BULKHEAD DOCK WALL - ANCHORED SHEET PILING WALL DESIGN

Wall Geometry

$H := 20\ ft$ — *design wall height*

$H_{anchor} := 1\ ft$ — *Tie-back height (from top of wall)*

$\theta := 90\ deg$ — *angle of back face of wall to horizontal*

$S := \frac{1}{0.00001\%} = 1 \cdot 10^{7}$ — *ground slope behind face of wall*

$\beta := \text{try} \ \| \ \text{atan}\left(\frac{1}{S}\right) \ \text{on error} \ \| \ 0 \ = \left(5.73 \cdot 10^{-6}\right)\ deg$ — *Ground slope angle behind face of wall (β < ϕf)*

$\alpha := 90\ deg$ — *Wall slope angle from horizontal (90o for vertical, <90deg if back of wall is battered outward or >90deg if wall battered inward)*

Project Parameters

$DesignLife := 75\ yr$ — *Wall design life, LRFD 11.5.1*

Soil properties

$\gamma_w := 62.4\ pcf$ — *Unit weight of water*

$H_{water} := 15\ ft$ — *Height of water (measured from dredge line)*

Backfill soil design parameters:

$H_{dry} := H - H_{water} = 5\ ft$ — *Height of soil above water line*

$\phi_{f\_fill} := 30\ deg$ — *Angle of internal friction*

$\delta_{fill} := \frac{1}{3} \cdot \phi_{f\_fill} = 10\ deg$ — *Angle of friction between soil and wall (usually assumed to be 2/3ϕ to 1/3ϕ)*

$\gamma'_{fill} := 60\ pcf$ — *Effective unit weight*

$\gamma_{fill} := 110\ pcf$ — *Unit weight of soil*

$c_{fill} := 0\ psf$ — *Cohesion*

Existing soil design parameters:

$\phi_{f\_soil} := 32\ deg$ — *Angle of internal friction*

$\delta_{soil} := \frac{1}{3} \cdot \phi_{f\_soil} = 10.667\ deg$ — *Angle of friction between soil and wall (usually assumed to be 2/3ϕ to 1/3ϕ)*

$\gamma'_{soil} := 65\ pcf$ — *Effective unit weight*

$c_{soil} := 0\ psf$ — *Cohesion*

Live Load Surcharge Parameter

$h_{eq} := 2 \cdot 9.1\ ft$ *height of equivalent soil*

$\gamma_{ES} := 1$ *Earth surcharge load factor (Table 3.4.1-2) γ_{ES} = 1.5 ; 0.75 (LRFD) or γ_{ES} = 1 (ASD)*

$SUR := \gamma_{ES} \cdot \gamma_{fill} \cdot h_{eq} = 2002\ psf$ *Live load surcharge for wall (14.4.5.4.2)*

Compute Active Earth Pressure

$$K_A(\phi_f, \delta) := \frac{\sin(\alpha + \phi_f)^2}{\left(\sin(\alpha)^2 \cdot \sin(\alpha - \delta)\right) \cdot \left(1 + \sqrt{\frac{\sin(\phi_f + \delta) \cdot \sin(\phi_f - \beta)}{\sin(\alpha - \delta) \cdot \sin(\alpha + \beta)}}\right)^2}$$

$K_{A\_fill\_coulomb} := K_A(\phi_{f\_fill}, \delta_{fill}) = 0.308$

$K_{A\_soil\_coulomb} := K_A(\phi_{f\_soil}, \delta_{soil}) = 0.284$

Compute Passive Earth Pressure

$$K_P(\phi_f, \delta) := \frac{\sin(\alpha - \phi_f)^2}{\left(\sin(\alpha)^2 \cdot \sin(\alpha + \delta)\right) \cdot \left(1 - \sqrt{\frac{\sin(\phi_f + \delta) \cdot \sin(\phi_f + \beta)}{\sin(\alpha + \delta) \cdot \sin(\alpha + \beta)}}\right)^2}$$

$K_{P\_fill\_coulomb} := K_P(\phi_{f\_fill}, \delta_{fill}) = 4.143$

$K_{P\_soil\_coulomb} := K_P(\phi_{f\_soil}, \delta_{soil}) = 4.679$

Compute Loads Factors

Compute the active earth pressure coefficient

$\gamma_{EH} := 1.0$ *Horizontal earth pressure load factor (Table 3.4.1-2) γ_{EH} = 1.5 ; 0.9 (LRFD) or γ_{EH} = 1.0 (ASD)*

$K_{a\_fill} := \gamma_{EH} \cdot K_{A\_fill\_coulomb} = 0.308$

$K_{a\_soil} := \gamma_{EH} \cdot K_{A\_soil\_coulomb} = 0.284$

Compute the passive earth pressure coefficient

$\phi_p := 1.0$ *Non-gravity cantilevered / anchored wall resistance factor for flexural capacity of vertical element (11.5.7-1) ϕ_p = 0.75 (LRFD) or = 1.0 (ASD)*

$K_{p\_fill} := \phi_p \cdot K_{P\_fill\_coulomb} = 4.143$

$K_{p\_soil} := \phi_p \cdot K_{P\_soil\_coulomb} = 4.679$

Compute Wall Embedment Depth and Bending Moment

Earth Pressure

$P_{a\_sur\_fill} := K_{a\_fill} \cdot SUR = 617.549 \ psf$

$P_{a\_sur\_soil} := K_{a\_soil} \cdot SUR = 569.087 \ psf$

$P_{a\_fill\_top} := \gamma_{fill} \cdot K_{a\_fill} \cdot H_{dry} = 169.656 \ psf$

$P_{a\_fill\_bottom} := P_{a\_fill\_top} + \gamma'_{fill} \cdot K_{a\_fill} \cdot H_{water} = 447.275 \ psf$

$P_{a\_soil\_top} := P_{a\_fill\_bottom} \cdot \frac{K_{a\_soil}}{K_{a\_fill}} = 412.176 \ psf$

Location of Zero pressure

$D_0 := \frac{P_{a\_soil\_top} + P_{a\_sur\_soil}}{\gamma'_{soil} \cdot (K_{p\_soil} - K_{a\_soil})} = 3.435 \ ft$

Force

$F_{sur\_fill} := P_{a\_sur\_fill} \cdot H = 12350.971 \ \frac{lbf}{ft}$

$F_{sur\_soil} := P_{a\_sur\_soil} \cdot D_0 = 1954.705 \ \frac{lbf}{ft}$

$F_{a\_fill\_top} := P_{a\_fill\_top} \cdot \frac{H_{dry}}{2} = 424.14 \ \frac{lbf}{ft}$

$F_{a\_fill\_water} := P_{a\_fill\_top} \cdot H_{water} = 2544.843 \ \frac{lbf}{ft}$

$F_{a\_fill\_bottom} := (P_{a\_fill\_bottom} - P_{a\_fill\_top}) \cdot \frac{H_{water}}{2} = 2082.144 \ \frac{lbf}{ft}$

$F_{a\_soil\_zero} := P_{a\_soil\_top} \cdot \frac{D_0}{2} = 707.873 \ \frac{lbf}{ft}$

Moment Arm to anchor point

$d_{sur\_fill} := \frac{H}{2} - H_{anchor} = 9 \ ft$

$d_{sur\_soil} := H - H_{anchor} + \frac{D_0}{2} = 20.717 \ ft$

$d_{a\_fill\_top} := \frac{2}{3} \cdot H_{dry} - H_{anchor} = 2.333 \ ft$

$d_{a\_fill\_water} := \frac{H_{water}}{2} + H_{dry} - H_{anchor} = 11.5 \ ft$

$d_{a\_fill\_bottom} := \frac{2}{3} \cdot H_{water} + H_{dry} - H_{anchor} = 14 \ ft$

$d_{a\_fill\_zero} := \frac{D_0}{3} + H - H_{anchor} = 20.145 \ ft$

Equilibrium of Moments (at Anchor point)

Determine the Passive Soil Reaction

Solve Block

Guess Values

$R := 1 \ \frac{lbf}{ft}$

Constraints

$$F_{sur\_fill} \cdot d_{sur\_fill} + F_{sur\_soil} \cdot d_{sur\_soil} + F_{a\_fill\_top} \cdot d_{a\_fill\_top} + F_{a\_fill\_water} \cdot d_{a\_fill\_water} + F_{a\_fill\_bottom} \cdot d_{a\_fill\_bottom} + F_{a\_soil\_zero} \cdot d_{a\_fill\_zero} + R \cdot (H + D_0) = 0$$

Solver

$Reaction := \textbf{Find}(\textbf{R})$

$Reaction = -9614.782 \ \frac{lbf}{ft}$

Equilibrium of Forces

Determine Tie Rod Tension

$T_{anchor} := (F_{sur\_fill} + F_{sur\_soil} + F_{a\_fill\_top} + F_{a\_fill\_water} + F_{a\_fill\_bottom} + F_{a\_soil\_zero} + Reaction)$

$T_{anchor} = 10449.895 \frac{lbf}{ft}$

Finding the Minimum Embedment Depth (Equilibrium of Moments)

Guess Values

$D_1 := H + D_0$

Constraints

$\gamma'_{soil} \cdot (K_{p\_soil} - K_{a\_soil}) \cdot \frac{D_1^2}{2} \cdot \frac{D_1}{3} + Reaction \cdot D_1 = 0$

Solver

$D_{min} := \textbf{Find}(\mathbf{D_1})$

$D_{min} = 14.21\ ft$

To provide a margin of safety, the embedment depth should be increased between 20% to 40%.

$D_{calc} := D_0 + D_{min} = 17.645\ ft$

$D_{embeded} := \text{Floor}(\text{mean}(1.2 \cdot D_{calc}, 1.4 \cdot D_{calc}), 1 \cdot ft) = 22\ ft$

$D_{embeded} = 22\ ft \geq 1.2 \cdot D_{calc} = 21.174\ ft$

Total wall length

$H_{total} := H + D_{embeded} = 42\ ft$

$H_{total} = 42\ ft$

Finding the location of Zero Shear

$V_0(x) := -T_{anchor} + F_{a\_fill\_top} + P_{a\_sur\_fill} \cdot (x + H_{dry}) + P_{a\_fill\_top} \cdot x + \gamma'_{fill} \cdot K_{a\_fill} \cdot \frac{x^2}{2}$

$x_{shear} := \textbf{root}(V_0(x), x, 0, H_{total}) = 8.051\ ft$

$x_{shear} = 8.051\ ft$ *measured from Water elevation

Determining the maximum moment

Force

$FM_{sur\_fill} := P_{a\_sur\_fill} \cdot (H_{dry} + x_{shear}) = 8059.888 \frac{lbf}{ft}$

$FM_{a\_fill\_top} := P_{a\_fill\_top} \cdot \frac{H_{dry}}{2} = 424.14 \frac{lbf}{ft}$

$FM_{a\_fill\_water} := P_{a\_fill\_top} \cdot x_{shear} = 1365.974 \frac{lbf}{ft}$

$FM_{a\_fill\_bottom} := (P_{a\_fill\_bottom} - P_{a\_fill\_top}) \cdot \frac{x_{shear}}{2} = 1117.615 \frac{lbf}{ft}$

$T_{anchor} = 10449.895 \frac{lbf}{ft}$

Moment Arm

$dM_{sur\_fill} := \frac{H_{dry} + x_{shear}}{2} = 6.526\ ft$

$dM_{a\_fill\_top} := \frac{H_{dry}}{3} + x_{shear} = 9.718\ ft$

$dM_{a\_fill\_water} := \frac{x_{shear}}{2} = 4.026\ ft$

$dM_{a\_fill\_bottom} := \frac{x_{shear}}{3} = 2.684\ ft$

$dT_{anchor} := x_{shear} + H_{dry} - H_{anchor} = 12.051\ ft$

Maximum Moment

$M_{max} := |FM_{sur\_fill} \cdot dM_{sur\_fill} + FM_{a\_fill\_top} \cdot dM_{a\_fill\_top} + FM_{a\_fill\_water} \cdot dM_{a\_fill\_water} + FM_{a\_fill\_bottom} \cdot dM_{a\_fill\_bottom} - T_{anchor} \cdot dT_{anchor}|$

$M_{max} = 60719.288 \frac{lbf \cdot ft}{ft}$

Compute the Required Flexural Resistance

The following is a design check for flexural resistance:

Mmax <= Mn / Ω_f Mmax = Fy S / Ω_f

$\Omega_f := 2$ — *Safety factor for flexural*

M_n — *Nominal flexural capacity of the section*

$F_y := 50\ ksi$ — *Steel yield stress (assumed A572 Grade 50)*

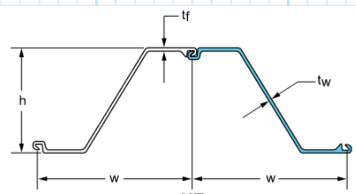
S — *Elastic section modulus*

$$S_{reqd} := \frac{M_{max} \cdot \Omega_f}{F_y} \qquad S_{reqd} = 29.145\ \frac{in^3}{ft}$$

Minimum required elastic section modulus

Wall Design using Sheet Piling (NZ section) - Alternative 1

Steel sheet piling mechanical properties



NZ

SECTION	Width (w) in mm	Height (h) in mm	THICKNESS Flange (t_f) in mm	THICKNESS Web (t_w) in mm	Cross Sectional Area in²/ft cm²/m	WEIGHT Single Pile lb/ft kg/m	WEIGHT Wall Area lb/ft² kg/m²	SECTION MODULUS Elastic in³/ft cm³/m	SECTION MODULUS Plastic in³/ft cm³/m	Moment of Inertia in⁴/ft cm⁴/m	COATING AREA Both Sides ft²/ft of single m²/m	COATING AREA Wall Surface ft²/ft² m²/m²
NZ 14	30.31 770	13.39 340	0.375 9.5	0.375 9.5	6.40 135.4	55 81.26	21.77 106.30	25.65 1379	30.50 1640	171.7 23447	6.10 1.86	1.20 1.20
NZ 19	27.56 700	16.14 410	0.375 9.5	0.375 9.5	7.07 149.6	55 81.85	24.05 117.40	35.08 1886	41.33 2222	283.1 38659	6.18 1.88	1.35 1.35
NZ 20	27.56 700	16.16 411	0.394 10.0	0.394 10.0	7.34 155.4	57 85.37	24.82 122.00	36.24 1948	42.80 2301	292.8 39984	6.18 1.88	1.35 1.35
NZ 21	27.56 700	16.20 412	0.433 11.0	0.433 11.0	7.80 165.2	61 90.78	26.56 129.70	38.69 2080	45.85 2465	313.4 42797	6.18 1.88	1.35 1.35
NZ 22	27.56 700.0	16.25 413.0	0.480 12.20	0.480 12.20	8.57 181.4	67 99.71	29.20 142.44	41.47 2230	49.34 2653	336.9 46006	6.18 1.88	1.35 1.35
NZ 26	27.56 700	17.32 440	0.500 12.7	0.500 12.7	9.08 192.2	71 105.66	30.99 151.30	48.50 2608	57.01 3065	419.9 57340	6.49 1.98	1.41 1.41
NZ 28	27.56 700	17.38 441	0.560 14.2	0.560 14.2	9.98 211.2	78 116.08	33.96 165.82	52.62 2829	62.16 3342	457.4 62461	6.49 1.98	1.41 1.41
NZ 38	27.56 700	19.69 500	0.689 17.5	0.500 12.7	11.00 232.9	86 127.99	37.45 182.83	70.84 3809	81.57 4386	697.3 95214	6.58 2.01	1.43 1.43
NZ 40	27.56 700.0	19.73 501.0	0.735 18.70	0.551 14.00	11.77 249.1	92 136.91	40.06 195.59	74.97 4031	86.75 4664	739.6 100997	6.58 2.01	1.43 1.43
NZ 42	27.56 700.0	19.77 502.0	0.769 19.50	0.589 15.0	12.41 262.7	97 144.36	42.24 206.23	78.17 4203	90.80 4881	772.5 105490	6.58 2.01	1.43 1.43

Selected NZ profile section properties:

$$\begin{bmatrix} w_{NZ1} \\ S_{NZ1} \\ I_{NZ1} \end{bmatrix} := \text{NZ: 19}$$

Width $w_{NZ1} = 27.56\ in$

Section Modulus $S_{NZ1} = 35.08\ \frac{in^3}{ft}$

Moment of Inertia $I_{NZ1} = 283.1\ \frac{in^4}{ft}$

Section Modulus Utilization

$$U_{Section\_NZ} := \left| \frac{S_{reqd}}{S_{NZ1}} \right| = 83.082\%$$

$$\text{if}\left(U_{Section\_NZ} < 1, \text{“OK”}, \text{“NG”}\right) = \text{“OK”}$$

Wall Deflection estimation

$E_{steel} := 29000\ ksi$ — *Steel modulus of elasticity*

$W_{distributed} := P_{a\_sur\_fill} + P_{a\_fill\_bottom} = 1064.824\ psf$

$$\delta_{max\_NZ} := \frac{W_{distributed} \cdot H_{total}^{4}}{185 \cdot E_{steel} \cdot I_{NZ1}} = 3.77\ in$$ *Maximum deflection*

$\delta_{limit} := 1\% \cdot H_{total} = 5.04\ in$ — *assuming 1% of wall height*

$\text{if}\left(\delta_{max\_NZ} < \delta_{limit}, \text{“OK”}, \text{“NG – increase section”}\right) = \text{“OK”}$

Check maximum allowable stress

$$\sigma_{NZ} := \frac{\Omega_f \cdot M_{max}}{S_{NZ1}} = 41.541\ ksi$$

Stress - Demand / Capacity Ratio (DCR)

$$DCR_{\sigma\_NZ} := \frac{\sigma_{NZ}}{F_y} = 83.082\%$$

$\text{if}\left(DCR_{\sigma\_NZ} < 1, \text{“OK”}, \text{“NG”}\right) = \text{“OK”}$

Wall Design using Pipe-Z Combination - Alternative 2

Determine minimum pipe diameter for required section modulus

Pipe	Pipe OD	Thickness (in)													
12	12.75	0.250	0.313	0.375	0.500										
14	14	0.250	0.313	0.375	0.500	0.625									
16	16	0.250	0.313	0.375	0.500	0.625									
18	18	0.250	0.313	0.375	0.500	0.625									
20	20	0.250	0.313	0.375	0.500	0.625									
24	24	0.250	0.313	0.375	0.500	0.625	0.750	0.875	1.000						
30	30	0.250	0.313	0.375	0.500	0.625	0.750	0.875	1.000						
36	36	0.250	0.313	0.375	0.500	0.625	0.750	0.875	1.000						
42	42	0.250		0.375	0.500	0.625	0.750	0.875	1.000						
48	48			0.375	0.500	0.625	0.750	0.875	1.000	1.250	1.375				
54	54			0.375	0.500	0.625	0.750	0.875	1.000	1.250	1.375				
60	60			0.375	0.500	0.625	0.750	0.875	1.000	1.250		1.500			
72	72			0.375	0.500	0.625	0.750	0.875	1.000	1.250	1.375	1.500			
84	84			0.375	0.500	0.625	0.750	0.875	1.000	1.250		1.500	1.625		
96	96			0.375	0.500	0.625	0.750	0.875	1.000	1.250		1.500		1.750	2.000
108	108			0.375	0.500	0.625	0.750	0.875	1.000	1.250		1.500		1.750	2.000
120	120			0.375	0.500	0.625	0.750	0.875	1.000	1.250		1.500		1.750	2.000
132	132			0.375	0.500	0.625	0.750	0.875	1.000	1.250		1.500		1.750	2.000
144	144				0.500	0.625	0.750	0.875	1.000	1.250		1.500		1.750	2.000
156	156					0.625	0.750	0.875	1.000	1.250		1.500		1.750	2.000
168	168						0.750	0.875	1.000	1.250		1.500		1.750	2.000

assuming pipe wall thickness $t := 0.5\ in$

Guess Values

$D_{try} := 1\ in$

Constraints

$$\frac{\pi}{32} \cdot \frac{\left(D_{try}^{4} - \left(D_{try} - 2 \cdot t\right)^{4}\right)}{D_{try}} \cdot \left(\frac{1}{3 \cdot D_{try}}\right) - S_{reqd} = 0$$

Solver

$D_{pipe\_min} := \mathbf{Find}\left(\mathbf{D_{try}}\right) = 20.005\ in$

Elastic section modulus of selected Pipe section:

$D_{pipeZ\_seld} := \text{PipeDiameter: 24} = 2\ ft$

Moment of Inertial of the pipe

$$I_{pipeZ} := \frac{\pi}{64} \cdot \left(D_{pipeZ\_seld}^{\ 4} - \left(D_{pipeZ\_seld} - 2 \cdot t\right)^4\right) = 2549.353\ in^4$$

Section properties of sheet piling

$$\begin{bmatrix} w_{NZ} \\ S_{NZ\_ft} \\ I_{NZ\_ft} \end{bmatrix} := \text{NZ: 14}$$

Width $w_{NZ} = 30.31\ in$

Section Modulus $S_{NZ\_ft} = 25.65\ \frac{in^3}{ft}$

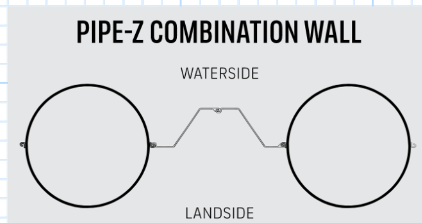
Moment of Inertia $I_{NZ\_ft} = 171.7\ \frac{in^4}{ft}$

$$I_{NZ} := I_{NZ\_ft} \cdot w_{NZ} = 433.686\ in^4$$

pipe spacing assumes NZ sheet pile between pipes $s_{pipeZ} := D_{pipeZ\_seld} + 2 \cdot w_{NZ} = 7.052\ ft$

Moment of Inertial of the system (Pipe-Z Combination wall)

$$I_{system} := \frac{I_{pipeZ} + 2 \cdot I_{NZ}}{s_{pipeZ}} = 484.527\ \frac{in^4}{ft}$$



Elastic section modulus of Pipe-Z Combination wall

$$S_{system} := \frac{I_{system}}{\frac{D_{pipeZ\_seld}}{2}} = 40.377\ \frac{in^3}{ft}$$

Section Modulus Utilization

$$U_{Section\_pipeZ} := \left|\frac{S_{reqd}}{S_{system}}\right| = 72.182\%$$

$$\text{if}\left(U_{Section\_pipeZ} < 1, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

Wall Deflection estimation

$E_{steel} = 29000\ ksi$ *Steel modulus of elasticity*

$$W_{distributed} = 1064.824\ \frac{1}{ft} \cdot \frac{lbf}{ft}$$

$$\delta_{max\_pipeZ} := \frac{W_{distributed} \cdot H_{total}^{\ 4}}{185 \cdot E_{steel} \cdot I_{system}} = 2.203\ in$$ *Maximum deflection*

$\delta_{limit} = 5.04\ in$ *assuming 1% of wall height*

$$\text{if}\left(\delta_{max\_pipeZ} < \delta_{limit}, \text{"OK"}, \text{"NG - increase section"}\right) = \text{"OK"}$$

Check maximum allowable stress

$$\sigma_{pipeZ} := \frac{\Omega_f \cdot M_{max}}{S_{system}} = 36.091\ ksi$$

Stress - Demand / Capacity Ratio (DCR)

$$DCR_{\sigma\_pipeZ} := \left|\frac{\sigma_{pipeZ}}{F_y}\right| = 72.182\%$$

$$\text{if}\left(DCR_{\sigma\_pipeZ} < 1, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

Tie-back Design with Concrete Deadman anchor - Alternative 1

Considering: $L_{anchor\_spacing1} := w_{NZ1} \cdot 4 = 9.187\ ft$ — *maximum tie-back anchor spacing*

$\alpha_{anchor} := 15\ deg$ — *maximum tie-back angle of inclination*

$$T_{per\_anchor1} := \frac{T_{anchor} \cdot L_{anchor\_spacing1}}{\cos(\alpha_{anchor})}$$

$T_{per\_anchor1} = 99.386\ kip$ — *maximum tie-back tension force*

Determining the Tie-back length

$$x_{min} := \frac{H + 0.5 \cdot D_{embeded}}{\tan(\phi_{f\_fill})} = 53.694\ ft$$ *minimum length of tie-back*

$L_{tie\_back} := \mathrm{Ceil}(x_{min}, 5\ ft)$ $\quad L_{tie\_back} = 55\ ft$

Required steel cross-sectional area

$\Omega_a := 2$ — *Safety factor for axial load*

$F_{y\_rebar} := 60\ ksi$ — *rebar yield stress*

$$A_{s\_req'd\_rebar} := \frac{\Omega_a \cdot T_{per\_anchor1}}{F_{y\_rebar}}$$ $A_{s\_req'd\_rebar} = 3.313\ in^2$

Concrete tie-back

Concrete tie-back dimensions:

$b_{tie\_back} := 12\ in$

$h_{tie\_back} := 12\ in$

Determining the rebar diameter

$n_{rebar} := 4$

$$\phi_{min\_rebar} := \sqrt{\frac{A_{s\_req'd\_rebar}}{n_{rebar}} \cdot \frac{4}{\pi}} = 1.027\ in$$ *minimum diameter*

$\phi_{rebar} := \mathrm{Ceil}\left(\phi_{min\_rebar}, \frac{1}{8}\ in\right) = 1.125\ in$ $\quad no := \frac{\phi_{rebar}}{in} \cdot 8 = 9$ $\quad$ Use 4 - $no = 9$ rebars with #4 stirrups at 12"

Design Concrete deadman anchor

Backfill angle of friction $\quad \phi_{f\_backfill} := 35\ deg$ — *Angle of internal friction*

$\delta_{backfill} := \frac{1}{3} \cdot \phi_{f\_backfill} = 11.667\ deg$ — *Angle of friction between soil and wall (usually assumed to be 2/3ϕ to 1/3ϕ)*

$K_{A\_backfill} := K_A(\phi_{f\_backfill}, \delta_{backfill}) = 0.251$

$K_{P\_backfill} := K_P(\phi_{f\_backfill}, \delta_{backfill}) = 5.68$

Height of deadman $\quad h_{deadman} := 7\ ft$

Length of deadman $\quad l_{deadman} := 5\ ft \quad \leq \quad L_{anchor\_spacing1} = 9.187\ ft$

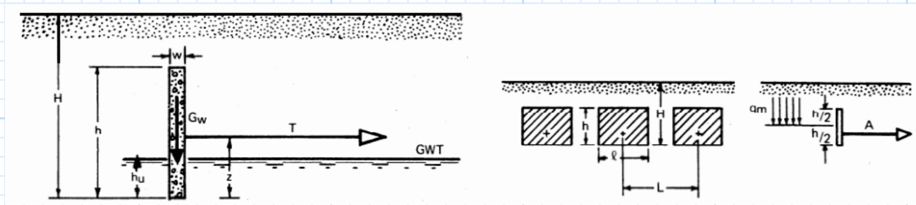
Considering: $h_{soil\_cover} := 2\ ft$ — *soil cover above deadman*

$H_{deadman} := h_{soil\_cover} + h_{deadman} = 9\ ft$ — *depth of deadman*

$h_{dry} := H_{dry} - h_{soil\_cover} = 3\ ft$ — *height of deadman above water*

$h_{under\_water} := h_{deadman} - h_{dry} = 4\ ft$ — *height of deadman below water*

Find R/Ro based on Equation:



$R_o := K_{P\_backfill} - K_{A\_backfill} = 5.429$

$E := 1 - \dfrac{h_{deadman}}{H_{deadman}} = 0.222$

$B := 1 - \left(\dfrac{l_{deadman}}{L_{anchor\_spacing1}}\right)^2 = 0.704$ $\quad \dfrac{l_{deadman}}{L_{anchor\_spacing1}} = 0.544$ $\quad \dfrac{l_{deadman}}{h_{deadman}} = 0.714$ $\quad \dfrac{h_{deadman}}{H_{deadman}} = 0.778$

$$R\_R_{o\_EQUATION} := 1 + R_o^{\frac{2}{3}} \cdot \left(1.1 \cdot E^4 + \dfrac{1.6 \cdot B}{1 + 5 \cdot \dfrac{l_{deadman}}{h_{deadman}}} + \dfrac{0.4 \cdot R_o \cdot E^3 \cdot B^2}{1 + 0.05 \cdot \dfrac{l_{deadman}}{h_{deadman}}}\right) = 1.804$$

$q_m := \gamma_{fill} \cdot \left(H_{deadman} - \dfrac{1}{2} \cdot h_{deadman}\right) = 605\ psf$

$A_{ult} := q_m \cdot h_{deadman} \cdot l_{deadman} \cdot \left(R\_R_{o\_EQUATION} \cdot R_o\right) = 207445.48\ lbf$

Ultimate capacity of deadman

Factor of Safety $FoS := 2$

$T_{ult\_deadman} := \dfrac{A_{ult}}{FoS}$ $\quad T_{ult\_deadman} = 103722.74\ ft \cdot \dfrac{lbf}{ft}$

Deadman - Demand / Capacity Ratio (DCR)

$DCR_{deadman} := \dfrac{T_{per\_anchor1}}{T_{ult\_deadman}} = 95.819\%$ $\quad$ if $\left(DCR_{deadman} < 1, \text{“OK”}, \text{“NG”}\right) = \text{“OK”}$

Tie-back Design with Sheet piling wall anchor - Alternative 2

Considering: $L_{anchor\_spacing2} := s_{pipeZ} = 7.052\ ft$ — *maximum tie-back anchor spacing*

$\alpha_{anchor} = 15\ deg$ — *maximum tie-back angle of inclination*

$$T_{per\_anchor2} := \frac{T_{anchor} \cdot L_{anchor\_spacing2}}{\cos(\alpha_{anchor})}$$

$T_{per\_anchor2} = 76.289\ kip$ — *maximum tie-back tension force*

$H_{wall\_anchor} := 6\ ft$ — *depth of wall anchor (from top of soil)*

Determining the Tie-back length

$L_{tie\_back} = 55\ ft$ — *minimum length of tie-back*

Required steel cross-sectional area

$\Omega_a = 2$ — *Safety factor for axial load*

$F_{y\_threadbar} := 120\ ksi$ — *threaded bar yield stress*

$$A_{s\_req'd\_threadbar} := \frac{\Omega_a \cdot T_{per\_anchor2}}{F_{y\_threadbar}}$$

$A_{s\_req'd\_threadbar} = 1.271\ in^2$

Steel tie-back (threaded bar)

$n_{thread.bar} := 1$ — *considering 1 threaded bar*

$$\phi_{min\_thread.bar} := \sqrt{\frac{A_{s\_req'd\_threadbar}}{n_{thread.bar}} \cdot \frac{4}{\pi}} = 1.272\ in$$ — *minimum diameter*

$$\phi_{thread.bar} := \text{Ceil}\left(\phi_{min\_thread.bar}, \frac{1}{4}\ in\right) = 1.5\ in$$

Use 1- $\phi_{thread.bar} = 1.5\ in$ threaded bar

Finding the Minimum Embedment Depth (Equilibrium of Forces and Moments)

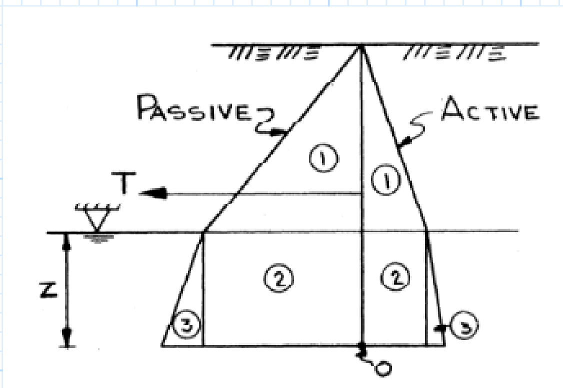
Horizontal Soil Pressure

$$P_1 = \gamma_{fill} \cdot (K_{p\_fill} - K_{a\_fill}) \cdot \frac{H_{dry}^2}{2}$$

$$P_2 = \gamma_{fill} \cdot (K_{p\_fill} - K_{a\_fill}) \cdot H_{dry} \cdot Z$$

$$P_3 = \gamma'_{fill} \cdot (K_{p\_fill} - K_{a\_fill}) \cdot \frac{Z^2}{2}$$

$$K_{net} := K_{p\_fill} - K_{a\_fill} = 3.835$$



$Z_1 := 1\ ft$

$$\gamma_{fill} \cdot K_{net} \cdot \frac{H_{dry}^2}{2} \cdot \left(\frac{H_{dry}}{3} + Z_1\right) + \gamma_{fill} \cdot K_{net} \cdot H_{dry} \cdot Z_1 \cdot \left(\frac{Z_1}{2}\right) + \gamma'_{fill} \cdot K_{net} \cdot \frac{Z_1^2}{2} \cdot \left(\frac{Z_1}{3}\right) + -\left(\left(\gamma_{fill} \cdot (K_{net}) \cdot \frac{H_{dry}^2}{2} + \gamma_{fill} \cdot K_{net} \cdot H_{dry} \cdot Z_1 + \gamma'_{fill} \cdot K_{net} \cdot \frac{Z_1^2}{2}\right) \cdot (H_{dry} - H_{wall\_anchor} + Z_1)\right) = 0$$

$Z_{min\_wall} := \mathbf{Find}(Z_1)$

$Z_{min\_wall} = 4.267\ ft$

Factor of Safety on Wall anchor

$$T_{wall} := \gamma_{fill} \cdot (K_{net}) \cdot \frac{H_{dry}^2}{2} + \gamma_{fill} \cdot (K_{net}) \cdot H_{dry} \cdot Z_{min\_wall} + \gamma'_{fill} \cdot (K_{net}) \cdot \frac{Z_{min\_wall}^2}{2} = 16366.071\ \frac{lbf}{ft}$$

$T_{anchor} = 10449.895\ \frac{lbf}{ft}$

$FOS_{wall\_anchor} := \frac{T_{wall}}{T_{anchor}} = 1.566$ $\quad$ $\text{if}\left(FOS_{wall\_anchor} > 1.5, \text{“OK”}, \text{“NG”}\right) = \text{“OK”}$

To provide a margin of safety, the embedment depth should be increased between 20% to 40%.

$D_{embeded\_wall} := \text{Ceil}\left(\text{mean}\left(1.2 \cdot Z_{min\_wall}, 1.4 \cdot Z_{min\_wall}\right), 1 \cdot ft\right) = 6\ ft$ $\quad$ $D_{embeded\_wall} = 6\ ft$ $\quad \geq \quad 1.2 \cdot Z_{min\_wall} = 5.12\ ft$

Total wall anchor length

$H_{total\_wall\_amchor} := H_{dry} + D_{embeded\_wall} = 11\ ft$ $\quad$ $H_{total\_wall\_amchor} = 11\ ft$

Wale Design

$M_{max\_wale} := \frac{1}{8} \cdot T_{anchor} \cdot L_{anchor\_spacing2}^2$ *maximum moment*

Considering:

$\Omega_f = 2$ *Safety factor for flexural*

M_n *Nominal flexural capacity of the section*

$F_y = 50\ ksi$ *Steel yield stress (assumed A572 Grade 50)*

S *Elastic section modulus*

$S_{wale\_reqd} := \frac{M_{max\_wale} \cdot \Omega_f}{F_y}$ $\quad$ $S_{wale\_reqd} = 31.178\ in^3$ *Minimum required elastic section modulus*

Determine minimum channel for required section modulus

American Standard Steel C Channels - Dimensions and Static Parameters

Designation	Dimensions					Static Parameters			
						Moment of Inertia		Elastic Section Modulus	
Imperial (in x lb/ft)	Depth - h - (in) (mm)	With - w - (in) (mm)	Web Thickness - s - (in) (mm)	Sectional Area (in^2)	Weight (lb_f/ft)	I_x (in^4)	I_y (in^4)	S_x (in^3)	S_y (in^3)
C 15 x 50	15	3.716	0.716	14.7	50	404	11.0	53.8	3.78
C 15 x 40	15	3.520	0.520	11.8	40	349	9.23	46.5	3.37
C 15 x 33.9	15	3.400	0.400	9.96	33.9	315	8.13	42.0	3.11
C 12 x 30	12	3.170	0.510	8.82	30	162	5.14	27.0	2.06
C 12 x 25	12	3.047	0.387	7.35	25	144	4.47	24.1	1.88
C 12 x 20.7	12	2.942	0.282	6.09	20.7	129	3.88	21.5	1.73
C 10 x 30	10	3.033	0.673	8.82	30	103	3.94	20.7	1.65
C 10 x 25	10	2.886	0.526	7.35	25	91.2	3.36	18.2	1.48
C 10 x 20	10	2.739	0.379	5.88	20	78.9	2.81	15.8	1.32
C 10 x 15.3	10	2.600	0.240	4.49	15.3	67.4	2.28	13.5	1.16
C 9 x 20	9	2.648	0.448	5.88	20	60.9	2.42	13.5	1.17
C 9 x 15	9	2.485	0.285	4.41	15	51.0	1.93	11.3	1.01
C 9 x 13.4	9	2.433	0.233	3.94	13.4	47.9	1.76	10.6	0.96
C 8 x 18.75	8	2.527	0.487	5.51	18.75	44.0	1.98	11.0	1.01
C 8 x 13.75	8	2.343	0.303	4.04	13.75	36.1	1.53	9.03	0.85
C 8 x 11.5	8	2.260	0.220	3.38	11.5	32.6	1.32	8.14	0.78
C 7 x 14.75	7	2.299	0.419	4.33	14.75	27.2	1.38	7.78	0.78
C 7 x 12.25	7	2.194	0.314	3.60	12.25	24.2	1.17	6.93	0.70
C 7 x 9.8	7	2.090	0.210	2.87	9.8	21.3	0.97	6.08	0.63
C 6 x 13	6	2.157	0.437	3.83	13	17.4	1.05	5.80	0.64
C 6 x 10.5	6	2.034	0.314	3.09	10.5	15.2	0.87	5.06	0.56
C 6 x 8.2	6	1.920	0.200	2.40	8.2	13.1	0.69	4.38	0.49
C 5 x 9	5	1.885	0.325	2.64	9	8.90	0.63	3.56	0.45
C 5 x 6.7	5	1.750	0.190	1.97	6.7	7.49	0.48	3.00	0.38
C 4 x 7.25	4	1.721	0.321	2.13	7.25	4.59	0.43	2.29	0.34
C 4 x 5.4	4	1.584	0.184	1.59	5.4	3.85	0.32	1.93	0.28
C 3 x 6	3	1.596	0.356	1.76	6	2.07	0.31	1.38	0.27
C 3 x 5	3	1.498	0.258	1.47	5	1.85	0.25	1.24	0.23
C 3 x 4.1	3	1.410	0.170	1.21	4.1	1.66	0.20	1.10	0.20

$$\begin{bmatrix} w_C \\ S_C \\ I_C \end{bmatrix} := \text{C: 10x20}$$

Width: $w_C = 10\ in$

Section Modulus: $S_C = 15.8\ in^3$

Moment of Inertia: $I_C = 78.9\ in^4$

Section Modulus Utilization

$$U_{Section\_2C} := \frac{S_{wale\_reqd}}{2 \cdot S_C} = 98.664\%$$

$$\text{if}\left(U_{Section\_2C} < 1, \text{“OK”}, \text{“NG”}\right) = \text{“OK”}$$

Wall Deflection estimation

$E_{steel} = 29000\ ksi$ — *Steel modulus of elasticity*

$W_{distributed\_wale} := T_{anchor} = 10.45\ \frac{1}{ft} \cdot kip$

$$\delta_{max\_2C} := \frac{5 \cdot W_{distributed\_wale} \cdot L_{anchor\_spacing2}^{4}}{384 \cdot E_{steel} \cdot 2 \cdot I_C} = 0.127\ in$$

Maximum deflection

$$\delta_{limit\_wale} := \frac{L_{anchor\_spacing2}}{360} = 0.235\ in$$

assuming L/360

$\text{if}\left(\delta_{max\_2C} < \delta_{limit\_wale}, \text{"OK"}, \text{"NG – increase section"}\right) = \text{"OK"}$

Check maximum allowable stress

$$\sigma_{2C} := \frac{\Omega_f \cdot M_{max\_wale}}{2 \cdot S_C} = 49.332\ ksi$$

Stress - Demand / Capacity Ratio (DCR)

$$DCR_{\sigma\_2C} := \frac{\sigma_{2C}}{F_y} = 98.664\%$$

$\text{if}\left(DCR_{\sigma\_2C} < 1, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$