BULKHEAD DOCK WALL - CANTILEVERED STEEL PIPE WALL DESIGN

Wall Geometry

$H := 20\ ft$ — *design wall height*

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

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

$\beta := \text{try} \left\| \text{atan}\left(\frac{1}{S}\right) \right. \text{ on error } \| 0 = \left(5.73 \cdot 10^{-6}\right)\ deg$ — *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

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

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

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

Compute Passive Earth Pressure

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

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

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

Compute Loads

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)*

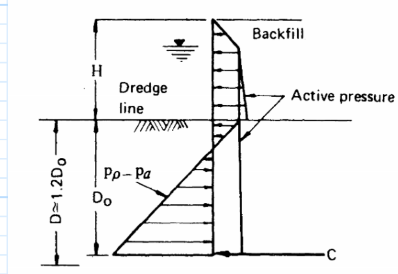
$K_{p\_fill} := \phi_p \cdot K_{P\_fill\_coulomb} = 4.143$

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

Compute Wall Embedment Depth and Bending Moment

Compute the required embedment depth, D_0, corresponding to the depth where the factored active and passive moments are in equilibrium from the Figure shown below. Trial-and-error is used to determine the depth by adjusting D_0 in the following equations:

$D_0 := 27.81\ ft$ *try and error until moment equilibrium



Earth Pressure

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

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

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

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

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

$$P_{a\_soil\_bottom} := P_{a\_soil\_top} + \gamma'_{soil} \cdot K_{a\_soil} \cdot D_0 = 926.017\ psf$$

$$P_{p\_soil\_bottom} := \gamma'_{soil} \cdot K_{p\_soil} \cdot D_0 = 8458.652\ psf$$

Force

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

$$F_{a\_sur\_soil} := P_{a\_sur\_soil} \cdot D_0 = 15826.307\ \frac{lbf}{ft}$$

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

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

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

$$F_{a\_soil\_top} := P_{a\_soil\_top} \cdot D_0 = 11462.61\ \frac{lbf}{ft}$$

$$F_{a\_soil\_bottom} := \left(P_{a\_soil\_bottom} - P_{a\_soil\_top}\right) \cdot \frac{D_0}{2} = 7144.961\ \frac{lbf}{ft}$$

$$F_{p\_soil\_bottom} := P_{p\_soil\_bottom} \cdot \frac{D_0}{2} = 117617.557\ \frac{lbf}{ft}$$

Moment Arm from the bottom of wall

$$d_{a\_sur\_fill} := \frac{H}{2} + D_0 = 37.81\ ft$$

$$d_{a\_sur\_soil} := \frac{D_0}{2} = 13.905\ ft$$

$$d_{a\_fill\_top} := \frac{H_{dry}}{3} + H_{water} + D_0 = 44.477\ ft$$

$$d_{a\_fill\_water} := \frac{H_{water}}{2} + D_0 = 35.31\ ft$$

$$d_{a\_fill\_bottom} := \frac{H_{water}}{3} + D_0 = 32.81\ ft$$

$$d_{a\_soil\_top} := \frac{D_0}{2} = 13.905\ ft$$

$$d_{a\_soil\_bottom} := \frac{D_0}{3} = 9.27\ ft$$

$$d_{p\_soil\_bottom} := \frac{D_0}{3} = 9.27\ ft$$

Active moments

$$M_a := F_{a\_sur\_fill} \cdot d_{a\_sur\_fill} + F_{a\_sur\_soil} \cdot d_{a\_sur\_soil} + F_{a\_fill\_top} \cdot d_{a\_fill\_top} + F_{a\_fill\_water} \cdot d_{a\_fill\_water} + F_{a\_fill\_bottom} \cdot d_{a\_fill\_bottom} + F_{a\_soil\_top} \cdot d_{a\_soil\_top} + F_{a\_soil\_bottom} \cdot d_{a\_soil\_bottom} = 1089.714\ \frac{kip \cdot ft}{ft}$$

Passive moments

$$M_p := F_{p\_soil\_bottom} \cdot d_{a\_soil\_bottom} = 1090.315 \ \frac{kip \cdot ft}{ft}$$

Moment Equilibrium

$$\Sigma M := M_p - M_a = 0.6 \ \frac{kip \cdot ft}{ft}$$

(Approximately equal to zero)

$$\text{if}\left(0 \le \Sigma M \le 1\% \cdot M_a, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

Bending Moment Ratio at D0

$$Moment.Ratio := \left|\frac{M_p}{M_a}\right| = 1.001$$

$$\text{if}\left(Moment.Ratio \ge 1, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

Compute the required embedment depth, $D_{embeded}$. Since the wall embedment depth uses the Simplified Method with continuous vertical elements a 20% to 40% increase in embedment will be included

$$D_{embeded} := \text{Floor}\left(\text{mean}\left(1.2 \cdot D_0, 1.4 \cdot D_0\right), 1 \cdot ft\right) = 36 \ ft$$

$$D_{embeded} = 36 \ ft \ \ge \ 1.2 \cdot D_0 = 33.372 \ ft$$

Total length of sheet pile

$$H_{total} := H + D_{embeded} = 56 \ ft$$

$$H_{total} = 56 \ ft$$

Find the point of Zero Shear

$$V_0(y) := F_{a\_sur\_fill} + P_{a\_sur\_soil} \cdot y + F_{a\_fill\_top} + F_{a\_fill\_water} + F_{a\_fill\_bottom} + \left(\gamma_{fill} \cdot H_{dry} + \gamma'_{fill} \cdot H_{water}\right) \cdot K_{a\_soil} \cdot y + \gamma'_{soil} \cdot K_{a\_soil} \cdot \frac{y^2}{2} - \gamma'_{soil} \cdot K_{p\_soil} \cdot \frac{y^2}{2}$$

$$y_{shear} := \text{root}\left(V_0(y), y, 0, D_{embeded}\right) = 14.995 \ ft$$

measured from dredge line

Compute the maximum moment at the location of zero shear

Force

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

$$FM_{a\_sur\_soil} := P_{a\_sur\_soil} \cdot y_{shear} = 8533.174 \ \frac{lbf}{ft}$$

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

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

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

$$FM_{a\_soil\_top} := P_{a\_soil\_top} \cdot y_{shear} = 6180.371 \ \frac{lbf}{ft}$$

$$FM_{a\_soil\_bottom} := \left(\gamma'_{soil} \cdot K_{a\_soil} \cdot y_{shear}\right) \cdot \frac{y_{shear}}{2} = 2077.122 \ \frac{lbf}{ft}$$

$$FM_{p\_soil} := \gamma'_{soil} \cdot K_{p\_soil} \cdot y_{shear} \cdot \frac{y_{shear}}{2} = 34192.765 \ \frac{lbf}{ft}$$

Moment Arm from the point of zero shear

$$dM_{a\_sur\_fill} := \frac{H}{2} + y_{shear} = 24.995 \ ft$$

$$dM_{a\_sur\_soil} := \frac{y_{shear}}{2} = 7.497 \ ft$$

$$dM_{a\_fill\_top} := \frac{H_{dry}}{3} + H_{water} + y_{shear} = 31.661 \ ft$$

$$dM_{a\_fill\_water} := \frac{H_{water}}{2} + y_{shear} = 22.495 \ ft$$

$$dM_{a\_fill\_bottom} := \frac{H_{water}}{3} + y_{shear} = 19.995 \ ft$$

$$dM_{a\_soil\_top} := \frac{y_{shear}}{2} = 7.497 \ ft$$

$$dM_{a\_soil\_bottom} := \frac{y_{shear}}{3} = 4.998 \ ft$$

$$dM_{p\_soil} := \frac{y_{shear}}{3} = 4.998 \ ft$$

Maximum Moment

$$M_{max} := FM_{a\_sur\_fill} \cdot dM_{a\_sur\_fill} + FM_{a\_sur\_soil} \cdot dM_{a\_sur\_soil} + FM_{a\_fill\_top} \cdot dM_{a\_fill\_top} + FM_{a\_fill\_water} \cdot dM_{a\_fill\_water} + FM_{a\_fill\_bottom} \cdot dM_{a\_fill\_bottom} + FM_{a\_soil\_top} \cdot dM_{a\_soil\_top} + FM_{a\_soil\_bottom} \cdot dM_{a\_soil\_bottom} - FM_{p\_soil} \cdot dM_{p\_soil}$$

$$M_{max} = 370803.329 \ \frac{lbf \cdot ft}{ft}$$

Compute the Required Flexural Resistance

The following is a design check for flexural resistance:

Mmax <= Mn / Ω_f Mmax = Fy S / Ω_f

$\Omega_f := 2$ *Factor of Safety 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*

$$S_{req'd} := \frac{M_{max} \cdot \Omega_f}{F_y} \qquad S_{req'd} = 177.986 \ \frac{in^3}{ft}$$

Wall Design using Secant Pipe - Alternative 1

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 $t := 1 \ in$

Solver — Guess Values

$D_{try} := 1 \ in$

Constraints

$$\frac{\pi}{32} \cdot \frac{\left(D_{try}^{\ 4} - \left(D_{try} - 2 \cdot t\right)^4\right)}{D_{try}} \cdot \left(\frac{1}{2 \cdot D_{try}}\right) - S_{req'd} = 0$$

$$D_{pipe\_min} := \mathbf{Find}\left(\mathbf{D_{try}}\right) = 40.673 \ in$$

Elastic section modulus of selected Pipe section:

$D_{pipe\_seld} := \text{PipeDiameter: 48} = 4\ ft$

$$S_{sel'd} := \frac{\pi}{32} \cdot \frac{\left(D_{pipe\_seld}{}^4 - \left(D_{pipe\_seld} - 2 \cdot t\right)^4\right)}{D_{pipe\_seld}} \cdot \left(\frac{1}{D_{pipe\_seld}}\right) = 424.892\ \frac{in^3}{ft}$$

Section Modulus Utilization

$$U_{Section\_pipe} := \frac{S_{req'd}}{S_{sel'd}} = 41.89\%$$

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

Wall Deflection estimation

Conservatively, pipe is NOT considered to be filled with concrete.

$W_{distributed} := P_{a\_sur\_fill} + P_{a\_fill\_bottom} = 1064.824\ psf$ — *Assumed Distributed load*

$$I_{pipe} := \frac{\pi}{64} \cdot \left(D_{pipe\_seld}{}^4 - \left(D_{pipe\_seld} - 2 \cdot t\right)^4\right) \cdot \left(\frac{1}{D_{pipe\_seld}}\right) = 10197.413\ \frac{in^4}{ft}$$

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

$f'_c := 4.5\ ksi$ — *Concrete compressive strength*

$E_{concrete} := 1820 \sqrt{\frac{f'_c}{ksi}}\ ksi = 3860.803\ ksi$ — *Concrete modulus of elasticity*

$$I_{fill\_conc} := \frac{\pi}{64} \cdot \left(D_{pipe\_seld} - 2 \cdot t\right)^4 \cdot \left(\frac{1}{D_{pipe\_seld}}\right) = 54946.652\ \frac{in^4}{ft}$$

$I_{comb} := I_{pipe} + I_{fill\_conc} \cdot \frac{E_{concrete}}{E_{steel}} = 17512.524\ \frac{in^4}{ft}$ — *Combined Moment of Inertia*

$\delta_{max} := \frac{W_{distributed} \cdot H_{total}{}^4}{8 \cdot E_{steel} \cdot I_{pipe}} = 7.649\ in$ — *Maximum estimated wall deflection (steel pipe only)*

$\delta_{limit} := 1\% \cdot H_{total} = 6.72\ in$ — *assuming 1% of wall height*

$\text{if}\left(\delta_{max} < \delta_{limit}, \text{“OK”}, \text{“NG – increase diam.”}\right) = \text{“NG – increase diam.”}$ — *acceptable*

Check maximum allowable stress

$$\sigma_{pipe} := \frac{\Omega_f \cdot M_{max}}{S_{sel'd}} = 20.945\ ksi$$

Stress - Demand / Capacity Ratio (DCR)

$$DCR_{\sigma\_pipe} := \left|\frac{\sigma_{pipe}}{F_y}\right| = 41.89\%$$

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

Wall Design using Pipe-Z Combination - Alternative 2

Determine minimum pipe diameter for required section modulus

assuming pipe wall thickness $t_{pipeZ} := 1\ in$

Guess Values

$D_{try} := 1\ in$

Constraints

$$\frac{\pi}{32} \cdot \frac{\left(D_{try}^{4} - \left(D_{try} - 2 \cdot t_{pipeZ}\right)^{4}\right)}{D_{try}} \cdot \left(\frac{1}{2 \cdot D_{try}}\right) - S_{req'd} = 0$$

Solver

$D_{pipeZ\_min} := \mathbf{Find}\left(D_{try}\right) = 40.673\ in$

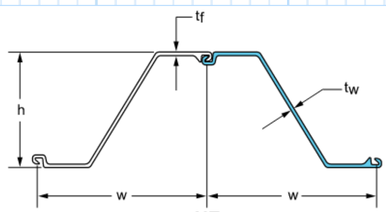
Selected Pipe diameter:

$D_{pipeZ\_seld} :=$ PipeDiameter: 48 $= 4\ ft$

Moment of Inertial of the pipe

$$I_{pipeZ} := \frac{\pi}{64} \cdot \left(D_{pipeZ\_seld}^{4} - \left(D_{pipeZ\_seld} - 2 \cdot t_{pipeZ}\right)^{4}\right) = 40789.654\ in^{4}$$

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

in

Selected NZ profile section properties:

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

Width $w_{NZ} = 30.31\ in$

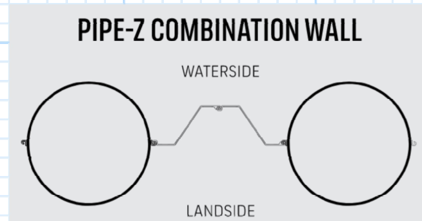
Section Modulus $S_{NZ\_ft} = 25.65\ \frac{in^3}{ft}$

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 $s_{pipeZ} := D_{pipeZ\_seld} + 2 \cdot w_{NZ} = 9.052\ ft$

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



$$I_{system} := \frac{I_{pipeZ} + 2 \cdot I_{NZ}}{s_{pipeZ}} = 4602.139\ \frac{in^4}{ft}$$

Elastic section modulus of Pipe-Z Combination wall

$$S_{system} := \frac{I_{system}}{\frac{D_{pipeZ\_seld}}{2}} = 191.756\ \frac{in^3}{ft}$$

Section Modulus Utilization

$$U_{Section\_pipeZ} := \left| \frac{S_{req'd}}{S_{system}} \right| = 92.819\%$$

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

Wall Deflection estimation

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

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

$$\delta_{max\_pipeZ} := \frac{W_{distributed} \cdot H_{total}^4}{185 \cdot E_{steel} \cdot I_{system}} = 0.733\ in$$

Maximum deflection

$\delta_{limit} = 6.72\ in$ *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

$$\sigma_{pipeZ} := \frac{\Omega_f \cdot M_{max}}{S_{system}} = 46.409\ ksi$$

Stress - Demand / Capacity Ratio (DCR)

$$DCR_{\sigma\_pipeZ} := \left| \frac{\sigma_{pipeZ}}{F_y} \right| = 92.819\%$$

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