Appendix D

Structural Engineering

Puyallup River Basin
Flood Risk Management Feasibility Study

Department of the Army
Seattle District, US Army Corps of Engineers

March 2016

DRAFT

This page intentionally left blank

Structural Design Documentation

Introduction

The Puyallup GI is a Flood Risk Reduction Study. In several locations this includes new or improved levees. In locations where the full levee footprint will not fit in the available area, flood walls have been determined to be the appropriate solution. This appendix discusses the design considerations for the flood walls. Flood walls are being considered for 2 areas:

- Lower Puyallup (left and right bank) – also called the river road levee
- Middle Puyallup - near State Route 410, also called the river grove levee

This design information is related to the TSP level of design. Because of this, there is significant information that has not been determined at this point and will be determined during future project phases.

For a full description of the project features, see the main Feasibility/EIS Report.

Design Requirements and Criteria

Floodwall Design:

- EM 1110-2-2502 Retaining and Flood Walls

Concrete Design:

- EM 1110-2-2000 Standard Practice for Concrete for Civil Works Structures
- EM 1110-2-2104 Strength Design for Reinforced-Concrete Hydraulic Structures.

Loads and load combinations, safety factors, and other design requirements will be in accordance with these documents.

Loads:

Seismic Loads

- The seismic loading from water is determined based on the Westergaard method contained in EM 1110-2-2502. The C_E for these walls was determined to be 0.051 kip/ft^3
- The seismic load due to wall self-weight is also from EM 1110-2-2502. The K_h value used was 0.2 per EM recommendations.

Flood

- The top of wall elevations include a 3ft freeboard. Because of this, the full flood load is based on water to 3ft below the top of the wall. There is also a load case with water to the top of the wall, with reduced safety factor requirements per the EM requirements.

DRAFT

- The normal water flow was assumed for the walls for this stage of designs.

Uplift

Uplift was assumed to be 90% of the total head at the heel decreasing linearly to 10% of the total head at the toe. A seepage cutoff wall was not included in the design. However, this will be investigated during feasibility design. The use of a cutoff wall may decrease uplift and lead to a more efficient design.

Material Properties Assumed:

- Concrete Compressive Stress– 4000psi
- Rebar Tensile Strength (ASTM A615 Grade 60) – 60ksi
- Soil Bearing Capacity – 2000psf

Data Received From Others

Top of floodwall elevations were determined through the H&H modeling efforts. Existing ground profiles were provided from the civil engineers along the proposed floodwall alignments. Based on the required top of wall elevations and the existing terrain, stretches of each reach were assigned a flood wall height.

Soil parameters were obtained from an estimate from the geotechnical engineer and will be updated based on actual results from site exploration and soil tests.

Design Restrictions and Considerations

It will be required of these flood walls to fit within the allowable real estate available to them. As this project progresses into further stages, these requirements will be further coordinated. However, at this stage it appears that the flood walls will fit in the allowable space.

Calculation Summary

Floodwalls were designed to resist sliding, overturning, and soil bearing pressure for gravity, flood, and earthquake loads. A seepage cutoff wall was not included in this conceptual stage of design but may be included at later stages of design to reduce the expected uplift. The floodwalls were not designed for concrete strength, but were only estimated for size and reinforcing for cost estimating quantities. The full and complete design of the floodwalls will be completed at later stages of design. A summary of quantities is below.

See calculations for additional information.

DRAFT

Levee - Alternative 2

River Grove Levee			Quantities			
Height (ft)	Length (ft)	Rounded Length (ft)	Concrete (yd^3 per ft)	Rebar (lb per ft)	total concrete (yd^3)	total rebar (lb)
6	634	700	1.04	113.50	726	79,450
8	2207	2300	1.93	233.00	4,439	535,900
10	439	500	2.85	407.00	1,425	203,500
12	936	1000	4.10	533.50	4,100	533,500
Total	4216	4500		Total	10,690	1,352,350

Levee - Alternative 2

River Road - Raise			Quantities			
Height (ft)	Length (ft)	Rounded Length (ft)	Concrete (yd^3 per ft)	Rebar (lb per ft)	total concrete (yd^3)	total rebar (lb)
4	1292	1300	0.59	52.50	767	68,250
6	6611	6700	1.93	233.00	12,931	1,561,100
8	13065	13100	2.85	407.00	37,335	5,331,700
10	2058	2100	4.10	533.50	8,610	1,120,350
Total	23026	23200		Total	59,643	8,081,400

Levee - Alternative 2

River Road - Setback			Quantities			
Height (ft)	Length (ft)	Rounded Length (ft)	Concrete (yd^3 per ft)	Rebar (lb per ft)	total concrete (yd^3)	total rebar (lb)
4	9607	9700	0.59	52.50	5,723	509,250
6	6935	7000	1.93	233.00	13,510	1,631,000
8	6487	6500	2.85	407.00	18,525	2,645,500
Total	23029	23200		Total	37,758	4,785,750

Dredge - Alternative 3

River Road - Dredge			Quantities			
Height (ft)	Length (ft)	Rounded Length (ft)	Concrete (yd^3 per ft)	Rebar (lb per ft)	total concrete (yd^3)	total rebar (lb)
4	8685	8700	0.59	52.50	5,133	456,750
6	1776	1800	1.93	233.00	3,474	419,400
8	0	0	2.85	407.00	0	0
Total	10461	10500		Total	8,607	876,150

DRAFT

Risks, next steps, and future study

Risks

The conceptual design is based on preliminary information. It is likely that some of the information will change during feasibility design, such as final alignment and extent of flood walls and soil information.

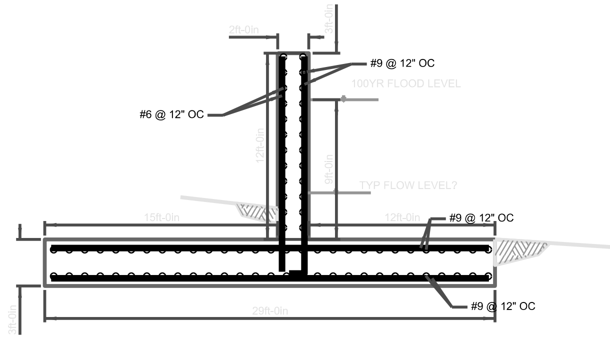
Depending on how the information changes, it could cause a significant re-formulation of the flood wall design.

During conceptual design, the walls were only sized to resist overturning and sliding and to meet bearing capacity requirements. The concrete of the walls was not designed. As this design is conducted, it is likely that the size of the walls and the quantity of reinforcement will be changed. Additionally, if a seepage cut-off wall is added to the design, it is likely that this will change the design. The combination of all these factors may increase or decrease construction costs.

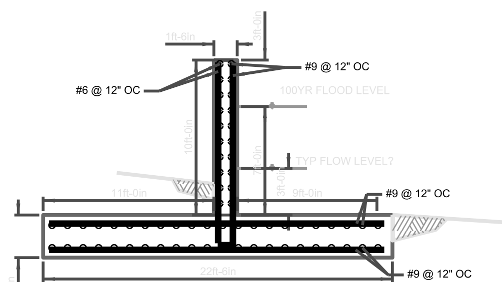
<u>Further Study:</u>

During the preparation of the feasibility documents, design of floodwalls will be refined. It is expected that the design for the flood walls will become more accurate and economical. Additionally, locations and heights of floodwalls will be refined. As the study continues, further refinements and changes will be made to reflect any new or updated information obtained. A seepage cutoff wall will be investigated as part of the future design efforts.   Transitions between different wall heights and between levees and flood walls may be conceptually investigated in feasibility design, but will not be fully designed until PED.

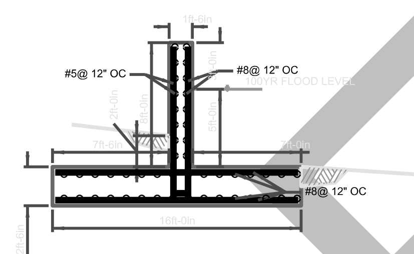
DRAFT



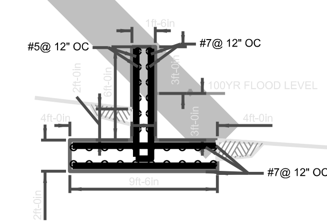
12'-0" FROM GRADE TO TOP OF WALL
REINFORCING IS ESTIMATED
112 SQFT AREA = 4.1 CU YDS CONCRETE/FT OF WALL
(12) #6, 15' OF #6 = 27FT X 1.5LB/FT = 40.5LB/FT OF WALL
(72) #9, 73' OF #9 = 145FT X 3.4LB/FT = 493LB/FT OF WALL



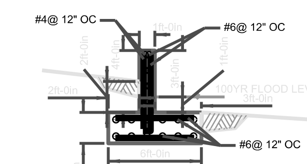
10'-0" FROM GRADE TO TOP OF WALL
REINFORCING IS ESTIMATED
77 SQFT AREA = 2.85 CU YDS CONCRETE/FT OF WALL
(10) #6, 12' OF #6 = 22FT X 1.5LB/FT = 33LB/FT OF WALL
(54) #9, 55' OF #9 = 109FT X 3.4LB/FT = 374/FT OF WALL



8'-0" FROM GRADE TO TOP OF WALL
REINFORCING IS ESTIMATED
52 SQFT AREA = 1.93 CU YRDS CONCRETE/FT OF WALL
(8) #5, 10' OF #5 = 18FT X 1.04LB/FT = 19LB/FT OF WALL
(40) #8, 40 OF #8 = 80FT X 2.67LB/FT = 214LB/FT OF WALL



6'-0" FROM GRADE TO TOP OF WALL
REINFORCING IS ESTIMATED
28 SQFT AREA = 1.04 CU YRDS CONCRETE/FT OF WALL
(6) #5, 7' OF #5 = 13FT X 1.04LB/FT = 13.5LB/FT OF WALL
(28) #7, 25' OF #7 = 50FT X 2.04LB/FT = 100LB/FT OF WALL



4'-0" FROM GRADE TO TOP OF WALL
REINFORCING IS ESTIMATED
16 SQFT AREA = 0.59 CU YRDS CONCRETE/FT OF WALL
(4) #4, 5' OF #4 = 9FT X 0.67LB/FT = 6LB/FT OF WALL
(16) #6, 15' OF #6 = 31FT X 1.5LB/FT = 46.5LB/FT OF WALL

Levee - Alternative 2

River Grove Levee			Quantities			
Height ft	Length ft	Rounded	Concrete yd^3 p	Rebar lb per	total concrete (yd^3)	total rebar (lb)
6	634	700	1.04	113.50	726	79,450
8	2207	2300	1.93	233.00	4,439	535,900
10	439	500	2.85	407.00	1,425	203,500
12	936	1000	4.10	533.50	4,100	533,500
Total	4216	4500		Total	10,690	1,352,350

Levee - Alternative 2

River Road - Raise			Quantities			
Height ft	Length ft	Rounded	Concrete yd^3 p	Rebar lb per	total concrete (yd^3)	total rebar (lb)
4	1292	1300	0.59	52.50	767	68,250
6	6611	6700	1.93	233.00	12,931	1,561,100
8	13065	13100	2.85	407.00	37,335	5,331,700
10	2058	2100	4.10	533.50	8,610	1,120,350
Total	23026	23200		Total	59,643	8,081,400

Levee - Alternative 2

River Road - Setback			Quantities			
Height ft	Length ft	Rounded	Concrete yd^3 p	Rebar lb per	total concrete (yd^3)	total rebar (lb)
4	9607	9700	0.59	52.50	5,723	509,250
6	6935	7000	1.93	233.00	13,510	1,631,000
8	6487	6500	2.85	407.00	18,525	2,645,500
Total	23029	23200		Total	37,758	4,785,750

Dredge - Alternative 3

River Road - Dredge			Quantities			
Height ft	Length ft	Rounded	Concrete yd^3 p	Rebar lb per	total concrete (yd^3)	total rebar (lb)
4	8685	8700	0.59	52.50	5,133	456,750
6	1776	1800	1.93	233.00	3,474	419,400
8	0	0	2.85	407.00	0	0
Total	10461	10500		Total	8,607	876,150

DRAFT

Flood Wall Design

Project - Puyallup GI Study
This is for areas with 4ft between grade and top of wall

▸ Formulas, Tables, Etc

▾ Input Variables

Wall Thickness	$t_w := 12in$	
Foundation Thickness	$t_f := 2ft$	
Wall Height Above Soil	$h_{height} := 4ft$	
Soil Depth - Protected Side	$d_{soil\_prct} := 2ft$	
Soil Depth - Flood Side	$d_{soil\_flood} := 0ft$	
Wall Height	$h_{wall} := d_{soil\_flood} + h_{height}$	$h_{wall} = 4\ ft$
Freeboard at 100yr flood	$d_{freeboard} := 3ft$	
Water Depth (design Depth)	$d_{water} := h_{wall} - d_{freeboard}$	$d_{water} = 1\ ft$
Water Depth (normal Flow)	$d_{water\_norm} := 2ft$	
Heel Length	$l_{heel} := 3ft$	
Toe Length	$l_{toe} := 2ft$	
Concrete Strength	$f'_c := 4000psi$	
Rebar Strength	$f_y := 60000psi$	
Unit Weight of Concrete	$\gamma_c := 150pcf$	
Unit Weight of Water	$\gamma_{h2o} := 62.4pcf$	
Dry Unit Weight of Soil	$\gamma_{dry} := 100pcf$	
Wet Unit Weight of Soil	$\gamma_{wet} := 115pcf$	
Submerged Unit Weight of Soil	$\gamma_{sub} := \gamma_{wet} - \gamma_{h2o}$	$\gamma_{sub} = 52.6 \cdot pcf$
Bearing Capacity of Soil	$b_{soil} := 2000psf$	
At Rest Soil Coefficient	$K_0 := 0.5$	

DRAFT

Active Soil Coefficient	$K_a := 0.33$
Passive Soil Coefficient	$K_p := 3.0$
Angle of Internal Friction	$\phi_s := 30deg$
Coeficient of Friction	$\mu := 0.2$
Cohesion	$c := 0psf$
Modulus of Subgrade Reaction	$K_s := 350pci$
Frost Depth	$d_{frost} := 18in$
Earthquake design acceleration	$k_h := 0.2$

Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Assumed percent of total pressure toe $pore\_toe := 10\%$

Assumed Percent of total pressure at heel $pore\_heel := 90\%$

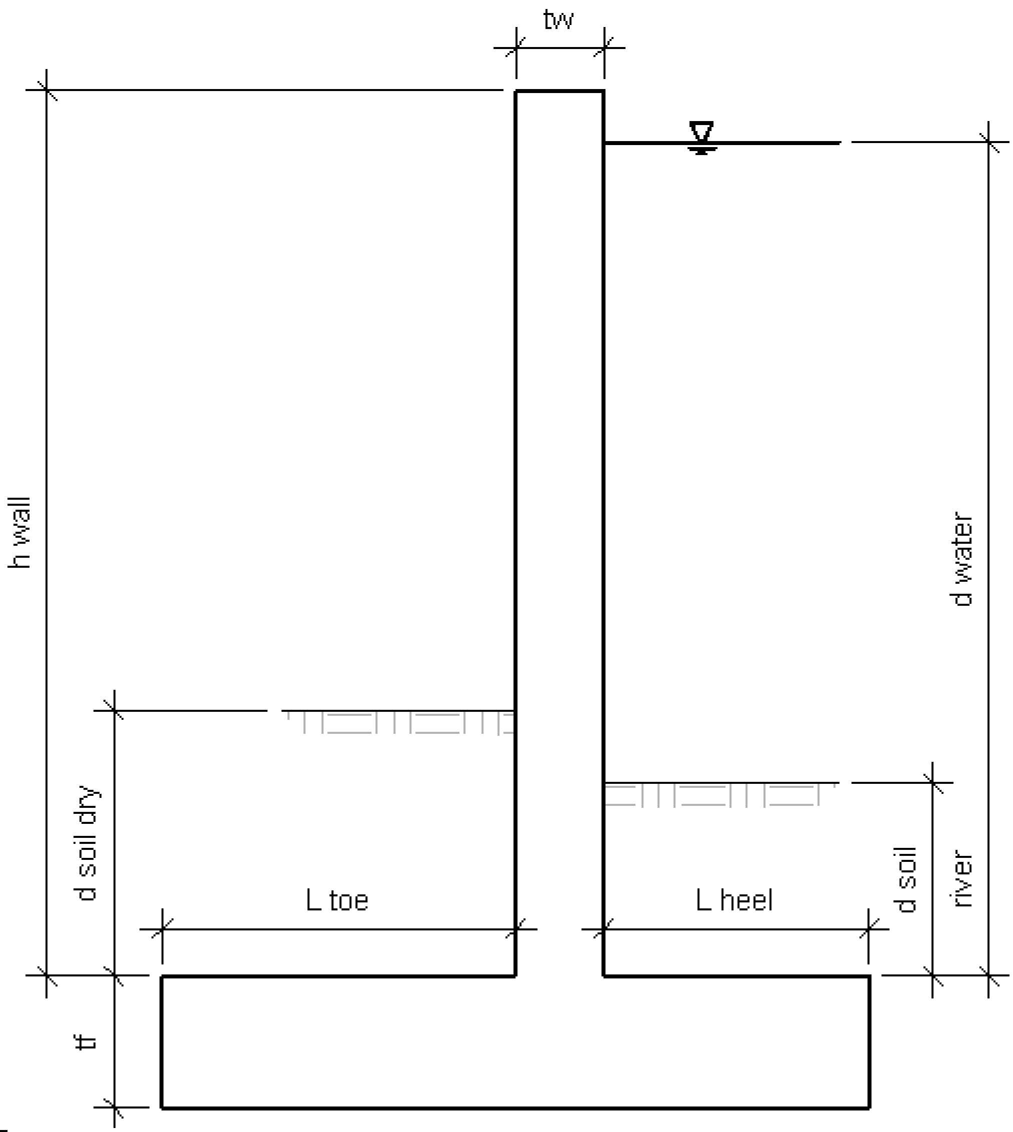
Uplift Reduction Factor $uplift\_reduce := \frac{pore\_toe + pore\_heel}{2}$

$uplift\_reduce = 50 \cdot \%$

Location of Reaction from toe (percent) $uplift\_react := 1 - \left[\frac{2 \cdot pore\_toe + pore\_heel}{3 \cdot (pore\_toe + pore\_heel)}\right]$

$uplift\_react = 63.333 \cdot \%$

DRAFT



Input Variables

Loads and Load Cases

Horizontal Loads

Land Side At Rest Soil Load - Resisting Load Assumed to be zero to be conservative

Flood Side at Rest Soil Load (wet not suburged)

Peak Pressure from soil $p_{soil\_flood\_wet} := \gamma_{wet} \cdot K_0 \cdot \left(d_{soil\_flood} + t_f\right)$

$p_{soil\_flood\_wet} = 115 \cdot psf$

Distance of resultant from bottom of footing

$$h_{soil\_flood} := \frac{\left(d_{soil\_flood} + t_f\right)}{3} \qquad h_{soil\_flood} = 0.667\ ft$$

Total Resultant force from Soil

$$R_{soil\_flood\_wet} := \frac{p_{soil\_flood\_wet} \cdot \left(d_{soil\_flood} + t_f\right)}{2}$$

$$R_{soil\_flood\_wet} = 0.115 \cdot \frac{kip}{ft}$$

Flood Side at Rest Soil Load (suburged)

Peak Pressure from soil $p_{soil\_flood\_sub} := \gamma_{sub} \cdot K_0 \cdot \left(d_{soil\_flood} + t_f\right)$

$p_{soil\_flood\_sub} = 52.6 \cdot psf$

Distance of resultant from bottom of footing $h_{soil\_flood} = 0.667\ ft$

Total Resultant force from Soil

$$R_{soil\_flood\_sub} := \frac{p_{soil\_flood\_sub} \cdot \left(d_{soil\_flood} + t_f\right)}{2}$$

$$R_{soil\_flood\_sub} = 0.053 \cdot \frac{kip}{ft}$$

Protected Side At Rest Soil Pressure

Peak Pressure from soil $p_{soil\_prct\_wet} := \gamma_{wet} \cdot K_0 \cdot \left(d_{soil\_prct} + t_f\right)$

$p_{soil\_prct\_wet} = 230 \cdot psf$

Distance of resultant from bottom of footing

$$h_{soil\_prct} := \frac{\left(d_{soil\_prct} + t_f\right)}{3} \qquad h_{soil\_prct} = 1.333\ ft$$

Total Resultant force from Soil

$$R_{soil\_prct\_wet} := \frac{p_{soil\_prct\_wet} \cdot \left(d_{soil\_prct} + t_f\right)}{2}$$

$$R_{soil\_prct\_wet} = 0.46 \cdot \frac{kip}{ft}$$

Flood Side Design Flood Pressure

Peak Pressure from water at design flood elevation $p_{water} := \gamma_{h2o} \cdot \left(d_{water} + t_f\right) \qquad p_{water} = 187.2 \cdot psf$

DRAFT

Distance of resultant from bottom of footing

$$h_{water} := \frac{d_{water} + t_f}{3} \qquad h_{water} = 1\,ft$$

Total Resultant force from Soil

$$R_{water} := \frac{p_{water} \cdot (d_{water} + t_f)}{2} \qquad R_{water} = 0.281 \cdot \frac{kip}{ft}$$

Fllod Side Flood Pressure - Water at top of wall

Peak Pressure from water up to the top of the wall

$$p_{water2} := \gamma_{h2o} \cdot (t_f + h_{wall}) \qquad p_{water2} = 374.4 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water2} := \frac{h_{wall} + t_f}{3} \qquad h_{water2} = 2\,ft$$

Total Resultant force from Water

$$R_{water2} := \frac{p_{water2} \cdot (h_{wall} + t_f)}{2} \qquad R_{water2} = 1.123 \cdot \frac{kip}{ft}$$

Flood Side Water Pressure - Normal Flow Conditions

Peak Pressure from water at normal flow conditions

$$p_{water3} := \gamma_{h2o} \cdot (t_f + d_{water\_norm}) \qquad p_{water3} = 249.6 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water3} := \frac{d_{water\_norm} + t_f}{3} \qquad h_{water3} = 1.333\,ft$$

Total Resultant force from Water

$$R_{water3} := \frac{p_{water3} \cdot (d_{water\_norm} + t_f)}{2} \qquad R_{water3} = 0.499 \cdot \frac{kip}{ft}$$

Vertical Loads

Uplift on Foundation due to water.
Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

DRAFT

Uplift from water at design flood load

$p_{uplift} := p_{water}$ $p_{uplift} = 187.2 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} := (l_{toe} + l_{heel} + t_w) \cdot uplift\_react$ $L_{uplift} = 3.8\,ft$

Total Uplift Force

$R_{uplift} := uplift\_reduce\, p_{uplift} \cdot (l_{toe} + l_{heel} + t_w)$

$R_{uplift} = 0.562 \cdot \frac{kip}{ft}$

Uplift force from water to top of wall

$P_{uplift2} := p_{water2}$ $P_{uplift2} = 374.4 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} = 3.8\,ft$

Total Uplift Force

$R_{uplift2} := uplift\_reduce\, P_{uplift2} \cdot (l_{toe} + l_{heel} + t_w)$

$R_{uplift2} = 1.123 \cdot \frac{kip}{ft}$

Uplift force from water at normal flow levels

$P_{uplift3} := p_{water3}$ $P_{uplift3} = 249.6 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} = 3.8\,ft$

Total Uplift Force

$R_{uplift3} := uplift\_reduce\, P_{uplift3} \cdot (l_{toe} + l_{heel} + t_w)$

$R_{uplift3} = 0.749 \cdot \frac{kip}{ft}$

Weight of Water above Heel at design flood level

DRAFT

$$W_{water} := \gamma_{h2o} \cdot d_{water} \cdot l_{heel} \qquad W_{water} = 0.187 \cdot \frac{kip}{ft}$$

Distance of Water Weight from toe

$$L_{water} := l_{toe} + t_w + \frac{l_{heel}}{2} \qquad L_{water} = 4.5\,ft$$

Weight of Water above Heel at design flood level

$$W_{water2} := \gamma_{h2o} \cdot h_{wall} \cdot l_{heel} \qquad W_{water2} = 0.749 \cdot \frac{kip}{ft}$$

Distance of Water Weight from toe

$$L_{water} = 4.5\,ft$$

Weight of Water at normal flow levels

$$W_{water3} := \gamma_{h2o} \cdot d_{water\_norm} \cdot l_{heel} \qquad W_{water3} = 0.374 \cdot \frac{kip}{ft}$$

Weight of Soil On Toe - Wet Soil, not submurged

$$W_{soil\_toe\_wet} := \gamma_{wet} \cdot d_{soil\_prct} \cdot l_{toe}$$

$$W_{soil\_toe\_wet} = 0.46 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe

$$L_{soil\_toe} := \frac{l_{toe}}{2} \qquad L_{soil\_toe} = 1\,ft$$

Weight of Soil On Toe - Submurged Soil

$$W_{soil\_toe\_sub} := \gamma_{sub} \cdot d_{soil\_prct} \cdot l_{toe}$$

$$W_{soil\_toe\_sub} = 0.21 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe $L_{soil\_toe} = 1\,ft$

Weight of Soil On Heel - Wet Soil, not submurged

DRAFT

$$W_{soil\_heel\_wet} := \gamma_{wet} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_wet} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe

$$L_{soil\_heel} := l_{toe} + t_w + \frac{l_{heel}}{2} \qquad L_{soil\_heel} = 4.5\,ft$$

Weight of Soil On Toe - Submurged Soil

$$W_{soil\_heel\_sub} := \gamma_{sub} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_sub} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe $L_{soil\_heel} = 4.5\,ft$

Weight of wall Stem

$$W_{stem} := \gamma_c \cdot t_w \cdot \left(h_{wall} + t_f\right) \qquad W_{stem} = 0.9 \cdot \frac{kip}{ft}$$

Distance of Stem Wight from Toe

$$L_{stem} := l_{toe} + \frac{t_w}{2} \qquad L_{stem} = 2.5\,ft$$

Weight of wall Heel

$$W_{heel} := \gamma_c \cdot t_f \cdot l_{heel} \qquad W_{heel} = 0.9 \cdot \frac{kip}{ft}$$

Distance from Heel Weight to Toe

$$L_{heel} := l_{toe} + t_f + \frac{l_{heel}}{2} \qquad L_{heel} = 5.5\,ft$$

Weight of Toe

$$W_{toe} := \gamma_c \cdot l_{toe} \cdot t_f \qquad W_{toe} = 0.6 \cdot \frac{kip}{ft}$$

Distance from Toe weight to Toe end

$$L_{toe} := \frac{l_{toe}}{2} \qquad L_{toe} = 1\,ft$$

Earthquake Loading

Use Westegard for water loading under earthquakes

Westergaard factor - per EM 1110-2-2502 $C_E := 0.051 \frac{kip}{ft^3}$

DRAFT

Total Earthquake Force $P_E := \frac{2}{3} \cdot C_E \cdot k_h \cdot \left(d_{water\_norm} - d_{soil\_flood}\right)^2$

$$P_E = 0.027 \cdot \frac{kip}{ft}$$

Distance of water EQ force from bottom of foundation

$$h_{EQ} := d_{soil\_flood} + 0.4\left(d_{water\_norm} - d_{soil\_flood}\right) + t_f \qquad h_{EQ} = 2.8\,ft$$

Lateral Load from Wall's own wieght

$$F_w := k_h \cdot \left(W_{stem} + W_{toe} + W_{heel} + W_{soil\_heel\_wet}\right) \qquad F_w = 0.48 \cdot \frac{kip}{ft}$$

Distance of Wall EQ force from top of foundation

$$h_{EQ\_wall} := \frac{h_{wall}}{2} + t_f \qquad h_{EQ\_wall} = 4\,ft$$

Wind Loading

Based on ASCE 7-05 6.5.14 Freestanding walls and signs

Wind Speed $V := 85mph$

Directionality Coefficient $K_d := 0.85$

Velocity Pressure Coefficient $K_z := 0.85$ Assumes exposure C at 15ft or less

Topographic Coefficient $K_{zt} := 1.0$

Importance Factor $I := 1.15$ Assumes that it is catagory III

Velocity Pressure $q_h := 0.00256 K_z \cdot K_{zt} \cdot K_d \cdot \left(\frac{V}{mph}\right)^2 \cdot I \cdot psf$

$$q_h = 15.368 \cdot psf$$

Gusset Effect Factor $G := 0.85$

Net Force Coefficient $C_f := 1.3$

Design Wind Pressure $p_{wind} := q_h \cdot G \cdot C_f$ $\quad p_{wind} = 16.981 \cdot psf$

Lateral Load from Wind $F_{wind} := p_{wind} \cdot \left(h_{height}\right)$ $\quad F_{wind} = 0.068 \cdot \frac{kip}{ft}$

Distance of Wind load from bottom of foundation

$$h_{wind} := \frac{h_{wall}}{2} + t_f \qquad h_{wind} = 4\,ft$$

DRAFT

Load Cases:

Look at the load cases in ASCE7/IBC/ACI318 for guidance on what to include in which combination, and what load factors to use.

Design Flood Loading

Water to Top of Wall

Earthquake Loading

Construction and Short Duration Loading

Loads and Load Cases

Stability/Overturning

Design Flood Load

Overturning moment - caused by design water flood load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot} := R_{water} \cdot h_{water} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift} \cdot L_{uplift}$$

$$M_{ot} = 2.45 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right} = 9.102 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

DRAFT

$$\Sigma V = 2.486 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_R := \frac{M_{right} - M_{ot}}{\Sigma V}$ $x_R = 2.676\,ft$

Resultant Ratio: $Ratio := \frac{x_R}{(l_{toe} + t_w + l_{heel})}$ $Ratio = 0.446$

About what percent of foundation is in compression?

$$base\_compression_1 := percent_{comp}(Ratio)$$

$$base\_compression_1 = 100 \cdot \%$$

Water to Top of Wall Load

Overturning moment - caused by water to top of wall load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot2} := R_{water2} \cdot h_{water2} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift2} \cdot L_{uplift}$$

$$M_{ot2} = 6.55 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right2} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water2} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right2} = 11.63 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$\Sigma V_2 = 2.486 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R2} := \frac{M_{right2} - M_{ot2}}{\Sigma V_2}$ $x_{R2} = 2.044\,ft$

Resultant Ratio: $Ratio_2 := \frac{x_{R2}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_2 = 0.341$

DRAFT

About what percent of foundation is in compression?

$$base\_compression_2 := percent_{comp}(Ratio_2)$$

$$base\_compression_2 = 100 \cdot \%$$

Earthquake Load

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and the added earthquake load based on water weight and wall self weight. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot3} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + P_E \cdot h_{EQ} + F_w \cdot h_{EQ\_wall}$$

$$M_{ot3} = 5.542 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right3} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right3} = 9.945 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_3 = 2.486 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R3} := \frac{M_{right3} - M_{ot3}}{\Sigma V_3}$ $x_{R3} = 1.771\ ft$

Resultant Ratio: $Ratio_3 := \frac{x_{R3}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_3 = 0.295$

About what percent of foundation is in compression?

$$base\_compression_3 := percent_{comp}(Ratio_3)$$

$$base\_compression_3 = 75 \cdot \%$$

Wind Load

DRAFT

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and wind loads. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot4} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + F_{wind} \cdot h_{wind}$$

$$M_{ot4} = 3.818 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right4} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right4} = 9.945 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_4 = 2.486 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R4} := \frac{M_{right4} - M_{ot4}}{\Sigma V_4}$ $x_{R4} = 2.465\ ft$

Resultant Ratio: $Ratio_4 := \frac{x_{R4}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_4 = 0.411$

About what percent of foundation is in compression?

$$base\_compression_4 := percent_{comp}(Ratio_4)$$

$$base\_compression_4 = 100 \cdot \%$$

Stability/Overturning

Stability/Sliding

Design Flood Load

Lateral Loads come from hydrostatic loads at design flood level There will be seepage/uplift that will lower the normal force that increases friction.

DRAFT

Actual Shear Force

$$V_1 := \left|R_{water} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet}\right| \qquad V_1 = 0.127 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_1 := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

$$N_1 = 2.486 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s1} := \frac{N_1 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_1} \qquad FS_{s1} = 11.335$$

Water to top of Wall Load

Lateral Loads come from hydrostatic loads at the top of the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_2 := R_{water2} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet} \qquad V_2 = 0.716 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$N_2 = 2.486 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s2} := \frac{N_2 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_2} \qquad FS_{s2} = 2.005$$

Earthquake Load

Lateral Loads come from Earthquake loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

DRAFT

$$V_3 := R_{water3} + R_{soil\_flood\_sub} + P_E + F_w \qquad V_3 = 1.059 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_3 = 2.486 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s3} := \frac{N_3 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_3} \qquad FS_{s3} = 1.355$$

Wind Load

Lateral Loads come from Wind loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_4 := R_{water3} + R_{soil\_flood\_sub} + F_{wind} \qquad V_4 = 0.62 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_4 = 2.486 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s4} := \frac{N_4 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_4} \qquad FS_{s4} = 2.316$$

Stability/Sliding

Soil Bearing Capacity

Design Flood Load

Distance of base reaction to toe $$x_1 := \frac{M_{right} - M_{ot}}{N_1} \qquad x_1 = 2.676\ ft$$

DRAFT

Distance of Base reaction from center of footing $e_1 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_1$

$e_1 = 0.324\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_1 := N_1 \cdot e_1$ $M_1 = 0.804 \cdot \frac{kip \cdot ft}{ft}$

$$q_{1a} := \frac{N_1}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_1}{\left(l_{toe} + l_{heel} + t_w\right)^2}$$ $q_{1a} = 0.548 \cdot ksf$

Maximum moment if reaction is outside the kern:

$q_{1b} := \frac{2 \cdot N_1}{3 \cdot x_1}$ $q_{1b} = 0.619 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern := \frac{l_{toe} + l_{heel} + t_w}{6}$ $kern = 1\ ft$

Maximum bearing pressure: $q_1 := if\left(e_1 \le kern, q_{1a}, q_{1b}\right)$

$q_1 = 0.548 \cdot ksf$

Safety Factor $SF_1 := \frac{b_{soil}}{q_1}$ $SF_1 = 3.647$

Water to top of Wall Load

Distance of base reaction to toe $x_2 := \frac{M_{right2} - M_{ot2}}{N_2}$ $x_2 = 2.044\ ft$

Distance of Base reaction from center of footing $e_2 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_2$

$e_2 = 0.956\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_2 := N_2 \cdot e_2$ $M_2 = 2.377 \cdot \frac{kip \cdot ft}{ft}$

$$q_{2a} := \frac{N_2}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_2}{\left(l_{toe} + l_{heel} + t_w\right)^2}$$ $q_{2a} = 0.81 \cdot ksf$

Maximum moment if reaction is outside the kern:

DRAFT

$$q_{2b} := \frac{2 \cdot N_2}{3 \cdot x_2} \qquad q_{2b} = 0.811 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 1\ ft$

Maximum bearing pressure: $q_2 := if\left(e_2 \le kern, q_{2a}, q_{2b}\right)$ $q_2 = 0.81 \cdot ksf$

Safety Factor $SF_2 := \frac{b_{soil}}{q_2}$ $SF_2 = 2.468$

Earthquake Load

Distance of base reaction to toe $x_3 := \frac{M_{right3} - M_{ot3}}{N_3}$ $x_3 = 1.771\ ft$

Distance of Base reaction from center of footing $e_3 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_3$

$e_3 = 1.229\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_3 := N_3 \cdot e_3$ $M_3 = 3.054 \cdot \frac{kip \cdot ft}{ft}$

$$q_{3a} := \frac{N_3}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_3}{\left(l_{toe} + l_{heel} + t_w\right)^2} \qquad q_{3a} = 0.923 \cdot ksf$$

Maximum moment if reaction is outside the kern:

$$q_{3b} := \frac{2 \cdot N_3}{3 \cdot x_3} \qquad q_{3b} = 0.936 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 1\ ft$

Maximum bearing pressure: $q_3 := if\left(e_3 \le kern, q_{3a}, q_{3b}\right)$ $q_3 = 0.936 \cdot ksf$

Safety Factor $SF_3 := \frac{b_{soil}}{q_3}$ $SF_3 = 2.138$

Wind Load

DRAFT

Distance of base reaction to toe $x_4 := \frac{M_{right4} - M_{ot4}}{N_4}$ $x_4 = 2.465\ ft$

Distance of Base reaction from center of footing $e_4 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_4$

$e_4 = 0.535\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_4 := N_4 \cdot e_4$ $M_4 = 1.33 \cdot \frac{kip \cdot ft}{ft}$

$$q_{4a} := \frac{N_4}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_4}{(l_{toe} + l_{heel} + t_w)^2}$$ $q_{4a} = 0.636 \cdot ksf$

Maximum moment if reaction is outside the kern:

$$q_{4b} := \frac{2 \cdot N_4}{3 \cdot x_4}$$ $q_{4b} = 0.672 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern = 1\ ft$

Maximum bearing pressure: $q_4 := if(e_4 \le kern, q_{4a}, q_{4b})$ $q_4 = 0.636 \cdot ksf$

Safety Factor $SF_4 := \frac{b_{soil}}{q_4}$ $SF_4 = 3.145$

Soil Bearing Capacity

Summary

Sliding Safety Factor

Flood Load $FS_{s1} = 11.335$ $Slide_1 := if(FS_{s1} \ge 1.5, "OK", "NG")$ $Slide_1 = "OK"$

Water to Top of Wall $FS_{s2} = 2.005$ $Slide_2 := if(FS_{s2} \ge 1.33, "OK", "NG")$ $Slide_2 = "OK"$

DRAFT

Earthquake $FS_{s3} = 1.355$ $Slide_3 := if(FS_{s3} \geq 1.1, "OK", "NG")$ $Slide_3 = "OK"$

Wind $FS_{s4} = 2.316$ $Slide_4 := if(FS_{s4} \geq 1.33, "OK", "NG")$ $Slide_4 = "OK"$

Overturning Compression

Flood Load $base\_compression_1 = 100 \cdot \%$

$OT_1 := if(base\_compression_1 \geq 1.0, "OK", "NG")$ $OT_1 = "OK"$

Water to Top of Wall $base\_compression_2 = 100 \cdot \%$

$OT_2 := if(base\_compression_2 \geq 0.75, "OK", "NG")$ $OT_2 = "OK"$

Earthquake $base\_compression_3 = 75 \cdot \%$

$OT_3 := if(base\_compression_3 \geq 0.5, "OK", "NG")$ $OT_3 = "OK"$

Wind $base\_compression_4 = 100 \cdot \%$

$OT_4 := if(base\_compression_4 \geq 0.75, "OK", "NG")$ $OT_4 = "OK"$

Bearing Capacity Safety Factor

Flood Load $SF_1 = 3.647$ $Bearing_1 := if(SF_1 \geq 3.0, "OK", "NG")$ $Bearing_1 = "OK"$

Water to Top of Wall $SF_2 = 2.468$ $Bearing_2 := if(SF_2 \geq 2.0, "OK", "NG")$ $Bearing_2 = "OK"$

Earthquake $SF_3 = 2.138$ $Bearing_3 := if(SF_3 > 1.0, "OK", "NG")$ $Bearing_3 = "OK"$

Wind $SF_4 = 3.145$ $Bearing_4 := if(SF_4 \geq 2.0, "OK", "NG")$ $Bearing_4 = "OK"$

Summary

DRAFT

Flood Wall Design

Project - Puyallup GI Study
This is for areas with 6ft between grade and top of wall

▶ Formulas, Tables, Etc

▼ Input Variables

Wall Thickness	$t_w := 18in$	
Foundation Thickness	$t_f := 2ft$	
Wall Height Above Soil	$h_{height} := 6ft$	
Soil Depth - Protected Side	$d_{soil\_prct} := 2ft$	
Soil Depth - Flood Side	$d_{soil\_flood} := 0ft$	
Wall Height	$h_{wall} := d_{soil\_flood} + h_{height}$	$h_{wall} = 6\ ft$
Freeboard at 100yr flood	$d_{freeboard} := 3ft$	
Water Depth (design Depth)	$d_{water} := h_{wall} - d_{freeboard}$	$d_{water} = 3\ ft$
Water Depth (normal Flow)	$d_{water\_norm} := 2ft$	
Heel Length	$l_{heel} := 4ft$	
Toe Length	$l_{toe} := 4ft$	
Concrete Strength	$f'_c := 4000psi$	
Rebar Strength	$f_y := 60000psi$	
Unit Weight of Concrete	$\gamma_c := 150pcf$	
Unit Weight of Water	$\gamma_{h2o} := 62.4pcf$	
Dry Unit Weight of Soil	$\gamma_{dry} := 100pcf$	
Wet Unit Weight of Soil	$\gamma_{wet} := 115pcf$	
Submerged Unit Weight of Soil	$\gamma_{sub} := \gamma_{wet} - \gamma_{h2o}$	$\gamma_{sub} = 52.6 \cdot pcf$
Bearing Capacity of Soil	$b_{soil} := 2000psf$	
At Rest Soil Coefficient	$K_0 := 0.5$	

DRAFT

Active Soil Coefficient $K_a := 0.33$

Passive Soil Coefficient $K_p := 3.0$

Angle of Internal Friction $\phi_s := 30deg$

Coeficient of Friction $\mu := 0.2$

Cohesion $c := 0psf$

Modulus of Subgrade Reaction $K_s := 350pci$

Frost Depth $d_{frost} := 18in$

Earthquake design acceleration $k_h := 0.2$

Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Assumed percent of total pressure toe $pore\_toe := 10\%$

Assumed Percent of total pressure at heel $pore\_heel := 90\%$

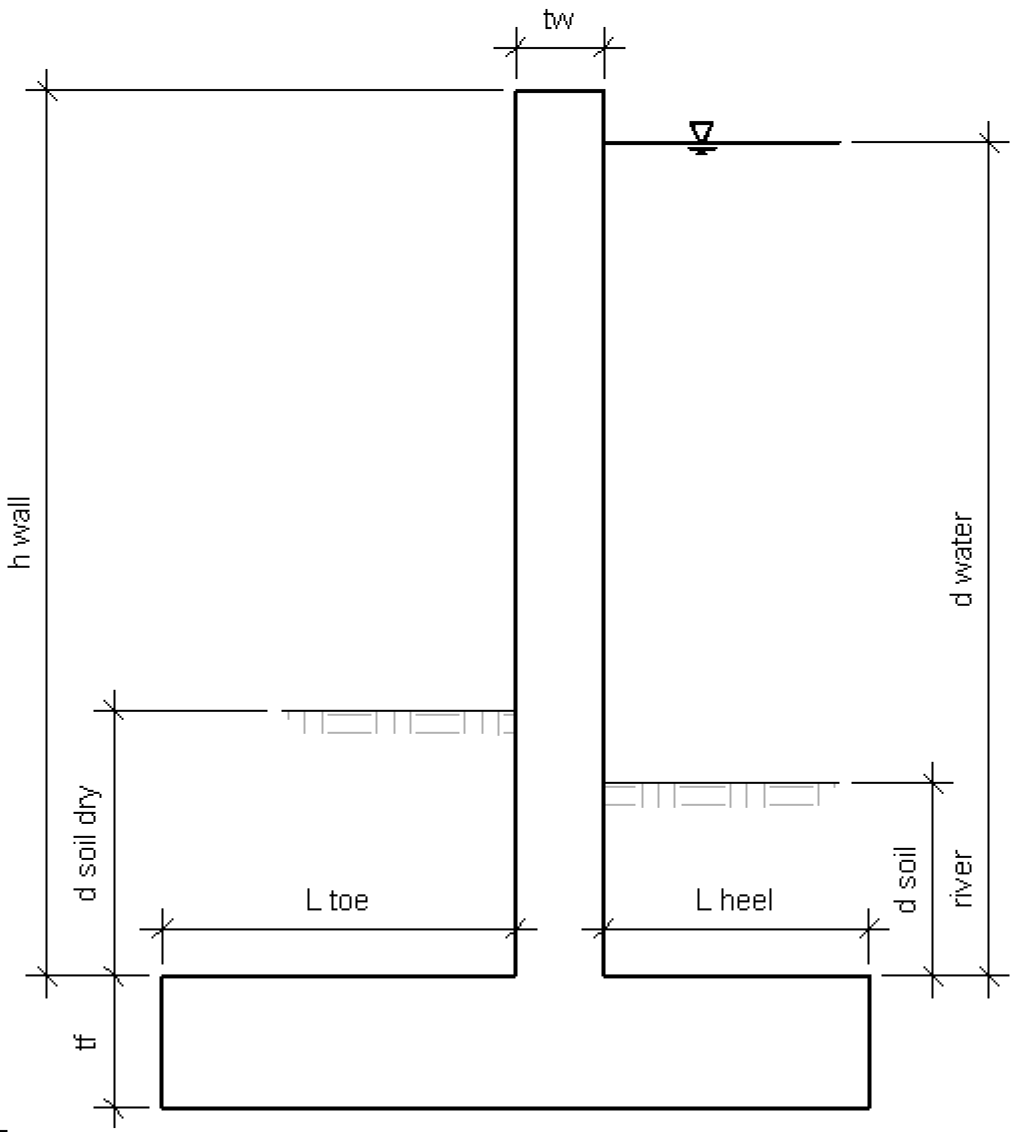
Uplift Reduction Factor $uplift\_reduce := \frac{pore\_toe + pore\_heel}{2}$

$uplift\_reduce = 50 \cdot \%$

Location of Reaction from toe (percent) $uplift\_react := 1 - \left[\frac{2 \cdot pore\_toe + pore\_heel}{3 \cdot (pore\_toe + pore\_heel)}\right]$

$uplift\_react = 63.333 \cdot \%$

DRAFT



Input Variables

Loads and Load Cases

Horizontal Loads

Land Side At Rest Soil Load - Resisting Load Assumed to be zero to be conservative

Flood Side at Rest Soil Load (wet not suburged)

Peak Pressure from soil $p_{soil\_flood\_wet} := \gamma_{wet} \cdot K_0 \cdot (d_{soil\_flood} + t_f)$

$p_{soil\_flood\_wet} = 115 \cdot psf$

Distance of resultant from bottom of footing

$$h_{soil\_flood} := \frac{\left(d_{soil\_flood} + t_f\right)}{3} \qquad h_{soil\_flood} = 0.667\ ft$$

Total Resultant force from Soil

$$R_{soil\_flood\_wet} := \frac{p_{soil\_flood\_wet} \cdot \left(d_{soil\_flood} + t_f\right)}{2}$$

$$R_{soil\_flood\_wet} = 0.115 \cdot \frac{kip}{ft}$$

Flood Side at Rest Soil Load (suburged)

Peak Pressure from soil $p_{soil\_flood\_sub} := \gamma_{sub} \cdot K_0 \cdot \left(d_{soil\_flood} + t_f\right)$

$p_{soil\_flood\_sub} = 52.6 \cdot psf$

Distance of resultant from bottom of footing $h_{soil\_flood} = 0.667\ ft$

Total Resultant force from Soil

$$R_{soil\_flood\_sub} := \frac{p_{soil\_flood\_sub} \cdot \left(d_{soil\_flood} + t_f\right)}{2}$$

$$R_{soil\_flood\_sub} = 0.053 \cdot \frac{kip}{ft}$$

Protected Side At Rest Soil Pressure

Peak Pressure from soil $p_{soil\_prct\_wet} := \gamma_{wet} \cdot K_0 \cdot \left(d_{soil\_prct} + t_f\right)$

$p_{soil\_prct\_wet} = 230 \cdot psf$

Distance of resultant from bottom of footing

$$h_{soil\_prct} := \frac{\left(d_{soil\_prct} + t_f\right)}{3} \qquad h_{soil\_prct} = 1.333\ ft$$

Total Resultant force from Soil

$$R_{soil\_prct\_wet} := \frac{p_{soil\_prct\_wet} \cdot \left(d_{soil\_prct} + t_f\right)}{2}$$

$$R_{soil\_prct\_wet} = 0.46 \cdot \frac{kip}{ft}$$

Flood Side Design Flood Pressure

Peak Pressure from water at design flood elevation $p_{water} := \gamma_{h2o} \cdot \left(d_{water} + t_f\right)$ $\qquad p_{water} = 312 \cdot psf$

DRAFT

Distance of resultant from bottom of footing

$$h_{water} := \frac{d_{water} + t_f}{3} \qquad h_{water} = 1.667\ ft$$

Total Resultant force from Soil

$$R_{water} := \frac{p_{water} \cdot \left(d_{water} + t_f\right)}{2} \qquad R_{water} = 0.78 \cdot \frac{kip}{ft}$$

Fllod Side Flood Pressure - Water at top of wall

Peak Pressure from water up to the top of the wall

$$p_{water2} := \gamma_{h2o} \cdot \left(t_f + h_{wall}\right) \qquad p_{water2} = 499.2 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water2} := \frac{h_{wall} + t_f}{3} \qquad h_{water2} = 2.667\ ft$$

Total Resultant force from Water

$$R_{water2} := \frac{p_{water2} \cdot \left(h_{wall} + t_f\right)}{2} \qquad R_{water2} = 1.997 \cdot \frac{kip}{ft}$$

Flood Side Water Pressure - Normal Flow Conditions

Peak Pressure from water at normal flow conditions

$$p_{water3} := \gamma_{h2o} \cdot \left(t_f + d_{water\_norm}\right) \qquad p_{water3} = 249.6 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water3} := \frac{d_{water\_norm} + t_f}{3} \qquad h_{water3} = 1.333\ ft$$

Total Resultant force from Water

$$R_{water3} := \frac{p_{water3} \cdot \left(d_{water\_norm} + t_f\right)}{2} \qquad R_{water3} = 0.499 \cdot \frac{kip}{ft}$$

DRAFT

<u>Vertical Loads</u>

Uplift on Foundation due to water.
Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Uplift from water at design flood load

$p_{uplift} := p_{water}$ $p_{uplift} = 312 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} := \left(l_{toe} + l_{heel} + t_w\right) \cdot uplift\_react$ $L_{uplift} = 6.017\ ft$

Total Uplift Force

$R_{uplift} := uplift\_reduce\, p_{uplift} \cdot \left(l_{toe} + l_{heel} + t_w\right)$

$R_{uplift} = 1.482 \cdot \frac{kip}{ft}$

Uplift force from water to top of wall

$P_{uplift2} := p_{water2}$ $P_{uplift2} = 499.2 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} = 6.017\ ft$

Total Uplift Force

$R_{uplift2} := uplift\_reduce\, P_{uplift2} \cdot \left(l_{toe} + l_{heel} + t_w\right)$

$R_{uplift2} = 2.371 \cdot \frac{kip}{ft}$

Uplift force from water at normal flow levels

$P_{uplift3} := p_{water3}$ $P_{uplift3} = 249.6 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} = 6.017\ ft$

Total Uplift Force $R_{uplift3} := uplift\_reduce\, P_{uplift3} \cdot \left(l_{toe} + l_{heel} + t_w\right)$

$R_{uplift3} = 1.186 \cdot \frac{kip}{ft}$

Weight of Water above Heel at design flood level

DRAFT

$W_{water} := \gamma_{h2o} \cdot d_{water} \cdot l_{heel}$ $W_{water} = 0.749 \cdot \frac{kip}{ft}$

Distance of Water Weight from toe

$L_{water} := l_{toe} + t_w + \frac{l_{heel}}{2}$ $L_{water} = 7.5\,ft$

Weight of Water above Heel at design flood level

$W_{water2} := \gamma_{h2o} \cdot h_{wall} \cdot l_{heel}$ $W_{water2} = 1.498 \cdot \frac{kip}{ft}$

Distance of Water Weight from toe

$L_{water} = 7.5\,ft$

Weight of Water at normal flow levels

$W_{water3} := \gamma_{h2o} \cdot d_{water\_norm} \cdot l_{heel}$ $W_{water3} = 0.499 \cdot \frac{kip}{ft}$

Weight of Soil On Toe - Wet Soil, not submurged

$W_{soil\_toe\_wet} := \gamma_{wet} \cdot d_{soil\_prct} \cdot l_{toe}$

$W_{soil\_toe\_wet} = 0.92 \cdot \frac{kip}{ft}$

Distance of Soil Weight from toe

$L_{soil\_toe} := \frac{l_{toe}}{2}$ $L_{soil\_toe} = 2\,ft$

Weight of Soil On Toe - Submurged Soil

$W_{soil\_toe\_sub} := \gamma_{sub} \cdot d_{soil\_prct} \cdot l_{toe}$

$W_{soil\_toe\_sub} = 0.421 \cdot \frac{kip}{ft}$

Distance of Soil Weight from toe $L_{soil\_toe} = 2\,ft$

Weight of Soil On Heel - Wet Soil, not submurged

DRAFT

$$W_{soil\_heel\_wet} := \gamma_{wet} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_wet} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe

$$L_{soil\_heel} := l_{toe} + t_w + \frac{l_{heel}}{2} \qquad L_{soil\_heel} = 7.5\,ft$$

Weight of Soil On Toe - Submurged Soil

$$W_{soil\_heel\_sub} := \gamma_{sub} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_sub} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe $L_{soil\_heel} = 7.5\,ft$

Weight of wall Stem

$$W_{stem} := \gamma_c \cdot t_w \cdot \left(h_{wall} + t_f\right) \qquad W_{stem} = 1.8 \cdot \frac{kip}{ft}$$

Distance of Stem Wight from Toe

$$L_{stem} := l_{toe} + \frac{t_w}{2} \qquad L_{stem} = 4.75\,ft$$

Weight of wall Heel

$$W_{heel} := \gamma_c \cdot t_f \cdot l_{heel} \qquad W_{heel} = 1.2 \cdot \frac{kip}{ft}$$

Distance from Heel Weight to Toe

$$L_{heel} := l_{toe} + t_f + \frac{l_{heel}}{2} \qquad L_{heel} = 8\,ft$$

Weight of Toe

$$W_{toe} := \gamma_c \cdot l_{toe} \cdot t_f \qquad W_{toe} = 1.2 \cdot \frac{kip}{ft}$$

Distance from Toe weight to Toe end $L_{toe} := \frac{l_{toe}}{2}$ $L_{toe} = 2\,ft$

Earthquake Loading

Use Westegard for water loading under earthquakes

Westergaard factor - per EM 1110-2-2502 $C_E := 0.051 \frac{kip}{ft^3}$

DRAFT

Total Earthquake Force $$P_E := \frac{2}{3} \cdot C_E \cdot k_h \cdot \left(d_{water\_norm} - d_{soil\_flood}\right)^2$$

$$P_E = 0.027 \cdot \frac{kip}{ft}$$

Distance of water EQ force from bottom of foundation

$$h_{EQ} := d_{soil\_flood} + 0.4\left(d_{water\_norm} - d_{soil\_flood}\right) + t_f \qquad h_{EQ} = 2.8\,ft$$

Lateral Load from Wall's own wieght

$$F_w := k_h \cdot \left(W_{stem} + W_{toe} + W_{heel} + W_{soil\_heel\_wet}\right) \qquad F_w = 0.84 \cdot \frac{kip}{ft}$$

Distance of Wall EQ force from top of foundation

$$h_{EQ\_wall} := \frac{h_{wall}}{2} + t_f \qquad h_{EQ\_wall} = 5\,ft$$

Wind Loading

Based on ASCE 7-05 6.5.14 Freestanding walls and signs

Wind Speed $V := 85mph$

Directionality Coefficient $K_d := 0.85$

Velocity Pressure Coefficient $K_z := 0.85$ Assumes exposure C at 15ft or less

Topographic Coefficient $K_{zt} := 1.0$

Importance Factor $I := 1.15$ Assumes that it is catagory III

Velocity Pressure $$q_h := 0.00256 K_z \cdot K_{zt} \cdot K_d \cdot \left(\frac{V}{mph}\right)^2 \cdot I \cdot psf$$

$$q_h = 15.368 \cdot psf$$

Gusset Effect Factor $G := 0.85$

Net Force Coefficient $C_f := 1.3$

Design Wind Pressure $p_{wind} := q_h \cdot G \cdot C_f$ $\qquad p_{wind} = 16.981 \cdot psf$

Lateral Load from Wind $F_{wind} := p_{wind} \cdot \left(h_{height}\right)$ $\qquad F_{wind} = 0.102 \cdot \frac{kip}{ft}$

Distance of Wind load from bottom of foundation

$$h_{wind} := \frac{h_{wall}}{2} + t_f \qquad h_{wind} = 5\,ft$$

DRAFT

Load Cases:

Look at the load cases in ASCE7/IBC/ACI318 for guidance on what to include in which combination, and what load factors to use.

Design Flood Loading

Water to Top of Wall

Earthquake Loading

Construction and Short Duration Loading

Loads and Load Cases

Stability/Overturning

Design Flood Load

Overturning moment - caused by design water flood load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot} := R_{water} \cdot h_{water} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift} \cdot L_{uplift}$$

$$M_{ot} = 10.252 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right} = 28.006 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

DRAFT

$\Sigma V = 4.387 \cdot \frac{kip}{ft}$

Distance of resultant from toe: $x_R := \frac{M_{right} - M_{ot}}{\Sigma V}$ $\quad x_R = 4.047\ ft$

Resultant Ratio: $Ratio := \frac{x_R}{(l_{toe} + t_w + l_{heel})}$ $\quad Ratio = 0.426$

About what percent of foundation is in compression?

$base\_compression_1 := percent_{comp}(Ratio)$

$base\_compression_1 = 100 \cdot \%$

Water to Top of Wall Load

Overturning moment - caused by water to top of wall load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot2} := R_{water2} \cdot h_{water2} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift2} \cdot L_{uplift}$$

$$M_{ot2} = 19.627 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right2} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water2} \cdot L_{water} \cdots$$
$$+ W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right2} = 33.622 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$\Sigma V_2 = 4.246 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R2} := \frac{M_{right2} - M_{ot2}}{\Sigma V_2}$ $\quad x_{R2} = 3.296\ ft$

Resultant Ratio: $Ratio_2 := \frac{x_{R2}}{(l_{toe} + t_w + l_{heel})}$ $\quad Ratio_2 = 0.347$

DRAFT

About what percent of foundation is in compression?

$$base\_compression_2 := percent_{comp}(Ratio_2)$$

$$base\_compression_2 = 100 \cdot \%$$

Earthquake Load

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and the added earthquake load based on water weight and wall self weight. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot3} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + P_E \cdot h_{EQ} + F_w \cdot h_{EQ\_wall}$$

$$M_{ot3} = 12.11 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right3} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right3} = 26.134 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_3 = 4.434 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R3} := \dfrac{M_{right3} - M_{ot3}}{\Sigma V_3}$ $x_{R3} = 3.163\,ft$

Resultant Ratio: $Ratio_3 := \dfrac{x_{R3}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_3 = 0.333$

About what percent of foundation is in compression?

$$base\_compression_3 := percent_{comp}(Ratio_3)$$

$$base\_compression_3 = 75 \cdot \%$$

Wind Load

DRAFT

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and wind loads. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot4} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + F_{wind} \cdot h_{wind}$$

$$M_{ot4} = 8.343 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right4} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right4} = 26.134 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_4 = 4.434 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R4} := \frac{M_{right4} - M_{ot4}}{\Sigma V_4}$ $x_{R4} = 4.013\ ft$

Resultant Ratio: $Ratio_4 := \frac{x_{R4}}{\left(l_{toe} + t_w + l_{heel}\right)}$ $Ratio_4 = 0.422$

About what percent of foundation is in compression?

$$base\_compression_4 := percent_{comp}\left(Ratio_4\right)$$

$$base\_compression_4 = 100 \cdot \%$$

Stability/Overturning

Stability/Sliding

Design Flood Load

Lateral Loads come from hydrostatic loads at design flood level There will be seepage/uplift that will lower the normal force that increases friction.

DRAFT

Actual Shear Force

$$V_1 := \left|R_{water} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet}\right| \qquad V_1 = 0.373 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_1 := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

$$N_1 = 4.387 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s1} := \frac{N_1 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_1} \qquad FS_{s1} = 6.797$$

Water to top of Wall Load

Lateral Loads come from hydrostatic loads at the top of the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_2 := R_{water2} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet} \qquad V_2 = 1.589 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$N_2 = 4.246 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s2} := \frac{N_2 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_2} \qquad FS_{s2} = 1.543$$

Earthquake Load

Lateral Loads come from Earthquake loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

DRAFT

$$V_3 := R_{water3} + R_{soil\_flood\_sub} + P_E + F_w \qquad V_3 = 1.419 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_3 = 4.434 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s3} := \frac{N_3 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_3} \qquad FS_{s3} = 1.804$$

Wind Load

Lateral Loads come from Wind loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_4 := R_{water3} + R_{soil\_flood\_sub} + F_{wind} \qquad V_4 = 0.654 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_4 = 4.434 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s4} := \frac{N_4 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_4} \qquad FS_{s4} = 3.916$$

Stability/Sliding

Soil Bearing Capacity

Design Flood Load

Distance of base reaction to toe $x_1 := \frac{M_{right} - M_{ot}}{N_1}$ $x_1 = 4.047\ ft$

DRAFT

Distance of Base reaction from center of footing $e_1 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_1$

$e_1 = 0.703\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_1 := N_1 \cdot e_1$ $M_1 = 3.083 \cdot \frac{kip \cdot ft}{ft}$

$q_{1a} := \frac{N_1}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_1}{(l_{toe} + l_{heel} + t_w)^2}$ $q_{1a} = 0.667 \cdot ksf$

Maximum moment if reaction is outside the kern:

$q_{1b} := \frac{2 \cdot N_1}{3 \cdot x_1}$ $q_{1b} = 0.723 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern := \frac{l_{toe} + l_{heel} + t_w}{6}$ $kern = 1.583\ ft$

Maximum bearing pressure: $q_1 := if(e_1 \le kern, q_{1a}, q_{1b})$

$q_1 = 0.667 \cdot ksf$

Safety Factor $SF_1 := \frac{b_{soil}}{q_1}$ $SF_1 = 3$

Water to top of Wall Load

Distance of base reaction to toe $x_2 := \frac{M_{right2} - M_{ot2}}{N_2}$ $x_2 = 3.296\ ft$

Distance of Base reaction from center of footing $e_2 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_2$

$e_2 = 1.454\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_2 := N_2 \cdot e_2$ $M_2 = 6.175 \cdot \frac{kip \cdot ft}{ft}$

$q_{2a} := \frac{N_2}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_2}{(l_{toe} + l_{heel} + t_w)^2}$ $q_{2a} = 0.858 \cdot ksf$

Maximum moment if reaction is outside the kern:

DRAFT

$$q_{2b} := \frac{2 \cdot N_2}{3 \cdot x_2} \qquad q_{2b} = 0.859 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 1.583\ ft$

Maximum bearing pressure: $q_2 := if(e_2 \le kern, q_{2a}, q_{2b})$ $q_2 = 0.858 \cdot ksf$

Safety Factor $SF_2 := \frac{b_{soil}}{q_2}$ $SF_2 = 2.332$

Earthquake Load

Distance of base reaction to toe $x_3 := \frac{M_{right3} - M_{ot3}}{N_3}$ $x_3 = 3.163\ ft$

Distance of Base reaction from center of footing $e_3 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_3$

$e_3 = 1.587\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_3 := N_3 \cdot e_3$ $M_3 = 7.036 \cdot \frac{kip \cdot ft}{ft}$

$$q_{3a} := \frac{N_3}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_3}{(l_{toe} + l_{heel} + t_w)^2} \qquad q_{3a} = 0.934 \cdot ksf$$

Maximum moment if reaction is outside the kern:

$$q_{3b} := \frac{2 \cdot N_3}{3 \cdot x_3} \qquad q_{3b} = 0.934 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 1.583\ ft$

Maximum bearing pressure: $q_3 := if(e_3 \le kern, q_{3a}, q_{3b})$ $q_3 = 0.934 \cdot ksf$

Safety Factor $SF_3 := \frac{b_{soil}}{q_3}$ $SF_3 = 2.14$

Wind Load

DRAFT

Distance of base reaction to toe $x_4 := \frac{M_{right4} - M_{ot4}}{N_4}$ $x_4 = 4.013\ ft$

Distance of Base reaction from center of footing $e_4 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_4$

$e_4 = 0.737\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_4 := N_4 \cdot e_4$ $M_4 = 3.269 \cdot \frac{kip \cdot ft}{ft}$

$$q_{4a} := \frac{N_4}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_4}{(l_{toe} + l_{heel} + t_w)^2}$$ $q_{4a} = 0.684 \cdot ksf$

Maximum moment if reaction is outside the kern:

$q_{4b} := \frac{2 \cdot N_4}{3 \cdot x_4}$ $q_{4b} = 0.737 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern = 1.583\ ft$

Maximum bearing pressure: $q_4 := if(e_4 \le kern, q_{4a}, q_{4b})$ $q_4 = 0.684 \cdot ksf$

Safety Factor $SF_4 := \frac{b_{soil}}{q_4}$ $SF_4 = 2.924$

Soil Bearing Capacity

Summary

Sliding Safety Factor

Flood Load $FS_{s1} = 6.797$ $Slide_1 := if(FS_{s1} \ge 1.5, "OK", "NG")$ $Slide_1 = "OK"$

Water to Top of Wall $FS_{s2} = 1.543$ $Slide_2 := if(FS_{s2} \ge 1.33, "OK", "NG")$ $Slide_2 = "OK"$

DRAFT

Earthquake $FS_{s3} = 1.804$ $Slide_3 := if\left(FS_{s3} \geq 1.1, \text{"OK"}, \text{"NG"}\right)$ $Slide_3 = \text{"OK"}$

Wind $FS_{s4} = 3.916$ $Slide_4 := if\left(FS_{s4} \geq 1.33, \text{"OK"}, \text{"NG"}\right)$ $Slide_4 = \text{"OK"}$

Overturning Compression

Flood Load $base\_compression_1 = 100 \cdot \%$

$OT_1 := if\left(base\_compression_1 \geq 1.0, \text{"OK"}, \text{"NG"}\right)$ $OT_1 = \text{"OK"}$

Water to Top of Wall $base\_compression_2 = 100 \cdot \%$

$OT_2 := if\left(base\_compression_2 \geq 0.75, \text{"OK"}, \text{"NG"}\right)$ $OT_2 = \text{"OK"}$

Earthquake $base\_compression_3 = 75 \cdot \%$

$OT_3 := if\left(base\_compression_3 \geq 0.5, \text{"OK"}, \text{"NG"}\right)$ $OT_3 = \text{"OK"}$

Wind $base\_compression_4 = 100 \cdot \%$

$OT_4 := if\left(base\_compression_4 \geq 0.75, \text{"OK"}, \text{"NG"}\right)$ $OT_4 = \text{"OK"}$

Bearing Capacity Safety Factor

Flood Load $SF_1 = 3$ $Bearing_1 := if\left(SF_1 \geq 3.0, \text{"OK"}, \text{"NG"}\right)$ $Bearing_1 = \text{"NG"}$ OK

Water to Top of Wall $SF_2 = 2.332$ $Bearing_2 := if\left(SF_2 \geq 2.0, \text{"OK"}, \text{"NG"}\right)$ $Bearing_2 = \text{"OK"}$

Earthquake $SF_3 = 2.14$ $Bearing_3 := if\left(SF_3 > 1.0, \text{"OK"}, \text{"NG"}\right)$ $Bearing_3 = \text{"OK"}$

Wind $SF_4 = 2.924$ $Bearing_4 := if\left(SF_4 \geq 2.0, \text{"OK"}, \text{"NG"}\right)$ $Bearing_4 = \text{"OK"}$

Summary

DRAFT

Flood Wall Design

Project - Puyallup GI Study
This is for areas with 8ft between grade and top of wall

Formulas, Tables, Etc

Input Variables

Wall Thickness	$t_w := 18in$	
Foundation Thickness	$t_f := 2.5ft$	
Wall Height Above Soil	$h_{height} := 8ft$	
Soil Depth - Protected Side	$d_{soil\_prct} := 2ft$	
Soil Depth - Flood Side	$d_{soil\_flood} := 0ft$	
Wall Height	$h_{wall} := d_{soil\_flood} + h_{height}$	$h_{wall} = 8\ ft$
Freeboard at 100yr flood	$d_{freeboard} := 3ft$	
Water Depth (design Depth)	$d_{water} := h_{wall} - d_{freeboard}$	$d_{water} = 5\ ft$
Water Depth (normal Flow)	$d_{water\_norm} := 2ft$	
Heel Length	$l_{heel} := 7ft$	
Toe Length	$l_{toe} := 7.5ft$	
Concrete Strength	$f'_c := 4000psi$	
Rebar Strength	$f_y := 60000psi$	
Unit Weight of Concrete	$\gamma_c := 150pcf$	
Unit Weight of Water	$\gamma_{h2o} := 62.4pcf$	
Dry Unit Weight of Soil	$\gamma_{dry} := 100pcf$	
Wet Unit Weight of Soil	$\gamma_{wet} := 115pcf$	
Submerged Unit Weight of Soil	$\gamma_{sub} := \gamma_{wet} - \gamma_{h2o}$	$\gamma_{sub} = 52.6 \cdot pcf$
Bearing Capacity of Soil	$b_{soil} := 2000psf$	
At Rest Soil Coefficient	$K_0 := 0.5$	

DRAFT

Active Soil Coefficient	$K_a := 0.33$
Passive Soil Coefficient	$K_p := 3.0$
Angle of Internal Friction	$\phi_s := 30deg$
Coeficient of Friction	$\mu := 0.2$
Cohesion	$c := 0psf$
Modulus of Subgrade Reaction	$K_s := 350pci$
Frost Depth	$d_{frost} := 18in$
Earthquake design acceleration	$k_h := 0.2$

Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Assumed percent of total pressure toe $\quad pore\_toe := 10\%$

Assumed Percent of total pressure at heel $\quad pore\_heel := 90\%$

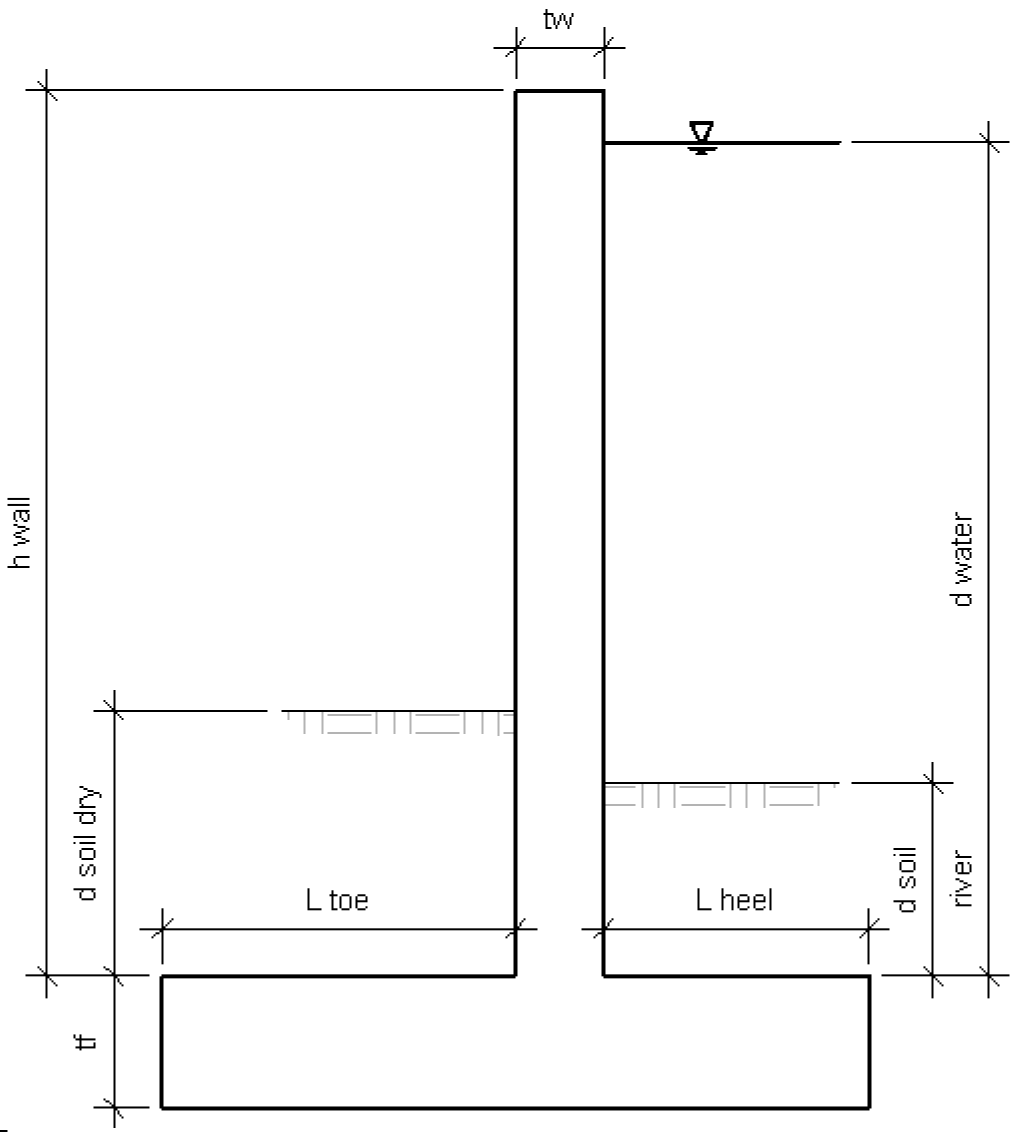
Uplift Reduction Factor $\quad uplift\_reduce := \frac{pore\_toe + pore\_heel}{2}$

$uplift\_reduce = 50 \cdot \%$

Location of Reaction from toe (percent) $\quad uplift\_react := 1 - \left[\frac{2 \cdot pore\_toe + pore\_heel}{3 \cdot (pore\_toe + pore\_heel)}\right]$

$uplift\_react = 63.333 \cdot \%$

DRAFT



Input Variables

Loads and Load Cases

Horizontal Loads

Land Side At Rest Soil Load - Resisting Load Assumed to be zero to be conservative

Flood Side at Rest Soil Load (wet not suburged)

Peak Pressure from soil $p_{soil\_flood\_wet} := \gamma_{wet} \cdot K_0 \cdot \left(d_{soil\_flood} + t_f\right)$

$$p_{soil\_flood\_wet} = 143.75 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{soil\_flood} := \frac{\left(d_{soil\_flood} + t_f\right)}{3} \qquad h_{soil\_flood} = 0.833\ ft$$

Total Resultant force from Soil

$$R_{soil\_flood\_wet} := \frac{p_{soil\_flood\_wet} \cdot \left(d_{soil\_flood} + t_f\right)}{2}$$

$$R_{soil\_flood\_wet} = 0.18 \cdot \frac{kip}{ft}$$

Flood Side at Rest Soil Load (suburged)

Peak Pressure from soil

$$p_{soil\_flood\_sub} := \gamma_{sub} \cdot K_0 \cdot \left(d_{soil\_flood} + t_f\right)$$

$$p_{soil\_flood\_sub} = 65.75 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{soil\_flood} = 0.833\ ft$$

Total Resultant force from Soil

$$R_{soil\_flood\_sub} := \frac{p_{soil\_flood\_sub} \cdot \left(d_{soil\_flood} + t_f\right)}{2}$$

$$R_{soil\_flood\_sub} = 0.082 \cdot \frac{kip}{ft}$$

Protected Side At Rest Soil Pressure

Peak Pressure from soil

$$p_{soil\_prct\_wet} := \gamma_{wet} \cdot K_0 \cdot \left(d_{soil\_prct} + t_f\right)$$

$$p_{soil\_prct\_wet} = 258.75 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{soil\_prct} := \frac{\left(d_{soil\_prct} + t_f\right)}{3} \qquad h_{soil\_prct} = 1.5\ ft$$

Total Resultant force from Soil

$$R_{soil\_prct\_wet} := \frac{p_{soil\_prct\_wet} \cdot \left(d_{soil\_prct} + t_f\right)}{2}$$

$$R_{soil\_prct\_wet} = 0.582 \cdot \frac{kip}{ft}$$

Flood Side Design Flood Pressure

Peak Pressure from water
at design flood elevation

$$p_{water} := \gamma_{h2o} \cdot \left(d_{water} + t_f\right) \qquad p_{water} = 468 \cdot psf$$

DRAFT

Distance of resultant from bottom of footing

$$h_{water} := \frac{d_{water} + t_f}{3} \qquad h_{water} = 2.5\,ft$$

Total Resultant force from Soil

$$R_{water} := \frac{p_{water} \cdot (d_{water} + t_f)}{2} \qquad R_{water} = 1.755 \cdot \frac{kip}{ft}$$

Fllod Side Flood Pressure - Water at top of wall

Peak Pressure from water up to the top of the wall

$$p_{water2} := \gamma_{h2o} \cdot (t_f + h_{wall}) \qquad p_{water2} = 655.2 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water2} := \frac{h_{wall} + t_f}{3} \qquad h_{water2} = 3.5\,ft$$

Total Resultant force from Water

$$R_{water2} := \frac{p_{water2} \cdot (h_{wall} + t_f)}{2} \qquad R_{water2} = 3.44 \cdot \frac{kip}{ft}$$

Flood Side Water Pressure - Normal Flow Conditions

Peak Pressure from water at normal flow conditions

$$p_{water3} := \gamma_{h2o} \cdot (t_f + d_{water\_norm}) \qquad p_{water3} = 280.8 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water3} := \frac{d_{water\_norm} + t_f}{3} \qquad h_{water3} = 1.5\,ft$$

Total Resultant force from Water

$$R_{water3} := \frac{p_{water3} \cdot (d_{water\_norm} + t_f)}{2} \qquad R_{water3} = 0.632 \cdot \frac{kip}{ft}$$

DRAFT

Vertical Loads

Uplift on Foundation due to water.
Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Uplift from water at design flood load

$$p_{uplift} := p_{water}$$ $$p_{uplift} = 468 \cdot psf$$

Distance from the toe to centroid of uplift

$$L_{uplift} := \left(l_{toe} + l_{heel} + t_w\right) \cdot uplift\_react$$ $$L_{uplift} = 10.133\,ft$$

Total Uplift Force

$$R_{uplift} := uplift\_reduce\, p_{uplift} \cdot \left(l_{toe} + l_{heel} + t_w\right)$$

$$R_{uplift} = 3.744 \cdot \frac{kip}{ft}$$

Uplift force from water to top of wall

$$P_{uplift2} := p_{water2}$$ $$P_{uplift2} = 655.2 \cdot psf$$

Distance from the toe to centroid of uplift

$$L_{uplift} = 10.133\,ft$$

Total Uplift Force

$$R_{uplift2} := uplift\_reduce\, P_{uplift2} \cdot \left(l_{toe} + l_{heel} + t_w\right)$$

$$R_{uplift2} = 5.242 \cdot \frac{kip}{ft}$$

Uplift force from water at normal flow levels

$$P_{uplift3} := p_{water3}$$ $$P_{uplift3} = 280.8 \cdot psf$$

Distance from the toe to centroid of uplift

$$L_{uplift} = 10.133\,ft$$

Total Uplift Force

$$R_{uplift3} := uplift\_reduce\, P_{uplift3} \cdot \left(l_{toe} + l_{heel} + t_w\right)$$

$$R_{uplift3} = 2.246 \cdot \frac{kip}{ft}$$

Weight of Water above Heel at design flood level

DRAFT

$$W_{water} := \gamma_{h2o} \cdot d_{water} \cdot l_{heel} \qquad W_{water} = 2.184 \cdot \frac{kip}{ft}$$

Distance of Water Weight from toe

$$L_{water} := l_{toe} + t_w + \frac{l_{heel}}{2} \qquad L_{water} = 12.5\,ft$$

Weight of Water above Heel at design flood level

$$W_{water2} := \gamma_{h2o} \cdot h_{wall} \cdot l_{heel} \qquad W_{water2} = 3.494 \cdot \frac{kip}{ft}$$

Distance of Water Weight from toe

$$L_{water} = 12.5\,ft$$

Weight of Water at normal flow levels

$$W_{water3} := \gamma_{h2o} \cdot d_{water\_norm} \cdot l_{heel} \qquad W_{water3} = 0.874 \cdot \frac{kip}{ft}$$

Weight of Soil On Toe - Wet Soil, not submurged

$$W_{soil\_toe\_wet} := \gamma_{wet} \cdot d_{soil\_prct} \cdot l_{toe}$$

$$W_{soil\_toe\_wet} = 1.725 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe

$$L_{soil\_toe} := \frac{l_{toe}}{2} \qquad L_{soil\_toe} = 3.75\,ft$$

Weight of Soil On Toe - Submurged Soil

$$W_{soil\_toe\_sub} := \gamma_{sub} \cdot d_{soil\_prct} \cdot l_{toe}$$

$$W_{soil\_toe\_sub} = 0.789 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe $L_{soil\_toe} = 3.75\,ft$

Weight of Soil On Heel - Wet Soil, not submurged

DRAFT

$$W_{soil\_heel\_wet} := \gamma_{wet} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_wet} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe

$$L_{soil\_heel} := l_{toe} + t_w + \frac{l_{heel}}{2} \qquad L_{soil\_heel} = 12.5\,ft$$

Weight of Soil On Toe - Submurged Soil

$$W_{soil\_heel\_sub} := \gamma_{sub} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_sub} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe $L_{soil\_heel} = 12.5\,ft$

Weight of wall Stem

$$W_{stem} := \gamma_c \cdot t_w \cdot \left(h_{wall} + t_f\right) \qquad W_{stem} = 2.362 \cdot \frac{kip}{ft}$$

Distance of Stem Wight from Toe

$$L_{stem} := l_{toe} + \frac{t_w}{2} \qquad L_{stem} = 8.25\,ft$$

Weight of wall Heel

$$W_{heel} := \gamma_c \cdot t_f \cdot l_{heel} \qquad W_{heel} = 2.625 \cdot \frac{kip}{ft}$$

Distance from Heel Weight to Toe

$$L_{heel} := l_{toe} + t_f + \frac{l_{heel}}{2} \qquad L_{heel} = 13.5\,ft$$

Weight of Toe

$$W_{toe} := \gamma_c \cdot l_{toe} \cdot t_f \qquad W_{toe} = 2.812 \cdot \frac{kip}{ft}$$

Distance from Toe weight to Toe end $L_{toe} := \frac{l_{toe}}{2} \qquad L_{toe} = 3.75\,ft$

Earthquake Loading

Use Westegard for water loading under earthquakes

Westergaard factor - per EM 1110-2-2502 $C_E := 0.051 \frac{kip}{ft^3}$

DRAFT

Total Earthquake Force $P_E := \frac{2}{3} \cdot C_E \cdot k_h \cdot \left(d_{water\_norm} - d_{soil\_flood}\right)^2$

$P_E = 0.027 \cdot \frac{kip}{ft}$

Distance of water EQ force from bottom of foundation

$h_{EQ} := d_{soil\_flood} + 0.4\left(d_{water\_norm} - d_{soil\_flood}\right) + t_f$ $h_{EQ} = 3.3\,ft$

Lateral Load from Wall's own wieght

$F_w := k_h \cdot \left(W_{stem} + W_{toe} + W_{heel} + W_{soil\_heel\_wet}\right)$ $F_w = 1.56 \cdot \frac{kip}{ft}$

Distance of Wall EQ force from top of foundation

$h_{EQ\_wall} := \frac{h_{wall}}{2} + t_f$ $h_{EQ\_wall} = 6.5\,ft$

Wind Loading

Based on ASCE 7-05 6.5.14 Freestanding walls and signs

Wind Speed $V := 85mph$

Directionality Coefficient $K_d := 0.85$

Velocity Pressure Coefficient $K_z := 0.85$ Assumes exposure C at 15ft or less

Topographic Coefficient $K_{zt} := 1.0$

Importance Factor $I := 1.15$ Assumes that it is catagory III

Velocity Pressure $q_h := 0.00256 K_z \cdot K_{zt} \cdot K_d \cdot \left(\frac{V}{mph}\right)^2 \cdot I \cdot psf$

$q_h = 15.368 \cdot psf$

Gusset Effect Factor $G := 0.85$

Net Force Coefficient $C_f := 1.3$

Design Wind Pressure $p_{wind} := q_h \cdot G \cdot C_f$ $p_{wind} = 16.981 \cdot psf$

Lateral Load from Wind $F_{wind} := p_{wind} \cdot \left(h_{height}\right)$ $F_{wind} = 0.136 \cdot \frac{kip}{ft}$

Distance of Wind load from bottom of foundation

$h_{wind} := \frac{h_{wall}}{2} + t_f$ $h_{wind} = 6.5\,ft$

DRAFT

Load Cases:

Look at the load cases in ASCE7/IBC/ACI318 for guidance on what to include in which combination, and what load factors to use.

Design Flood Loading

Water to Top of Wall

Earthquake Loading

Construction and Short Duration Loading

Loads and Load Cases

Stability/Overturning

Design Flood Load

Overturning moment - caused by design water flood load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot} := R_{water} \cdot h_{water} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift} \cdot L_{uplift}$$

$$M_{ot} = 42.395 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right} = 99.244 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

DRAFT

$$\Sigma V = 7.965 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_R := \frac{M_{right} - M_{ot}}{\Sigma V}$ $x_R = 7.137\,ft$

Resultant Ratio: $Ratio := \frac{x_R}{(l_{toe} + t_w + l_{heel})}$ $Ratio = 0.446$

About what percent of foundation is in compression?

$$base\_compression_1 := percent_{comp}(Ratio)$$

$$base\_compression_1 = 100 \cdot \%$$

Water to Top of Wall Load

Overturning moment - caused by water to top of wall load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot2} := R_{water2} \cdot h_{water2} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift2} \cdot L_{uplift}$$

$$M_{ot2} = 65.223 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right2} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water2} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right2} = 115.624 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$\Sigma V_2 = 7.778 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R2} := \frac{M_{right2} - M_{ot2}}{\Sigma V_2}$ $x_{R2} = 6.48\,ft$

Resultant Ratio: $Ratio_2 := \frac{x_{R2}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_2 = 0.405$

DRAFT

About what percent of foundation is in compression?

$$base\_compression_2 := percent_{comp}(Ratio_2)$$

$$base\_compression_2 = 100 \cdot \%$$

Earthquake Load

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and the added earthquake load based on water weight and wall self weight. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot3} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + P_E \cdot h_{EQ} + F_w \cdot h_{EQ\_wall}$$

$$M_{ot3} = 34.009 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right3} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right3} = 82.864 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_3 = 8.152 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R3} := \frac{M_{right3} - M_{ot3}}{\Sigma V_3}$ $x_{R3} = 5.993\ ft$

Resultant Ratio: $Ratio_3 := \frac{x_{R3}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_3 = 0.375$

About what percent of foundation is in compression?

$$base\_compression_3 := percent_{comp}(Ratio_3)$$

$$base\_compression_3 = 100 \cdot \%$$

Wind Load

DRAFT

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and wind loads. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot4} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + F_{wind} \cdot h_{wind}$$

$$M_{ot4} = 24.663 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right4} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right4} = 82.864 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_4 = 8.152 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R4} := \frac{M_{right4} - M_{ot4}}{\Sigma V_4}$ $x_{R4} = 7.139\ ft$

Resultant Ratio: $Ratio_4 := \frac{x_{R4}}{\left(l_{toe} + t_w + l_{heel}\right)}$ $Ratio_4 = 0.446$

About what percent of foundation is in compression?

$$base\_compression_4 := percent_{comp}\left(Ratio_4\right)$$

$$base\_compression_4 = 100 \cdot \%$$

Stability/Overturning

Stability/Sliding

Design Flood Load

Lateral Loads come from hydrostatic loads at design flood level There will be seepage/uplift that will lower the normal force that increases friction.

DRAFT

Actual Shear Force

$$V_1 := \left| R_{water} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet} \right| \qquad V_1 = 1.255 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_1 := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

$$N_1 = 7.965 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s1} := \frac{N_1 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_1} \qquad FS_{s1} = 3.664$$

Water to top of Wall Load

Lateral Loads come from hydrostatic loads at the top of the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_2 := R_{water2} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet} \qquad V_2 = 2.94 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$N_2 = 7.778 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s2} := \frac{N_2 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_2} \qquad FS_{s2} = 1.527$$

Earthquake Load

Lateral Loads come from Earthquake loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

DRAFT

$$V_3 := R_{water3} + R_{soil\_flood\_sub} + P_E + F_w \qquad V_3 = 2.301 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_3 = 8.152 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s3} := \frac{N_3 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_3} \qquad FS_{s3} = 2.045$$

Wind Load

Lateral Loads come from Wind loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_4 := R_{water3} + R_{soil\_flood\_sub} + F_{wind} \qquad V_4 = 0.85 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_4 = 8.152 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s4} := \frac{N_4 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_4} \qquad FS_{s4} = 5.538$$

Stability/Sliding

Soil Bearing Capacity

Design Flood Load

Distance of base reaction to toe $x_1 := \frac{M_{right} - M_{ot}}{N_1}$ $x_1 = 7.137\ ft$

DRAFT

Distance of Base reaction from center of footing $e_1 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_1$

$e_1 = 0.863\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_1 := N_1 \cdot e_1$ $M_1 = 6.871 \cdot \frac{kip \cdot ft}{ft}$

$$q_{1a} := \frac{N_1}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_1}{(l_{toe} + l_{heel} + t_w)^2} \qquad q_{1a} = 0.659 \cdot ksf$$

Maximum moment if reaction is outside the kern:

$$q_{1b} := \frac{2 \cdot N_1}{3 \cdot x_1} \qquad q_{1b} = 0.744 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern := \frac{l_{toe} + l_{heel} + t_w}{6}$ $kern = 2.667\ ft$

Maximum bearing pressure: $q_1 := if(e_1 \le kern, q_{1a}, q_{1b})$

$q_1 = 0.659 \cdot ksf$

Safety Factor $SF_1 := \frac{b_{soil}}{q_1}$ $SF_1 = 3.036$

Water to top of Wall Load

Distance of base reaction to toe $x_2 := \frac{M_{right2} - M_{ot2}}{N_2}$ $x_2 = 6.48\ ft$

Distance of Base reaction from center of footing $e_2 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_2$

$e_2 = 1.52\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_2 := N_2 \cdot e_2$ $M_2 = 11.821 \cdot \frac{kip \cdot ft}{ft}$

$$q_{2a} := \frac{N_2}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_2}{(l_{toe} + l_{heel} + t_w)^2} \qquad q_{2a} = 0.763 \cdot ksf$$

Maximum moment if reaction is outside the kern:

DRAFT

$$q_{2b} := \frac{2 \cdot N_2}{3 \cdot x_2} \qquad q_{2b} = 0.8 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 2.667\ ft$

Maximum bearing pressure: $q_2 := if(e_2 \le kern, q_{2a}, q_{2b})$ $q_2 = 0.763 \cdot ksf$

Safety Factor $SF_2 := \frac{b_{soil}}{q_2}$ $SF_2 = 2.621$

Earthquake Load

DRAFT

Distance of base reaction to toe $x_3 := \frac{M_{right3} - M_{ot3}}{N_3}$ $x_3 = 5.993\ ft$

Distance of Base reaction from center of footing $e_3 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_3$

$e_3 = 2.007\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_3 := N_3 \cdot e_3$ $M_3 = 16.363 \cdot \frac{kip \cdot ft}{ft}$

$$q_{3a} := \frac{N_3}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_3}{(l_{toe} + l_{heel} + t_w)^2} \qquad q_{3a} = 0.893 \cdot ksf$$

Maximum moment if reaction is outside the kern:

$$q_{3b} := \frac{2 \cdot N_3}{3 \cdot x_3} \qquad q_{3b} = 0.907 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 2.667\ ft$

Maximum bearing pressure: $q_3 := if(e_3 \le kern, q_{3a}, q_{3b})$ $q_3 = 0.893 \cdot ksf$

Safety Factor $SF_3 := \frac{b_{soil}}{q_3}$ $SF_3 = 2.24$

Wind Load

Distance of base reaction to toe $x_4 := \frac{M_{right4} - M_{ot4}}{N_4}$ $x_4 = 7.139\ ft$

Distance of Base reaction from center of footing $e_4 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_4$

$e_4 = 0.861\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_4 := N_4 \cdot e_4$ $M_4 = 7.017 \cdot \frac{kip \cdot ft}{ft}$

$$q_{4a} := \frac{N_4}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_4}{\left(l_{toe} + l_{heel} + t_w\right)^2}$$ $q_{4a} = 0.674 \cdot ksf$

Maximum moment if reaction is outside the kern:

$q_{4b} := \frac{2 \cdot N_4}{3 \cdot x_4}$ $q_{4b} = 0.761 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern = 2.667\ ft$

Maximum bearing pressure: $q_4 := if\left(e_4 \le kern, q_{4a}, q_{4b}\right)$ $q_4 = 0.674 \cdot ksf$

Safety Factor $SF_4 := \frac{b_{soil}}{q_4}$ $SF_4 = 2.968$

DRAFT

Soil Bearing Capacity

Summary

Sliding Safety Factor

Flood Load	$FS_{s1} = 3.664$	$Slide_1 := if\left(FS_{s1} \ge 1.5, \text{"OK"}, \text{"NG"}\right)$	$Slide_1 = \text{"OK"}$
Water to Top of Wall	$FS_{s2} = 1.527$	$Slide_2 := if\left(FS_{s2} \ge 1.33, \text{"OK"}, \text{"NG"}\right)$	$Slide_2 = \text{"OK"}$

Earthquake $FS_{s3} = 2.045$ $Slide_3 := if(FS_{s3} \ge 1.1, "OK", "NG")$ $Slide_3 = "OK"$

Wind $FS_{s4} = 5.538$ $Slide_4 := if(FS_{s4} \ge 1.33, "OK", "NG")$ $Slide_4 = "OK"$

Overturning Compression

Flood Load $base\_compression_1 = 100 \cdot \%$

$OT_1 := if(base\_compression_1 \ge 1.0, "OK", "NG")$ $OT_1 = "OK"$

Water to Top of Wall $base\_compression_2 = 100 \cdot \%$

$OT_2 := if(base\_compression_2 \ge 0.75, "OK", "NG")$ $OT_2 = "OK"$

Earthquake $base\_compression_3 = 100 \cdot \%$

$OT_3 := if(base\_compression_3 \ge 0.5, "OK", "NG")$ $OT_3 = "OK"$

Wind $base\_compression_4 = 100 \cdot \%$

$OT_4 := if(base\_compression_4 \ge 0.75, "OK", "NG")$ $OT_4 = "OK"$

Bearing Capacity Safety Factor

Flood Load $SF_1 = 3.036$ $Bearing_1 := if(SF_1 \ge 3.0, "OK", "NG")$ $Bearing_1 = "OK"$

Water to Top of Wall $SF_2 = 2.621$ $Bearing_2 := if(SF_2 \ge 2.0, "OK", "NG")$ $Bearing_2 = "OK"$

Earthquake $SF_3 = 2.24$ $Bearing_3 := if(SF_3 > 1.0, "OK", "NG")$ $Bearing_3 = "OK"$

Wind $SF_4 = 2.968$ $Bearing_4 := if(SF_4 \ge 2.0, "OK", "NG")$ $Bearing_4 = "OK"$

Summary

DRAFT

Flood Wall Design

Project - Puyallup GI Study
This is for areas with 10ft between grade and top of wall

Formulas, Tables, Etc

Input Variables

Wall Thickness	$t_w := 18in$	
Foundation Thickness	$t_f := 2.75ft$	
Wall Height Above Soil	$h_{height} := 10ft$	
Soil Depth - Protected Side	$d_{soil\_prct} := 2ft$	
Soil Depth - Flood Side	$d_{soil\_flood} := 0ft$	
Wall Height	$h_{wall} := d_{soil\_flood} + h_{height}$	$h_{wall} = 10\,ft$
Freeboard at 100yr flood	$d_{freeboard} := 3ft$	
Water Depth (design Depth)	$d_{water} := h_{wall} - d_{freeboard}$	$d_{water} = 7\,ft$
Water Depth (normal Flow)	$d_{water\_norm} := 3ft$	
Heel Length	$l_{heel} := 9ft$	
Toe Length	$l_{toe} := 11ft$	
Concrete Strength	$f'_c := 4000psi$	
Rebar Strength	$f_y := 60000psi$	
Unit Weight of Concrete	$\gamma_c := 150pcf$	
Unit Weight of Water	$\gamma_{h2o} := 62.4pcf$	
Dry Unit Weight of Soil	$\gamma_{dry} := 100pcf$	
Wet Unit Weight of Soil	$\gamma_{wet} := 115pcf$	
Submerged Unit Weight of Soil	$\gamma_{sub} := \gamma_{wet} - \gamma_{h2o}$	$\gamma_{sub} = 52.6 \cdot pcf$
Bearing Capacity of Soil	$b_{soil} := 2000psf$	
At Rest Soil Coefficient	$K_0 := 0.5$	

DRAFT

Active Soil Coefficient	$K_a := 0.33$
Passive Soil Coefficient	$K_p := 3.0$
Angle of Internal Friction	$\phi_s := 30deg$
Coeficient of Friction	$\mu := 0.20$
Cohesion	$c := 0psf$
Modulus of Subgrade Reaction	$K_s := 350pci$
Frost Depth	$d_{frost} := 18in$
Earthquake design acceleration	$k_h := 0.2$

Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Assumed percent of total pressure toe $pore\_toe := 10\%$

Assumed Percent of total pressure at heel $pore\_heel := 90\%$

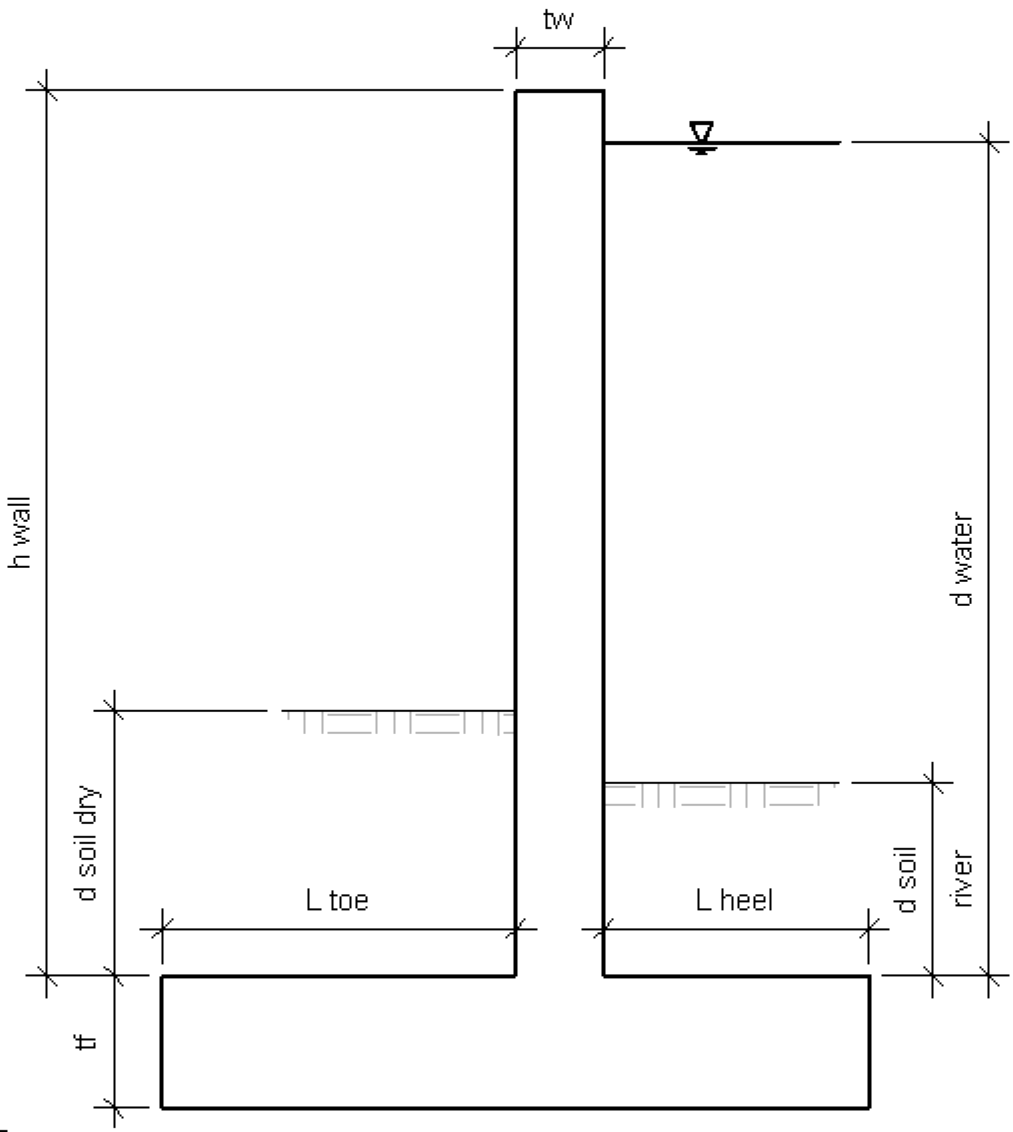
Uplift Reduction Factor $uplift\_reduce := \frac{pore\_toe + pore\_heel}{2}$

$uplift\_reduce = 50 \cdot \%$

Location of Reaction from toe (percent) $uplift\_react := 1 - \left[\frac{2 \cdot pore\_toe + pore\_heel}{3 \cdot (pore\_toe + pore\_heel)}\right]$

$uplift\_react = 63.333 \cdot \%$

DRAFT



Input Variables

Loads and Load Cases

Horizontal Loads

Land Side At Rest Soil Load - Resisting Load Assumed to be zero to be conservative

Flood Side at Rest Soil Load (wet not suburged)

Peak Pressure from soil $p_{soil\_flood\_wet} := \gamma_{wet} \cdot K_0 \cdot \left(d_{soil\_flood} + t_f\right)$

$$p_{soil\_flood\_wet} = 158.125 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{soil\_flood} := \frac{\left(d_{soil\_flood} + t_f\right)}{3} \qquad h_{soil\_flood} = 0.917\ ft$$

Total Resultant force from Soil

$$R_{soil\_flood\_wet} := \frac{p_{soil\_flood\_wet} \cdot \left(d_{soil\_flood} + t_f\right)}{2}$$

$$R_{soil\_flood\_wet} = 0.217 \cdot \frac{kip}{ft}$$

Flood Side at Rest Soil Load (suburged)

Peak Pressure from soil

$$p_{soil\_flood\_sub} := \gamma_{sub} \cdot K_0 \cdot \left(d_{soil\_flood} + t_f\right)$$

$$p_{soil\_flood\_sub} = 72.325 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{soil\_flood} = 0.917\ ft$$

Total Resultant force from Soil

$$R_{soil\_flood\_sub} := \frac{p_{soil\_flood\_sub} \cdot \left(d_{soil\_flood} + t_f\right)}{2}$$

$$R_{soil\_flood\_sub} = 0.099 \cdot \frac{kip}{ft}$$

Protected Side At Rest Soil Pressure

Peak Pressure from soil

$$p_{soil\_prct\_wet} := \gamma_{wet} \cdot K_0 \cdot \left(d_{soil\_prct} + t_f\right)$$

$$p_{soil\_prct\_wet} = 273.125 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{soil\_prct} := \frac{\left(d_{soil\_prct} + t_f\right)}{3} \qquad h_{soil\_prct} = 1.583\ ft$$

Total Resultant force from Soil

$$R_{soil\_prct\_wet} := \frac{p_{soil\_prct\_wet} \cdot \left(d_{soil\_prct} + t_f\right)}{2}$$

$$R_{soil\_prct\_wet} = 0.649 \cdot \frac{kip}{ft}$$

Flood Side Design Flood Pressure

Peak Pressure from water at design flood elevation

$$p_{water} := \gamma_{h2o} \cdot \left(d_{water} + t_f\right) \qquad p_{water} = 608.4 \cdot psf$$

DRAFT

Distance of resultant from bottom of footing

$$h_{water} := \frac{d_{water} + t_f}{3} \qquad h_{water} = 3.25\,ft$$

Total Resultant force from Soil

$$R_{water} := \frac{p_{water} \cdot (d_{water} + t_f)}{2} \qquad R_{water} = 2.966 \cdot \frac{kip}{ft}$$

Fllod Side Flood Pressure - Water at top of wall

Peak Pressure from water up to the top of the wall

$$p_{water2} := \gamma_{h2o} \cdot (t_f + h_{wall}) \qquad p_{water2} = 795.6 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water2} := \frac{h_{wall} + t_f}{3} \qquad h_{water2} = 4.25\,ft$$

Total Resultant force from Water

$$R_{water2} := \frac{p_{water2} \cdot (h_{wall} + t_f)}{2} \qquad R_{water2} = 5.072 \cdot \frac{kip}{ft}$$

Flood Side Water Pressure - Normal Flow Conditions

Peak Pressure from water at normal flow conditions

$$p_{water3} := \gamma_{h2o} \cdot (t_f + d_{water\_norm}) \qquad p_{water3} = 358.8 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water3} := \frac{d_{water\_norm} + t_f}{3} \qquad h_{water3} = 1.917\,ft$$

Total Resultant force from Water

$$R_{water3} := \frac{p_{water3} \cdot (d_{water\_norm} + t_f)}{2} \qquad R_{water3} = 1.032 \cdot \frac{kip}{ft}$$

DRAFT

Vertical Loads

Uplift on Foundation due to water.
Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Uplift from water at design flood load

$p_{uplift} := p_{water}$ $p_{uplift} = 608.4 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} := \left(l_{toe} + l_{heel} + t_w\right) \cdot uplift\_react$ $L_{uplift} = 13.617\,ft$

Total Uplift Force

$R_{uplift} := uplift\_reduce\, p_{uplift} \cdot \left(l_{toe} + l_{heel} + t_w\right)$

$R_{uplift} = 6.54 \cdot \frac{kip}{ft}$

Uplift force from water to top of wall

$P_{uplift2} := p_{water2}$ $P_{uplift2} = 795.6 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} = 13.617\,ft$

Total Uplift Force

$R_{uplift2} := uplift\_reduce\, P_{uplift2} \cdot \left(l_{toe} + l_{heel} + t_w\right)$

$R_{uplift2} = 8.553 \cdot \frac{kip}{ft}$

Uplift force from water at normal flow levels

$P_{uplift3} := p_{water3}$ $P_{uplift3} = 358.8 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} = 13.617\,ft$

Total Uplift Force

$R_{uplift3} := uplift\_reduce\, P_{uplift3} \cdot \left(l_{toe} + l_{heel} + t_w\right)$

$R_{uplift3} = 3.857 \cdot \frac{kip}{ft}$

Weight of Water above Heel at design flood level

DRAFT

$W_{water} := \gamma_{h2o} \cdot d_{water} \cdot l_{heel}$ $W_{water} = 3.931 \cdot \frac{kip}{ft}$

Distance of Water Weight from toe

$L_{water} := l_{toe} + t_w + \frac{l_{heel}}{2}$ $L_{water} = 17\,ft$

Weight of Water above Heel at design flood level

$W_{water2} := \gamma_{h2o} \cdot h_{wall} \cdot l_{heel}$ $W_{water2} = 5.616 \cdot \frac{kip}{ft}$

Distance of Water Weight from toe

$L_{water} = 17\,ft$

Weight of Water at normal flow levels

$W_{water3} := \gamma_{h2o} \cdot d_{water\_norm} \cdot l_{heel}$ $W_{water3} = 1.685 \cdot \frac{kip}{ft}$

Weight of Soil On Toe - Wet Soil, not submurged

$W_{soil\_toe\_wet} := \gamma_{wet} \cdot d_{soil\_prct} \cdot l_{toe}$

$W_{soil\_toe\_wet} = 2.53 \cdot \frac{kip}{ft}$

Distance of Soil Weight from toe

$L_{soil\_toe} := \frac{l_{toe}}{2}$ $L_{soil\_toe} = 5.5\,ft$

Weight of Soil On Toe - Submurged Soil

$W_{soil\_toe\_sub} := \gamma_{sub} \cdot d_{soil\_prct} \cdot l_{toe}$

$W_{soil\_toe\_sub} = 1.157 \cdot \frac{kip}{ft}$

Distance of Soil Weight from toe $L_{soil\_toe} = 5.5\,ft$

Weight of Soil On Heel - Wet Soil, not submurged

DRAFT

$$W_{soil\_heel\_wet} := \gamma_{wet} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_wet} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe

$$L_{soil\_heel} := l_{toe} + t_w + \frac{l_{heel}}{2} \qquad L_{soil\_heel} = 17\,ft$$

Weight of Soil On Toe - Submurged Soil

$$W_{soil\_heel\_sub} := \gamma_{sub} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_sub} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe $\quad L_{soil\_heel} = 17\,ft$

Weight of wall Stem

$$W_{stem} := \gamma_c \cdot t_w \cdot \left(h_{wall} + t_f\right) \qquad W_{stem} = 2.869 \cdot \frac{kip}{ft}$$

Distance of Stem Wight from Toe

$$L_{stem} := l_{toe} + \frac{t_w}{2} \qquad L_{stem} = 11.75\,ft$$

Weight of wall Heel

$$W_{heel} := \gamma_c \cdot t_f \cdot l_{heel} \qquad W_{heel} = 3.713 \cdot \frac{kip}{ft}$$

Distance from Heel Weight to Toe

$$L_{heel} := l_{toe} + t_f + \frac{l_{heel}}{2} \qquad L_{heel} = 18.25\,ft$$

Weight of Toe

$$W_{toe} := \gamma_c \cdot l_{toe} \cdot t_f \qquad W_{toe} = 4.537 \cdot \frac{kip}{ft}$$

Distance from Toe weight to Toe end $\quad L_{toe} := \frac{l_{toe}}{2} \qquad L_{toe} = 5.5\,ft$

Earthquake Loading

Use Westegard for water loading under earthquakes

Westergaard factor - per EM 1110-2-2502 $\quad C_E := 0.051\,\frac{kip}{ft^3}$

DRAFT

Total Earthquake Force $P_E := \frac{2}{3} \cdot C_E \cdot k_h \cdot \left(d_{water\_norm} - d_{soil\_flood}\right)^2$

$$P_E = 0.061 \cdot \frac{kip}{ft}$$

Distance of water EQ force from bottom of foundation

$$h_{EQ} := d_{soil\_flood} + 0.4\left(d_{water\_norm} - d_{soil\_flood}\right) + t_f \qquad h_{EQ} = 3.95\,ft$$

Lateral Load from Wall's own wieght

$$F_w := k_h \cdot \left(W_{stem} + W_{toe} + W_{heel} + W_{soil\_heel\_wet}\right) \qquad F_w = 2.224 \cdot \frac{kip}{ft}$$

Distance of Wall EQ force from top of foundation

$$h_{EQ\_wall} := \frac{h_{wall}}{2} + t_f \qquad h_{EQ\_wall} = 7.75\,ft$$

Wind Loading

Based on ASCE 7-05 6.5.14 Freestanding walls and signs

Wind Speed $V := 85mph$

Directionality Coefficient $K_d := 0.85$

Velocity Pressure Coefficient $K_z := 0.85$ Assumes exposure C at 15ft or less

Topographic Coefficient $K_{zt} := 1.0$

Importance Factor $I := 1.15$ Assumes that it is catagory III

Velocity Pressure $q_h := 0.00256 K_z \cdot K_{zt} \cdot K_d \cdot \left(\frac{V}{mph}\right)^2 \cdot I \cdot psf$

$$q_h = 15.368 \cdot psf$$

Gusset Effect Factor $G := 0.85$

Net Force Coefficient $C_f := 1.3$

Design Wind Pressure $p_{wind} := q_h \cdot G \cdot C_f \qquad p_{wind} = 16.981 \cdot psf$

Lateral Load from Wind $F_{wind} := p_{wind} \cdot \left(h_{height}\right) \qquad F_{wind} = 0.17 \cdot \frac{kip}{ft}$

Distance of Wind load from bottom of foundation

$$h_{wind} := \frac{h_{wall}}{2} + t_f \qquad h_{wind} = 7.75\,ft$$

DRAFT

Load Cases:

Look at the load cases in ASCE7/IBC/ACI318 for guidance on what to include in which combination, and what load factors to use.

Design Flood Loading

Water to Top of Wall

Earthquake Loading

Construction and Short Duration Loading

Loads and Load Cases

Stability/Overturning

Design Flood Load

Overturning moment - caused by design water flood load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot} := R_{water} \cdot h_{water} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift} \cdot L_{uplift}$$

$$M_{ot} = 98.788 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right} = 207.163 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

DRAFT

$\Sigma V = 11.04 \cdot \frac{kip}{ft}$

Distance of resultant from toe: $x_R := \frac{M_{right} - M_{ot}}{\Sigma V}$ $x_R = 9.817\,ft$

Resultant Ratio: $Ratio := \frac{x_R}{(l_{toe} + t_w + l_{heel})}$ $Ratio = 0.457$

About what percent of foundation is in compression?

$base\_compression_1 := percent_{comp}(Ratio)$

$base\_compression_1 = 100 \cdot \%$

Water to Top of Wall Load

Overturning moment - caused by water to top of wall load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot2} := R_{water2} \cdot h_{water2} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift2} \cdot L_{uplift}$$

$$M_{ot2} = 138.106 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right2} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water2} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right2} = 235.804 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$\Sigma V_2 = 10.712 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R2} := \frac{M_{right2} - M_{ot2}}{\Sigma V_2}$ $x_{R2} = 9.12\,ft$

Resultant Ratio: $Ratio_2 := \frac{x_{R2}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_2 = 0.424$

DRAFT

About what percent of foundation is in compression?

$$base\_compression_2 := percent_{comp}(Ratio_2)$$

$$base\_compression_2 = 100 \cdot \%$$

Earthquake Load

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and the added earthquake load based on water weight and wall self weight. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot3} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + P_E \cdot h_{EQ} + F_w \cdot h_{EQ\_wall}$$

$$M_{ot3} = 72.065 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right3} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right3} = 168.974 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_3 = 11.476 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R3} := \dfrac{M_{right3} - M_{ot3}}{\Sigma V_3}$ $\quad x_{R3} = 8.444\ ft$

Resultant Ratio: $Ratio_3 := \dfrac{x_{R3}}{(l_{toe} + t_w + l_{heel})}$ $\quad Ratio_3 = 0.393$

About what percent of foundation is in compression?

$$base\_compression_3 := percent_{comp}(Ratio_3)$$

$$base\_compression_3 = 100 \cdot \%$$

Wind Load

DRAFT

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and wind loads. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot4} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + F_{wind} \cdot h_{wind}$$

$$M_{ot4} = 55.905 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right4} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right4} = 168.974 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_4 = 11.476 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R4} := \frac{M_{right4} - M_{ot4}}{\Sigma V_4}$ $x_{R4} = 9.852\ ft$

Resultant Ratio: $Ratio_4 := \frac{x_{R4}}{\left(l_{toe} + t_w + l_{heel}\right)}$ $Ratio_4 = 0.458$

About what percent of foundation is in compression?

$$base\_compression_4 := percent_{comp}\left(Ratio_4\right)$$

$$base\_compression_4 = 100 \cdot \%$$

Stability/Overturning

Stability/Sliding

Design Flood Load

Lateral Loads come from hydrostatic loads at design flood level There will be seepage/uplift that will lower the normal force that increases friction.

DRAFT

Actual Shear Force

$$V_1 := \left|R_{water} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet}\right| \qquad V_1 = 2.417 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_1 := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

$$N_1 = 11.04 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s1} := \frac{N_1 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_1} \qquad FS_{s1} = 2.637$$

Water to top of Wall Load

Lateral Loads come from hydrostatic loads at the top of the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_2 := R_{water2} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet} \qquad V_2 = 4.523 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$N_2 = 10.712 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s2} := \frac{N_2 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_2} \qquad FS_{s2} = 1.367$$

Earthquake Load

Lateral Loads come from Earthquake loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

DRAFT

$$V_3 := R_{water3} + R_{soil\_flood\_sub} + P_E + F_w \qquad V_3 = 3.416 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_3 = 11.476 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s3} := \frac{N_3 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_3} \qquad FS_{s3} = 1.94$$

DRAFT

Wind Load

Lateral Loads come from Wind loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_4 := R_{water3} + R_{soil\_flood\_sub} + F_{wind} \qquad V_4 = 1.301 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_4 = 11.476 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s4} := \frac{N_4 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_4} \qquad FS_{s4} = 5.094$$

Stability/Sliding

Soil Bearing Capacity

Design Flood Load

Distance of base reaction to toe $x_1 := \frac{M_{right} - M_{ot}}{N_1}$ $x_1 = 9.817\ ft$

Distance of Base reaction from center of footing $e_1 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_1$

$e_1 = 0.933\,ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_1 := N_1 \cdot e_1$ $M_1 = 10.301 \cdot \frac{kip \cdot ft}{ft}$

$$q_{1a} := \frac{N_1}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_1}{\left(l_{toe} + l_{heel} + t_w\right)^2}$$ $q_{1a} = 0.647 \cdot ksf$

Maximum moment if reaction is outside the kern:

$q_{1b} := \frac{2 \cdot N_1}{3 \cdot x_1}$ $q_{1b} = 0.75 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern := \frac{l_{toe} + l_{heel} + t_w}{6}$ $kern = 3.583\,ft$

Maximum bearing pressure: $q_1 := if\left(e_1 \le kern, q_{1a}, q_{1b}\right)$

$q_1 = 0.647 \cdot ksf$

Safety Factor $SF_1 := \frac{b_{soil}}{q_1}$ $SF_1 = 3.09$

Water to top of Wall Load

Distance of base reaction to toe $x_2 := \frac{M_{right2} - M_{ot2}}{N_2}$ $x_2 = 9.12\,ft$

Distance of Base reaction from center of footing $e_2 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_2$

$e_2 = 1.63\,ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_2 := N_2 \cdot e_2$ $M_2 = 17.457 \cdot \frac{kip \cdot ft}{ft}$

$$q_{2a} := \frac{N_2}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_2}{\left(l_{toe} + l_{heel} + t_w\right)^2}$$ $q_{2a} = 0.725 \cdot ksf$

Maximum moment if reaction is outside the kern:

DRAFT

$$q_{2b} := \frac{2 \cdot N_2}{3 \cdot x_2} \qquad q_{2b} = 0.783 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 3.583\ ft$

Maximum bearing pressure: $q_2 := if\left(e_2 \le kern, q_{2a}, q_{2b}\right)$ $q_2 = 0.725 \cdot ksf$

Safety Factor $SF_2 := \frac{b_{soil}}{q_2}$ $SF_2 = 2.759$

Earthquake Load

Distance of base reaction to toe $x_3 := \frac{M_{right3} - M_{ot3}}{N_3}$ $x_3 = 8.444\ ft$

Distance of Base reaction from center of footing $e_3 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_3$

$e_3 = 2.306\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_3 := N_3 \cdot e_3$ $M_3 = 26.463 \cdot \frac{kip \cdot ft}{ft}$

$$q_{3a} := \frac{N_3}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_3}{\left(l_{toe} + l_{heel} + t_w\right)^2} \qquad q_{3a} = 0.877 \cdot ksf$$

Maximum moment if reaction is outside the kern:

$$q_{3b} := \frac{2 \cdot N_3}{3 \cdot x_3} \qquad q_{3b} = 0.906 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 3.583\ ft$

Maximum bearing pressure: $q_3 := if\left(e_3 \le kern, q_{3a}, q_{3b}\right)$ $q_3 = 0.877 \cdot ksf$

Safety Factor $SF_3 := \frac{b_{soil}}{q_3}$ $SF_3 = 2.28$

Wind Load

DRAFT

Distance of base reaction to toe $x_4 := \frac{M_{right4} - M_{ot4}}{N_4}$ $x_4 = 9.852\ ft$

Distance of Base reaction from center of footing $e_4 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_4$

$e_4 = 0.898\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_4 := N_4 \cdot e_4$ $M_4 = 10.303 \cdot \frac{kip \cdot ft}{ft}$

$$q_{4a} := \frac{N_4}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_4}{\left(l_{toe} + l_{heel} + t_w\right)^2}$$ $q_{4a} = 0.668 \cdot ksf$

Maximum moment if reaction is outside the kern:

$q_{4b} := \frac{2 \cdot N_4}{3 \cdot x_4}$ $q_{4b} = 0.777 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern = 3.583\ ft$

Maximum bearing pressure: $q_4 := if\left(e_4 \le kern, q_{4a}, q_{4b}\right)$ $q_4 = 0.668 \cdot ksf$

Safety Factor $SF_4 := \frac{b_{soil}}{q_4}$ $SF_4 = 2.996$

Soil Bearing Capacity

Summary

Sliding Safety Factor

Flood Load $FS_{s1} = 2.637$ $Slide_1 := if\left(FS_{s1} \ge 1.5, "OK", "NG"\right)$ $Slide_1 = "OK"$

Water to Top of Wall $FS_{s2} = 1.367$ $Slide_2 := if\left(FS_{s2} \ge 1.33, "OK", "NG"\right)$ $Slide_2 = "OK"$

DRAFT

Earthquake $FS_{s3} = 1.94$ $Slide_3 := if\left(FS_{s3} \geq 1.1, "OK", "NG"\right)$ $Slide_3 = "OK"$

Wind $FS_{s4} = 5.094$ $Slide_4 := if\left(FS_{s4} \geq 1.33, "OK", "NG"\right)$ $Slide_4 = "OK"$

Overturning Compression

Flood Load $base\_compression_1 = 100 \cdot \%$

$OT_1 := if\left(base\_compression_1 \geq 1.0, "OK", "NG"\right)$ $OT_1 = "OK"$

Water to Top of Wall $base\_compression_2 = 100 \cdot \%$

$OT_2 := if\left(base\_compression_2 \geq 0.75, "OK", "NG"\right)$ $OT_2 = "OK"$

Earthquake $base\_compression_3 = 100 \cdot \%$

$OT_3 := if\left(base\_compression_3 \geq 0.5, "OK", "NG"\right)$ $OT_3 = "OK"$

Wind $base\_compression_4 = 100 \cdot \%$

$OT_4 := if\left(base\_compression_4 \geq 0.75, "OK", "NG"\right)$ $OT_4 = "OK"$

Bearing Capacity Safety Factor

Flood Load $SF_1 = 3.09$ $Bearing_1 := if\left(SF_1 \geq 3.0, "OK", "NG"\right)$ $Bearing_1 = "OK"$

Water to Top of Wall $SF_2 = 2.759$ $Bearing_2 := if\left(SF_2 \geq 2.0, "OK", "NG"\right)$ $Bearing_2 = "OK"$

Earthquake $SF_3 = 2.28$ $Bearing_3 := if\left(SF_3 > 1.0, "OK", "NG"\right)$ $Bearing_3 = "OK"$

Wind $SF_4 = 2.996$ $Bearing_4 := if\left(SF_4 \geq 2.0, "OK", "NG"\right)$ $Bearing_4 = "OK"$

Summary

DRAFT

Flood Wall Design

Project - Puyallup GI Study
This is for areas with 12ft between grade and top of wall

▸ Formulas, Tables, Etc

▾ Input Variables

Wall Thickness	$t_w := 24in$	
Foundation Thickness	$t_f := 3ft$	
Wall Height Above Soil	$h_{height} := 12ft$	
Soil Depth - Protected Side	$d_{soil\_prct} := 2ft$	
Soil Depth - Flood Side	$d_{soil\_flood} := 0ft$	
Wall Height	$h_{wall} := d_{soil\_flood} + h_{height}$	$h_{wall} = 12\,ft$
Freeboard at 100yr flood	$d_{freeboard} := 3ft$	
Water Depth (design Depth)	$d_{water} := h_{wall} - d_{freeboard}$	$d_{water} = 9\,ft$
Water Depth (normal Flow)	$d_{water\_norm} := 3ft$	
Heel Length	$l_{heel} := 12ft$	
Toe Length	$l_{toe} := 15ft$	
Concrete Strength	$f'_c := 4000psi$	
Rebar Strength	$f_y := 60000psi$	
Unit Weight of Concrete	$\gamma_c := 150pcf$	
Unit Weight of Water	$\gamma_{h2o} := 62.4pcf$	
Dry Unit Weight of Soil	$\gamma_{dry} := 100pcf$	
Wet Unit Weight of Soil	$\gamma_{wet} := 115pcf$	
Submerged Unit Weight of Soil	$\gamma_{sub} := \gamma_{wet} - \gamma_{h2o}$	$\gamma_{sub} = 52.6 \cdot pcf$
Bearing Capacity of Soil	$b_{soil} := 2000psf$	
At Rest Soil Coefficient	$K_0 := 0.5$	

DRAFT

Active Soil Coefficient	$K_a := 0.33$
Passive Soil Coefficient	$K_p := 3$
Angle of Internal Friction	$\phi_s := 30deg$
Coeficient of Friction	$\mu := 0.20$
Cohesion	$c := 0psf$
Modulus of Subgrade Reaction	$K_s := 350pci$
Frost Depth	$d_{frost} := 18in$
Earthquake design acceleration	$k_h := 0.2$

Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Assumed percent of total pressure toe $pore\_toe := 10\%$

Assumed Percent of total pressure at heel $pore\_heel := 90\%$

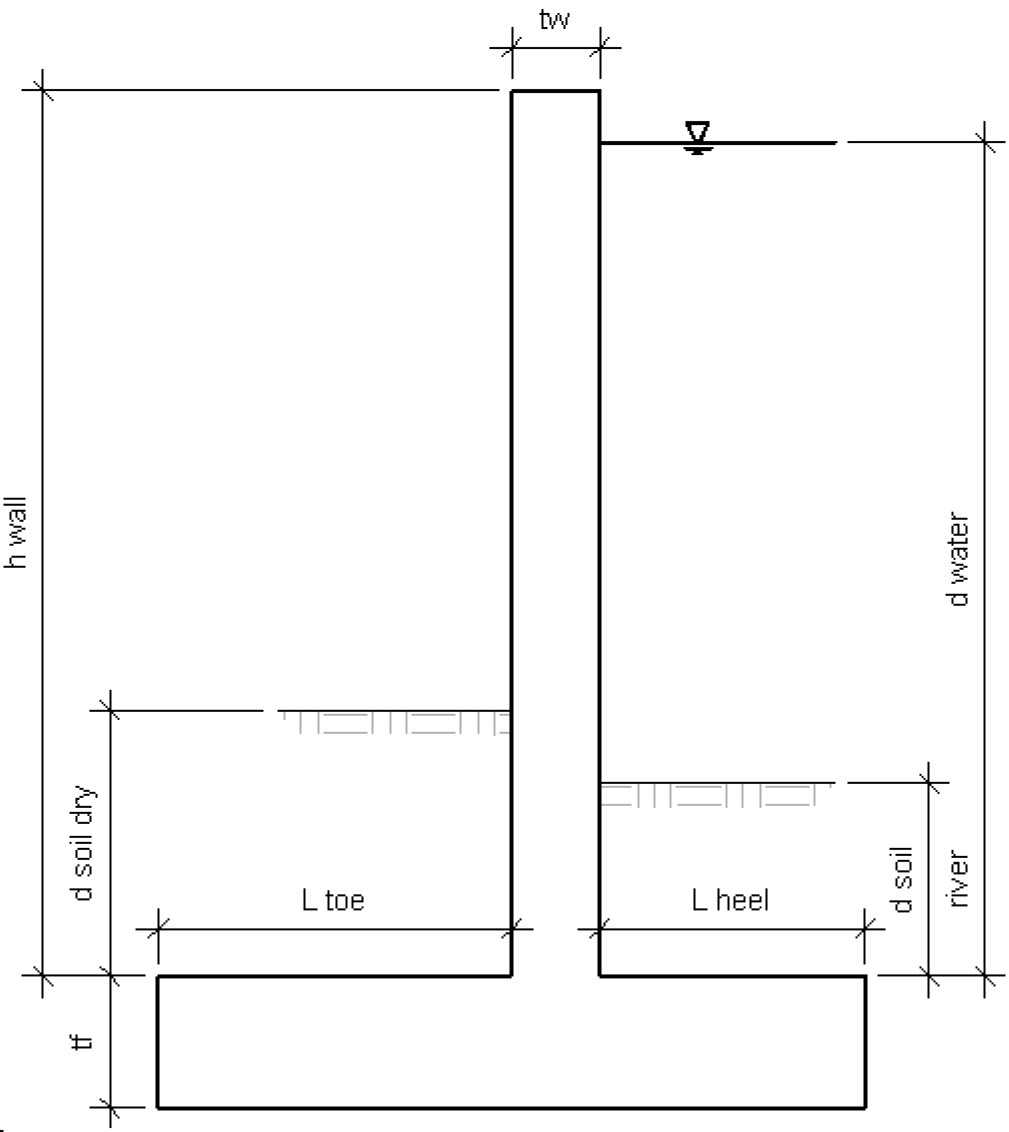
Uplift Reduction Factor $uplift\_reduce := \frac{pore\_toe + pore\_heel}{2}$

$uplift\_reduce = 50 \cdot \%$

Location of Reaction from toe (percent) $uplift\_react := 1 - \left[\frac{2 \cdot pore\_toe + pore\_heel}{3 \cdot (pore\_toe + pore\_heel)}\right]$

$uplift\_react = 63.333 \cdot \%$

DRAFT



Input Variables

Loads and Load Cases

Horizontal Loads

Land Side At Rest Soil Load - Resisting Load Assumed to be zero to be conservative

Flood Side at Rest Soil Load (wet not suburged)

Peak Pressure from soil $p_{soil\_flood\_wet} := \gamma_{wet} \cdot K_0 \cdot \left(d_{soil\_flood} + t_f\right)$

$p_{soil\_flood\_wet} = 172.5 \cdot psf$

Distance of resultant from bottom of footing

$h_{soil\_flood} := \frac{(d_{soil\_flood} + t_f)}{3}$ $h_{soil\_flood} = 1\ ft$

Total Resultant force from Soil

$R_{soil\_flood\_wet} := \frac{p_{soil\_flood\_wet} \cdot (d_{soil\_flood} + t_f)}{2}$

$R_{soil\_flood\_wet} = 0.259 \cdot \frac{kip}{ft}$

Flood Side at Rest Soil Load (suburged)

Peak Pressure from soil $p_{soil\_flood\_sub} := \gamma_{sub} \cdot K_0 \cdot (d_{soil\_flood} + t_f)$

$p_{soil\_flood\_sub} = 78.9 \cdot psf$

Distance of resultant from bottom of footing $h_{soil\_flood} = 1\ ft$

Total Resultant force from Soil

$R_{soil\_flood\_sub} := \frac{p_{soil\_flood\_sub} \cdot (d_{soil\_flood} + t_f)}{2}$

$R_{soil\_flood\_sub} = 0.118 \cdot \frac{kip}{ft}$

Protected Side At Rest Soil Pressure

Peak Pressure from soil $p_{soil\_prct\_wet} := \gamma_{wet} \cdot K_0 \cdot (d_{soil\_prct} + t_f)$

$p_{soil\_prct\_wet} = 287.5 \cdot psf$

Distance of resultant from bottom of footing

$h_{soil\_prct} := \frac{(d_{soil\_prct} + t_f)}{3}$ $h_{soil\_prct} = 1.667\ ft$

Total Resultant force from Soil

$R_{soil\_prct\_wet} := \frac{p_{soil\_prct\_wet} \cdot (d_{soil\_prct} + t_f)}{2}$

$R_{soil\_prct\_wet} = 0.719 \cdot \frac{kip}{ft}$

Flood Side Design Flood Pressure

Peak Pressure from water at design flood elevation $p_{water} := \gamma_{h2o} \cdot (d_{water} + t_f)$ $p_{water} = 748.8 \cdot psf$

DRAFT

Distance of resultant from bottom of footing

$$h_{water} := \frac{d_{water} + t_f}{3} \qquad h_{water} = 4\,ft$$

Total Resultant force from Soil

$$R_{water} := \frac{p_{water} \cdot (d_{water} + t_f)}{2} \qquad R_{water} = 4.493 \cdot \frac{kip}{ft}$$

Fllod Side Flood Pressure - Water at top of wall

Peak Pressure from water up to the top of the wall

$$p_{water2} := \gamma_{h2o} \cdot (t_f + h_{wall}) \qquad p_{water2} = 936 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water2} := \frac{h_{wall} + t_f}{3} \qquad h_{water2} = 5\,ft$$

Total Resultant force from Water

$$R_{water2} := \frac{p_{water2} \cdot (h_{wall} + t_f)}{2} \qquad R_{water2} = 7.02 \cdot \frac{kip}{ft}$$

Flood Side Water Pressure - Normal Flow Conditions

Peak Pressure from water at normal flow conditions

$$p_{water3} := \gamma_{h2o} \cdot (t_f + d_{water\_norm}) \qquad p_{water3} = 374.4 \cdot psf$$

Distance of resultant from bottom of footing

$$h_{water3} := \frac{d_{water\_norm} + t_f}{3} \qquad h_{water3} = 2\,ft$$

Total Resultant force from Water

$$R_{water3} := \frac{p_{water3} \cdot (d_{water\_norm} + t_f)}{2} \qquad R_{water3} = 1.123 \cdot \frac{kip}{ft}$$

DRAFT

Vertical Loads

Uplift on Foundation due to water.
Becuase the pore pressure decreases as you move towards the protected edge, assume that less of the uplift still exists at the toe, so the total uplift will be only a portion of the uplift assuming that the uplift was constant across the base. This should be conservative. Assume that the resultant is farther away from the toe than the midspan because of this unbalanced load.

Uplift from water at design flood load

$p_{uplift} := p_{water}$ $p_{uplift} = 748.8 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} := (l_{toe} + l_{heel} + t_w) \cdot uplift\_react$ $L_{uplift} = 18.367\,ft$

Total Uplift Force

$R_{uplift} := uplift\_reduce\, p_{uplift} \cdot (l_{toe} + l_{heel} + t_w)$

$R_{uplift} = 10.858 \cdot \frac{kip}{ft}$

Uplift force from water to top of wall

$P_{uplift2} := p_{water2}$ $P_{uplift2} = 936 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} = 18.367\,ft$

Total Uplift Force

$R_{uplift2} := uplift\_reduce\, P_{uplift2} \cdot (l_{toe} + l_{heel} + t_w)$

$R_{uplift2} = 13.572 \cdot \frac{kip}{ft}$

Uplift force from water at normal flow levels

$P_{uplift3} := p_{water3}$ $P_{uplift3} = 374.4 \cdot psf$

Distance from the toe to centroid of uplift

$L_{uplift} = 18.367\,ft$

Total Uplift Force

$R_{uplift3} := uplift\_reduce\, P_{uplift3} \cdot (l_{toe} + l_{heel} + t_w)$

$R_{uplift3} = 5.429 \cdot \frac{kip}{ft}$

Weight of Water above Heel at design flood level

DRAFT

$$W_{water} := \gamma_{h2o} \cdot d_{water} \cdot l_{heel} \qquad W_{water} = 6.739 \cdot \frac{kip}{ft}$$

Distance of Water Weight from toe

$$L_{water} := l_{toe} + t_w + \frac{l_{heel}}{2} \qquad L_{water} = 23\,ft$$

Weight of Water above Heel at design flood level

$$W_{water2} := \gamma_{h2o} \cdot h_{wall} \cdot l_{heel} \qquad W_{water2} = 8.986 \cdot \frac{kip}{ft}$$

Distance of Water Weight from toe

$$L_{water} = 23\,ft$$

Weight of Water at normal flow levels

$$W_{water3} := \gamma_{h2o} \cdot d_{water\_norm} \cdot l_{heel} \qquad W_{water3} = 2.246 \cdot \frac{kip}{ft}$$

Weight of Soil On Toe - Wet Soil, not submurged

$$W_{soil\_toe\_wet} := \gamma_{wet} \cdot d_{soil\_prct} \cdot l_{toe}$$

$$W_{soil\_toe\_wet} = 3.45 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe

$$L_{soil\_toe} := \frac{l_{toe}}{2} \qquad L_{soil\_toe} = 7.5\,ft$$

Weight of Soil On Toe - Submurged Soil

$$W_{soil\_toe\_sub} := \gamma_{sub} \cdot d_{soil\_prct} \cdot l_{toe}$$

$$W_{soil\_toe\_sub} = 1.578 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe $L_{soil\_toe} = 7.5\,ft$

Weight of Soil On Heel - Wet Soil, not submurged

DRAFT

$$W_{soil\_heel\_wet} := \gamma_{wet} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_wet} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe

$$L_{soil\_heel} := l_{toe} + t_w + \frac{l_{heel}}{2} \qquad L_{soil\_heel} = 23\,ft$$

Weight of Soil On Toe - Submurged Soil

$$W_{soil\_heel\_sub} := \gamma_{sub} \cdot d_{soil\_flood} \cdot l_{heel}$$

$$W_{soil\_heel\_sub} = 0 \cdot \frac{kip}{ft}$$

Distance of Soil Weight from toe $L_{soil\_heel} = 23\,ft$

Weight of wall Stem

$$W_{stem} := \gamma_c \cdot t_w \cdot \left(h_{wall} + t_f\right) \qquad W_{stem} = 4.5 \cdot \frac{kip}{ft}$$

Distance of Stem Wight from Toe

$$L_{stem} := l_{toe} + \frac{t_w}{2} \qquad L_{stem} = 16\,ft$$

Weight of wall Heel

$$W_{heel} := \gamma_c \cdot t_f \cdot l_{heel} \qquad W_{heel} = 5.4 \cdot \frac{kip}{ft}$$

Distance from Heel Weight to Toe

$$L_{heel} := l_{toe} + t_f + \frac{l_{heel}}{2} \qquad L_{heel} = 24\,ft$$

Weight of Toe

$$W_{toe} := \gamma_c \cdot l_{toe} \cdot t_f \qquad W_{toe} = 6.75 \cdot \frac{kip}{ft}$$

Distance from Toe weight to Toe end

$$L_{toe} := \frac{l_{toe}}{2} \qquad L_{toe} = 7.5\,ft$$

Earthquake Loading

Use Westegard for water loading under earthquakes

Westergaard factor - per EM 1110-2-2502 $C_E := 0.051 \frac{kip}{ft^3}$

DRAFT

Total Earthquake Force $P_E := \frac{2}{3} \cdot C_E \cdot k_h \cdot \left(d_{water\_norm} - d_{soil\_flood}\right)^2$

$P_E = 0.061 \cdot \frac{kip}{ft}$

Distance of water EQ force from bottom of foundation

$h_{EQ} := d_{soil\_flood} + 0.4\left(d_{water\_norm} - d_{soil\_flood}\right) + t_f \qquad h_{EQ} = 4.2\,ft$

Lateral Load from Wall's own wieght

$F_w := k_h \cdot \left(W_{stem} + W_{toe} + W_{heel} + W_{soil\_heel\_wet}\right) \qquad F_w = 3.33 \cdot \frac{kip}{ft}$

Distance of Wall EQ force from top of foundation

$h_{EQ\_wall} := \frac{h_{wall}}{2} + t_f \qquad h_{EQ\_wall} = 9\,ft$

Wind Loading

Based on ASCE 7-05 6.5.14 Freestanding walls and signs

Wind Speed $V := 85mph$

Directionality Coefficient $K_d := 0.85$

Velocity Pressure Coefficient $K_z := 0.85$ Assumes exposure C at 15ft or less

Topographic Coefficient $K_{zt} := 1.0$

Importance Factor $I := 1.15$ Assumes that it is catagory III

Velocity Pressure $q_h := 0.00256 K_z \cdot K_{zt} \cdot K_d \cdot \left(\frac{V}{mph}\right)^2 \cdot I \cdot psf$

$q_h = 15.368 \cdot psf$

Gusset Effect Factor $G := 0.85$

Net Force Coefficient $C_f := 1.3$

Design Wind Pressure $p_{wind} := q_h \cdot G \cdot C_f \qquad p_{wind} = 16.981 \cdot psf$

Lateral Load from Wind $F_{wind} := p_{wind} \cdot \left(h_{height}\right) \qquad F_{wind} = 0.204 \cdot \frac{kip}{ft}$

Distance of Wind load from bottom of foundation

$h_{wind} := \frac{h_{wall}}{2} + t_f \qquad h_{wind} = 9\,ft$

DRAFT

Load Cases:

Look at the load cases in ASCE7/IBC/ACI318 for guidance on what to include in which combination, and what load factors to use.

Design Flood Loading

Water to Top of Wall

Earthquake Loading

Construction and Short Duration Loading

Loads and Load Cases

Stability/Overturning

Design Flood Load

Overturning moment - caused by design water flood load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot} := R_{water} \cdot h_{water} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift} \cdot L_{uplift}$$

$$M_{ot} = 217.507 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right} = 433.102 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

DRAFT

$\Sigma V = 15.982 \cdot \frac{kip}{ft}$

Distance of resultant from toe: $x_R := \frac{M_{right} - M_{ot}}{\Sigma V}$ $x_R = 13.49\ ft$

Resultant Ratio: $Ratio := \frac{x_R}{(l_{toe} + t_w + l_{heel})}$ $Ratio = 0.465$

About what percent of foundation is in compression?

$base\_compression_1 := percent_{comp}(Ratio)$

$base\_compression_1 = 100 \cdot \%$

Water to Top of Wall Load

Overturning moment - caused by water to top of wall load, with soil. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$M_{ot2} := R_{water2} \cdot h_{water2} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift2} \cdot L_{uplift}$

$M_{ot2} = 284.491 \cdot \frac{kip \cdot ft}{ft}$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$M_{right2} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water2} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$

$M_{right2} = 484.769 \cdot \frac{kip \cdot ft}{ft}$

Total Vertical Load - sum of all weights -uplift forces

$\Sigma V_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$

$\Sigma V_2 = 15.514 \cdot \frac{kip}{ft}$

Distance of resultant from toe: $x_{R2} := \frac{M_{right2} - M_{ot2}}{\Sigma V_2}$ $x_{R2} = 12.91\ ft$

Resultant Ratio: $Ratio_2 := \frac{x_{R2}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_2 = 0.445$

DRAFT

About what percent of foundation is in compression?

$$base\_compression_2 := percent_{comp}(Ratio_2)$$

$$base\_compression_2 = 100 \cdot \%$$

Earthquake Load

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and the added earthquake load based on water weight and wall self weight. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot3} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + P_E \cdot h_{EQ} + F_w \cdot h_{EQ\_wall}$$

$$M_{ot3} = 132.301 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right3} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right3} = 329.767 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_3 = 16.918 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R3} := \frac{M_{right3} - M_{ot3}}{\Sigma V_3}$ $x_{R3} = 11.672\,ft$

Resultant Ratio: $Ratio_3 := \frac{x_{R3}}{(l_{toe} + t_w + l_{heel})}$ $Ratio_3 = 0.402$

About what percent of foundation is in compression?

$$base\_compression_3 := percent_{comp}(Ratio_3)$$

$$base\_compression_3 = 100 \cdot \%$$

Wind Load

DRAFT

Overturning moment - caused by water at "typical" flow levels, soil at typical levels, and wind loads. Uplift will come from water seepage/pressure underneath the footing. The water pressure at the bottom will be used at this preliminary stage.

$$M_{ot4} := R_{water3} \cdot h_{water3} + R_{soil\_flood\_sub} \cdot h_{soil\_flood} + R_{uplift3} \cdot L_{uplift} + F_{wind} \cdot h_{wind}$$

$$M_{ot4} = 103.908 \cdot \frac{kip \cdot ft}{ft}$$

Righting Moment - Caused by the weight of concrete wall, as well as the soil and water on the heel of the wall.

$$M_{right4} := W_{stem} \cdot L_{stem} + W_{heel} \cdot L_{heel} + W_{toe} \cdot L_{toe} + W_{water3} \cdot L_{water} \cdots + W_{soil\_heel\_sub} \cdot L_{soil\_heel} + W_{soil\_toe\_wet} \cdot L_{soil\_toe}$$

$$M_{right4} = 329.767 \cdot \frac{kip \cdot ft}{ft}$$

Total Vertical Load - sum of all weights -uplift forces

$$\Sigma V_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$\Sigma V_4 = 16.918 \cdot \frac{kip}{ft}$$

Distance of resultant from toe: $x_{R4} := \frac{M_{right4} - M_{ot4}}{\Sigma V_4}$ $x_{R4} = 13.351\,ft$

Resultant Ratio: $Ratio_4 := \frac{x_{R4}}{\left(l_{toe} + t_w + l_{heel}\right)}$ $Ratio_4 = 0.46$

About what percent of foundation is in compression?

$$base\_compression_4 := percent_{comp}\left(Ratio_4\right)$$

$$base\_compression_4 = 100 \cdot \%$$

Stability/Overturning

Stability/Sliding

Design Flood Load

Lateral Loads come from hydrostatic loads at design flood level There will be seepage/uplift that will lower the normal force that increases friction.

DRAFT

Actual Shear Force

$$V_1 := \left|R_{water} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet}\right| \qquad V_1 = 3.892 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_1 := W_{stem} + W_{heel} + W_{toe} + W_{water} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift}$$

$$N_1 = 15.982 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s1} := \frac{N_1 \cdot \tan\left(\phi_s\right) + c \cdot \left(l_{toe} + l_{heel} + t_w\right)}{V_1} \qquad FS_{s1} = 2.371$$

DRAFT

Water to top of Wall Load

Lateral Loads come from hydrostatic loads at the top of the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_2 := R_{water2} + R_{soil\_flood\_sub} - R_{soil\_prct\_wet} \qquad V_2 = 6.42 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_2 := W_{stem} + W_{heel} + W_{toe} + W_{water2} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift2}$$

$$N_2 = 15.514 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s2} := \frac{N_2 \cdot \tan\left(\phi_s\right) + c \cdot \left(l_{toe} + l_{heel} + t_w\right)}{V_2} \qquad FS_{s2} = 1.395$$

Earthquake Load

Lateral Loads come from Earthquake loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_3 := R_{water3} + R_{soil\_flood\_sub} + P_E + F_w \qquad V_3 = 4.633 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_3 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_3 = 16.918 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s3} := \frac{N_3 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_3} \qquad FS_{s3} = 2.108$$

Wind Load

Lateral Loads come from Wind loads on the wall. There will be seepage/uplift that will lower the normal force that increases friction.

Actual Shear Force

$$V_4 := R_{water3} + R_{soil\_flood\_sub} + F_{wind} \qquad V_4 = 1.445 \cdot \frac{kip}{ft}$$

Total Normal Force

$$N_4 := W_{stem} + W_{heel} + W_{toe} + W_{water3} + W_{soil\_heel\_sub} + W_{soil\_toe\_wet} - R_{uplift3}$$

$$N_4 = 16.918 \cdot \frac{kip}{ft}$$

Sliding Factor of Safety

$$FS_{s4} := \frac{N_4 \cdot \tan(\phi_s) + c \cdot (l_{toe} + l_{heel} + t_w)}{V_4} \qquad FS_{s4} = 6.758$$

Stability/Sliding

Soil Bearing Capacity

Design Flood Load

Distance of base reaction to toe

$$x_1 := \frac{M_{right} - M_{ot}}{N_1} \qquad x_1 = 13.49 \, ft$$

DRAFT

Distance of Base reaction from center of footing $e_1 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_1$

$e_1 = 1.01\,ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_1 := N_1 \cdot e_1$ $M_1 = 16.139 \cdot \frac{kip \cdot ft}{ft}$

$$q_{1a} := \frac{N_1}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_1}{(l_{toe} + l_{heel} + t_w)^2}$$ $q_{1a} = 0.666 \cdot ksf$

Maximum moment if reaction is outside the kern:

$$q_{1b} := \frac{2 \cdot N_1}{3 \cdot x_1}$$ $q_{1b} = 0.79 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern := \frac{l_{toe} + l_{heel} + t_w}{6}$ $kern = 4.833\,ft$

Maximum bearing pressure: $q_1 := if(e_1 \le kern, q_{1a}, q_{1b})$

$q_1 = 0.666 \cdot ksf$

Safety Factor $SF_1 := \frac{b_{soil}}{q_1}$ $SF_1 = 3.002$

Water to top of Wall Load

Distance of base reaction to toe $x_2 := \frac{M_{right2} - M_{ot2}}{N_2}$ $x_2 = 12.91\,ft$

Distance of Base reaction from center of footing $e_2 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_2$

$e_2 = 1.59\,ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_2 := N_2 \cdot e_2$ $M_2 = 24.669 \cdot \frac{kip \cdot ft}{ft}$

$$q_{2a} := \frac{N_2}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_2}{(l_{toe} + l_{heel} + t_w)^2}$$ $q_{2a} = 0.711 \cdot ksf$

Maximum moment if reaction is outside the kern:

DRAFT

$$q_{2b} := \frac{2 \cdot N_2}{3 \cdot x_2} \qquad q_{2b} = 0.801 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 4.833\ ft$

Maximum bearing pressure: $q_2 := \text{if}\left(e_2 \le kern, q_{2a}, q_{2b}\right)$

$q_2 = 0.711 \cdot ksf$

Safety Factor $SF_2 := \frac{b_{soil}}{q_2}$ $SF_2 = 2.813$

Earthquake Load

Distance of base reaction to toe $x_3 := \frac{M_{right3} - M_{ot3}}{N_3}$ $x_3 = 11.672\ ft$

Distance of Base reaction from center of footing $e_3 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_3$

$e_3 = 2.828\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_3 := N_3 \cdot e_3$ $M_3 = 47.839 \cdot \frac{kip \cdot ft}{ft}$

$$q_{3a} := \frac{N_3}{\left(l_{toe} + l_{heel} + t_w\right)} + \frac{6M_3}{\left(l_{toe} + l_{heel} + t_w\right)^2} \qquad q_{3a} = 0.925 \cdot ksf$$

Maximum moment if reaction is outside the kern:

$$q_{3b} := \frac{2 \cdot N_3}{3 \cdot x_3} \qquad q_{3b} = 0.966 \cdot ksf$$

Kern distance (defines center 1/3 of footing) $kern = 4.833\ ft$

Maximum bearing pressure: $q_3 := \text{if}\left(e_3 \le kern, q_{3a}, q_{3b}\right)$

$q_3 = 0.925 \cdot ksf$

Safety Factor $SF_3 := \frac{b_{soil}}{q_3}$ $SF_3 = 2.163$

Wind Load

DRAFT

Distance of base reaction to toe $x_4 := \frac{M_{right4} - M_{ot4}}{N_4}$ $x_4 = 13.351\ ft$

Distance of Base reaction from center of footing $e_4 := \frac{l_{toe} + l_{heel} + t_w}{2} - x_4$

$e_4 = 1.149\ ft$

Maximum bearing forces if reaction is in the kern:

Moment centered around the center of the footing $M_4 := N_4 \cdot e_4$ $M_4 = 19.446 \cdot \frac{kip \cdot ft}{ft}$

$$q_{4a} := \frac{N_4}{(l_{toe} + l_{heel} + t_w)} + \frac{6M_4}{(l_{toe} + l_{heel} + t_w)^2}$$ $q_{4a} = 0.722 \cdot ksf$

Maximum moment if reaction is outside the kern:

$q_{4b} := \frac{2 \cdot N_4}{3 \cdot x_4}$ $q_{4b} = 0.845 \cdot ksf$

Kern distance (defines center 1/3 of footing) $kern = 4.833\ ft$

Maximum bearing pressure: $q_4 := if(e_4 \le kern, q_{4a}, q_{4b})$ $q_4 = 0.722 \cdot ksf$

Safety Factor $SF_4 := \frac{b_{soil}}{q_4}$ $SF_4 = 2.77$

DRAFT

Soil Bearing Capacity

Summary

Sliding Safety Factor

Flood Load $FS_{s1} = 2.371$ $Slide_1 := if(FS_{s1} \ge 1.5, "OK", "NG")$ $Slide_1 = "OK"$

Water to Top of Wall $FS_{s2} = 1.395$ $Slide_2 := if(FS_{s2} \ge 1.33, "OK", "NG")$ $Slide_2 = "OK"$

Earthquake	$FS_{s3} = 2.108$	$Slide_3 := if(FS_{s3} \geq 1.1, "OK", "NG")$	$Slide_3 = "OK"$
Wind	$FS_{s4} = 6.758$	$Slide_4 := if(FS_{s4} \geq 1.33, "OK", "NG")$	$Slide_4 = "OK"$

Overturning Compression

Flood Load

$base\_compression_1 = 100 \cdot \%$

$OT_1 := if(base\_compression_1 \geq 1.0, "OK", "NG")$ $OT_1 = "OK"$

Water to Top of Wall

$base\_compression_2 = 100 \cdot \%$

$OT_2 := if(base\_compression_2 \geq 0.75, "OK", "NG")$ $OT_2 = "OK"$

Earthquake

$base\_compression_3 = 100 \cdot \%$

$OT_3 := if(base\_compression_3 \geq 0.5, "OK", "NG")$ $OT_3 = "OK"$

Wind

$base\_compression_4 = 100 \cdot \%$

$OT_4 := if(base\_compression_4 \geq 0.75, "OK", "NG")$ $OT_4 = "OK"$

Bearing Capacity Safety Factor

Flood Load	$SF_1 = 3.002$	$Bearing_1 := if(SF_1 \geq 3.0, "OK", "NG")$	$Bearing_1 = "OK"$
Water to Top of Wall	$SF_2 = 2.813$	$Bearing_2 := if(SF_2 \geq 2.0, "OK", "NG")$	$Bearing_2 = "OK"$
Earthquake	$SF_3 = 2.163$	$Bearing_3 := if(SF_3 > 1.0, "OK", "NG")$	$Bearing_3 = "OK"$
Wind	$SF_4 = 2.77$	$Bearing_4 := if(SF_4 \geq 2.0, "OK", "NG")$	$Bearing_4 = "OK"$

Summary

DRAFT