 | 121.628 | -34.751 |
| -170.859 | -54.282 | -448.867 | 208.506 |
| 121.628 | -448.867 | 154.224 | -553.119 |
| -34.751 | 208.506 | -553.119 | 362.730 |

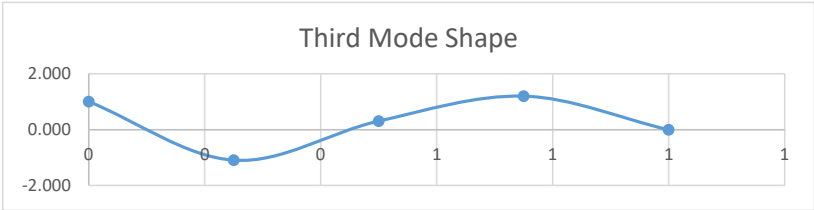
| | | | |
|---|---|---|---|
| -0.0066994 | 0.0012726 | 0.0057915 | -170.859 |
| 0.0012726 | -0.0016927 | -0.0033126 | 121.628 |
| 0.0057915 | -0.0033126 | -0.0056236 | -34.751 |

$\phi_3$ =

| |
|---|
| 1 |
| -1.098 |
| 0.308 |
| 1.197 |

Mode Shape Plot

| | |
|---|---|
| 0 | 1.000 |
| 0.250 | -1.098 |
| 0.500 | 0.308 |
| 0.750 | 1.197 |
| 1.000 | 0 |



| | | | |
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Fourth Mode

$K-w_4^2M$

| | | | |
|---|---|---|---|
| -710.988 | -170.859 | 121.628 | -34.751 |
| -170.859 | -1109.218 | -448.867 | 208.506 |
| 121.628 | -448.867 | -900.712 | -553.119 |
| -34.751 | 208.506 | -553.119 | -692.207 |

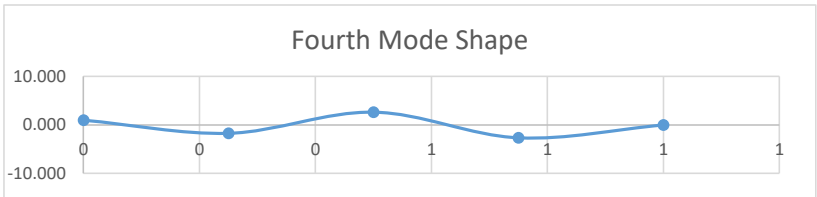
| | | | |
|---|---|---|---|
| -0.0045324 | 0.0060811 | -0.0062244 | -170.859 |
| 0.0060811 | -0.0103388 | 0.0100931 | 121.628 |
| -0.0062244 | 0.0100931 | -0.0113846 | -34.751 |

$\phi_4$ =

| |
|---|
| 1 |
| -1.730 |
| 2.647 |
| -2.687 |

Mode Shape Plot

| | |
|---|---|
| 0 | 1.000 |
| 0.250 | -1.730 |
| 0.500 | 2.647 |
| 0.750 | -2.687 |
| 1.000 | 0.000 |




Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 1.000 | 1.000 | 1.000 |
| 0.654 | -0.272 | -1.098 | -1.730 |
| 0.336 | -0.828 | 0.308 | 2.647 |
| 0.096 | -0.454 | 1.197 | -2.687 |

Transpose Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 0.654 | 0.336 | 0.096 |
| 1.000 | -0.272 | -0.828 | -0.454 |
| 1.000 | -1.098 | 0.308 | 1.197 |
| 1.000 | -1.730 | 2.647 | -2.687 |

| | | | |
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| | | | | |
|---|---|---|---|---|
| Generalized Mass | 0.0009 | 0.0011 | 0.0006 | 0.0002 |
| | 0.0009 | -0.0005 | -0.0014 | -0.0008 |
| | 0.0009 | -0.0019 | 0.0005 | 0.0021 |
| | 0.0009 | -0.0030 | 0.0046 | -0.0047 |
| $M_n$ = | 0.002 | 0.000 | 0.000 | 0.000 |
| | 0.000 | 0.003 | 0.000 | 0.000 |
| | 0.000 | 0.000 | 0.006 | 0.000 |
| | 0.000 | 0.000 | 0.000 | 0.031 |
| Generalized Stiffness | 1.068 | 1.397 | 0.718 | 0.205 |
| | 36.907 | -20.111 | -61.131 | -33.544 |
| | 258.814 | -568.446 | 159.528 | 619.609 |
| | 786.282 | -2721.057 | 4162.953 | -4225.060 |
| $K_n$ = | 2.243 | 0.000 | 0.000 | 0.000 |
| | 0.000 | 108.257 | 0.000 | 0.000 |
| | 0.000 | 0.000 | 1673.913 | 0.000 |
| | 0.000 | 0.000 | 0.000 | 27866.551 |

Verify Natural Frequency

| Mode | $\omega$ | Eigen Value | Equation |
|---|---|---|---|
| 1 | 34.954 | 34.954 | 35.956 |
| 2 | 205.453 | 205.453 | 225.289 |
| 3 | 544.065 | 544.065 | 630.972 |
| 4 | 948.300 | 948.300 | 1236.378 |

| | | | | |
|---|---|---|---|---|
| Generalized Force $P_n$ | 0.000874352 | 0.001143793 | 0.000587483 | 0.000167646 |
| | 0.000874352 | -0.00047644 | -0.001448233 | -0.000794671 |
| | 0.000874352 | -0.001920383 | 0.000538935 | 0.002093227 |
| | 0.000874352 | -0.003025839 | 0.004629239 | -0.004698302 |
| Directional Vector | 1 | | 0.002773274 | |
| | 1 | | -0.001844992 | |
| | 1 | | 0.001586131 | |
| | 1 | | -0.00222055 | |
| $P_n$ | 1.5106 | | | |
| | -0.7194 | | | |
| | 0.2805 | | | |
| | -0.0717 | | | |

| | | | |
|---|---|---|---|
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| BY | MGH | DATE | 6/18/2021 |
| CHK'D. BY | BJD | DATE | 6/18/2021 |

**SEISMIC DESIGN PARAMETERS**

| | | | |
|---|---|---|---|
| Peak Ground Acceleration | PGA = | 0.422 | |
| Spectral Acceleration at 0.2 Second | $S_S$ = | 0.959 | g |
| Spectral Acceleration at 1 Second | $S_1$ = | 0.278 | g |
| Site Class | D | | |
| Site Factors: | $F_{pga}$ | 1.178 | |
| | $F_a$ = | 1.116 | |
| | $F_v$ = | 2.044 | |
| Response Spectrum | $S_{DS}$ = | 1.070 | g |
| | $S_{D1}$ = | 0.568 | g |
| | $T_S$ = | 0.531 | |
| | $T_o$ = | 0.106 | |
| | $A_S$ = | 0.497 | |

**ELASTIC SEISMIC RESPONSE COEFFICIENT $C_{sm}$**

AASHTO LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$
- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| Mode | ω (rad/sec) | T (sec) | $C_{sm}$ | $C_{Disp}$ |
|---|---|---|---|---|
| 1 | 34.954 | 0.180 | 1.070 | 0.51075 |
| 2 | 205.453 | 0.031 | 0.662 | -0.00436 |
| 3 | 544.065 | 0.012 | 0.559 | 0.00020 |
| 4 | 948.300 | 0.007 | 0.533 | -0.00002 |

**MODAL SPECTRUM ANALYSIS**

**Modal Displacements**

| Mode 1 | | Mode 2 | |
|---|---|---|---|
| $\phi_1$ = | u1 | $\phi_2$ = | u2 |
| 1.000 | 0.51075 | 1.000 | -0.00436 |
| 0.654 | 0.33407 | -0.272 | 0.00119 |
| 0.336 | 0.17159 | -0.828 | 0.00361 |
| 0.096 | 0.04896 | -0.454 | 0.00198 |
| Mode 3 | | Mode 4 | |
| $\phi_3$ = | u3 | $\phi_4$ = | u4 |
| 1.000 | 0.00020 | 1.000 | -0.000016 |
| -1.098 | -0.00022 | -1.730 | 0.000028 |
| 0.308 | 0.00006 | 2.647 | -0.000043 |
| 1.197 | 0.00024 | -2.687 | 0.000044 |

| | | | |
|---|---|---|---|
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**Total Displacements**

| | | |
|---|---|---|
| $u_1$ = | 0.51 | in |
| $u_2$ = | 0.33 | in |
| $u_3$ = | 0.17 | in |
| $u_4$ = | 0.05 | in |

Modal Base Shear

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 |
|---|---|---|---|---|
| $V_1$ | 0.546 | -0.161 | 0.053 | -0.013 |
| $V_2$ | 0.714 | 0.088 | -0.116 | 0.045 |
| $V_3$ | 0.367 | 0.266 | 0.033 | -0.068 |
| $V_4$ | 0.105 | 0.146 | 0.127 | 0.069 |
| Total | 1.731 | 0.339 | 0.096 | 0.033 |

**Base Shear**

| | | |
|---|---|---|
| SRSS | **1.77** | kips |
| **Base Moment** | **22.58** | kips-ft |

| | | | |
|---|---|---|---|
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## Stem Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2 |
| Arch. Treatments = | 2 | in | |
| h = | 10.00 | in | |
| b = | 12 | in | AASHTO 5.10.1 |
| cover = | 2 | in | |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 10 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| Mu = | 27.16 | k-ft | Extreme Event |
| M(service) = | 6.40 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.20 | | |
| Rebar Area = | 0.79 | $in^2$ | |
| As= | 0.95 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 7.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.39 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.64 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 29.02 | k-ft | |
| **ΦMn > Mu ?** | **YES** | | |

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 200 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6* Mcr = | 20 | kips-ft |
| 1.33 * Mu = | 36 | kips-ft |
| **ΦMn > MIN(1.6*Mcr,1.33*Mu ?** | **YES** | |

| | | | |
|---|---|---|---|
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**Check Crack Control: (LRFD 5.6.7)**

$\rho$ = As/(b*d)
$\rho$ = 0.01053
$\rho$*n = 0.08427
k = SQRT($\rho n^2$ + 2*$\rho$n)-$\rho$n
k = 0.33482
j = 1-(k/3)
j = 0.888
fs = M(service)/(As*j*d)
fs = 12.15 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy** **OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.38 ksi
fT > 0.8*fr **DOES NOT EXCEED**
**IGNORE THIS SECTION**
$d_c$ = cover + Rebar Diameter/2
$d_c$ = 2.5 in
$\beta_s$ = 1 + $d_c$/(0.7*(h-$d_c$)) LRFD 5.6.7.2
$\beta_s$ = 1.48
$\Upsilon_e$ = 0.75 for class 2 exposure condition
s <= (700*$\Upsilon$e / ($\beta$s*fs))-2*$d_c$
s <= 24.27 in
**Provided Spacing = 10 in** **OKAY**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= 1.3*b*h/(2*(b+h)*$f_y$)
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 15 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 15 in **OKAY**
As = 0.16 $in^2$/ft **OKAY**

| | | | |
|---|---|---|---|
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**Wall Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Vu = 2.00 kips

Shear Bar = 4
Area per Bar = 0.20 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.4 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 3.75 in

Vc= 2*SQRT(f'c)*b*d
Vc= 11.38 kips
Req'd Vn= Vu/$\phi_v$
Req'd Vn= 2.22 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 10 **OKAY**

**Development Length of Hooked Rebar in Stem and Grade Beam (LRFD 5.10.8.2.1a):**

$l_{db}$ = 2.4*$d_b$*$f_y$/SQRT(f'$_c$)
$l_{db}$ = 72 in
$\lambda$ = 1.0 for normal weight concrete
$\lambda$ = 1
$\lambda_{rl}$ = reinforcement location factor, 1.3 if more than 12" concrete below reinf.
$\lambda_{rl}$ = 1
$\lambda_{cf}$ = coating factor
$\lambda_{cf}$ = 1
$d_b$ = 1
$c_b$ = MIN(cover,bar spacing/2)
$c_b$ = 2
$k_{tr}$ = cross-sect area of transv reinf.
$k_{tr}$ = 0
$\lambda_{rc}$ = reinforcement confinement factor, $d_b/(c_b+k_{tr})$
$\lambda_{rc}$ = 0.5
$As_{required}$ = (Mu/$\phi$)/($f_y$*(d-a/2))
$As_{required}$ = 0.89 $in^2$
$\lambda_{er}$ = 1.0 for seismic-force-resisting systems
$\lambda_{er}$ = 1.00
$l_d$ = $l_{db}$ *($\lambda$rl*$\lambda_{cf}$*$\lambda_{rc}$*$\lambda_{er}$)/$\lambda$
$l_d$ = 36.00 in

| | | | |
|---|---|---|---|
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**Vertical Flexural Rebar to be Lapped with Hooked Rebar Design (AISC 14th Ed. Table 3-23-19):**

$M_{max} = M_u$

$M_{max} =$ 27.16 kip-ft

L = Height of Noise Wall

L = 18.00 ft

$w = 2*M_{max}/L^2$

w = 0.17 kip/ft

x = Height of Noise Wall -Development Length of Hooked Rebar

x = 15.00 ft

$M_{at\ x} = w*x^2/2$

$M_{at\ x} =$ 18.86 kip-ft

$\Phi =$ 0.90

Try Rebar Size 7

Try Spacing 10.00 in

# of rebar = 1.20

Rebar Area = 0.60 $in^2$

As= 0.72 $in^2$

d = h-cover-(Rebar Diameter/2)

d = 7.50 in

$\beta_1 =$ 0.85

a = (As*fy)/(0.85*fc*b)

a = 1.06 in

$c = a/\beta_1$

c = 1.25 in

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

$\Phi Mn =$ 22.58 k-ft

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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## Footing Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| h = | 12 | in | |
| b = | 12 | in | |
| cover = | 3 | in | AASHTO 5.10.1 |
| Rebar # = | 8 | | |
| Rebar Diameter = | 1 | in | |
| Spacing = | 10 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| $q_{extr}$ = | 2.41 | ksf | Max bearing pressure applied |
| $q_{serv}$ = | 1.31 | ksf | Service Load bearing pressure |
| L = | 4.25 | ft | Heel of Footing Length |
| Mu = | $q*L^2/2$ | | |
| Mu = | 21.80 | k-ft | Extreme Event |
| M(service) = | 11.79 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.20 | | |
| Rebar Area = | 0.79 | $in^2$/ per bar | |
| As= | 0.95 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 8.50 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 1.39 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 1.64 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 33.29 | k-ft | |

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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**Check Min. Reinforcement: (LRFD 5.6.3.3)**

fr = 0.37*SQRT(fc)
fr = 0.74 ksi
Sx = $b*h^2/6$
Sx = 288 $in^3$
1.6 * Mcr = 1.6*fr*Sx
1.6 * Mcr = 28.42 kips-ft
1.33 * Mu = 29 kips-ft
**ΦMn > MIN(1.6*Mcr,1.33*Mu) ? YES**

**Check Crack Control: (LRFD 5.6.7)**

ρ = As/(b*d)
ρ = 0.00929
ρ*n = 0.07435
k = SQRT($ρn^2$ + 2*ρn)-ρn
k = 0.31837
j = 1-(k/3)
j = 0.894
fs = M(service)/(As*j*d)
fs = 19.64 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.49 ksi
fT > 0.8*fr **EXCEEDS**

$d_c$ = cover + Rebar Diameter/2
$d_c$ = 3.5 in
$\beta_s$ = 1 + $d_c$/(0.7*(h-$d_c$)) LRFD 5.6.7.2
$\beta_s$ = 1.59
$\Upsilon_e$ = 1.00 for class 1 exposure condition
s <= (700*ϒe / (βs*fs))-2*$d_c$
s <= 15.44 in
**Provided Spa. = 10 in OKAY**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= 1.3*b*h/(2*(b+h)*$f_y$)
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 18 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 18 in **OKAY**
As = 0.13 $in^2$/ft **OKAY**

| | | | |
|---|---|---|---|
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**Footing Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Footing Width = 9.50 ft
Stem Width = 1.00 ft
Critical Section = Ls = (Footing Width -Stem Width)/2-d
Ls = 3.54 ft
Vu = q*Ls
Vu = 8.55 kips

Shear Bar = 5
Area per Bar = 0.79 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 1.58 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 4.25 in

Vc= $0.0316*\beta*\lambda*\sqrt{(f'_c)}*b*d_v$ LRFD 5.7.3.3-3
$\lambda$ = 1 LRFD 5.4.2.8
$\beta$ = 2 LRFD 5.7.3.4
$d_v$ = MAX(0.9*d,0.72*h)
$d_v$ = 8.64 in
Vc= 13.11 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 9 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 12 **OKAY**

| | | | |
|---|---|---|---|
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**Preliminary Analysis for:**
**Cast-In-Place Concrete Noise Wall on Footing**
**Maximum Total Wall Height = 11' with Minimum Embedment**

DESIGN CRITERIA:
- WSDOT Bridge Design Manual, July 2019
- AASHTO LRFD 8th Edition
- Geotechnical Engineering Report: Soldier Pile Wall 10.35L and Noise Wall 6

DESIGN ASSUMPTIONS:
- Exposed Wall Height is maximum 9.0' front face and 8.0' back face.
- Noise Wall is supporting 1' of fill.
- Seismic design is based on WSDOT BDM 8.2.2 and AASHTO LRFD 4.7.4.3.3.
- Noise Wall Dimensions are based on WSDOT Bridge Manual for Non-Standard Walls, page 8-23.
- Wind load is considered.
- Seismic soil forces are considered.
- Seismic internal wall forces are considered.
- Moment is positive with right hand rule at bottom center of footing. Right of center is positive, Left of center is negative.

Try:

| | | | |
|---|---|---|---|
| Footing Width = | 6.00 | ft | |
| Footing Thickness = | 1.00 | ft | |
| Wall Height = | 11.00 | ft | |
| Exposed Wall Height = | 9.00 | ft | |
| Wall Thickness = | 1.000 | ft | - Includes form liner on each face |
| Footing Toe Width = | 2.500 | ft | |
| Footing Heel Width = | 2.500 | ft | |

DEAD LOAD (DC):

Loads based on linear foot of wall

| Item | Density | Length | Thickness | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Noise Wall | 0.150 | 11 | 1.00 | 1 | 11.00 | 1.65 | 0.00 | 0.00 |
| Footing | 0.150 | 6.0 | 1.00 | 1 | 6.00 | 0.90 | 0.00 | 0.00 |
| | | | | | Totals = | 2.55 | | 0.00 |

| | | | |
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VERTICAL SOIL LOAD (EV):

Loads based on linear foot of wall

| Item | Density | Width | Height | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Toe | 0.130 | 2.50 | 2.00 | 1 | 5.00 | 0.65 | -1.75 | -1.14 |
| Heel | 0.130 | 2.50 | 3.00 | 1 | 7.50 | 0.98 | 1.75 | 1.71 |
| | | | | | Totals = | 1.63 | | 0.57 |

HORIZONTAL SOIL LOAD (EH): - Not required when seismic soil is being included. (AASHTO C11.6.5.1)

$EH = (1/2)*Ka*Y*H^2$

| | | | | | |
|---|---|---|---|---|---|
| EH = | 0.02 | klf | ϕ= | 38 | degrees |
| Moment Arm @ B/Footing = | 0.33 | ft | Ka = | 0.24 | |
| Moment = | 0.0 | k*ft | Y= | 0.13 | kcf |
| | | | H = | 1.00 | ft |

WIND LOAD (WS): (AASHTO 3.8.1.2.4)

$P_Z = 2.56X10^{-6}*V^2*K_Z*G*C_D$

| | | | |
|---|---|---|---|
| $V_{STR\ III}$= | 110 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{STR\ V}$= | 80 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{SERV\ I}$= | 70 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $K_{Z_STR}$= | 0.71 | | (AASHTO Table C3.8.1.2.1-1) |
| $K_{Z_SERV}$= | 1.0 | | (AASHTO 3.8.1.2.1) |
| G= | 0.85 | | (AASHTO Table 3.8.1.2.1-1) |
| $C_D$ = | 1.2 | | (AASHTO Table 3.8.1.2.1-2) |
| Z= | 8.00 | = Exposed Noise Wall Height at the Back Face | |

| | | |
|---|---|---|
| $P_{Z_STR\ III}$= | 0.022 | ksf |
| $P_{Z_STR\ V}$= | 0.012 | ksf |
| $P_{Z_SERV\ I}$= | 0.013 | ksf |

$P_W = P_Z*Z$ (AASHTO 3.8.1.2.4)

Moment Arm @ B/Footing = 8.4 ft

| | Linear feet of Wall | |
|---|---|---|
| | $P_W$ | Moment |
| | klf | k*ft |
| STR III | 0.18 | 1.5 |
| STR V | 0.09 | 0.8 |
| SERV I | 0.10 | 0.9 |

- $P_W$ is a line load applied at 0.55*Z from the top of roadway. (AASHTO 3.8.1.2.4)
- Moment Arm is from the top of the retaining wall.
  = 0.55*(Noise Wall Height + Traffic Barrier Height) + Slab Thickness

| | | | |
|---|---|---|---|
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SEISMIC ACTIVE EARTH PRESSURES ($EQ_{soil}$):

$P_{seis} = P_{AE}$ LRFD 11.6.5.1

$P_{seis} =$ 0.048 klf $P_{seis}$ is applied 1/3 height of soil.

$P_{AE} =$ 0.048 klf LRFD 11.6.5.3-2

$P_{AE} = 0.5*\Upsilon*K_{AE}*h^2$

- Monobe-Okabe Analysis LRFD A11.3.1

**Figure A11.3.1-1—Mononobe-Okabe Method Force Diagrams**

$$K_{AE} = \frac{\cos^2(\phi - \theta_{MO} - \beta)}{\cos\theta_{MO}\cos^2\beta\cos(\delta + \beta + \theta_{MO})} \times \left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \theta_{MO} - i)}{\cos(\delta + \beta + \theta_{MO})\cos(i - \beta)}}\right]^{-2} \quad \text{(A11.3.1-1)}$$

where:

$K_{AE}$ = seismic active earth pressure coefficient (dim)
$\gamma$ = unit weight of soil (kcf)
$H$ = height of wall (ft)
$h$ = height of wall at back of wall heel considering height of sloping surcharge, if present (ft)
$\phi_f$ = friction angle of soil (degrees)
$\theta_{MO}$ = arc tan $[k_h/(1 - k_v)]$ (degrees)
$\delta$ = wall backfill interface friction angle (degrees)
$k_h$ = horizontal seismic acceleration coefficient (dim.)
$k_v$ = vertical seismic acceleration coefficient (dim.)
$i$ = backfill slope angle (degrees)
$\beta$ = slope of wall to the vertical, negative as shown (degrees)

$k_{AE} =$ 0.732

$\psi =$ 0.42

$$\psi = \left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \theta_{MO} - i)}{\cos(\delta + \beta + \theta_{MO})\cos(i - \beta)}}\right]^{-2}$$

$\Upsilon_{soil} =$ 0.130 kcf

$H =$ 1.0 ft Height of soil and footing

$\phi =$ 38.00 degrees

$\theta =$ 26.4 degrees

$\delta = 2/3*\phi =$ 25.3 degrees

$k_h = 1.0*k_{h0} =$ 0.497 Note: 0.5*kho=0.249, by using 1.0*kho this increased the Extreme Event Moment by 0% and the Lateral load by 2%. This small increase does not affect the outcome of the calc.

$k_{h0} = A_s =$ 0.497

$k_v =$ 0.0

$i =$ 0.0 degrees

$\beta =$ 0.0 degrees

Moment Arm @ B/Footing = 0.33 ft

Moment = 0.0 k*ft

| | | | |
|---|---|---|---|
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SEISMIC FORCES ON WALL ($EQ_{wall}$): (See Attached Calc)

Shear at base of wall = 0.9 k
Moment on wall = 6.8 k*ft

LOAD SUMMARY

| Load | Force | | Moment |
|---|---|---|---|
| | Vertical | Lateral | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) |
| DC | 2.6 | | 0.0 |
| EV | 1.6 | | 0.6 |
| EH | | 0.1 | 0.0 |
| $WS_{STR\ III}$ | | 0.18 | 1.5 |
| $WS_{STR\ V}$ | | 0.09 | 0.8 |
| $WS_{SERV\ I}$ | | 0.10 | 0.9 |
| $EQ_{soil}$ | | 0.0 | 0.0 |
| $EQ_{wall}$ | | 0.9 | 6.8 |

**Calculate Bearing Pressure**

Load Combinations (AASHTO Table 3.4.1-1)

| Load Combination | Force | | Moment | e | B' | $\sigma_v$ |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | ft | **ksf** |
| STRENGTH III: 1.25DC+1.5EH+1.0(EV+WS) | 4.8 | 0.3 | 2.1 | 0.4 | 5.1 | **0.94** |
| STRENGTH V: 1.25DC+1.5EH+1.0(EV+WS) | 4.8 | 0.2 | 1.4 | 0.3 | 5.4 | **0.89** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.2 | 0.9 | 7.4 | 1.8 | 2.5 | **1.69** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.2 | 0.2 | 1.5 | 0.4 | 5.3 | **0.79** |

Eccentricity = e =M/$P_y$

B = 6.00 ft B' = B - 2e

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\sum V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

**Check Eccentricity Limits** (AASHTO 11.6.3.3)

- The location of the resultant is limited to the middle two-thirds of the width of the foundation.

emax = B/3 2.00 ft

| Load Combination | Force | | Moment | e | Middle Two-Thirds | |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | | |
| STRENGTH III: 0.9DC+1.5EH+1.00(EV+WS) | 3.9 | 0.3 | 2.1 | 0.4 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 3.9 | 0.2 | 1.4 | 0.3 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.2 | 0.9 | 7.4 | 1.8 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.2 | 0.2 | 1.5 | 0.4 | Yes | **OK** |

**Check Sliding** (AASHTO 10.6.3.4 and AASHTO 11.5.6)

| Load Combination | Force | | $\phi_T R\tau$ | Is Rτ > Vx? | |
|---|---|---|---|---|---|
| | Vertical | Lateral | | | |
| | $P_y$ (kips) | $P_X$ (kips) | kips | | |
| STRENGTH III: 0.90DC+1.5EH+1.00(EV+WS) | 3.9 | 0.3 | 2.5 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 3.9 | 0.2 | 2.5 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.2 | 0.9 | 2.6 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.2 | 0.2 | 2.6 | Yes | **OK** |

Sliding Resistance = $\phi_T R\tau = \phi_T C P_y \tan \phi_f$ (AASHTO 10.6.3.4-2)

$\phi_T$ = 0.8 (AASHTO Table 10.5.5.2.2-1)

C = 1.0

$\phi_f$ = 38 degrees

Coeffient of Friction = tan $\phi_f$ = 0.78 (AASHTO C3.11.5.3)

| | | | |
|---|---|---|---|
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| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | MGH | DATE | 6/18/2021 |

## SOUND BARRIER DESIGN FORCE

**NOISE BARRIER WALL TYPE 11 GEOMETRY**

| | | | |
|---|---|---|---|
| Wall Length | L = | 1 | ft |
| Wall/Wall Height | H = | 11 | ft |
| Wall Thickness | T = | 12 | in |

**MATERIALS**

| | | | |
|---|---|---|---|
| Wall Concrete | $f_c'$ = | 4 | ksi |
| | $\gamma_c$ = | 0.15 | kcf |
| | $E_c$ = | 4266 | ksi |
| Reinforcing Steel | $f_y$ = | 60 | ksi |
| | $E_s$ = | 29000 | ksi |

**DEAD LOAD**

Weight of Walls

| | | | |
|---|---|---|---|
| Vertical Dead Load | D = | 1.65 | kips |

**SEISMIC FORCE**

Seismic design shall be in accordance with AASHTO LRFD Article 3.10.2.1-General Procedure, considering site class D:

a. Modal analysis shall be performed for the first 4 periods. Elastic seismic response coefficient Csm shall be computed for each modal period in accordance with LRFD Article 3.10.4.2 and all 4 Csm coefficients shall be combined through the SRSS method.

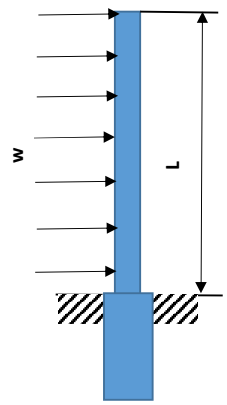
b. The resultant seismic force shall be considered to act at a height of 0.71H above the top of the shaft, where H is the total height measured from the top of the Wall to the top of the shaft.

**Structural Modeling**

Modeling the column as a cantilever beam

The mass of column and ajacent Walls is uniformly distributed along the column

| | | | |
|---|---|---|---|
| Uniform Weight | w = | 0.15 | kips/ft |
| Uniform Mass | m = | 0.0004 | |
| Column | I = | 1728 | $in^4$ |
| Modulus | E = | 4266 | ksi |
| Gravity | g = | 386 | $in/sec^2$ |



| | | | |
|---|---|---|---|
| wood. | JOB NO. PS19203160 | SHEET | 2 of 9 |
| | JOB NAME I-405 - Renton to Bellevue Design-Build | | |
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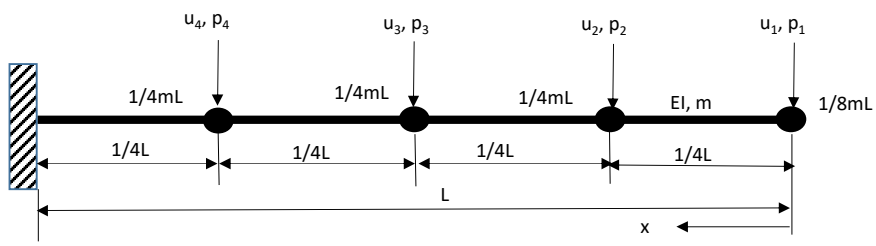
**Modal Analysis**




Flexibility Matrix

| | | |
|---|---|---|
| $p_1$ = | 1 | |
| | x | u |
| $u_1$ | 0.00 | 0.33333333 |
| $u_2$ | 0.25 | 0.21093750 |
| $u_3$ | 0.50 | 0.10416667 |
| $u_4$ | 0.75 | 0.02864583 |

| | | |
|---|---|---|
| $p_2$ = | 1 | |
| a = | 0.25 | |
| b = | 0.75 | |
| | x | u |
| $u_1$ | 0.00 | 0.2109375 |
| $u_2$ | 0.25 | 0.1406250 |
| $u_3$ | 0.50 | 0.0729167 |
| $u_4$ | 0.75 | 0.0208333 |

| | | |
|---|---|---|
| $p_3$ = | 1 | |
| a = | 0.5 | |
| b = | 0.5 | |
| | x | u |
| $u_1$ | 0 | 0.104166667 |
| $u_2$ | 0.25 | 0.072916667 |
| $u_3$ | 0.5 | 0.041666667 |
| $u_4$ | 0.75 | 0.013020833 |

| | | |
|---|---|---|
| $p_4$ = | 1 | |
| a = | 0.75 | |
| b = | 0.25 | |
| | x | u |
| $u_1$ | 0.00 | 0.028645833 |
| $u_2$ | 0.25 | 0.020833333 |
| $u_3$ | 0.50 | 0.013020833 |
| $u_4$ | 0.75 | 0.005208333 |

| | | | |
|---|---|---|---|
| wood. | JOB NO. PS19203160 | SHEET | 3 of 9 |
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| | BY RUK | DATE | 6/18/2021 |
| | CHK'D. BY MGH | DATE | 6/18/2021 |

Flexibility Matrix

| | $p_1 = 1$ | $p_2 = 1$ | $p_3 = 1$ | $p_4 = 1$ |
|---|---|---|---|---|
| $u_1 = L^3/EI^*$ | 0.3333 | 0.2109 | 0.1042 | 0.0286 |
| $u_2 = L^3/EI^*$ | 0.2109 | 0.1406 | 0.0729 | 0.0208 |
| $u_3 = L^3/EI^*$ | 0.1042 | 0.0729 | 0.0417 | 0.0130 |
| $u_4 = L^3/EI^*$ | 0.0286 | 0.0208 | 0.0130 | 0.0052 |

Stiffness Matrix K

| | | | | |
|---|---|---|---|---|
| $EI/L^3$ | 102.928 | -233.567 | 166.268 | -47.505 |
| $EI/L^3$ | -233.567 | 633.402 | -613.608 | 285.031 |
| $EI/L^3$ | 166.268 | -613.608 | 918.433 | -756.124 |
| $EI/L^3$ | -47.505 | 285.031 | -756.124 | 1203.464 |

K =

| | | | |
|---|---|---|---|
| 329.912 | -748.647 | 532.935 | -152.267 |
| -748.647 | 2030.229 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 2943.832 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 3857.435 |

Mass Matrix M

| | | | |
|---|---|---|---|
| 1/8mL | 0 | 0 | 0 |
| 0 | 1/4mL | 0 | 0 |
| 0 | 0 | 1/4mL | 0 |
| 0 | 0 | 0 | 1/4mL |

M =

| | | | |
|---|---|---|---|
| 0.000534326 | 0 | 0 | 0 |
| 0 | 0.001068653 | 0 | 0 |
| 0 | 0 | 0.001068653 | 0 |
| 0 | 0 | 0 | 0.001068653 |

First Mode

| $w_1^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 8760.381 | 325.231 | -748.647 | 532.935 | -152.267 |
| | -748.647 | 2020.867 | -1966.784 | 913.603 |
| | 532.935 | -1966.784 | 2934.470 | -2423.586 |
| | -152.267 | 913.603 | -2423.586 | 3848.073 |

$Det(K-w_n^2*M)=0$ 0.00003 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_1$ = 93.597 rad/sec $T_1$ = 0.067 sec

Second Mode

| $w_2^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 302652.26 | 168.1970731 | -748.647 | 532.935 | -152.267 |
| | -748.647 | 1706.799 | -1966.784 | 913.603 |
| | 532.935 | -1966.784 | 2620.402 | -2423.586 |
| | -152.267 | 913.603 | -2423.586 | 3534.004 |

$Det(K-w_n^2*M)=0$ -0.00007 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_2$ = 550.138 rad/sec $T_2$ = 0.011 sec

| | | | |
|---|---|---|---|
| wood. | JOB NO. PS19203160 | SHEET | 4 of 9 |
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| | BY RUK | DATE | 6/18/2021 |
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Third Mode

| $w_3^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 2122367.04 | -804.125 | -748.647 | 532.935 | -152.267 |
| | -748.647 | -237.845 | -1966.784 | 913.603 |
| | 532.935 | -1966.784 | 675.758 | -2423.586 |
| | -152.267 | 913.603 | -2423.586 | 1589.361 |

$Det(K-w_n^2*M)=0$ -0.003579556 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_3$ = 1456.835 rad/sec $T_3$ = 0.004 sec

Fourth Mode

| $w_4^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 6447794.46 | -3115.315 | -748.647 | 532.935 | -152.267 |
| | -748.647 | -4860.225 | -1966.784 | 913.603 |
| | 532.935 | -1966.784 | -3946.622 | -2423.586 |
| | -152.267 | 913.603 | -2423.586 | -3033.019 |

$Det(K-w_n^2*M)=0$ -0.135426612 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_4$ = 2539.251 rad/sec $T_4$ = 0.002 sec

Summary

| Mode | ω (rad/sec) | T (sec) |
|---|---|---|
| 1 | 93.597 | 0.067 |
| 2 | 550.138 | 0.011 |
| 3 | 1456.835 | 0.004 |
| 4 | 2539.251 | 0.002 |

NATURAL PERIODS By Equation

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$T_n = 1/f_n$ $\omega_n = 2\pi/T_n$

| | | |
|---|---|---|
| First Mode | $K_1$ = | 3.52 |
| Second Mode | $K_1$ = | 22.03 |
| Third Mode | $K_3$ = | 61.7 |
| Fourth Mode | $K_4$ = | 120.9 |
| | g = | 386 |

| Mode | Natural Frequency | Natural period | Natural Frequency |
|---|---|---|---|
| | $f_n$ (Hz) | $T_n$ (second) | $\omega_n$ (Rad/Sec) |
| 1 | 15.323 | 0.065 | 96.279 |
| 2 | 96.011 | 0.010 | 603.252 |
| 3 | 268.899 | 0.004 | 1689.544 |
| 4 | 526.903 | 0.002 | 3310.631 |

| | | | |
|---|---|---|---|
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| CHK'D. BY | MGH | DATE | 6/18/2021 |

First Mode

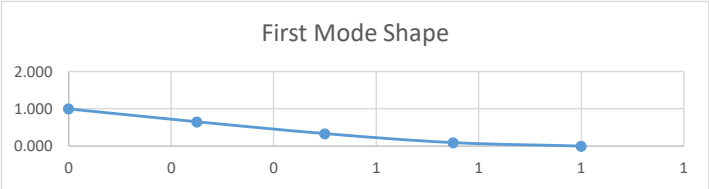
$K-w_1^2M$

| | | | |
|---|---|---|---|
| 325.231 | -748.647 | 532.935 | -152.267 |
| -748.647 | 2020.867 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 2934.470 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 3848.073 |

| | | | |
|---|---|---|---|
| 0.0023307 | 0.0023031 | 0.0008972 | -749 |
| 0.0023031 | 0.0029860 | 0.0013339 | 533 |
| 0.0008972 | 0.0013339 | 0.0008870 | -152 |

$\phi_1 =$

| | | |
|---|---|---|
| | Mode Shape Plot | |
| 1 | 0 | 1.000 |
| 0.654 | 0.250 | 0.654 |
| 0.336 | 0.500 | 0.336 |
| 0.096 | 0.750 | 0.096 |
| | 1.000 | 0.000 |




Secod Mode

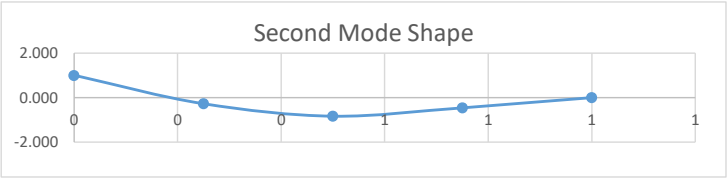
$K-w_2^2M$

| | | | |
|---|---|---|---|
| 168.197 | -748.647 | 532.935 | -152.267 |
| -748.647 | 1706.799 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 2620.402 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 3534.004 |

| | | | |
|---|---|---|---|
| -0.0024768 | -0.0034639 | -0.0017352 | -748.647 |
| -0.0034639 | -0.0038008 | -0.0017111 | 532.935 |
| -0.0017352 | -0.0017111 | -0.0004419 | -152.267 |

$\phi_2 =$

| | | |
|---|---|---|
| | Mode Shape Plot | |
| 1 | 0 | 1.000 |
| -0.272 | 0.250 | -0.272 |
| -0.828 | 0.500 | -0.828 |
| -0.454 | 0.750 | -0.454 |
| | 1.000 | 0.000 |



| | | | |
|---|---|---|---|
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Third Mode

$K-w_3^2M$

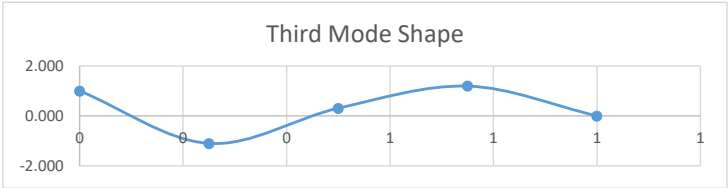
| | | | |
|---|---|---|---|
| -804.125 | -748.647 | 532.935 | -152.267 |
| -748.647 | -237.845 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 675.758 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 1589.361 |

| | | | |
|---|---|---|---|
| -0.0015290 | 0.0002904 | 0.0013218 | -748.647 |
| 0.0002904 | -0.0003863 | -0.0007560 | 532.935 |
| 0.0013218 | -0.0007560 | -0.0012834 | -152.267 |

$\phi_3$ =

| | | | |
|---|---|---|---|
| 1 | | 0 | 1.000 |
| -1.098 | | 0.250 | -1.098 |
| 0.308 | | 0.500 | 0.308 |
| 1.197 | | 0.750 | 1.197 |
| | | 1.000 | 0 |

Mode Shape Plot




Fourth Mode

$K-w_4^2M$

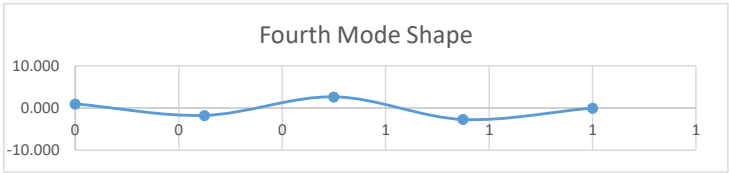
| | | | |
|---|---|---|---|
| -3115.315 | -748.647 | 532.935 | -152.267 |
| -748.647 | -4860.225 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | -3946.622 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | -3033.019 |

| | | | |
|---|---|---|---|
| -0.0010344 | 0.0013878 | -0.0014206 | -748.647 |
| 0.0013878 | -0.0023596 | 0.0023035 | 532.935 |
| -0.0014206 | 0.0023035 | -0.0025982 | -152.267 |

$\phi_4$ =

| | | | |
|---|---|---|---|
| 1 | | 0 | 1.000 |
| -1.730 | | 0.250 | -1.730 |
| 2.647 | | 0.500 | 2.647 |
| -2.687 | | 0.750 | -2.687 |
| | | 1.000 | 0.000 |

Mode Shape Plot



| | | | | |
|---|---|---|---|---|
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| CHK'D. BY | MGH | DATE | 6/18/2021 |

| | | | | |
|---|---|---|---|---|
| Mode Shape Matrix | 1.000 | 1.000 | 1.000 | 1.000 |
| | 0.654 | -0.272 | -1.098 | -1.730 |
| | 0.336 | -0.828 | 0.308 | 2.647 |
| | 0.096 | -0.454 | 1.197 | -2.687 |
| Transpose Mode Shape Matrix | 1.000 | 0.654 | 0.336 | 0.096 |
| | 1.000 | -0.272 | -0.828 | -0.454 |
| | 1.000 | -1.098 | 0.308 | 1.197 |
| | 1.000 | -1.730 | 2.647 | -2.687 |
| Generalized Mass | 0.0005 | 0.0007 | 0.0004 | 0.0001 |
| | 0.0005 | -0.0003 | -0.0009 | -0.0005 |
| | 0.0005 | -0.0012 | 0.0003 | 0.0013 |
| | 0.0005 | -0.0018 | 0.0028 | -0.0029 |
| $M_n$ = | 0.001 | 0.000 | 0.000 | 0.000 |
| | 0.000 | 0.002 | 0.000 | 0.000 |
| | 0.000 | 0.000 | 0.003 | 0.000 |
| | 0.000 | 0.000 | 0.000 | 0.019 |
| Generalized Stiffness | 4.681 | 6.123 | 3.145 | 0.898 |
| | 161.715 | -88.120 | -267.857 | -146.978 |
| | 1134.037 | -2490.741 | 699.000 | 2714.920 |
| | 3445.227 | -11922.770 | 18240.676 | -18512.810 |
| $K_n$ = | 9.829 | 0.000 | 0.000 | 0.000 |
| | 0.000 | 474.348 | 0.000 | 0.000 |
| | 0.000 | 0.000 | 7334.532 | 0.000 |
| | 0.000 | 0.000 | 0.000 | 122101.972 |

Verify Natural Frequency

| Mode | ω | Eigen Value | Equation |
|---|---|---|---|
| 1 | 93.597 | 93.597 | 96.279 |
| 2 | 550.138 | 550.138 | 603.252 |
| 3 | 1456.835 | 1456.835 | 1689.544 |
| 4 | 2539.251 | 2539.251 | 3310.631 |

| | | | | |
|---|---|---|---|---|
| Generalized Force $P_n$ | 0.000534326 | 0.000698984 | 0.000359017 | 0.00010245 |
| | 0.000534326 | -0.000291158 | -0.000885032 | -0.000485632 |
| | 0.000534326 | -0.001173567 | 0.000329349 | 0.001279194 |
| | 0.000534326 | -0.001849124 | 0.002828979 | -0.002871185 |

| | | |
|---|---|---|
| Directional Vector | 1 | 0.001694778 |
| | 1 | -0.001127495 |
| | 1 | 0.000969303 |
| | 1 | -0.001357003 |

| | |
|---|---|
| $P_n$ | 1.5106 |
| | -0.7194 |
| | 0.2805 |
| | -0.0717 |

**SEISMIC DESIGN PARAMETERS**

| | | | |
|---|---|---|---|
| Peak Ground Acceleration | PGA = | 0.422 | |
| Spectral Acceleration at 0.2 Second | $S_S$ = | 0.959 | g |
| Spectral Acceleration at 1 Second | $S_1$ = | 0.278 | g |
| Site Class | D | | |
| Site Factors: | $F_{pga}$ | 1.178 | |
| | $F_a$ = | 1.116 | |
| | $F_v$ = | 2.044 | |
| Response Spectrum | $S_{DS}$ = | 1.070 | g |
| | $S_{D1}$ = | 0.568 | g |
| | $T_S$ = | 0.531 | |
| | $T_o$ = | 0.106 | |
| | $A_S$ = | 0.497 | |

**ELASTIC SEISMIC RESPONSE COEFFICIENT $C_{sm}$**

AASHTO LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$
- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| Mode | ω (rad/sec) | T (sec) | $C_{sm}$ | $C_{Disp}$ |
|---|---|---|---|---|
| 1 | 93.597 | 0.067 | 0.859 | 0.05720 |
| 2 | 550.138 | 0.011 | 0.559 | -0.00051 |
| 3 | 1456.835 | 0.004 | 0.520 | 0.00003 |
| 4 | 2539.251 | 0.002 | 0.510 | 0.00000 |

| | | | |
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**MODAL SPECTRUM ANALYSIS**

**Modal Displacements**

| Mode 1 | | Mode 2 | |
|---|---|---|---|
| $\phi_1$ = | u1 | $\phi_2$ = | u2 |
| 1.000 | 0.05720 | 1.000 | -0.00051 |
| 0.654 | 0.03742 | -0.272 | 0.00014 |
| 0.336 | 0.01922 | -0.828 | 0.00042 |
| 0.096 | 0.00548 | -0.454 | 0.00023 |

| Mode 3 | | Mode 4 | |
|---|---|---|---|
| $\phi_3$ = | u3 | $\phi_4$ = | u4 |
| 1.000 | 0.00003 | 1.000 | -0.000002 |
| -1.098 | -0.00003 | -1.730 | 0.000004 |
| 0.308 | 0.00001 | 2.647 | -0.000006 |
| 1.197 | 0.00003 | -2.687 | 0.000006 |

**Total Displacements**

| | | |
|---|---|---|
| $u_1$ = | 0.06 | in |
| $u_2$ = | 0.04 | in |
| $u_3$ = | 0.02 | in |
| $u_4$ = | 0.01 | in |

Modal Base Shear

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 |
|---|---|---|---|---|
| $V_1$ | 0.268 | -0.083 | 0.030 | -0.008 |
| $V_2$ | 0.350 | 0.045 | -0.066 | 0.026 |
| $V_3$ | 0.180 | 0.137 | 0.019 | -0.040 |
| $V_4$ | 0.051 | 0.075 | 0.072 | 0.041 |
| Total | 0.849 | 0.175 | 0.055 | 0.019 |

**Base Shear**

| | | |
|---|---|---|
| SRSS | **0.87** | kips |
| **Base Moment** | **6.79** | kips-ft |

| | | | |
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## Stem Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| Arch. Treatments = | 2 | in | |
| h = | 10.00 | in | |
| b = | 12 | in | AASHTO 5.10.1 |
| cover = | 2 | in | |
| Rebar # = | 6 | | |
| Rebar Diameter = | 0.75 | in | |
| Spacing = | 12 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| Mu = | 7.36 | k-ft | Extreme Event |
| M(service) = | 1.43 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.00 | | |
| Rebar Area = | 0.44 | $in^2$ | |
| As= | 0.44 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 7.63 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 0.65 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 0.76 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 14.46 | k-ft | |

**ΦMn > Mu ? YES**

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

| | | |
|---|---|---|
| fr = | 0.37*SQRT(fc) | |
| fr = | 0.74 | ksi |
| Sx = | $b*h^2/6$ | |
| Sx = | 200 | $in^3$ |
| 1.6 * Mcr = | 1.6*fr*Sx | |
| 1.6* Mcr = | 20 | kips-ft |
| 1.33 * Mu = | 10 | kips-ft |

**ΦMn > MIN(1.6*Mcr,1.33*Mu ? YES**

| | | | |
|---|---|---|---|
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**Check Crack Control: (LRFD 5.6.7)**

| | | | |
|---|---|---|---|
| ρ = | As/(b*d) | | |
| ρ = | 0.00481 | | |
| ρ*n = | 0.03847 | | |
| k = | SQRT($\rho n^2$ + 2*ρn)-ρn | | |
| k = | 0.24157 | | |
| j = | 1-(k/3) | | |
| j = | 0.919 | | |
| fs = | M(service)/(As*j*d) | | |
| fs = | 5.58 | ksi | |
| 0.6*fy = | 36 | ksi | |
| **fs <=** | **0.6*fy** | | **OKAY** |

**Check if tension in cross-section exceeds 80% of modulus of rupture**

| | | | |
|---|---|---|---|
| fr = | 0.24*SQRT(f'c) | | |
| fr = | 0.48 | ksi | |
| 0.8*fr = | 0.38 | ksi | |
| fT = | M(service)/Sx | | |
| fT = | 0.09 | ksi | |
| fT > | 0.8*fr | | **DOES NOT EXCEED** |

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

| | | | |
|---|---|---|---|
| $A_s$ >= | 1.3*b*h/(2*(b+h)*$f_y$) | | |
| $As_{min}$ = | 0.11 | $in^2$ | |
| $S_{max}$ = | 15 | in | |
| Try Bar # = | 4 | | |
| $A_{bar}$ = | 0.20 | $in^2$ | |
| Spacing = | 15 | in | **OKAY** |
| As = | 0.16 | $in^2/ft$ | **OKAY** |

| | | | |
|---|---|---|---|
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**Wall Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Vu = 0.89 kips

Shear Bar = 4
Area per Bar = 0.20 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.4 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 3.81 in

Vc= 2*SQRT(f'c)*b*d
Vc= 11.57 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 0.99 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 10 **OKAY**

**Development Length of Hooked Rebar in Stem and Grade Beam (LRFD 5.10.8.2.1a):**

$l_{db}$ = $2.4*d_b*f_y/SQRT(f'_c)$
$l_{db}$ = 54 in
$\lambda$ = 1.0 for normal weight concrete
$\lambda$ = 1
$\lambda_{rl}$ = reinforcement location factor, 1.3 if more than 12" concrete below reinf.
$\lambda_{rl}$ = 1
$\lambda_{cf}$ = coating factor
$\lambda_{cf}$ = 1
$d_b$ = 0.75
$c_b$ = MIN(cover,bar spacing/2)
$c_b$ = 2
$k_{tr}$ = cross-sect area of transv reinf.
$k_{tr}$ = 0
$\lambda_{rc}$ = reinforcement confinement factor, $d_b/(c_b+k_{tr})$
$\lambda_{rc}$ = 0.375
$As_{required}$ = $(Mu/\phi)/(f_y*(d-a/2))$
$As_{required}$ = 0.22 $in^2$
$\lambda_{er}$ = 1.0 for seismic-force-resisting systems
$\lambda_{er}$ = 1.00
$l_d$ = $l_{db}*(\lambda rl*\lambda_{cf}*\lambda_{rc}*\lambda_{er})/\lambda$
$l_d$ = 20.25 in

| | | | |
|---|---|---|---|
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**Vertical Flexural Rebar to be Lapped with Hooked Rebar Design (AISC 14th Ed. Table 3-23-19):**

$M_{max} = M_u$

$M_{max} =$ 7.36 kip-ft

L = Height of Noise Wall

L = 11.00 ft

$w = 2*M_{max}/L^2$

w = 0.12 kip/ft

x = Height of Noise Wall -Development Length of Hooked Rebar

x = 9.31 ft

$M_{at\ x} = w*x^2/2$

$M_{at\ x} =$ 5.28 kip-ft

$\Phi =$ 0.90

Try Rebar Size 5

Try Spacing 12.00 in

# of rebar = 1.00

Rebar Area = 0.31 $in^2$

As= 0.31 $in^2$

d = h-cover-(Rebar Diameter/2)

d = 7.63 in

$\beta_1 =$ 0.85

a = (As*fy)/(0.85*fc*b)

a = 0.46 in

$c = a/\beta_1$

c = 0.54 in

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

$\Phi Mn =$ 10.32 k-ft

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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# Footing Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| h = | 12 | in | |
| b = | 12 | in | |
| cover = | 3 | in | AASHTO 5.10.1 |
| Rebar # = | 5 | | |
| Rebar Diameter = | 0.625 | in | |
| Spacing = | 12 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| $q_{extr}$ = | 1.69 | ksf | Max bearing pressure applied |
| $q_{serv}$ = | 0.79 | ksf | Service Load bearing pressure |
| L = | 2.50 | ft | Heel of Footing Length |
| Mu = | $q*L^2/2$ | | |
| Mu = | 5.28 | k-ft | Extreme Event |
| M(service) = | 2.46 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.00 | | |
| Rebar Area = | 0.31 | $in^2$/ per bar | |
| As= | 0.31 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 8.69 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 0.46 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 0.54 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 11.80 | k-ft | |

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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| Supervisor | WPM | TASK | CIP Noise Wall 6 |
| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | RUK | DATE | 6/18/2021 |

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

fr = 0.37*SQRT(fc)
fr = 0.74 ksi
Sx = $b*h^2/6$
Sx = 288 $in^3$
1.6 * Mcr = 1.6*fr*Sx
1.6 * Mcr = 28.42 kips-ft
1.33 * Mu = 7 kips-ft
**ΦMn > MIN(1.6*Mcr,1.33*Mu) ? YES**

**Check Crack Control: (LRFD 5.6.7)**

ρ = As/(b*d)
ρ = 0.00297
ρ*n = 0.02379
k = $SQRT(\rho n^2 + 2*\rho n)-\rho n$
k = 0.19563
j = 1-(k/3)
j = 0.935
fs = M(service)/(As*j*d)
fs = 11.70 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.10 ksi
fT > 0.8*fr **DOES NOT EXCEED**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= $1.3*b*h/(2*(b+h)*f_y)$
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 18 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 18 in **OKAY**
As = 0.13 $in^2/ft$ **OKAY**

| | | | |
|---|---|---|---|
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**Footing Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Footing Width = 6.42 ft
Stem Width = 1.00 ft
Critical Section = Ls = (Footing Width -Stem Width)/2-d
Ls = 1.98 ft
Vu = q*Ls
Vu = 3.35 kips

Shear Bar = 5
Area per Bar = 0.31 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.62 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 4.34 in

Vc= $0.0316*\beta*\lambda*\sqrt{(f'_c)}*b*d_v$ LRFD 5.7.3.3-3
$\lambda$ = 1 LRFD 5.4.2.8
$\beta$ = 2 LRFD 5.7.3.4
$d_v$ = MAX(0.9*d,0.72*h)
$d_v$ = 8.64 in
Vc= 13.11 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 4 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 12 **OKAY**

| | | | |
|---|---|---|---|
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| CHK'D. BY | MGH | DATE | 12/22/2021 |

**Preliminary Analysis for:**
**Cast-In-Place Concrete Noise Wall on Footing**
**Maximum Total Wall Height = 11' with Maximum Embedment**

DESIGN CRITERIA:
- WSDOT Bridge Design Manual, July 2019
- AASHTO LRFD 8th Edition
- Geotechnical Engineering Report: Soldier Pile Wall 10.35L and Noise Wall 6

DESIGN ASSUMPTIONS:
- Exposed Wall Height is maximum 9.0' front face and 8.0' back face.
- Noise Wall is supporting 1' of fill.
- Seismic design is based on WSDOT BDM 8.2.2 and AASHTO LRFD 4.7.4.3.3.
- Noise Wall Dimensions are based on WSDOT Bridge Manual for Non-Standard Walls, page 8-23.
- Wind load is considered.
- Seismic soil forces are considered.
- Seismic internal wall forces are considered.
- Moment is positive with right hand rule at bottom center of footing. Right of center is positive, Left of center is negative.

Try:

| | | | |
|---|---|---|---|
| Footing Width = | 6.00 | ft | |
| Footing Thickness = | 1.00 | ft | |
| Wall Height = | 11.00 | ft | |
| Exposed Wall Height = | 9.00 | ft | |
| Wall Thickness = | 1.000 | ft | - Includes form liner on each face |
| Footing Toe Width = | 2.500 | ft | |
| Footing Heel Width = | 2.500 | ft | |

DEAD LOAD (DC):

Loads based on linear foot of wall

| Item | Density | Length | Thickness | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Noise Wall | 0.150 | 11 | 1.00 | 1 | 11.00 | 1.65 | 0.00 | 0.00 |
| Footing | 0.150 | 6.0 | 1.00 | 1 | 6.00 | 0.90 | 0.00 | 0.00 |
| | | | | | Totals = | 2.55 | | 0.00 |

| | | | |
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VERTICAL SOIL LOAD (EV):

Loads based on linear foot of wall

| Item | Density | Width | Height | Shape Factor | Area | Weight | Moment Arm @ CL of Footing | Moment |
|---|---|---|---|---|---|---|---|---|
| | kcf | ft | ft | | $ft^2$ | klf | ft | k*ft |
| Toe | 0.130 | 2.50 | 2.33 | 1 | 5.83 | 0.76 | -1.75 | -1.33 |
| Heel | 0.130 | 2.50 | 3.33 | 1 | 8.33 | 1.08 | 1.75 | 1.89 |
| | | | | | Totals = | 1.84 | | 0.57 |

HORIZONTAL SOIL LOAD (EH): - Not required when seismic soil is being included. (AASHTO C11.6.5.1)

$EH = (1/2)*Ka*\Upsilon*H^2$

| | | | | | |
|---|---|---|---|---|---|
| EH = | 0.02 | klf | ϕ= | 38 | degrees |
| Moment Arm @ B/Footing = | 0.33 | ft | Ka = | 0.24 | |
| Moment = | 0.0 | k*ft | Υ= | 0.13 | kcf |
| | | | H = | 1.00 | ft |

WIND LOAD (WS): (AASHTO 3.8.1.2.4)

$P_Z = 2.56X10^{-6}*V^2*K_Z*G*C_D$

| | | | |
|---|---|---|---|
| $V_{STR\ III}$= | 110 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{STR\ V}$= | 80 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $V_{SERV\ I}$= | 70 | mph | (AASHTO Table 3.8.1.1.2-1) |
| $K_{Z_STR}$= | 0.71 | | (AASHTO Table C3.8.1.2.1-1) |
| $K_{Z_SERV}$= | 1.0 | | (AASHTO 3.8.1.2.1) |
| G= | 0.85 | | (AASHTO Table 3.8.1.2.1-1) |
| $C_D$ = | 1.2 | | (AASHTO Table 3.8.1.2.1-2) |
| Z= | 7.67 | = Exposed Noise Wall Height at the Back Face | |

| | | |
|---|---|---|
| $P_{Z_STR\ III}$= | 0.022 | ksf |
| $P_{Z_STR\ V}$= | 0.012 | ksf |
| $P_{Z_SERV\ I}$= | 0.013 | ksf |

$P_W = P_Z*Z$ (AASHTO 3.8.1.2.4)

Moment Arm @ B/Footing = 8.5 ft

| | Linear feet of Wall | |
|---|---|---|
| | $P_W$ | Moment |
| | klf | k*ft |
| STR III | 0.17 | 1.5 |
| STR V | 0.09 | 0.8 |
| SERV I | 0.10 | 0.8 |

- $P_W$ is a line load applied at 0.55*Z from the top of roadway. (AASHTO 3.8.1.2.4)
- Moment Arm is from the top of the retaining wall.
  = 0.55*(Noise Wall Height + Traffic Barrier Height) + Slab Thickness

SEISMIC ACTIVE EARTH PRESSURES ($EQ_{soil}$):

$P_{seis} = P_{AE}$ LRFD 11.6.5.1

$P_{seis}$ = 0.048 klf $P_{seis}$ is applied 1/3 height of soil.

$P_{AE}$ = 0.048 klf LRFD 11.6.5.3-2

$P_{AE} = 0.5*\Upsilon*K_{AE}*h^2$

- Monobe-Okabe Analysis LRFD A11.3.1

**Figure A11.3.1-1—Mononobe-Okabe Method Force Diagrams**

$$K_{AE} = \frac{\cos^2(\phi - \theta_{MO} - \beta)}{\cos\theta_{MO}\cos^2\beta\cos(\delta + \beta + \theta_{MO})} \times \left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \theta_{MO} - i)}{\cos(\delta + \beta + \theta_{MO})\cos(i - \beta)}}\right]^{-2} \quad \text{(A11.3.1-1)}$$

where:

$K_{AE}$ = seismic active earth pressure coefficient (dim)
$\gamma$ = unit weight of soil (kcf)
$H$ = height of wall (ft)
$h$ = height of wall at back of wall heel considering height of sloping surcharge, if present (ft)
$\phi_f$ = friction angle of soil (degrees)
$\theta_{MO}$ = arc tan $[k_h/(1 - k_v)]$ (degrees)
$\delta$ = wall backfill interface friction angle (degrees)
$k_h$ = horizontal seismic acceleration coefficient (dim.)
$k_v$ = vertical seismic acceleration coefficient (dim.)
$i$ = backfill slope angle (degrees)
$\beta$ = slope of wall to the vertical, negative as shown (degrees)

$k_{AE}$ = 0.732

$\psi$ = 0.42

$$\psi = \left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \theta_{MO} - i)}{\cos(\delta + \beta + \theta_{MO})\cos(i - \beta)}}\right]^{-2}$$

$\Upsilon_{soil}$ = 0.130 kcf

H = 1.0 ft Height of soil and footing

$\phi$ = 38.00 degrees

$\theta$ = 26.4 degrees

$\delta = 2/3*\phi$ = 25.3 degrees

$k_h = 1.0*k_{h0}$ = 0.497 Note: 0.5*kho=0.249, by using 1.0*kho this increased the Extreme Event Moment by 0% and the Lateral load by 2%. This small increase does not affect the outcome of the calc.

$k_{h0} = A_s$ = 0.497

$k_v$ = 0.0

i = 0.0 degrees

$\beta$ = 0.0 degrees

Moment Arm @ B/Footing = 0.33 ft

Moment = 0.0 k*ft

| | | | |
|---|---|---|---|
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| Supervisor | WPM | TASK | CIP Noise Wall 6 |
| BY | RUK | DATE | 12/21/2021 |
| CHK'D. BY | MGH | DATE | 12/22/2021 |

SEISMIC FORCES ON WALL ($EQ_{wall}$): (See Attached Calc)

Shear at base of wall = 0.9 k
Moment on wall = 6.8 k*ft

LOAD SUMMARY

| Load | Force | | Moment |
|---|---|---|---|
| | Vertical | Lateral | |
| | $P_Y$ (kips) | $P_X$ (kips) | (kips) |
| DC | 2.6 | | 0.0 |
| EV | 1.8 | | 0.6 |
| EH | | 0.1 | 0.1 |
| $WS_{STR\ III}$ | | 0.17 | 1.5 |
| $WS_{STR\ V}$ | | 0.09 | 0.8 |
| $WS_{SERV\ I}$ | | 0.10 | 0.8 |
| $EQ_{soil}$ | | 0.0 | 0.0 |
| $EQ_{wall}$ | | 0.9 | 6.8 |

**Calculate Bearing Pressure**

Load Combinations (AASHTO Table 3.4.1-1)

| Load Combination | Force | | Moment | e | B' | $\sigma_v$ |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_Y$ (kips) | $P_X$ (kips) | (kips) | ft | ft | **ksf** |
| STRENGTH III: 1.25DC+1.5EH+1.0(EV+WS) | 5.0 | 0.3 | 2.1 | 0.4 | 5.2 | **0.98** |
| STRENGTH V: 1.25DC+1.5EH+1.0(EV+WS) | 5.0 | 0.2 | 1.4 | 0.3 | 5.4 | **0.93** |
| EXT EVENT I: 1.0(DC+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.4 | 0.9 | 7.4 | 1.7 | 2.6 | **1.66** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.4 | 0.2 | 1.5 | 0.3 | 5.3 | **0.82** |

Eccentricity = e =$M/P_y$

B = 6.00 ft B' = B - 2e

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\Sigma V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

**Check Eccentricity Limits** (AASHTO 11.6.3.3)

- The location of the resultant is limited to the middle two-thirds of the width of the foundation.

emax = B/3 2.00 ft

| Load Combination | Force | | Moment | e | Middle Two-Thirds | |
|---|---|---|---|---|---|---|
| | Vertical | Lateral | | | | |
| | $P_y$ (kips) | $P_X$ (kips) | (kips) | ft | | |
| STRENGTH III: 0.9DC+1.5EH+1.00(EV+WS) | 4.1 | 0.3 | 2.1 | 0.4 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 4.1 | 0.2 | 1.4 | 0.3 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.4 | 0.9 | 7.4 | 1.7 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.4 | 0.2 | 1.5 | 0.3 | Yes | **OK** |

**Check Sliding** (AASHTO 10.6.3.4 and AASHTO 11.5.6)

| Load Combination | Force | | $\phi_T R\tau$ | Is Rτ > Vx? | |
|---|---|---|---|---|---|
| | Vertical | Lateral | | | |
| | $P_y$ (kips) | $P_X$ (kips) | kips | | |
| STRENGTH III: 0.90DC+1.5EH+1.00(EV+WS) | 4.1 | 0.3 | 2.6 | Yes | **OK** |
| STRENGTH V: 0.9DC+1.5EH+1.00(EV+WS) | 4.1 | 0.2 | 2.6 | Yes | **OK** |
| EXT EVENT I: 1.0(DC+EH+EV+$EQ_{soil}$+$EQ_{wall}$) | 4.4 | 0.9 | 2.7 | Yes | **OK** |
| SERVICE I: 1.0(DC+EV+EH+WS) | 4.4 | 0.2 | 2.7 | Yes | **OK** |

Sliding Resistance = $\phi_T R\tau = \phi_T C P_y \tan \phi_f$ (AASHTO 10.6.3.4-2)

$\phi_T$ = 0.8 (AASHTO Table 10.5.5.2.2-1)

C = 1.0

$\phi_f$ = 38 degrees

Coeffient of Friction = tan $\phi_f$ = 0.78 (AASHTO C3.11.5.3)

| | | | |
|---|---|---|---|
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| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | BJD | DATE | 6/18/2021 |

## SOUND BARRIER DESIGN FORCE

**NOISE BARRIER WALL TYPE 11 GEOMETRY**

| | | | |
|---|---|---|---|
| Wall Length | L = | 1 | ft |
| Wall/Wall Height | H = | 11 | ft |
| Wall Thickness | T = | 12 | in |

**MATERIALS**

| | | | |
|---|---|---|---|
| Wall Concrete | $f_c'$ = | 4 | ksi |
| | $\gamma_c$ = | 0.15 | kcf |
| | $E_c$ = | 4266 | ksi |
| Reinforcing Steel | $f_y$ = | 60 | ksi |
| | $E_s$ = | 29000 | ksi |

**DEAD LOAD**

Weight of Walls

| | | | |
|---|---|---|---|
| Vertical Dead Load | D = | 1.65 | kips |

**SEISMIC FORCE**

Seismic design shall be in accordance with AASHTO LRFD Article 3.10.2.1-General Procedure, considering site class D:

a. Modal analysis shall be performed for the first 4 periods. Elastic seismic response coefficient Csm shall be computed for each modal period in accordance with LRFD Article 3.10.4.2 and all 4 Csm coefficients shall be combined through the SRSS method.

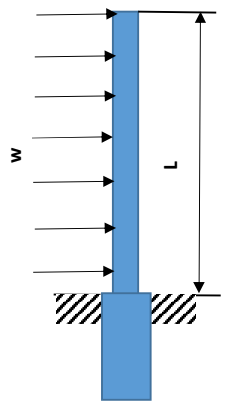
b. The resultant seismic force shall be considered to act at a height of 0.71H above the top of the shaft, where H is the total height measured from the top of the Wall to the top of the shaft.

**Structural Modeling**

Modeling the column as a cantilever beam

The mass of column and ajacent Walls is uniformly distributed along the column

| | | | |
|---|---|---|---|
| Uniform Weight | w = | 0.15 | kips/ft |
| Uniform Mass | m = | 0.0004 | |
| Column | I = | 1728 | $in^4$ |
| Modulus | E = | 4266 | ksi |
| Gravity | g = | 386 | $in/sec^2$ |



| | | | |
|---|---|---|---|
| wood. | JOB NO. PS19203160 | SHEET | 2 of 9 |
| | JOB NAME I-405 - Renton to Bellevue Design-Build | | |
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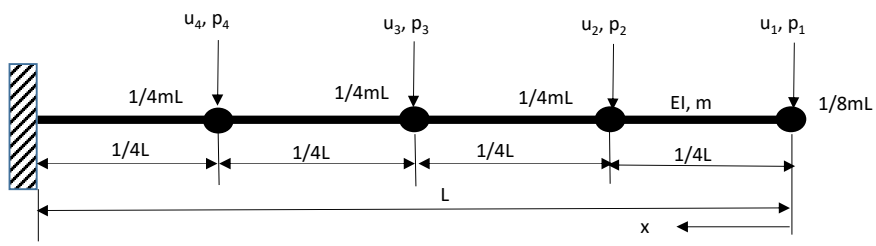
| | BY RUK | DATE | 6/18/2021 |
| | CHK'D. BY BJD | DATE | 6/18/2021 |

**Modal Analysis**




Flexibility Matrix

| | | |
|---|---|---|
| $p_1$ = | 1 | |
| | x | u |
| $u_1$ | 0.00 | 0.33333333 |
| $u_2$ | 0.25 | 0.21093750 |
| $u_3$ | 0.50 | 0.10416667 |
| $u_4$ | 0.75 | 0.02864583 |

| | | |
|---|---|---|
| $p_2$ = | 1 | |
| a = | 0.25 | |
| b = | 0.75 | |
| | x | u |
| $u_1$ | 0.00 | 0.2109375 |
| $u_2$ | 0.25 | 0.1406250 |
| $u_3$ | 0.50 | 0.0729167 |
| $u_4$ | 0.75 | 0.0208333 |

| | | |
|---|---|---|
| $p_3$ = | 1 | |
| a = | 0.5 | |
| b = | 0.5 | |
| | x | u |
| $u_1$ | 0 | 0.104166667 |
| $u_2$ | 0.25 | 0.072916667 |
| $u_3$ | 0.5 | 0.041666667 |
| $u_4$ | 0.75 | 0.013020833 |

| | | |
|---|---|---|
| $p_4$ = | 1 | |
| a = | 0.75 | |
| b = | 0.25 | |
| | x | u |
| $u_1$ | 0.00 | 0.028645833 |
| $u_2$ | 0.25 | 0.020833333 |
| $u_3$ | 0.50 | 0.013020833 |
| $u_4$ | 0.75 | 0.005208333 |

| | | | |
|---|---|---|---|
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| BY | RUK | DATE | 6/18/2021 |
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Flexibility Matrix

| | $p_1 = 1$ | $p_2 = 1$ | $p_3 = 1$ | $p_4 = 1$ |
|---|---|---|---|---|
| $u_1 = L^3/EI^*$ | 0.3333 | 0.2109 | 0.1042 | 0.0286 |
| $u_2 = L^3/EI^*$ | 0.2109 | 0.1406 | 0.0729 | 0.0208 |
| $u_3 = L^3/EI^*$ | 0.1042 | 0.0729 | 0.0417 | 0.0130 |
| $u_4 = L^3/EI^*$ | 0.0286 | 0.0208 | 0.0130 | 0.0052 |

Stiffness Matrix K

| | | | | |
|---|---|---|---|---|
| $EI/L^3$ | 102.928 | -233.567 | 166.268 | -47.505 |
| $EI/L^3$ | -233.567 | 633.402 | -613.608 | 285.031 |
| $EI/L^3$ | 166.268 | -613.608 | 918.433 | -756.124 |
| $EI/L^3$ | -47.505 | 285.031 | -756.124 | 1203.464 |

K =

| | | | |
|---|---|---|---|
| 329.912 | -748.647 | 532.935 | -152.267 |
| -748.647 | 2030.229 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 2943.832 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 3857.435 |

Mass Matrix M

| | | | |
|---|---|---|---|
| 1/8mL | 0 | 0 | 0 |
| 0 | 1/4mL | 0 | 0 |
| 0 | 0 | 1/4mL | 0 |
| 0 | 0 | 0 | 1/4mL |

M =

| | | | |
|---|---|---|---|
| 0.000534326 | 0 | 0 | 0 |
| 0 | 0.001068653 | 0 | 0 |
| 0 | 0 | 0.001068653 | 0 |
| 0 | 0 | 0 | 0.001068653 |

First Mode

$w_1^2$ — $K-w_n^2*M$

8760.381

| | | | |
|---|---|---|---|
| 325.231 | -748.647 | 532.935 | -152.267 |
| -748.647 | 2020.867 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 2934.470 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 3848.073 |

$Det(K-w_n^2*M)=0$ 0.00003 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_1$ = 93.597 rad/sec $T_1$ = 0.067 sec

Second Mode

$w_2^2$ — $K-w_n^2*M$

302652.26

| | | | |
|---|---|---|---|
| 168.1970731 | -748.647 | 532.935 | -152.267 |
| -748.647 | 1706.799 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 2620.402 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 3534.004 |

$Det(K-w_n^2*M)=0$ -0.00007 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_2$ = 550.138 rad/sec $T_2$ = 0.011 sec

| | | | |
|---|---|---|---|
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Third Mode

| $w_3^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 2122367.04 | -804.125 | -748.647 | 532.935 | -152.267 |
| | -748.647 | -237.845 | -1966.784 | 913.603 |
| | 532.935 | -1966.784 | 675.758 | -2423.586 |
| | -152.267 | 913.603 | -2423.586 | 1589.361 |

$Det(K-w_n^2*M)=0$ -0.003579556 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_3$ = 1456.835 rad/sec $T_3$ = 0.004 sec

Fourth Mode

| $w_4^2$ | $K-w_n^2*M$ | | | |
|---|---|---|---|---|
| 6447794.46 | -3115.315 | -748.647 | 532.935 | -152.267 |
| | -748.647 | -4860.225 | -1966.784 | 913.603 |
| | 532.935 | -1966.784 | -3946.622 | -2423.586 |
| | -152.267 | 913.603 | -2423.586 | -3033.019 |

$Det(K-w_n^2*M)=0$ 0.038693318 goal seek (Set cell: $Det(K-w_n^2*M)$, To value: 0, By changing cell: $w_1^2$)

$\omega_4$ = 2539.251 rad/sec $T_4$ = 0.002 sec

Summary

| Mode | ω (rad/sec) | T (sec) |
|---|---|---|
| 1 | 93.597 | 0.067 |
| 2 | 550.138 | 0.011 |
| 3 | 1456.835 | 0.004 |
| 4 | 2539.251 | 0.002 |

NATURAL PERIODS By Equation

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$T_n = 1/f_n$ $\omega_n = 2\pi/T_n$

| | | |
|---|---|---|
| First Mode | $K_1$ = | 3.52 |
| Second Mode | $K_1$ = | 22.03 |
| Third Mode | $K_3$ = | 61.7 |
| Fourth Mode | $K_4$ = | 120.9 |
| | g = | 386 |

| Mode | Natural Frequency | Natural period | Natural Frequency |
|---|---|---|---|
| | $f_n$ (Hz) | $T_n$ (second) | $\omega_n$ (Rad/Sec) |
| 1 | 15.323 | 0.065 | 96.279 |
| 2 | 96.011 | 0.010 | 603.252 |
| 3 | 268.899 | 0.004 | 1689.544 |
| 4 | 526.903 | 0.002 | 3310.631 |

| | | | |
|---|---|---|---|
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First Mode

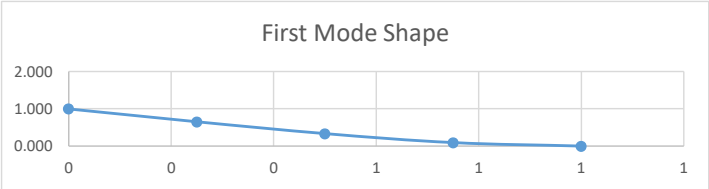
$K-w_1^2M$

| | | | |
|---|---|---|---|
| 325.231 | -748.647 | 532.935 | -152.267 |
| -748.647 | 2020.867 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 2934.470 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 3848.073 |

| | | | |
|---|---|---|---|
| 0.0023307 | 0.0023031 | 0.0008972 | -749 |
| 0.0023031 | 0.0029860 | 0.0013339 | 533 |
| 0.0008972 | 0.0013339 | 0.0008870 | -152 |

$\phi_1 =$

| | | | |
|---|---|---|---|
| 1 | | Mode Shape Plot | |
| 0.654 | | 0 | 1.000 |
| 0.336 | | 0.250 | 0.654 |
| 0.096 | | 0.500 | 0.336 |
| | | 0.750 | 0.096 |
| | | 1.000 | 0.000 |




Secod Mode

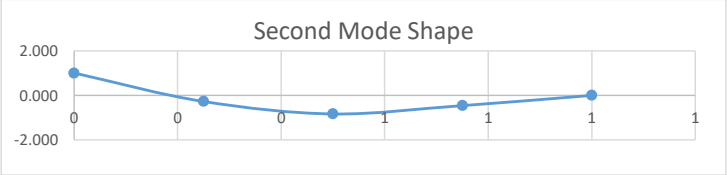
$K-w_2^2M$

| | | | |
|---|---|---|---|
| 168.197 | -748.647 | 532.935 | -152.267 |
| -748.647 | 1706.799 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 2620.402 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 3534.004 |

| | | | |
|---|---|---|---|
| -0.0024768 | -0.0034639 | -0.0017352 | -748.647 |
| -0.0034639 | -0.0038008 | -0.0017111 | 532.935 |
| -0.0017352 | -0.0017111 | -0.0004419 | -152.267 |

$\phi_2 =$

| | | | |
|---|---|---|---|
| 1 | | Mode Shape Plot | |
| -0.272 | | 0 | 1.000 |
| -0.828 | | 0.250 | -0.272 |
| -0.454 | | 0.500 | -0.828 |
| | | 0.750 | -0.454 |
| | | 1.000 | 0.000 |



| | | | |
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| CHK'D. BY | BJD | DATE | 6/18/2021 |

Third Mode

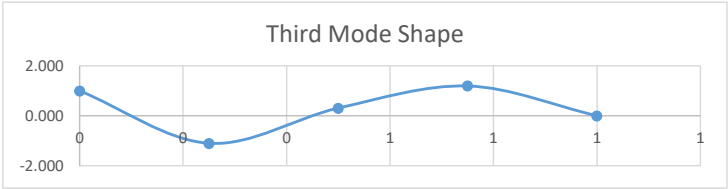
$K-w_3^2M$

| | | | |
|---|---|---|---|
| -804.125 | -748.647 | 532.935 | -152.267 |
| -748.647 | -237.845 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | 675.758 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | 1589.361 |

| | | | |
|---|---|---|---|
| -0.0015290 | 0.0002904 | 0.0013218 | -748.647 |
| 0.0002904 | -0.0003863 | -0.0007560 | 532.935 |
| 0.0013218 | -0.0007560 | -0.0012834 | -152.267 |

$\phi_3$ =

| | | | |
|---|---|---|---|
| 1 | Mode Shape Plot | 0 | 1.000 |
| -1.098 | | 0.250 | -1.098 |
| 0.308 | | 0.500 | 0.308 |
| 1.197 | | 0.750 | 1.197 |
| | | 1.000 | 0 |




Fourth Mode

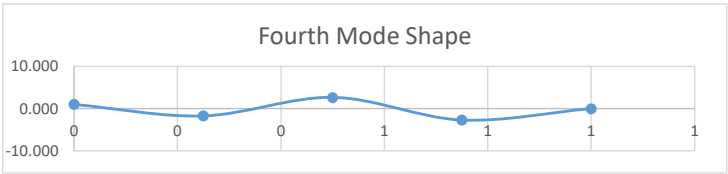
$K-w_4^2M$

| | | | |
|---|---|---|---|
| -3115.315 | -748.647 | 532.935 | -152.267 |
| -748.647 | -4860.225 | -1966.784 | 913.603 |
| 532.935 | -1966.784 | -3946.622 | -2423.586 |
| -152.267 | 913.603 | -2423.586 | -3033.019 |

| | | | |
|---|---|---|---|
| -0.0010344 | 0.0013878 | -0.0014206 | -748.647 |
| 0.0013878 | -0.0023596 | 0.0023035 | 532.935 |
| -0.0014206 | 0.0023035 | -0.0025982 | -152.267 |

$\phi_4$ =

| | | | |
|---|---|---|---|
| 1 | Mode Shape Plot | 0 | 1.000 |
| -1.730 | | 0.250 | -1.730 |
| 2.647 | | 0.500 | 2.647 |
| -2.687 | | 0.750 | -2.687 |
| | | 1.000 | 0.000 |



| | | | |
|---|---|---|---|
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| BY | RUK | DATE | 6/18/2021 |
| CHK'D. BY | BJD | DATE | 6/18/2021 |

Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 1.000 | 1.000 | 1.000 |
| 0.654 | -0.272 | -1.098 | -1.730 |
| 0.336 | -0.828 | 0.308 | 2.647 |
| 0.096 | -0.454 | 1.197 | -2.687 |

Transpose Mode Shape Matrix

| | | | |
|---|---|---|---|
| 1.000 | 0.654 | 0.336 | 0.096 |
| 1.000 | -0.272 | -0.828 | -0.454 |
| 1.000 | -1.098 | 0.308 | 1.197 |
| 1.000 | -1.730 | 2.647 | -2.687 |

Generalized Mass

| | | | |
|---|---|---|---|
| 0.0005 | 0.0007 | 0.0004 | 0.0001 |
| 0.0005 | -0.0003 | -0.0009 | -0.0005 |
| 0.0005 | -0.0012 | 0.0003 | 0.0013 |
| 0.0005 | -0.0018 | 0.0028 | -0.0029 |

$M_n$ =

| | | | |
|---|---|---|---|
| 0.001 | 0.000 | 0.000 | 0.000 |
| 0.000 | 0.002 | 0.000 | 0.000 |
| 0.000 | 0.000 | 0.003 | 0.000 |
| 0.000 | 0.000 | 0.000 | 0.019 |

Generalized Stiffness

| | | | |
|---|---|---|---|
| 4.681 | 6.123 | 3.145 | 0.898 |
| 161.715 | -88.120 | -267.857 | -146.978 |
| 1134.037 | -2490.741 | 699.000 | 2714.920 |
| 3445.227 | -11922.770 | 18240.676 | -18512.810 |

$K_n$ =

| | | | |
|---|---|---|---|
| 9.829 | 0.000 | 0.000 | 0.000 |
| 0.000 | 474.348 | 0.000 | 0.000 |
| 0.000 | 0.000 | 7334.532 | 0.000 |
| 0.000 | 0.000 | 0.000 | 122101.972 |

Verify Natural Frequency

| Mode | ω | Eigen Value | Equation |
|---|---|---|---|
| 1 | 93.597 | 93.597 | 96.279 |
| 2 | 550.138 | 550.138 | 603.252 |
| 3 | 1456.835 | 1456.835 | 1689.544 |
| 4 | 2539.251 | 2539.251 | 3310.631 |

Generalized Force $P_n$

| | | | |
|---|---|---|---|
| 0.000534326 | 0.000698984 | 0.000359017 | 0.00010245 |
| 0.000534326 | -0.000291158 | -0.000885032 | -0.000485632 |
| 0.000534326 | -0.001173567 | 0.000329349 | 0.001279194 |
| 0.000534326 | -0.001849124 | 0.002828979 | -0.002871185 |

Directional Vector

| | |
|---|---|
| 1 | 0.001694778 |
| 1 | -0.001127495 |
| 1 | 0.000969303 |
| 1 | -0.001357003 |

$P_n$

| |
|---|
| 1.5106 |
| -0.7194 |
| 0.2805 |
| -0.0717 |

| | | | |
|---|---|---|---|
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**SEISMIC DESIGN PARAMETERS**

| | | | |
|---|---|---|---|
| Peak Ground Acceleration | PGA = | 0.422 | |
| Spectral Acceleration at 0.2 Second | $S_S$ = | 0.959 | g |
| Spectral Acceleration at 1 Second | $S_1$ = | 0.278 | g |
| Site Class | D | | |
| Site Factors: | $F_{pga}$ | 1.178 | |
| | $F_a$ = | 1.116 | |
| | $F_v$ = | 2.044 | |
| Response Spectrum | $S_{DS}$ = | 1.070 | g |
| | $S_{D1}$ = | 0.568 | g |
| | $T_S$ = | 0.531 | |
| | $T_o$ = | 0.106 | |
| | $A_S$ = | 0.497 | |

**ELASTIC SEISMIC RESPONSE COEFFICIENT $C_{sm}$**

AASHTO LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$
- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| Mode | ω (rad/sec) | T (sec) | $C_{sm}$ | $C_{Disp}$ |
|---|---|---|---|---|
| 1 | 93.597 | 0.067 | 0.859 | 0.05720 |
| 2 | 550.138 | 0.011 | 0.559 | -0.00051 |
| 3 | 1456.835 | 0.004 | 0.520 | 0.00003 |
| 4 | 2539.251 | 0.002 | 0.510 | 0.00000 |

| | | | |
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**MODAL SPECTRUM ANALYSIS**

**Modal Displacements**

| Mode 1 | | Mode 2 | |
|---|---|---|---|
| $\phi_1$ = | u1 | $\phi_2$ = | u2 |
| 1.000 | 0.05720 | 1.000 | -0.00051 |
| 0.654 | 0.03742 | -0.272 | 0.00014 |
| 0.336 | 0.01922 | -0.828 | 0.00042 |
| 0.096 | 0.00548 | -0.454 | 0.00023 |
| Mode 3 | | Mode 4 | |
| $\phi_3$ = | u3 | $\phi_4$ = | u4 |
| 1.000 | 0.00003 | 1.000 | -0.000002 |
| -1.098 | -0.00003 | -1.730 | 0.000004 |
| 0.308 | 0.00001 | 2.647 | -0.000006 |
| 1.197 | 0.00003 | -2.687 | 0.000006 |

**Total Displacements**

| | | |
|---|---|---|
| $u_1$ = | 0.06 | in |
| $u_2$ = | 0.04 | in |
| $u_3$ = | 0.02 | in |
| $u_4$ = | 0.01 | in |

Modal Base Shear

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 |
|---|---|---|---|---|
| $V_1$ | 0.268 | -0.083 | 0.030 | -0.008 |
| $V_2$ | 0.350 | 0.045 | -0.066 | 0.026 |
| $V_3$ | 0.180 | 0.137 | 0.019 | -0.040 |
| $V_4$ | 0.051 | 0.075 | 0.072 | 0.041 |
| Total | 0.849 | 0.175 | 0.055 | 0.019 |

**Base Shear**

| | | |
|---|---|---|
| SRSS | **0.87** | kips |
| **Base Moment** | **6.79** | kips-ft |

| | | | |
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## Stem Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| Arch. Treatments = | 2 | in | |
| h = | 10.00 | in | |
| b = | 12 | in | AASHTO 5.10.1 |
| cover = | 2 | in | |
| Rebar # = | 6 | | |
| Rebar Diameter = | 0.75 | in | |
| Spacing = | 12 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| Mu = | 7.36 | k-ft | Extreme Event |
| M(service) = | 1.41 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.00 | | |
| Rebar Area = | 0.44 | $in^2$ | |
| As= | 0.44 | $in^2$ | |

d = h-cover-(Rebar Diameter/2)

| | | | |
|---|---|---|---|
| d = | 7.63 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |

a = (As*fy)/(0.85*fc*b)

| | | | |
|---|---|---|---|
| a = | 0.65 | in | |
| c = a/$\beta_1$ | | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 0.76 | in | |

| | | | |
|---|---|---|---|
| ΦMn = Φ*As*fy*(d-a/2) | | | AASHTO 5.6.3.2 |
| ΦMn = | 14.46 | k-ft | |

**ΦMn > Mu ? YES**

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

fr = 0.37*SQRT(fc)

| | | |
|---|---|---|
| fr = | 0.74 | ksi |

Sx = b*$h^2$/6

| | | |
|---|---|---|
| Sx = | 200 | $in^3$ |

1.6 * Mcr = 1.6*fr*Sx

| | | |
|---|---|---|
| 1.6* Mcr = | 20 | kips-ft |
| 1.33 * Mu = | 10 | kips-ft |

**ΦMn > MIN(1.6*Mcr,1.33*Mu ? YES**

| | | | |
|---|---|---|---|
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**Check Crack Control: (LRFD 5.6.7)**

$\rho$ = As/(b*d)
$\rho$ = 0.00481
$\rho$*n = 0.03847
k = SQRT($\rho n^2$ + 2*$\rho$n)-$\rho$n
k = 0.24157
j = 1-(k/3)
j = 0.919
fs = M(service)/(As*j*d)
fs = 5.50 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy** **OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.08 ksi
fT > 0.8*fr **DOES NOT EXCEED**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= 1.3*b*h/(2*(b+h)*$f_y$)
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 15 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 15 in **OKAY**
As = 0.16 $in^2$/ft **OKAY**

| | | | |
|---|---|---|---|
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**Wall Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Vu = 0.89 kips

Shear Bar = 4
Area per Bar = 0.20 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.4 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 3.81 in

Vc= 2*SQRT(f'c)*b*d
Vc= 11.57 kips
Req'd Vn= Vu/$\phi_v$
Req'd Vn= 0.99 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 10 **OKAY**

**Development Length of Hooked Rebar in Stem and Grade Beam (LRFD 5.10.8.2.1a):**

$l_{db}$ = 2.4*$d_b$*$f_y$/SQRT(f'$_c$)
$l_{db}$ = 54 in
$\lambda$ = 1.0 for normal weight concrete
$\lambda$ = 1
$\lambda_{rl}$ = reinforcement location factor, 1.3 if more than 12" concrete below reinf.
$\lambda_{rl}$ = 1
$\lambda_{cf}$ = coating factor
$\lambda_{cf}$ = 1
$d_b$ = 0.75
$c_b$ = MIN(cover,bar spacing/2)
$c_b$ = 2
$k_{tr}$ = cross-sect area of transv reinf.
$k_{tr}$ = 0
$\lambda_{rc}$ = reinforcement confinement factor, $d_b/(c_b+k_{tr})$
$\lambda_{rc}$ = 0.375
$As_{required}$ = (Mu/$\phi$)/($f_y$*(d-a/2))
$As_{required}$ = 0.22 $in^2$
$\lambda_{er}$ = 1.0 for seismic-force-resisting systems
$\lambda_{er}$ = 1.00
$l_d$ = $l_{db}$ *($\lambda$rl*$\lambda_{cf}$*$\lambda_{rc}$*$\lambda_{er}$)/$\lambda$
$l_d$ = 20.25 in

| | | | |
|---|---|---|---|
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**Vertical Flexural Rebar to be Lapped with Hooked Rebar Design (AISC 14th Ed. Table 3-23-19):**

$M_{max} = M_u$

$M_{max} =$ 7.36 kip-ft

L = Height of Noise Wall

L = 11.00 ft

$w = 2*M_{max}/L^2$

w = 0.12 kip/ft

x = Height of Noise Wall -Development Length of Hooked Rebar

x = 9.31 ft

$M_{at\ x} = w*x^2/2$

$M_{at\ x} =$ 5.28 kip-ft

$\Phi =$ 0.90

Try Rebar Size 5

Try Spacing 12.00 in

# of rebar = 1.00

Rebar Area = 0.31 $in^2$

As= 0.31 $in^2$

d = h-cover-(Rebar Diameter/2)

d = 7.63 in

$\beta_1 =$ 0.85

a = (As*fy)/(0.85*fc*b)

a = 0.46 in

$c = a/\beta_1$

c = 0.54 in

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

$\Phi Mn =$ 10.32 k-ft

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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# Footing Strength Design

**Parameters**

| | | | |
|---|---|---|---|
| $f_y$ = | 60 | ksi | WSDOT BDM 5.1.2/AASHTO 5.5.3.2 |
| $f_c$ = | 4 | ksi | WSDOT BDM 5.1.1.B.2/BDM 7.1.5 |
| h = | 12 | in | |
| b = | 12 | in | |
| cover = | 3 | in | AASHTO 5.10.1 |
| Rebar # = | 5 | | |
| Rebar Diameter = | 0.625 | in | |
| Spacing = | 12 | in | |
| n = | 8 | | |
| Φ = | 0.90 | | AASHTO 5.5.4.2 |
| $\phi_v$ = | 0.90 | | AASHTO 5.5.4.2 |

**Check Moment Strength:**

| | | | |
|---|---|---|---|
| $q_{extr}$ = | 1.66 | ksf | Max bearing pressure applied |
| $q_{serv}$ = | 0.82 | ksf | Service Load bearing pressure |
| L = | 2.50 | ft | Heel of Footing Length |
| Mu = | $q*L^2/2$ | | |
| Mu = | 5.19 | k-ft | Extreme Event |
| M(service) = | 2.56 | k-ft | Service I |
| Φ = | 0.90 | | |
| # of rebar = | 1.00 | | |
| Rebar Area = | 0.31 | $in^2$/ per bar | |
| As= | 0.31 | $in^2$ | |
| d = | h-cover-(Rebar Diameter/2) | | |
| d = | 8.69 | in | |
| $\beta_1$ = | 0.85 | | AASHTO 5.6.2.2 |
| a = | (As*fy)/(0.85*fc*b) | | |
| a = | 0.46 | in | |
| c = | $a/\beta_1$ | | AASHTO Eqn. 5.6.3.1.2-4 |
| c = | 0.54 | in | |
| ΦMn = | Φ*As*fy*(d-a/2) | | AASHTO 5.6.3.2 |
| ΦMn = | 11.80 | k-ft | |

**ΦMn > Mu ? YES**

| | | | |
|---|---|---|---|
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| BY | BJD | DATE | 6/18/2021 |
| CHK'D. BY | RUK | DATE | 6/18/2021 |

**Check Min. Reinforcement: (LRFD 5.6.3.3)**

fr = 0.37*SQRT(fc)
fr = 0.74 ksi
Sx = $b*h^2/6$
Sx = 288 $in^3$
1.6 * Mcr = 1.6*fr*Sx
1.6 * Mcr = 28.42 kips-ft
1.33 * Mu = 7 kips-ft
**ΦMn > MIN(1.6*Mcr,1.33*Mu) ? YES**

**Check Crack Control: (LRFD 5.6.7)**

ρ = As/(b*d)
ρ = 0.00297
ρ*n = 0.02379
k = $SQRT(\rho n^2 + 2*\rho n)-\rho n$
k = 0.19563
j = 1-(k/3)
j = 0.935
fs = M(service)/(As*j*d)
fs = 12.21 ksi
0.6*fy = 36 ksi
**fs <= 0.6*fy OKAY**

**Check if tension in cross-section exceeds 80% of modulus of rupture**

fr = 0.24*SQRT(f'c)
fr = 0.48 ksi
0.8*fr = 0.38 ksi
fT = M(service)/Sx
fT = 0.11 ksi
fT > 0.8*fr **DOES NOT EXCEED**

**Shrinkage and Temperature Reinforcement (LRFD 5.10.6)**

$A_s$ >= $1.3*b*h/(2*(b+h)*f_y)$
$As_{min}$ = 0.11 $in^2$
$S_{max}$ = 18 in
Try Bar # = 4
$A_{bar}$ = 0.20 $in^2$
Spacing = 18 in **OKAY**
As = 0.13 $in^2/ft$ **OKAY**

| | | | |
|---|---|---|---|
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**Footing Shear Design (LRFD 5.7)**

$\phi_v$ = 0.90
Footing Width = 6.42 ft
Stem Width = 1.00 ft
Critical Section = Ls = (Footing Width -Stem Width)/2-d
Ls = 1.98 ft
Vu = q*Ls
Vu = 3.29 kips

Shear Bar = 5
Area per Bar = 0.31 $in^2$
Legs per Bar = 2
Av = Area per Bar * Legs per Bar
Av = 0.62 $in^2$

$S_{max}$= Min (d/2, 24in)
$S_{max}$= 4.34 in

Vc= $0.0316*\beta*\lambda*\sqrt{(f'_c)}*b*d_v$ LRFD 5.7.3.3-3
$\lambda$ = 1 LRFD 5.4.2.8
$\beta$ = 2 LRFD 5.7.3.4
$d_v$ = MAX(0.9*d,0.72*h)
$d_v$ = 8.64 in
Vc= 13.11 kips
Req'd Vn= $Vu/\phi_v$
Req'd Vn= 4 kips

**Vc > Req'd Vn ?** **Shear Steel Not Required**

**$\phi$Vn = $\phi$(Vc+Vs) >= Vu**
$\phi$Vn = 12 **OKAY**