Woodland Glen 2nd Plat
Lee's Summit, Missouri

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Reinforced Soil Retaining Wall Design

SCHLAGEL
ENGINEERS PLANNERS SURVEYORS LANDSCAPE ARCHITECTS

☐ REVIEWED
☑ REVIEWED AS NOTED
☐ REVISE AND RESUBMIT
☐ REJECTED
☐ FOR INFORMATION ONLY

BY rmcginnis   DATE 5/25/2021

Revise minor grading to match plans dated 05/17/2021 (Rev. 3). Block Type and Color are acceptable.

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Submerged Segmental Retaining Wall Design Calculations per NCMA

Wall Geometry

Height	Backslope	Dead Load	Live Load	Distance to Slope	Wall below grade at toe	Height of Normal pool Water	Height of water for 100yr flood
$H := 13.00 \cdot ft$	$\beta := 8.0 \cdot deg$	$q_d := 0 \cdot psf$	$q_l := 0 \cdot psf$	$Z := 0.0 \cdot ft$	$H_{emb} := 1.00 \cdot ft$	$h_w := 3.00 \cdot ft$	$h_{wf} := 7.0 \cdot ft$

Soil Properties

Submerged Soil	Reinforced Soil (Internal)	Retained Soil (External)	Foundation Soil	Drainage Fill	Pullout	Water
$\gamma_s := 110 \cdot pcf$	$\gamma_i := 110 \cdot pcf$	$\gamma_e := 120 \cdot pcf$	$\gamma_f := 120 \cdot pcf$	$\gamma_d := 110 \cdot pcf$	$C_i := 0.8$	$\gamma_w := 62.4 \cdot pcf$
$\gamma_{ssat} := 120 \cdot pcf$	$\gamma_{isat} := 120 \cdot pcf$	$\gamma_{esat} := 130 \cdot pcf$	$\gamma_{fsat} := 130 \cdot pcf$	$\gamma_{dsat} := 120 \cdot pcf$		
$\phi_s := 32 \cdot deg$	$\phi_i := 32 \cdot deg$	$\phi_e := 26 \cdot deg$	$\phi_f := 26 \cdot deg$	$\phi_d := 32 \cdot deg$		
$\gamma'_s := \gamma_{ssat} - \gamma_w$	$\gamma'_i := \gamma_{isat} - \gamma_w$	$\gamma'_e := \gamma_{esat} - \gamma_w$	$\gamma'_f := \gamma_{fsat} - \gamma_w$	$\gamma'_d := \gamma_{dsat} - \gamma_w$		
$\gamma'_s = 57.6 \cdot pcf$	$\gamma'_i = 57.6 \cdot pcf$	$\gamma'_e = 67.6 \cdot pcf$	$\gamma'_f = 67.6 \cdot pcf$	$\gamma'_d = 57.6 \cdot pcf$		
	$C_{dsi} := 0.7$	$C_{dse} := 1.0$	$c_f := 0 \cdot psf$			

Rapid Drawdown height

$h_r := 1ft$

Segmental Unit Properties

Height	Length	Width	Setback	Center of Gravity
$H_u := 8 \cdot in$	$L_u := 18 \cdot in$	$W_u := 12.0 \cdot in$	$\Delta_u := 1.0 \cdot in$	$G_u := 6.0 \cdot in$

Batter

$$\omega := atan\left(\frac{\Delta_u}{H_u}\right)$$

$$\omega = 7.125 \cdot deg$$

Infilled Unit Weight

$\gamma_u := 120 \cdot pcf$

Hinge Height

$$H_h := if\left[tan(\omega) = 0, H, \left[2 \cdot \frac{(W_u - G_u)}{tan(\omega)}\right]\right] \Rightarrow H_h = 8\ ft$$ [Eq. 4-1]

Internal Interface Friction Angle

$$\delta_i := \frac{2}{3} \cdot \phi_i \qquad \delta_i = 21.33 \cdot deg$$ [Eq. 3-17]

Internal Active Earth Pressure

$$Ka_i := \frac{cos(\phi_i + \omega)^2}{cos(\omega)^2 \cdot cos(\omega - \delta_i) \cdot \left[1 + \sqrt{\left(\frac{sin(\phi_i + \delta_i) \cdot sin(\phi_i - \beta)}{cos(\omega - \delta_i) \cdot cos(\omega + \beta)}\right)}\right]^2}$$

[Eq. 3-11] $Ka_i = 0.249$

External Interface Friction Angle

$$\delta_e := if(\phi_i > \phi_e, \phi_e, \phi_i) \qquad \delta_e = 26 \cdot deg$$ [Eq. 3-16]

External Active Earth Pressure

$$Ka_e := \frac{cos(\phi_e + \omega)^2}{cos(\omega)^2 \cdot cos(\omega - \delta_e) \cdot \left[1 + \sqrt{\left[\frac{sin(\phi_e + \delta_e) \cdot sin((\phi_e - \beta))}{cos(\omega - \delta_e) \cdot cos(\omega + \beta)}\right]}\right]^2}$$

[Eq. 3-11] $Ka_e = 0.327$

Orientation of Critical Internal Failure Surface

$$\alpha_i := atan\left[\frac{-tan(\phi_i - \beta) + \sqrt{(tan(\phi_i - \beta)) \cdot (tan(\phi_i - \beta) + cot(\phi_i + \omega)) \cdot (1 + tan(\delta_i - \omega) \cdot cot(\phi_i + \omega))}}{1 + tan(\delta_i - \omega) \cdot (tan(\phi_i - \beta) + cot(\phi_i + \omega))}\right] + \phi_i$$

[Eq. 3-14]

$$\alpha_i = 52.892 \cdot deg$$

Orientation of Critical External Failure Surface

$$\alpha_e := \operatorname{atan}\left[\frac{-\tan(\phi_e-\beta)+\sqrt{\tan(\phi_e-\beta)\cdot\left(\tan(\phi_e-\beta)+\cot(\phi_e+\omega)\right)\cdot\left(1+\tan(\delta_e-\omega)\cdot\cot(\phi_e+\omega)\right)}}{1+\tan(\delta_e-\omega)\cdot\left(\tan(\phi_e-\beta)+\cot(\phi_e+\omega)\right)}\right]+\phi_e$$

[Eq. 3-14]

$\alpha_e = 47.198\cdot deg$

External Stability Analysis

Sliding

Given

$$1.5 = \frac{\min\left[\left[\begin{matrix} C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\left[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)\right]\ \ldots \\ +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_i) \\ C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\left[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)\right]\ \ldots \\ +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_d) \\ C_{dse}\cdot\left[c_f\cdot L+\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\left[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)\right]\ \ldots \\ +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_f)\right]\end{matrix}\right]\right]}{\begin{matrix}\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right]\ \ldots \\ +Ka_e\cdot\gamma_{esat}\cdot h_w\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\ \ldots \\ +\frac{1}{2}\cdot Ka_e\cdot\gamma_{esat}\cdot h_w^{2}\cdot\cos(\delta_e-\omega)\ \ldots \\ +(q_d+q_l)\cdot Ka_e\cdot\left[H+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\ \ldots \\ +\frac{1}{2}\cdot h_r^{2}\cdot\gamma_w\end{matrix}}$$

$L_{sliding} := \operatorname{Find}(L)$ $\qquad L_{sliding} = 8.945\ ft$

Overturning

Given

$$2.0 = \frac{\begin{aligned}&\left[\left[L\cdot\gamma_i\cdot\left(H-h_w\right)+\gamma'_i\cdot h_w\cdot L\right]\cdot\left[\frac{1}{2}\cdot(L+H\cdot\tan(\omega))\right]\right]\ \ldots\\&+\left[\frac{1}{2}\cdot\gamma_i\cdot\left(L-W_u-Z\right)\cdot\left[\left(L-W_u-Z\right)+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\left[\left[H\cdot\tan(\omega)+W_u+Z+\frac{2}{3}\cdot\left(L-W_u-Z\right)\right]\right]\ \ldots\\&+q_d\cdot\left[\left(L-W_u-Z\right)+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\left[\frac{Z+\left[\left(L-W_u-Z\right)+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]}{2}+\left[H+\left[\left(L-W_u-Z\right)+\frac{(L-\cdots}{1\cdots}\right.\right.\right.\end{aligned}}{\begin{aligned}&\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H-h_w+\left[\left[L-W_u+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]^2\cdot\cos\left(\delta_e-\omega\right)\right]\cdot\left[\frac{1}{3}\cdot\left[H-h_w+\left[\left[L-W_u+\frac{\left(L-W_u-\cdots\right.}{1-\tan\cdots}\right.\right.\right.\right.\\&+Ka_e\cdot\gamma_{esat}\cdot h_w\cdot\left[H-h_w+\left[\left[L-W_u+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos\left(\delta_e-\omega\right)\cdot\left(\frac{1}{2}\cdot h_w\right)\ \ldots\\&+\frac{1}{6}\cdot h_w^{\,3}\cdot\gamma_{esat}\cdot Ka_e\cdot\cos\left(\delta_e-\omega\right)\ \ldots\\&+\left[\left(q_d+q_l\right)\cdot Ka_e\cdot\left[\left[H+\left[\left[L-W_u+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos\left(\delta_e-\omega\right)\right]\right]\cdot\left[\frac{1}{2}\cdot\left[H+\left[\left[L-W_u+\frac{\left(L-W_u-Z\right)\cdot\tan\cdots}{1-\tan(\beta)\cdots}\right.\right.\right.\right.\\&+\left(\frac{1}{2}\cdot h_r^{\,2}\cdot\gamma_w\right)\cdot\left(h_w+\frac{h_r}{3}\right)\end{aligned}}$$

$L_{overturning} := \text{Find}(L)$ $\qquad L_{overturning} = 6.262\ ft$

$$L := \max\left(\begin{pmatrix}L_{sliding}\\L_{overturning}\\0.6\cdot H\end{pmatrix}\right) \qquad L = 8.945\ ft$$

Based on Overturning and Sliding: $L := 9.0\cdot ft$ *(Round up L)*

Eccentricity

$L' := L - W_u - Z$	$L' = 8\cdot ft$	[Fig. 2-10]	[Eq. 5-1]
$L'' := \dfrac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}$	$L'' = 0.143\ ft$	[Fig. 2-10]	[Eq. 5-2]
$L_\beta := L' + L''$	$L_\beta = 8.143\ ft$	[Fig. 2-10]	[Eq. 5-3]
$h := L_\beta\cdot\tan(\beta)$	$h = 1.144\ ft$	[Fig. 2-10]	[Eq. 5-4]
$W_{ri} := L\cdot\left[\gamma_i\cdot\left(H-h_w\right)+\left(\gamma_{isat}\cdot h_w\right)\right]$	$W_{ri} = 13140\cdot plf$	[Eq. 5-15]	
$X_{ri} := \dfrac{1}{2}\cdot(L+H\cdot\tan(\omega))$	$X_{ri} = 5.313\ ft$	[Eq. 5-19]	
$W_{r\beta} := \dfrac{1}{2}\cdot\gamma_i\cdot(L')\cdot h$	$W_{r\beta} = 503.55\cdot plf$	[Eq. 5-16]	
$X_{r\beta} := H\cdot\tan(\omega)+W_u+Z+\dfrac{2}{3}\cdot L'$	$X_{r\beta} = 7.958\ ft$	[Eq. 5-20]	
$X_{q\beta} := \dfrac{Z+L_\beta}{2}+[(H+h)\cdot\tan(\omega)]+W_u$	$X_{q\beta} = 6.84\ ft$	[Eq. 5-21]	

Actual Heigth of wall:

$H_s := (H + h)$ $H_s = 14.144\,ft$

Earth Pressures:

$P_{s1H} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot (H_s - h_w)^2 \cdot \cos(\delta_e - \omega)\right]$ $P_{s1H} = 2308.715 \cdot plf$ [Eq. 5-6]

$Y_{s1} := \frac{1}{3} \cdot (H_s - h_w) + h_w$ $Y_{s1} = 6.715\,ft$ [Eq. 5-9]

$P_{s2H} := \left[Ka_e \cdot \gamma_{esat} \cdot (H_s - h_w) \cdot h_w \cdot \cos(\delta_e - \omega)\right]$ $P_{s2H} = 1346.56 \cdot plf$ [Eq. 5-6]

$Y_{s2} := \frac{h_w}{2}$ $Y_{s2} = 1.5\,ft$ [Eq. 5-9]

$P_{s3H} := \frac{1}{2} \cdot Ka_e \cdot \gamma_{esat} \cdot (h_w)^2 \cdot \cos(\delta_e - \omega)$ $P_{s3H} = 181.242 \cdot plf$ [Eq. 5-6]

$Y_{s3} := \frac{h_w}{3}$ $Y_{s3} = 1\,ft$ [Eq. 5-9]

$P_{qH} := (q_d + q_l) \cdot Ka_e \cdot (H_s) \cdot \cos(\delta_e - \omega)$ $P_{qH} = 0 \cdot plf$ [Eq. 5-8]

$Y_q := \frac{1}{2} \cdot (H_s)$ $Y_q = 7.072\,ft$ [Eq. 5-10]

$P_w := \frac{1}{2} \cdot \gamma_w \cdot (h_r)^2$ $P_w = 31.2 \cdot plf$ [Eq. 5-6]

$Y_w := h_w + \frac{h_r}{3}$ $Y_w = 3.333\,ft$ [Eq. 5-9]

$$e := \frac{\left[P_{s1H} \cdot Y_{s1} + P_{s2H} \cdot Y_{s2} + P_{s3H} \cdot Y_{s3} + P_{qH} \cdot Y_q + P_w \cdot Y_w - W_{ri} \cdot \left(X_{ri} - \frac{L}{2}\right) - W_{r\beta} \cdot \left(X_{r\beta} - \frac{L}{2}\right) - q_d \cdot (L_\beta) \cdot \left(X_{q\beta} - \frac{L}{2}\right)\right]}{W_{ri} + W_{r\beta} + q_d \cdot (L_\beta)}$$ [Eq. 5-25]

$e = 0.3951\,ft$

Check $e := \text{if}(e \le 0, 0.075L, e)$ $e = 0.395\,ft$

Surcharge is applied over: $(L' + L") = 8.143\,ft$ $B := L - 2 \cdot e$ $B = 8.21\,ft$ [Eq. 5-24]

Bearing Capacity

$Q_a := \frac{\left[W_{ri} + W_{r\beta} + (q_d + q_l) \cdot (L' + L")\right]}{B}$ $Q_a = 1661.844 \cdot psf$

$N_q := \tan\left(45 \cdot deg + \frac{\phi_f}{2}\right)^2 \cdot \exp(\pi \cdot \tan(\phi_f))$ $N_q = 11.854$ [Fig. 4-5]

$N_c := if[\phi_f = 0, 5.14, (N_q - 1)\cdot cot(\phi_f)]$ $N_c = 22.254$ [Fig. 4-5]

$N_\gamma := 2\cdot(N_q + 1)\cdot tan(\phi_f)$ $N_\gamma = 12.539$ [Fig. 4-5]

$Q_{ult} := c_f\cdot N_c + \frac{1}{2}\cdot\gamma'_f\cdot B\cdot N_\gamma + \gamma_f\cdot H_{emb}\cdot N_q$ $Q_{ult} = 4901.956\cdot psf$ [Eq. 4-20]

$FS_{bearing} := \frac{Q_{ult}}{Q_a}$ $FS_{bearing} = 2.95$ [Eq. 4-19]

Internal Stability

Reinforcement Properties

Geogrid Design Data

Backfill Soil $Type := (gravel)$

	1	2	3	4	5	6	7	8	9
$Type^T =$	411	834	1199	1336	2004	2508	3011	3873	7914
$inter^T =$	1145	1145	1145	1145	1145	1145	0		
$slope^T =$	38	38	38	38	38	38	0		
$maxc^T =$	4540	4540	4540	4540	4540	4540	0		

Geogrid Number $GN1 := 2$ $GN2 := 2$

$x := 7..1$ x is the number of grids at the top of the wall of a different type

$T_a := Type_{GN1}\cdot plf$ $T_a = 834\cdot plf$ $T_{a2} := Type_{GN2}\cdot plf$ $T_{a2} = 834\cdot plf$

$a_{cs} := inter_{GN1}\cdot plf$ $a_{cs} = 1145\cdot plf$ | $\lambda_{cs} := slope_{GN1}\cdot deg$ $\lambda_{cs} = 38\cdot deg$ | $V_{csmax} := maxc_{GN1}\cdot plf$ $V_{csmax} = 4540\cdot plf$

$a_{cs2} := inter_{GN2}\cdot plf$ $a_{cs2} = 1145\cdot plf$ | $\lambda_{cs2} := slope_{GN2}\cdot deg$ $\lambda_{cs2} = 38\cdot deg$ | $V_{csmax2} := maxc_{GN2}\cdot plf$ $V_{csmax2} = 4540\cdot plf$

Tension in Geogrid

of grids for Depth of first

Number of Grids: $n_g := 5$

Grig Spacing (ft): $Spacing1 := 2$ $\quad Spacing2 := 1.33$

Make all zero when using one geogrid

that spacing: $n_1 := 5$ $\quad n_2 := 0$

grid (ft): $h_1 := 4.33$

Length of grids: $L_1 := 9.0$ $\quad L_2 := 9.0$ $\quad L_r := \frac{L}{ft}$

Note: make sure that the elevations don't excide the height of the wall (H) $H = 13\,ft$

$top := length(E)$ $\quad p := 2..top$ $\quad top = 5$

$grids := length(E)$ $\quad n := 1..top$ $\quad l := 1..grids - 1$

$$E = \begin{pmatrix} 4.33 \\ 6.33 \\ 8.33 \\ 10.33 \\ 12.33 \end{pmatrix} ft$$

$$T_{a_x} := T_{a2} \qquad T_{a_x} = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf \qquad T_a := \overrightarrow{\frac{L \cdot T_a}{L}} \qquad T_a = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$L = \begin{pmatrix} 9 \\ 9 \\ 9 \\ 9 \\ 9 \end{pmatrix} ft$$

$$T_a^T = (834 \;\; 834 \;\; 834 \;\; 834 \;\; 834 \;\; 834 \;\; 834) \cdot plf$$

$$D_p := \frac{E_{p-1} + E_p}{2} \qquad D_1 := 0 \cdot ft \qquad D_{grids+1} := H$$

$$D^T = (0 \;\; 5.33 \;\; 7.33 \;\; 9.33 \;\; 11.33 \;\; 13)\, ft$$

Total Applied Tensile Strength in the Geosynthetic reinf.:

$$F_{g_n} := \int_{D_n}^{D_{(n+1)}} if\left[D < (H - h_w), \left[(\gamma_i \cdot D + q_l + q_d) \cdot Ka_i \cdot \cos(\delta_i - \omega) + \left[if\left[D < (H - h_{wf}), 0plf, \gamma_w \cdot \left[D - (H_s - h_{wf})\right]\right]\right]\right], \left[Ka_i \cdot \left[\gamma_i \cdot (H_s - h_w) + (\gamma\right.\right.\right.$$

[Eq. 5-36]

$$F_g^T = (377.555 \;\; 296.699 \;\; 590.783 \;\; 735.95 \;\; 648.315) \cdot plf$$

Safety factor:

$$FS_{ten_n} := \frac{T_{a_n}}{F_{g_n}} \qquad FS_{ten}^T = (2.209 \;\; 2.811 \;\; 1.412 \;\; 1.133 \;\; 1.286)$$

Pullout Capacity

Anchorage Length of Geosynthetic

$$La_n := L_n - W_u - \left[\left(H_s\right) - E_n\right] \cdot \tan\left(90 \cdot deg - \alpha_i\right) + \left[\left(H_s\right) - E_n\right] \cdot \tan(\omega)$$ [Eq. 5-46]

$La^T = (1.802 \quad 3.065 \quad 4.328 \quad 5.591 \quad 6.854)\ ft$

Note: If the anchorage length is less than 1ft then there is not enough embedment length and it has to be increased. Note that in some cases it might just be the top two grids.

Average Depth of overburden on Anchorage length

$$d_n := E_n + \left[\left(H_s - E_n\right) \cdot \tan\left(90 \cdot deg - \alpha_i\right) + \frac{La_n}{2} - \left(Z + H \cdot \tan(\omega) - \Delta_u\right)\right] \cdot \tan(\beta)$$ [Eq. 5-47]

$d^T = (5.283 \quad 7.16 \quad 9.036 \quad 10.912 \quad 12.788)\ ft$

Anchorage Capacity

$$AC_n := \text{if}\left[D_n < \left(H - h_w\right), \left[2 \cdot La_n \cdot C_i \cdot \left[d_n \cdot \gamma_i + q_d + \gamma_w \cdot \left[d_n - \left(H_s - h_{wf}\right)\right]\right] \cdot \tan\left(\phi_i\right)\right], \left[2 \cdot La_n C_i \cdot \left[\gamma_i \cdot \left(H_s - h_w\right) + \left(\gamma_{isat}\right) \cdot \left[h_w - \left(H_s - d_n\right)\right] + \cdots\right.\right.\right.$$

[Eq. 5-45]

$AC^T = (837.881 \quad 2416.302 \quad 4811.582 \quad 8023.721 \quad 10179.749) \cdot plf$

$F_g{}^T = (377.555 \quad 296.699 \quad 590.783 \quad 735.95 \quad 648.315) \cdot plf$

Safety Factor

$$FS_{po} := \overrightarrow{\frac{AC}{F_g}}$$ [Eq. 5-44]

$FS_{po}{}^T = (2.219 \quad 8.144 \quad 8.144 \quad 10.903 \quad 15.702)$

Internal Sliding

Reduced reinforcement length

$$\Delta L_{l+1} := \begin{cases} \left[\left(E_{l+1} - E_l\right) \cdot \left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right)\right] & \text{if } n_g > 2 \\ Spacing1 \cdot ft \cdot \left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right) & \text{if } n_g = 2 \\ 0 & \text{if } n_g = 1 \end{cases}$$ [Eq. 5-51]

$\Delta L^T = (0 \quad 1.602 \quad 1.602 \quad 1.602 \quad 1.602)\ ft$

$$L'_{s_n} := L_n - W_u - \Delta L_n - Z$$ [Eq. 5-50]

$L'_s{}^T = (8 \quad 6.398 \quad 6.398 \quad 6.398 \quad 6.398)\ ft$

Length of sloping ground

$$L_{s\beta_n} := L'_{s_n} + \frac{\left(L'_{s_n}\right) \cdot \tan(\beta) \cdot \tan(\omega)}{1 - \tan(\beta) \cdot \tan(\omega)}$$ [Eq. 5-53 & 5-52]

$L_{s\beta}{}^T = (8.143 \quad 6.512 \quad 6.512 \quad 6.512 \quad 6.512)\ ft$

Height of slope above crest of wall

$h'_n := L'_{s_n} \cdot \tan(\beta)$ [Eq. 5-54]

$h'^T = (1.124 \quad 0.899 \quad 0.899 \quad 0.899 \quad 0.899)\ ft$

Weight of reduced reinforced area

$W'_{ri_n} := if[[(H) - E_n] \geq h_w, L'_{s_n} \cdot [(E_n \cdot \gamma_i) + [if[D_n < (H - h_{wf}), 0plf, \gamma_w \cdot [D_n - (H - h_{wf})]]]], L'_{s_n} \cdot [\gamma_i \cdot (H_s - h_w) + \gamma_w \cdot h_r + (\gamma_{isat}) \cdot [h_{\text{(cut off)}}$

$W'_{ri}{}^T = (3810 \quad 4455 \quad 6393 \quad 7617 \quad 9152) \cdot plf$ [Eq. 5-55]

Weight of wedge beyond reinforced soil zone

$W'_{r\beta_n} := \frac{1}{2} \cdot (L_{s\beta_n} \cdot h'_n) \cdot \gamma_i$ [Eq. 5-56]

$W'_{r\beta}{}^T = (503.55 \quad 322.05 \quad 322.05 \quad 322.05 \quad 322.05) \cdot plf$

Friction developed by weight

$R'_{s_n} := [C_{dsi} \cdot [q_d \cdot (L_{s\beta_n} + Z) + W'_{ri_n} + W'_{r\beta_n}] \cdot \tan(\phi_i)]$ [Eq. 5-49]

$R'_s{}^T = (1887 \quad 2089 \quad 2937 \quad 3473 \quad 4144) \cdot plf$

Shear capacity of facing elements

$V_{u_n} := \min[V_{csmax}, a_{cs} + (if(E_n > H_h, H_h, E_n) \cdot \gamma_u \cdot W_u) \cdot \tan(\lambda_{cs})]$ [Eq. 4-25]

$V_u{}^T = (1551 \quad 1738 \quad 1895 \quad 1895 \quad 1895) \cdot plf$

Driving Forces

From retained soil

$P_{s1H_n} := if\left[[(H) - E_n] < h_w, \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot (H_s - h_w)^2 \cdot \cos(\delta_e - \omega)\right], \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot (E_n + h)^2 \cdot \cos(\delta_e - \omega)\right]\right]$

$P_{s1H}{}^T = (557.099 \quad 1038.51 \quad 1668.633 \quad 2308.715 \quad 2308.715) \cdot plf$

$P_{s2H_n} := if[[(H) - E_n] < h_w, [Ka_e \cdot \gamma_{esat} \cdot (H_s - h_w) \cdot [h_w - (H_s - E_n)] \cdot \cos(\delta_e - \omega)], 0]$

$P_{s2H}{}^T = (0 \quad 0 \quad 0 \quad -365.56 \quad 532.146) \cdot plf$

$P_{s3H_n} := if\left[[(H) - E_n] < h_w, \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_{esat} \cdot [h_w - (H_s - E_n)]^2 \cdot \cos(\delta_e - \omega)\right], 0\right]$

$P_{s3H}{}^T = (0 \quad 0 \quad 0 \quad 13.358 \quad 28.305) \cdot plf$

From surcharge

$P_{qH_n} := (q_d + q_l) \cdot Ka_e \cdot (E_n) \cdot \cos(\delta_e - \omega)$

$P_{qH}{}^T = (0 \quad 0 \quad 0 \quad 0 \quad 0) \cdot plf$

$$P_{w_n} := \text{if}\left[\left[(H) - E_n\right] < h_w, \left(\frac{1}{2} \cdot h_r^2 \cdot \gamma_w\right), \left[\frac{\gamma_w}{2} \cdot \left[E_n - \left(H_s - h_{wf}\right)\right]^2\right]\right]$$

$$P_w^T = (247.136 \quad 20.695 \quad 43.854 \quad 31.2 \quad 31.2) \cdot plf$$

$$P_{a_n} := P_{s1H_n} + P_{s2H_n} + P_{s3H_n} + P_{qH_n} + P_{w_n}$$ [Eq. 5-11]

$$P_a^T = (804 \quad 1059 \quad 1712 \quad 1988 \quad 2900) \cdot plf$$

Factor of safety against internal sliding

$$FS_{sl_n} := \frac{R'_{s_n} + V_{u_n}}{\left(P_{a_n}\right)}$$ [Eq. 5-48]

$$FS_{sl}^T = (4.275 \quad 3.614 \quad 2.822 \quad 2.7 \quad 2.082)$$

Local Stability of Facing Units

Facing Connection Strength

$$T_{conn_n} := \min\left[V_{csmax_n}, a_{cs_n} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u\right) \cdot \tan\left(\lambda_{cs_n}\right)\right]$$ [Eq. 5-59]

$$T_{conn}^T = (1551 \quad 1738 \quad 1895 \quad 1895 \quad 1895) \cdot plf$$

$$FS_{conn_n} := \frac{T_{conn_n}}{F_{g_n}}$$

$$FS_{conn}^T = (4.108 \quad 5.859 \quad 3.208 \quad 2.575 \quad 2.923)$$

Resistance to Bulging

Shear capacity at each geogrid layer

$$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u\right) \cdot \tan\left(\lambda_{cs}\right)\right]$$ [Eq. 4-25]

$$V_u^T = (1551 \quad 1738 \quad 1895 \quad 1895 \quad 1895) \cdot plf$$

Driving Force at each geogrid layer

$$P_a^T = (804 \quad 1059 \quad 1712 \quad 1988 \quad 2900) \cdot plf$$

Sum of tension in reinforcement layers above layer being considered

$$F_{n+1} := \sum_{i=1}^{n} F_{g_i}$$

$$F^T = (0 \quad 378 \quad 674 \quad 1265 \quad 2001 \quad 2649) \cdot plf$$

$FS_{sc_n} := \frac{V_{u_n}}{P_{a_n} - F_n}$ [Eq. 5-61]

$FS_{sc}^{T} = (1.928 \quad 2.55 \quad 1.825 \quad 2.622 \quad 2.107)$

Maximum unreinforced height of SRW units

$y := E_1 = 4.33\,ft$ $q_l := 0 \cdot psf$

Moment equilibrium

Driving Moments

$P'_s := \left[\frac{1}{2} \cdot Ka_i \cdot \gamma_i \cdot (y)^2 \cdot \cos(\delta_i - \omega)\right]$ [Eq. 4-5] $P'_s = 249.173 \cdot plf$

$P'_q := (q_d + q_l) \cdot Ka_i \cdot (y) \cdot \cos(\delta_i - \omega)$ [Eq. 4-6] $P'_q = 0 \cdot plf$

$P'_a := P'_s + P'_q$ [Eq. 4-4] $P'_a = 249.173 \cdot plf$

$Y'_s := \frac{1}{3} \cdot y$ [Eq. 4-7] $Y'_s = 1.443\,ft$

$Y'_q := \frac{1}{2} \cdot y$ [Eq. 4-8] $Y'_q = 2.165\,ft$

$M'_o := P'_s \cdot Y'_s + P'_q \cdot Y'_q$ [Eq. 4-17] $M'_o = 359.64 \cdot lbf$

Resisting Moments

$W'_w := y \cdot \gamma_u \cdot W_u$ [Eq. 4-9] $W'_w = 519.6 \cdot plf$

$X'_w := G_u + \frac{1}{2} \cdot (y) \cdot \tan(\omega)$ [Eq. 4-16] $X'_w = 0.771\,ft$

$M'_r := W'_w \cdot X'_w$ [Eq. 4-15] $M'_r = 400.417\,ft \cdot plf$

$FS_{ot} := \frac{M'_r}{M'_o}$ [Eq. 4-14] $\begin{pmatrix} 1550.956 \\ 1550.956 \\ \vdots \end{pmatrix} \cdot plf$

Factor of Safety against Shear failure

$V'_u := a_{cs} + W'_w \cdot \tan(\lambda_{cs})$ [Eq. 4-25]

$FS_{sh} := \frac{V'_u}{P'_a}$ [Eq. 4-27]

$FS_{sh} = \begin{pmatrix} 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \end{pmatrix}$

Summary

Wall Height $H = 13\ ft$

Unreinforced Stability $FS_{ot} = 1.113$ $FS_{bearing} = 2.95$

Applied Bearing Stress $Q_a = 1662 \cdot psf$

Grid Elevation $E_n =$ (ft)	Geogrid Length $L_n =$ (ft)	Tensile Force $\frac{Fg_n}{plf} =$	Geogrid Strength $\frac{Ta_n}{plf} =$	Anch. Length $La_n =$ (ft)	Anch. Capacity $\frac{AC_n}{plf} =$	FS Grid Tension (1.0) $FS_{ten_n} =$	FS Pullout (1.5) $FS_{po_n} =$	FS Int Sliding (1.5) $FS_{sl_n} =$	FS Conn (1.5) $FS_{conn_n} =$	FS Bulging (1.5) $FS_{sc_n} =$
4.33	9	378	834	1.8	838	2.21	2.22	4.27	4.11	1.93
6.33	9	297	834	3.07	2416	2.81	8.14	3.61	5.86	2.55
8.33	9	591	834	4.33	4812	1.41	8.14	2.82	3.21	1.83
10.33	9	736	834	5.59	8024	1.13	10.9	2.7	2.57	2.62
12.33	9	648	834	6.85	10180	1.29	15.7	2.08	2.92	2.11

Submerged Segmental Retaining Wall Design Calculations per NCMA

Wall Geometry

Height	Backslope	Dead Load	Live Load	Distance to Slope	Wall below grade at toe	Height of Normal pool Water	Height of water for 100yr flood
$H := 11.00 \cdot ft$	$\beta := 8.0 \cdot deg$	$q_d := 0 \cdot psf$	$q_l := 0 \cdot psf$	$Z := 0.0 \cdot ft$	$H_{emb} := 1.00 \cdot ft$	$h_w := 3.00 \cdot ft$	$h_{wf} := 7.0 \cdot ft$

Soil Properties

Submerged Soil	Reinforced Soil (Internal)	Retained Soil (External)	Foundation Soil	Drainage Fill	Pullout	Water
$\gamma_s := 110 \cdot pcf$	$\gamma_i := 110 \cdot pcf$	$\gamma_e := 120 \cdot pcf$	$\gamma_f := 120 \cdot pcf$	$\gamma_d := 110 \cdot pcf$	$C_i := 0.8$	$\gamma_w := 62.4 \cdot pcf$
$\gamma_{ssat} := 120 \cdot pcf$	$\gamma_{isat} := 120 \cdot pcf$	$\gamma_{esat} := 130 \cdot pcf$	$\gamma_{fsat} := 130 \cdot pcf$	$\gamma_{dsat} := 120 \cdot pcf$		
$\phi_s := 32 \cdot deg$	$\phi_i := 32 \cdot deg$	$\phi_e := 26 \cdot deg$	$\phi_f := 26 \cdot deg$	$\phi_d := 32 \cdot deg$		
$\gamma'_s := \gamma_{ssat} - \gamma_w$	$\gamma'_i := \gamma_{isat} - \gamma_w$	$\gamma'_e := \gamma_{esat} - \gamma_w$	$\gamma'_f := \gamma_{fsat} - \gamma_w$	$\gamma'_d := \gamma_{dsat} - \gamma_w$		
$\gamma'_s = 57.6 \cdot pcf$	$\gamma'_i = 57.6 \cdot pcf$	$\gamma'_e = 67.6 \cdot pcf$	$\gamma'_f = 67.6 \cdot pcf$	$\gamma'_d = 57.6 \cdot pcf$		
	$C_{dsi} := 0.7$	$C_{dse} := 1.0$	$c_f := 0 \cdot psf$			

Rapid Drawdown height

$h_r := 1ft$

Segmental Unit Properties

Height	Length	Width	Setback	Center of Gravity
$H_u := 8 \cdot in$	$L_u := 18 \cdot in$	$W_u := 12.0 \cdot in$	$\Delta_u := 1.0 \cdot in$	$G_u := 6.0 \cdot in$

Batter

$$\omega := atan\left(\frac{\Delta_u}{H_u}\right)$$

$\omega = 7.125 \cdot deg$

Infilled Unit Weight

$\gamma_u := 120 \cdot pcf$

Hinge Height

$$H_h := if\left[\tan(\omega) = 0, H, \left[2 \cdot \frac{(W_u - G_u)}{\tan(\omega)}\right]\right] \Rightarrow H_h = 8\,ft$$ [Eq. 4-1]

Internal Interface Friction Angle

$$\delta_i := \frac{2}{3} \cdot \phi_i \qquad \delta_i = 21.33 \cdot deg$$ [Eq. 3-17]

Internal Active Earth Pressure

$$Ka_i := \frac{\cos(\phi_i + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_i) \cdot \left[1 + \sqrt{\left(\frac{\sin(\phi_i + \delta_i) \cdot \sin(\phi_i - \beta)}{\cos(\omega - \delta_i) \cdot \cos(\omega + \beta)}\right)}\right]^2}$$

[Eq. 3-11] $Ka_i = 0.249$

External Interface Friction Angle

$$\delta_e := if(\phi_i > \phi_e, \phi_e, \phi_i) \qquad \delta_e = 26 \cdot deg$$ [Eq. 3-16]

External Active Earth Pressure

$$Ka_e := \frac{\cos(\phi_e + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_e) \cdot \left[1 + \sqrt{\left[\frac{\sin(\phi_e + \delta_e) \cdot \sin((\phi_e - \beta))}{\cos(\omega - \delta_e) \cdot \cos(\omega + \beta)}\right]}\right]^2}$$

[Eq. 3-11] $Ka_e = 0.327$

Orientation of Critical Internal Failure Surface

$$\alpha_i := atan\left[\frac{-\tan(\phi_i - \beta) + \sqrt{(\tan(\phi_i - \beta)) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega)) \cdot (1 + \tan(\delta_i - \omega) \cdot \cot(\phi_i + \omega))}}{1 + \tan(\delta_i - \omega) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega))}\right] + \phi_i$$

[Eq. 3-14] $\alpha_i = 52.892 \cdot deg$

Orientation of Critical External Failure Surface

$$\alpha_e := \operatorname{atan}\left[\frac{-\tan(\phi_e-\beta)+\sqrt{\tan(\phi_e-\beta)\cdot(\tan(\phi_e-\beta)+\cot(\phi_e+\omega))\cdot(1+\tan(\delta_e-\omega)\cdot\cot(\phi_e+\omega))}}{1+\tan(\delta_e-\omega)\cdot(\tan(\phi_e-\beta)+\cot(\phi_e+\omega))}\right]+\phi_e$$

[Eq. 3-14]

$\alpha_e = 47.198 \cdot deg$

External Stability Analysis

Sliding

Given

$$1.5 = \frac{\min\left[\begin{array}{l} C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\left[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)\right]\ ... \right.\\ \left. +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_i) \\ C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\left[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)\right]\ ... \right.\\ \left. +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_d) \\ C_{dse}\cdot\left[c_f\cdot L+\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\left[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)\right]\ ... \right.\right.\\ \left.\left. +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_f)\right] \end{array}\right]}{\begin{array}{l} \left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right]\ ... \\ +Ka_e\cdot\gamma_{esat}\cdot h_w\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\ ... \\ +\frac{1}{2}\cdot Ka_e\cdot\gamma_{esat}\cdot h_w^2\cdot\cos(\delta_e-\omega)\ ... \\ +(q_d+q_l)\cdot Ka_e\cdot\left[H+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\ ... \\ +\frac{1}{2}\cdot h_r^2\cdot\gamma_w \end{array}}$$

$L_{sliding} := \mathrm{Find}(L)$

$L_{sliding} = 7.815\ ft$

Overturning

Given

$$2.0 = \frac{\left[\left[L\cdot\gamma_i\cdot(H-h_w)+\gamma'_i\cdot h_w\cdot L\right]\cdot\left[\frac{1}{2}\cdot(L+H\cdot\tan(\omega))\right]\right] \ldots + \left[\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\left[\left[H\cdot\tan(\omega)+W_u+Z+\frac{2}{3}\cdot(L-W_u-Z)\right]\right] \ldots + q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\left[\frac{Z+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]}{2}+\left[H+\left[(L-W_u-Z)+\frac{(L-\ldots}{1\ldots}\right.\right.\right.}{\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right]\cdot\left[\frac{1}{3}\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-\ldots}{1-\text{ta}\ldots}\right.\right.\right.\right. + Ka_e\cdot\gamma_{esat}\cdot h_w\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\cdot\left(\frac{1}{2}\cdot h_w\right) \ldots + \frac{1}{6}\cdot h_w^{\,3}\cdot\gamma_{esat}\cdot Ka_e\cdot\cos(\delta_e-\omega) \ldots + \left[(q_d+q_l)\cdot Ka_e\cdot\left[H+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\right]\cdot\left[\frac{1}{2}\cdot\left[H+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\text{ta}\ldots}{1-\tan(\beta)\ldots}\right.\right.\right.\right. + \left(\frac{1}{2}\cdot h_r^{\,2}\cdot\gamma_w\right)\cdot\left(h_w+\frac{h_r}{3}\right)}$$

$L_{overturning} := \text{Find}(L)$ $\qquad L_{overturning} = 5.384\ \text{ft}$

$$L := \max\begin{pmatrix} L_{sliding} \\ L_{overturning} \\ 0.6\cdot H \end{pmatrix} \qquad L = 7.815\ \text{ft}$$

Based on Overturning and Sliding: $\quad L := 8.0\cdot\text{ft}$ *(Round up L)*

Eccentricity

Definition	Result	Reference	
$L' := L - W_u - Z$	$L' = 7\cdot\text{ft}$	[Fig. 2-10]	[Eq. 5-1]
$L'' := \frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}$	$L'' = 0.125\ \text{ft}$	[Fig. 2-10]	[Eq. 5-2]
$L_\beta := L' + L''$	$L_\beta = 7.125\ \text{ft}$	[Fig. 2-10]	[Eq. 5-3]
$h := L_\beta\cdot\tan(\beta)$	$h = 1.001\ \text{ft}$	[Fig. 2-10]	[Eq. 5-4]
$W_{ri} := L\cdot\left[\gamma_i\cdot(H-h_w)+(\gamma_{isat}\cdot h_w)\right]$	$W_{ri} = 9920\cdot\text{plf}$	[Eq. 5-15]	
$X_{ri} := \frac{1}{2}\cdot(L+H\cdot\tan(\omega))$	$X_{ri} = 4.688\ \text{ft}$	[Eq. 5-19]	
$W_{r\beta} := \frac{1}{2}\cdot\gamma_i\cdot(L')\cdot h$	$W_{r\beta} = 385.53\cdot\text{plf}$	[Eq. 5-16]	
$X_{r\beta} := H\cdot\tan(\omega)+W_u+Z+\frac{2}{3}\cdot L'$	$X_{r\beta} = 7.042\ \text{ft}$	[Eq. 5-20]	
$X_{q\beta} := \frac{Z+L_\beta}{2}+[(H+h)\cdot\tan(\omega)]+W_u$	$X_{q\beta} = 6.063\ \text{ft}$	[Eq. 5-21]	

Actual Heigth of wall:

$H_s := (H + h)$ $\quad H_s = 12.001\ ft$

Earth Pressures:

$P_{s1H} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot (H_s - h_w)^2 \cdot \cos(\delta_e - \omega)\right]$ $\quad P_{s1H} = 1506.165 \cdot plf$ [Eq. 5-6]

$Y_{s1} := \frac{1}{3} \cdot (H_s - h_w) + h_w$ $\quad Y_{s1} = 6\ ft$ [Eq. 5-9]

$P_{s2H} := \left[Ka_e \cdot \gamma_{esat} \cdot (H_s - h_w) \cdot h_w \cdot \cos(\delta_e - \omega)\right]$ $\quad P_{s2H} = 1087.619 \cdot plf$ [Eq. 5-6]

$Y_{s2} := \frac{h_w}{2}$ $\quad Y_{s2} = 1.5\ ft$ [Eq. 5-9]

$P_{s3H} := \frac{1}{2} \cdot Ka_e \cdot \gamma_{esat} \cdot (h_w)^2 \cdot \cos(\delta_e - \omega)$ $\quad P_{s3H} = 181.242 \cdot plf$ [Eq. 5-6]

$Y_{s3} := \frac{h_w}{3}$ $\quad Y_{s3} = 1\ ft$ [Eq. 5-9]

$P_{qH} := (q_d + q_l) \cdot Ka_e \cdot (H_s) \cdot \cos(\delta_e - \omega)$ $\quad P_{qH} = 0 \cdot plf$ [Eq. 5-8]

$Y_q := \frac{1}{2} \cdot (H_s)$ $\quad Y_q = 6.001\ ft$ [Eq. 5-10]

$P_w := \frac{1}{2} \cdot \gamma_w \cdot (h_r)^2$ $\quad P_w = 31.2 \cdot plf$ [Eq. 5-6]

$Y_w := h_w + \frac{h_r}{3}$ $\quad Y_w = 3.333\ ft$ [Eq. 5-9]

$$e := \frac{\left[P_{s1H} \cdot Y_{s1} + P_{s2H} \cdot Y_{s2} + P_{s3H} \cdot Y_{s3} + P_{qH} \cdot Y_q + P_w \cdot Y_w - W_{ri} \cdot \left(X_{ri} - \frac{L}{2}\right) - W_{r\beta} \cdot \left(X_{r\beta} - \frac{L}{2}\right) - q_d \cdot (L_\beta) \cdot \left(X_{q\beta} - \frac{L}{2}\right)\right]}{W_{ri} + W_{r\beta} + q_d \cdot (L_\beta)}$$ [Eq. 5-25]

$e = 0.2874\ ft$

Check $\quad e := \text{if}(e \le 0, 0.075L, e)$ $\quad e = 0.287\ ft$

Surcharge is applied over: $(L' + L") = 7.125\ ft$ $\quad B := L - 2 \cdot e$ $\quad B = 7.425\ ft$ [Eq. 5-24]

Bearing Capacity

$Q_a := \frac{\left[W_{ri} + W_{r\beta} + (q_d + q_l) \cdot (L' + L")\right]}{B}$ $\quad Q_a = 1387.909 \cdot psf$

$N_q := \tan\left(45 \cdot deg + \frac{\phi_f}{2}\right)^2 \cdot \exp(\pi \cdot \tan(\phi_f))$ $\quad N_q = 11.854$ [Fig. 4-5]

$N_c := \text{if}\left[\phi_f = 0, 5.14, (N_q - 1)\cdot\cot(\phi_f)\right]$ $N_c = 22.254$ [Fig. 4-5]

$N_\gamma := 2\cdot(N_q + 1)\cdot\tan(\phi_f)$ $N_\gamma = 12.539$ [Fig. 4-5]

$Q_{ult} := c_f\cdot N_c + \frac{1}{2}\cdot\gamma'_f\cdot B\cdot N_\gamma + \gamma_f\cdot H_{emb}\cdot N_q$ $Q_{ult} = 4569.405\cdot psf$ [Eq. 4-20]

$FS_{bearing} := \frac{Q_{ult}}{Q_a}$ $FS_{bearing} = 3.292$ [Eq. 4-19]

Internal Stability

Reinforcement Properties

Geogrid Design Data

Backfill Soil $Type := (gravel)$

1 2 3 4 5 6 7 8 9 Geogrid Number

$Type^T = (411\ \ 834\ \ 1199\ \ 1336\ \ 2004\ \ 2508\ \ 3011\ \ 3873\ \ 7914)$ $GN1 := 2$ $GN2 := 2$

$inter^T = (1145\ \ 1145\ \ 1145\ \ 1145\ \ 1145\ \ 1145\ \ 0)$

$slope^T = (38\ \ 38\ \ 38\ \ 38\ \ 38\ \ 38\ \ 0)$

$maxc^T = (4540\ \ 4540\ \ 4540\ \ 4540\ \ 4540\ \ 4540\ \ 0)$ $x := 7..1$ x is the number of grids at the top of the wall of a different type

$T_a := Type_{GN1}\cdot plf$ $T_a = 834\cdot plf$ $T_{a2} := Type_{GN2}\cdot plf$ $T_{a2} = 834\cdot plf$

$a_{cs} := inter_{GN1}\cdot plf$ $a_{cs} = 1145\cdot plf$ | $\lambda_{cs} := slope_{GN1}\cdot deg$ $\lambda_{cs} = 38\cdot deg$ | $V_{csmax} := maxc_{GN1}\cdot plf$ $V_{csmax} = 4540\cdot plf$

$a_{cs2} := inter_{GN2}\cdot plf$ $a_{cs2} = 1145\cdot plf$ | $\lambda_{cs2} := slope_{GN2}\cdot deg$ $\lambda_{cs2} = 38\cdot deg$ | $V_{csmax2} := maxc_{GN2}\cdot plf$ $V_{csmax2} = 4540\cdot plf$

Tension in Geogrid

of grids for Depth of first

Number of Grids:	Grig Spacing (ft):	that spacing:	grid (ft):	Length of grids:		
$n_g := 4$	$Spacing1 := 2$	$n_1 := 4$	$h_1 := 4.33$	$L_1 := 8.0$	$L_2 := 8.0$	$L_r := \frac{L}{ft}$
	$Spacing2 := 1.33$	$n_2 := 0$				

Make all zero when using one geogrid

Note: make sure that the elevations don't excide the height of the wall (H) $H = 11\,ft$

$top := length(E)$ $p := 2..top$ $top = 4$

$grids := length(E)$ $n := 1..top$ $l := 1..grids - 1$

$$E = \begin{pmatrix} 4.33 \\ 6.33 \\ 8.33 \\ 10.33 \end{pmatrix} ft$$

$$T_{a_x} := T_{a2} \qquad T_{a_x} = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$T_a := \overrightarrow{\frac{L \cdot T_a}{L}} \qquad T_a = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$L = \begin{pmatrix} 8 \\ 8 \\ 8 \\ 8 \end{pmatrix} ft$$

$$T_a^T = (834 \;\; 834 \;\; 834 \;\; 834 \;\; 834 \;\; 834 \;\; 834) \cdot plf$$

$$D_p := \frac{E_{p-1} + E_p}{2} \qquad D_1 := 0 \cdot ft \qquad D_{grids+1} := H$$

$$D^T = (0 \;\; 5.33 \;\; 7.33 \;\; 9.33 \;\; 11)\,ft$$

Total Applied Tensile Strength in the Geosynthetic reinf.:

$$F_{g_n} := \int_{D_n}^{D_{(n+1)}} if\left[D < (H - h_w), \left[(\gamma_i \cdot D + q_l + q_d) \cdot Ka_i \cdot \cos(\delta_i - \omega) + \left[if\left[D < (H - h_{wf}), 0plf, \gamma_w \cdot \left[D - (H_s - h_{wf})\right]\right]\right]\right], \left[Ka_i \cdot \left[\gamma_i \cdot (H_s - h_w) + (\gamma\right.\right.\right.$$

[Eq. 5-36]

$$F_g^T = (349.482 \;\; 502.316 \;\; 636.069 \;\; 560.115) \cdot plf$$

Safety factor:

$$FS_{ten_n} := \frac{T_{a_n}}{F_{g_n}} \qquad FS_{ten}^T = (2.386 \;\; 1.66 \;\; 1.311 \;\; 1.489)$$

Pullout Capacity

Anchorage Length of Geosynthetic

$$La_n := L_n - W_u - \left[\left(H_s\right) - E_n\right]\cdot\tan\left(90\cdot deg - \alpha_i\right) + \left[\left(H_s\right) - E_n\right]\cdot\tan(\omega)$$ [Eq. 5-46]

$$La^T = (2.155 \quad 3.418 \quad 4.681 \quad 5.945)\ ft$$

Note: If the anchorage length is less than 1ft then there is not enough embedment length and it has to be increased. Note that in some cases it might just be the top two grids.

Average Depth of overburden on Anchorage length

$$d_n := E_n + \left[\left(H_s - E_n\right)\cdot\tan\left(90\cdot deg - \alpha_i\right) + \frac{La_n}{2} - \left(Z + H\cdot\tan(\omega) - \Delta_u\right)\right]\cdot\tan(\beta)$$ [Eq. 5-47]

$$d^T = (5.116 \quad 6.992 \quad 8.868 \quad 10.744)\ ft$$

Anchorage Capacity

$$AC_n := if\left[D_n < \left(H - h_w\right), \left[2\cdot La_n\cdot C_i\cdot\left[d_n\cdot\gamma_i + q_d + \gamma_w\cdot\left[d_n - \left(H_s - h_{wf}\right)\right]\right]\cdot\tan\left(\phi_i\right)\right], \left[2\cdot La_n C_i\cdot\left[\gamma_i\cdot\left(H_s - h_w\right) + \left(\gamma_{isat}\right)\cdot\left[h_w - \left(H_s - d_n\right)\right] + \cdot\right.\right.\right.$$

[Eq. 5-45]

$$AC^T = (1227.986 \quad 3052.992 \quad 5694.857 \quad 7498.336)\cdot plf$$

$$F_g^T = (349.482 \quad 502.316 \quad 636.069 \quad 560.115)\cdot plf$$

Safety Factor

$$FS_{po} := \overrightarrow{\frac{AC}{F_g}}$$ [Eq. 5-44]

$$FS_{po}^T = (3.514 \quad 6.078 \quad 8.953 \quad 13.387)$$

Internal Sliding

Reduced reinforcement length

$$\Delta L_{l+1} := \begin{cases} \left[\left(E_{l+1} - E_l\right)\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right)\right] & \text{if } n_g > 2 \\ Spacing1\cdot ft\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right) & \text{if } n_g = 2 \\ 0 & \text{if } n_g = 1 \end{cases}$$ [Eq. 5-51]

$$\Delta L^T = (0 \quad 1.602 \quad 1.602 \quad 1.602)\ ft$$

$$L'_{s_n} := L_n - W_u - \Delta L_n - Z$$ [Eq. 5-50]

$$L'^T_s = (7 \quad 5.398 \quad 5.398 \quad 5.398)\ ft$$

Length of sloping ground

$$L_{s\beta_n} := L'_{s_n} + \frac{\left(L'_{s_n}\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}$$ [Eq. 5-53 & 5-52]

$$L_{s\beta}^T = (7.125 \quad 5.494 \quad 5.494 \quad 5.494)\ ft$$

Height of slope above crest of wall

$h'_n := L'_{s_n} \cdot \tan(\beta)$ [Eq. 5-54]

$h'^T = (0.984 \quad 0.759 \quad 0.759 \quad 0.759)\ ft$

Weight of reduced reinforced area

$W'_{ri_n} := if\left[\left[(H) - E_n\right] \geq h_w, L'_{s_n} \cdot \left[\left(E_n \cdot \gamma_i\right) + \left[if\left[D_n < \left(H - h_{wf}\right), 0plf, \gamma_w \cdot \left[D_n - \left(H - h_{wf}\right)\right]\right]\right]\right], L'_{s_n} \cdot \left[\gamma_i \cdot \left(H_s - h_w\right) + \gamma_w \cdot h_r + \left(\gamma_{isat}\right) \cdot \left[h_{\ldots}\right.\right.$

$W'^T_{ri} = (3334 \quad 4206 \quad 5247 \quad 6542) \cdot plf$ [Eq. 5-55]

Weight of wedge beyond reinforced soil zone

$W'_{r\beta_n} := \frac{1}{2} \cdot \left(L_{s\beta_n} \cdot h'_n\right) \cdot \gamma_i$ [Eq. 5-56]

$W'^T_{r\beta} = (385.53 \quad 229.25 \quad 229.25 \quad 229.25) \cdot plf$

Friction developed by weight

$R'_{s_n} := \left[C_{dsi} \cdot \left[q_d \cdot \left(L_{s\beta_n} + Z\right) + W'_{ri_n} + W'_{r\beta_n}\right] \cdot \tan\left(\phi_i\right)\right]$ [Eq. 5-49]

$R'^T_s = (1627 \quad 1940 \quad 2395 \quad 2962) \cdot plf$

Shear capacity of facing elements

$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(if\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u\right) \cdot \tan\left(\lambda_{cs}\right)\right]$ [Eq. 4-25]

$V^T_u = (1551 \quad 1738 \quad 1895 \quad 1895) \cdot plf$

Driving Forces

From retained soil

$P_{s1H_n} := if\left[\left[(H) - E_n\right] < h_w, \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot \left(H_s - h_w\right)^2 \cdot \cos\left(\delta_e - \omega\right)\right], \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot \left(E_n + h\right)^2 \cdot \cos\left(\delta_e - \omega\right)\right]\right]$

$P^T_{s1H} = (528.364 \quad 999.138 \quad 1506.165 \quad 1506.165) \cdot plf$

$P_{s2H_n} := if\left[\left[(H) - E_n\right] < h_w, \left[Ka_e \cdot \gamma_{esat} \cdot \left(H_s - h_w\right) \cdot \left[h_w - \left(H_s - E_n\right)\right] \cdot \cos\left(\delta_e - \omega\right)\right], 0\right]$

$P^T_{s2H} = (0 \quad 0 \quad -243.401 \quad 481.678) \cdot plf$

$P_{s3H_n} := if\left[\left[(H) - E_n\right] < h_w, \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_{esat} \cdot \left[h_w - \left(H_s - E_n\right)\right]^2 \cdot \cos\left(\delta_e - \omega\right)\right], 0\right]$

$P^T_{s3H} = (0 \quad 0 \quad 9.077 \quad 35.548) \cdot plf$

From surcharge

$P_{qH_n} := \left(q_d + q_l\right) \cdot Ka_e \cdot \left(E_n\right) \cdot \cos\left(\delta_e - \omega\right)$

$P^T_{qH} = (0 \quad 0 \quad 0 \quad 0) \cdot plf$

$$P_{w_n} := \text{if}\left[\left[(H) - E_n\right] < h_w, \left(\frac{1}{2} \cdot h_r^2 \cdot \gamma_w\right), \left[\frac{\gamma_w}{2} \cdot \left[E_n - \left(H_s - h_{wf}\right)\right]^2\right]\right]$$

$$P_w^T = (14.063 \quad 55.075 \quad 31.2 \quad 31.2) \cdot plf$$

$$P_{a_n} := P_{s1H_n} + P_{s2H_n} + P_{s3H_n} + P_{qH_n} + P_{w_n}$$ [Eq. 5-11]

$$P_a^T = (542 \quad 1054 \quad 1303 \quad 2055) \cdot plf$$

Factor of safety against internal sliding

$$FS_{sl_n} := \frac{R'_{s_n} + V_{u_n}}{\left(P_{a_n}\right)}$$ [Eq. 5-48]

$$FS_{sl}^T = (5.859 \quad 3.49 \quad 3.292 \quad 2.364)$$

Local Stability of Facing Units

Facing Connection Strength

$$T_{conn_n} := \min\left[V_{csmax_n}, a_{cs_n} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u\right) \cdot \tan\left(\lambda_{cs_n}\right)\right]$$ [Eq. 5-59]

$$T_{conn}^T = (1551 \quad 1738 \quad 1895 \quad 1895) \cdot plf$$

$$FS_{conn_n} := \frac{T_{conn_n}}{F_{g_n}}$$

$$FS_{conn}^T = (4.438 \quad 3.461 \quad 2.979 \quad 3.383)$$

Resistance to Bulging

Shear capacity at each geogrid layer

$$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u\right) \cdot \tan\left(\lambda_{cs}\right)\right]$$ [Eq. 4-25]

$$V_u^T = (1551 \quad 1738 \quad 1895 \quad 1895) \cdot plf$$

Driving Force at each geogrid layer

$$P_a^T = (542 \quad 1054 \quad 1303 \quad 2055) \cdot plf$$

Sum of tension in reinforcement layers above layer being considered

$$F_{n+1} := \sum_{i=1}^{n} F_{g_i}$$

$$F^T = (0 \quad 349 \quad 852 \quad 1488 \quad 2048) \cdot plf$$

$FS_{sc_n} := \dfrac{V_{u_n}}{P_{a_n} - F_n}$ [Eq. 5-61]

$FS_{sc}^T = (2.859 \quad 2.467 \quad 4.2 \quad 3.344)$

Maximum unreinforced height of SRW units

$y := E_1 = 4.33\,ft$ $q_l := 0 \cdot psf$

Moment equilibrium

Driving Moments

$P'_s := \left[\frac{1}{2} \cdot Ka_i \cdot \gamma_i \cdot (y)^2 \cdot \cos(\delta_i - \omega)\right]$ [Eq. 4-5] $P'_s = 249.173 \cdot plf$

$P'_q := (q_d + q_l) \cdot Ka_i \cdot (y) \cdot \cos(\delta_i - \omega)$ [Eq. 4-6] $P'_q = 0 \cdot plf$

$P'_a := P'_s + P'_q$ [Eq. 4-4] $P'_a = 249.173 \cdot plf$

$Y'_s := \frac{1}{3} \cdot y$ [Eq. 4-7] $Y'_s = 1.443\,ft$

$Y'_q := \frac{1}{2} \cdot y$ [Eq. 4-8] $Y'_q = 2.165\,ft$

$M'_o := P'_s \cdot Y'_s + P'_q \cdot Y'_q$ [Eq. 4-17] $M'_o = 359.64 \cdot lbf$

Resisting Moments

$W'_w := y \cdot \gamma_u \cdot W_u$ [Eq. 4-9] $W'_w = 519.6 \cdot plf$

$X'_w := G_u + \frac{1}{2} \cdot (y) \cdot \tan(\omega)$ [Eq. 4-16] $X'_w = 0.771\,ft$

$M'_r := W'_w \cdot X'_w$ [Eq. 4-15] $M'_r = 400.417\,ft \cdot plf$

$FS_{ot} := \dfrac{M'_r}{M'_o}$ [Eq. 4-14]

$\begin{pmatrix} 1550.956 \\ 1550.956 \end{pmatrix} \cdot plf$

Factor of Safety against Shear failure

$V'_u := a_{cs} + W'_w \cdot \tan(\lambda_{cs})$ [Eq. 4-25]

$FS_{sh} := \dfrac{V'_u}{P'_a}$ [Eq. 4-27]

$FS_{sh} = \begin{pmatrix} 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \end{pmatrix}$

Summary

Wall Height $H = 11\,ft$

Unreinforced Stability $FS_{ot} = 1.113$ $FS_{bearing} = 3.292$

Applied Bearing Stress $Q_a = 1388\cdot psf$

Grid Elevation E_n = (ft)	Geogrid Length L_n = (ft)	Tensile Force $\frac{Fg_n}{plf}$ =	Geogrid Strength $\frac{Ta_n}{plf}$ =	Anch. Length La_n = (ft)	Anch. Capacity $\frac{AC_n}{plf}$ =	FS Grid Tension (1.0) FS_{ten_n} =	FS Pullout (1.5) FS_{po_n} =	FS Int Sliding (1.5) FS_{sl_n} =	FS Conn (1.5) FS_{conn_n} =	FS Bulging (1.5) FS_{sc_n} =
4.33	8	349	834	2.16	1228	2.39	3.51	5.86	4.44	2.86
6.33	8	502	834	3.42	3053	1.66	6.08	3.49	3.46	2.47
8.33	8	636	834	4.68	5695	1.31	8.95	3.29	2.98	4.2
10.33	8	560	834	5.94	7498	1.49	13.39	2.36	3.38	3.34

Submerged Segmental Retaining Wall Design Calculations per NCMA

Wall Geometry

Height	Backslope	Dead Load	Live Load	Distance to Slope	Wall below grade at toe	Height of Normal pool Water	Height of water for 100yr flood
$H := 9.00 \cdot ft$	$\beta := 8.0 \cdot deg$	$q_d := 0 \cdot psf$	$q_l := 0 \cdot psf$	$Z := 0.0 \cdot ft$	$H_{emb} := 1.00 \cdot ft$	$h_w := 3.00 \cdot ft$	$h_{wf} := 7.0 \cdot ft$

Soil Properties

Submerged Soil	Reinforced Soil (Internal)	Retained Soil (External)	Foundation Soil	Drainage Fill	Pullout	Water
$\gamma_s := 110 \cdot pcf$	$\gamma_i := 110 \cdot pcf$	$\gamma_e := 120 \cdot pcf$	$\gamma_f := 120 \cdot pcf$	$\gamma_d := 110 \cdot pcf$	$C_i := 0.8$	$\gamma_w := 62.4 \cdot pcf$
$\gamma_{ssat} := 120 \cdot pcf$	$\gamma_{isat} := 120 \cdot pcf$	$\gamma_{esat} := 130 \cdot pcf$	$\gamma_{fsat} := 130 \cdot pcf$	$\gamma_{dsat} := 120 \cdot pcf$		
$\phi_s := 32 \cdot deg$	$\phi_i := 32 \cdot deg$	$\phi_e := 26 \cdot deg$	$\phi_f := 26 \cdot deg$	$\phi_d := 32 \cdot deg$		
$\gamma'_s := \gamma_{ssat} - \gamma_w$	$\gamma'_i := \gamma_{isat} - \gamma_w$	$\gamma'_e := \gamma_{esat} - \gamma_w$	$\gamma'_f := \gamma_{fsat} - \gamma_w$	$\gamma'_d := \gamma_{dsat} - \gamma_w$		
$\gamma'_s = 57.6 \cdot pcf$	$\gamma'_i = 57.6 \cdot pcf$	$\gamma'_e = 67.6 \cdot pcf$	$\gamma'_f = 67.6 \cdot pcf$	$\gamma'_d = 57.6 \cdot pcf$		
	$C_{dsi} := 0.7$	$C_{dse} := 1.0$	$c_f := 0 \cdot psf$			

Rapid Drawdown height

$h_r := 1ft$

Segmental Unit Properties

Height	Length	Width	Setback	Center of Gravity
$H_u := 8 \cdot in$	$L_u := 18 \cdot in$	$W_u := 12.0 \cdot in$	$\Delta_u := 1.0 \cdot in$	$G_u := 6.0 \cdot in$

Batter

$$\omega := \operatorname{atan}\left(\frac{\Delta_u}{H_u}\right) \qquad \omega = 7.125 \cdot deg$$

Infilled Unit Weight

$\gamma_u := 120 \cdot pcf$

Hinge Height

$$H_h := \operatorname{if}\left[\tan(\omega) = 0, H, \left[2 \cdot \frac{(W_u - G_u)}{\tan(\omega)}\right]\right] \Rightarrow H_h = 8\,ft \qquad \text{[Eq. 4-1]}$$

Internal Interface Friction Angle

$$\delta_i := \frac{2}{3} \cdot \phi_i \qquad \delta_i = 21.33 \cdot deg \qquad \text{[Eq. 3-17]}$$

Internal Active Earth Pressure

$$Ka_i := \frac{\cos(\phi_i + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_i) \cdot \left[1 + \sqrt{\left(\frac{\sin(\phi_i + \delta_i) \cdot \sin(\phi_i - \beta)}{\cos(\omega - \delta_i) \cdot \cos(\omega + \beta)}\right)}\right]^2}$$

[Eq. 3-11] $Ka_i = 0.249$

External Interface Friction Angle

$$\delta_e := \operatorname{if}(\phi_i > \phi_e, \phi_e, \phi_i) \qquad \delta_e = 26 \cdot deg \qquad \text{[Eq. 3-16]}$$

External Active Earth Pressure

$$Ka_e := \frac{\cos(\phi_e + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_e) \cdot \left[1 + \sqrt{\left[\frac{\sin(\phi_e + \delta_e) \cdot \sin((\phi_e - \beta))}{\cos(\omega - \delta_e) \cdot \cos(\omega + \beta)}\right]}\right]^2}$$

[Eq. 3-11] $Ka_e = 0.327$

Orientation of Critical Internal Failure Surface

$$\alpha_i := \operatorname{atan}\left[\frac{-\tan(\phi_i - \beta) + \sqrt{(\tan(\phi_i - \beta)) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega)) \cdot (1 + \tan(\delta_i - \omega) \cdot \cot(\phi_i + \omega))}}{1 + \tan(\delta_i - \omega) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega))}\right] + \phi_i$$

[Eq. 3-14]

$\alpha_i = 52.892 \cdot deg$

Orientation of Critical External Failure Surface

$$\alpha_e := \operatorname{atan}\left[\frac{-\tan(\phi_e-\beta)+\sqrt{\tan(\phi_e-\beta)\cdot(\tan(\phi_e-\beta)+\cot(\phi_e+\omega))\cdot(1+\tan(\delta_e-\omega)\cdot\cot(\phi_e+\omega))}}{1+\tan(\delta_e-\omega)\cdot(\tan(\phi_e-\beta)+\cot(\phi_e+\omega))}\right]+\phi_e$$

[Eq. 3-14]

$\alpha_e = 47.198\cdot deg$

External Stability Analysis

Sliding

Given

$$1.5 = \frac{\min\left[\begin{array}{l} C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)] \ldots \\ +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_i) \\ C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)] \ldots \\ +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_d) \\ C_{dse}\cdot\left[c_f\cdot L+\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot[\gamma_i\cdot(H-h_w)+(\gamma'_i\cdot h_w)] \ldots \\ +\frac{1}{2}\cdot\gamma_i\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_f)\right]\end{array}\right]}{\begin{array}{l}\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right] \ldots \\ +Ka_e\cdot\gamma_{esat}\cdot h_w\cdot\left[H-h_w+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega) \ldots \\ +\frac{1}{2}\cdot Ka_e\cdot\gamma_{esat}\cdot h_w^2\cdot\cos(\delta_e-\omega) \ldots \\ +(q_d+q_l)\cdot Ka_e\cdot\left[H+\left[\left[L-W_u+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega) \ldots \\ +\frac{1}{2}\cdot h_r^2\cdot\gamma_w\end{array}}$$

$L_{sliding} := \operatorname{Find}(L)$ $L_{sliding} = 6.708\ ft$

Overturning

Given

$$2.0 = \frac{\begin{aligned}&\left[\left[L\cdot\gamma_i\cdot\left(H-h_w\right)+\gamma'_i\cdot h_w\cdot L\right]\cdot\left[\frac{1}{2}\cdot\left(L+H\cdot\tan(\omega)\right)\right]\right]\ \ldots\\&+\left[\frac{1}{2}\cdot\gamma_i\cdot\left(L-W_u-Z\right)\cdot\left[\left(L-W_u-Z\right)+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\left[\left[H\cdot\tan(\omega)+W_u+Z+\frac{2}{3}\cdot\left(L-W_u-Z\right)\right]\right]\ \ldots\\&+q_d\cdot\left[\left(L-W_u-Z\right)+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\left[\frac{Z+\left[\left(L-W_u-Z\right)+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]}{2}+\left[H+\left[\left(L-W_u-Z\right)+\frac{(L-\cdots}{1\cdots}\right.\right.\right.\end{aligned}}{\begin{aligned}&\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H-h_w+\left[\left[L-W_u+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]^2\cdot\cos\left(\delta_e-\omega\right)\right]\cdot\left[\frac{1}{3}\cdot\left[H-h_w+\left[\left[L-W_u+\frac{\left(L-W_u-\cdots\right.}{1-\mathrm{ta}\cdots}\right.\right.\right.\right.\\&+Ka_e\cdot\gamma_{esat}\cdot h_w\cdot\left[H-h_w+\left[\left[L-W_u+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos\left(\delta_e-\omega\right)\cdot\left(\frac{1}{2}\cdot h_w\right)\ \ldots\\&+\frac{1}{6}\cdot h_w^{\ 3}\cdot\gamma_{esat}\cdot Ka_e\cdot\cos\left(\delta_e-\omega\right)\ \ldots\\&+\left[\left(q_d+q_l\right)\cdot Ka_e\cdot\left[\left[H+\left[\left[L-W_u+\frac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]-Z\right]\cdot\tan(\beta)\right]\cdot\cos\left(\delta_e-\omega\right)\right]\right]\cdot\left[\frac{1}{2}\cdot\left[H+\left[\left[L-W_u+\frac{\left(L-W_u-Z\right)\cdot\mathrm{ta}\cdots}{1-\tan(\beta)\cdots}\right.\right.\right.\right.\\&+\left(\frac{1}{2}\cdot h_r^{\ 2}\cdot\gamma_w\right)\cdot\left(h_w+\frac{h_r}{3}\right)\end{aligned}}$$

$L_{overturning} := \mathrm{Find}(L)$ $\quad L_{overturning} = 4.518\ ft$

$L := \max\begin{pmatrix}L_{sliding}\\L_{overturning}\\0.6\cdot H\end{pmatrix}$ $\quad L = 6.708\ ft$

Based on Overturning and Sliding: $L := 7.0\cdot ft$ *(Round up L)*

Eccentricity

$L' := L - W_u - Z$	$L' = 6\cdot ft$	[Fig. 2-10]	[Eq. 5-1]
$L'' := \dfrac{\left(L-W_u-Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}$	$L'' = 0.107\ ft$	[Fig. 2-10]	[Eq. 5-2]
$L_\beta := L' + L''$	$L_\beta = 6.107\ ft$	[Fig. 2-10]	[Eq. 5-3]
$h := L_\beta\cdot\tan(\beta)$	$h = 0.858\ ft$	[Fig. 2-10]	[Eq. 5-4]
$W_{ri} := L\cdot\left[\gamma_i\cdot\left(H-h_w\right)+\left(\gamma_{isat}\cdot h_w\right)\right]$	$W_{ri} = 7140\cdot plf$	[Eq. 5-15]	
$X_{ri} := \dfrac{1}{2}\cdot\left(L+H\cdot\tan(\omega)\right)$	$X_{ri} = 4.063\ ft$	[Eq. 5-19]	
$W_{r\beta} := \dfrac{1}{2}\cdot\gamma_i\cdot(L')\cdot h$	$W_{r\beta} = 283.247\cdot plf$	[Eq. 5-16]	
$X_{r\beta} := H\cdot\tan(\omega)+W_u+Z+\dfrac{2}{3}\cdot L'$	$X_{r\beta} = 6.125\ ft$	[Eq. 5-20]	
$X_{q\beta} := \dfrac{Z+L_\beta}{2}+\left[(H+h)\cdot\tan(\omega)\right]+W_u$	$X_{q\beta} = 5.286\ ft$	[Eq. 5-21]	

Actual Heigth of wall:

$H_s := (H + h)$ $\quad H_s = 9.858\ ft$

Earth Pressures:

$P_{s1H} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot (H_s - h_w)^2 \cdot \cos(\delta_e - \omega)\right]$ $\quad P_{s1H} = 874.36 \cdot plf$ [Eq. 5-6]

$Y_{s1} := \frac{1}{3} \cdot (H_s - h_w) + h_w$ $\quad Y_{s1} = 5.286\ ft$ [Eq. 5-9]

$P_{s2H} := \left[Ka_e \cdot \gamma_{esat} \cdot (H_s - h_w) \cdot h_w \cdot \cos(\delta_e - \omega)\right]$ $\quad P_{s2H} = 828.678 \cdot plf$ [Eq. 5-6]

$Y_{s2} := \frac{h_w}{2}$ $\quad Y_{s2} = 1.5\ ft$ [Eq. 5-9]

$P_{s3H} := \frac{1}{2} \cdot Ka_e \cdot \gamma_{esat} \cdot (h_w)^2 \cdot \cos(\delta_e - \omega)$ $\quad P_{s3H} = 181.242 \cdot plf$ [Eq. 5-6]

$Y_{s3} := \frac{h_w}{3}$ $\quad Y_{s3} = 1\ ft$ [Eq. 5-9]

$P_{qH} := (q_d + q_l) \cdot Ka_e \cdot (H_s) \cdot \cos(\delta_e - \omega)$ $\quad P_{qH} = 0 \cdot plf$ [Eq. 5-8]

$Y_q := \frac{1}{2} \cdot (H_s)$ $\quad Y_q = 4.929\ ft$ [Eq. 5-10]

$P_w := \frac{1}{2} \cdot \gamma_w \cdot (h_r)^2$ $\quad P_w = 31.2 \cdot plf$ [Eq. 5-6]

$Y_w := h_w + \frac{h_r}{3}$ $\quad Y_w = 3.333\ ft$ [Eq. 5-9]

$$e := \frac{\left[P_{s1H} \cdot Y_{s1} + P_{s2H} \cdot Y_{s2} + P_{s3H} \cdot Y_{s3} + P_{qH} \cdot Y_q + P_w \cdot Y_w - W_{ri} \cdot \left(X_{ri} - \frac{L}{2}\right) - W_{r\beta} \cdot \left(X_{r\beta} - \frac{L}{2}\right) - q_d \cdot (L_\beta) \cdot \left(X_{q\beta} - \frac{L}{2}\right)\right]}{W_{ri} + W_{r\beta} + q_d \cdot (L_\beta)}$$ [Eq. 5-25]

$e = 0.1873\ ft$

Check $\quad e := if(e \le 0, 0.075L, e)$ $\quad e = 0.187\ ft$

Surcharge is applied over: $(L' + L'') = 6.107\ ft$ $\quad B := L - 2 \cdot e$ $\quad B = 6.625\ ft$ [Eq. 5-24]

Bearing Capacity

$Q_a := \frac{\left[W_{ri} + W_{r\beta} + (q_d + q_l) \cdot (L' + L'')\right]}{B}$ $\quad Q_a = 1120.426 \cdot psf$

$N_q := \tan\left(45 \cdot deg + \frac{\phi_f}{2}\right)^2 \cdot \exp(\pi \cdot \tan(\phi_f))$ $\quad N_q = 11.854$ [Fig. 4-5]

$N_c := if[\phi_f = 0, 5.14, (N_q - 1)\cdot cot(\phi_f)]$ $N_c = 22.254$ [Fig. 4-5]

$N_\gamma := 2\cdot(N_q + 1)\cdot tan(\phi_f)$ $N_\gamma = 12.539$ [Fig. 4-5]

$Q_{ult} := c_f\cdot N_c + \frac{1}{2}\cdot\gamma'_f\cdot B\cdot N_\gamma + \gamma_f\cdot H_{emb}\cdot N_q$ $Q_{ult} = 4230.422\cdot psf$ [Eq. 4-20]

$FS_{bearing} := \frac{Q_{ult}}{Q_a}$ $FS_{bearing} = 3.776$ [Eq. 4-19]

Internal Stability

Reinforcement Properties

Geogrid Design Data

Backfill Soil $Type := (gravel)$

	1	2	3	4	5	6	7	8	9
$Type^T =$	411	834	1199	1336	2004	2508	3011	3873	7914
$inter^T =$	1145	1145	1145	1145	1145	1145	0		
$slope^T =$	38	38	38	38	38	38	0		
$maxc^T =$	4540	4540	4540	4540	4540	4540	0		

Geogrid Number $GN1 := 2$ $GN2 := 2$

$x := 7..1$ x is the number of grids at the top of the wall of a different type

$T_a := Type_{GN1}\cdot plf$ $T_a = 834\cdot plf$ $T_{a2} := Type_{GN2}\cdot plf$ $T_{a2} = 834\cdot plf$

$a_{cs} := inter_{GN1}\cdot plf$ $a_{cs} = 1145\cdot plf$ | $\lambda_{cs} := slope_{GN1}\cdot deg$ $\lambda_{cs} = 38\cdot deg$ | $V_{csmax} := maxc_{GN1}\cdot plf$ $V_{csmax} = 4540\cdot plf$

$a_{cs2} := inter_{GN2}\cdot plf$ $a_{cs2} = 1145\cdot plf$ | $\lambda_{cs2} := slope_{GN2}\cdot deg$ $\lambda_{cs2} = 38\cdot deg$ | $V_{csmax2} := maxc_{GN2}\cdot plf$ $V_{csmax2} = 4540\cdot plf$

Tension in Geogrid

of grids for Depth of first

Number of Grids:	Grig Spacing (ft):	that spacing:	grid (ft):	Length of grids:		
$n_g := 3$	$Spacing1 := 2$	$n_1 := 3$	$h_1 := 4.33$	$L_1 := 7.0$	$L_2 := 7.0$	$L_r := \frac{L}{ft}$
	$Spacing2 := 1.33$	$n_2 := 0$				

Make all zero when using one geogrid

Note: make sure that the elevations don't excide the height of the wall (H) $H = 9\,ft$

$top := length(E)$ $p := 2..top$ $top = 3$

$grids := length(E)$ $n := 1..top$ $l := 1..grids - 1$

$$E = \begin{pmatrix} 4.33 \\ 6.33 \\ 8.33 \end{pmatrix} ft$$

$$T_{a_x} := T_{a2} \qquad T_{a_x} = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf \qquad T_a := \overrightarrow{\frac{L \cdot T_a}{L}} \qquad T_a = \begin{pmatrix} 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$L = \begin{pmatrix} 7 \\ 7 \\ 7 \end{pmatrix} ft$$

$$T_a^T = (834 \;\; 834 \;\; 834 \;\; 834 \;\; 834 \;\; 834 \;\; 834) \cdot plf$$

$$D_p := \frac{E_{p-1} + E_p}{2} \qquad D_1 := 0 \cdot ft \qquad D_{grids+1} := H$$

$$D^T = (0 \;\; 5.33 \;\; 7.33 \;\; 9)\,ft$$

Total Applied Tensile Strength in the Geosynthetic reinf.:

$$F_{g_n} := \int_{D_n}^{D_{(n+1)}} if\left[D < (H - h_w), \left[(\gamma_i \cdot D + q_l + q_d) \cdot Ka_i \cdot cos(\delta_i - \omega) + \left[if\left[D < (H - h_{wf}), 0plf, \gamma_w \cdot \left[D - (H_s - h_{wf})\right]\right]\right]\right], \left[Ka_i \cdot \left[\gamma_i \cdot (H_s - h_w) + (\gamma\right.\right.\right.$$

[Eq. 5-36]

$$F_g^T = (545.109 \;\; 536.187 \;\; 471.915) \cdot plf$$

Safety factor:

$$FS_{ten_n} := \frac{T_{a_n}}{F_{g_n}} \qquad FS_{ten}^T = (1.53 \;\; 1.555 \;\; 1.767)$$

Pullout Capacity

Anchorage Length of Geosynthetic

$$La_n := L_n - W_u - \left[\left(H_s\right) - E_n\right]\cdot\tan\left(90\cdot deg - \alpha_i\right) + \left[\left(H_s\right) - E_n\right]\cdot\tan(\omega)$$ [Eq. 5-46]

$La^T = (2.509 \quad 3.772 \quad 5.035)\ ft$

Note: If the anchorage length is less than 1ft then there is not enough embedment length and it has to be increased. Note that in some cases it might just be the top two grids.

Average Depth of overburden on Anchorage length

$$d_n := E_n + \left[\left(H_s - E_n\right)\cdot\tan\left(90\cdot deg - \alpha_i\right) + \frac{La_n}{2} - \left(Z + H\cdot\tan(\omega) - \Delta_u\right)\right]\cdot\tan(\beta)$$ [Eq. 5-47]

$d^T = (4.948 \quad 6.824 \quad 8.7)\ ft$

Anchorage Capacity

$$AC_n := if\left[D_n < \left(H - h_w\right), \left[2\cdot La_n\cdot C_i\cdot\left[d_n\cdot\gamma_i + q_d + \gamma_w\cdot\left[d_n - \left(H_s - h_{wf}\right)\right]\right]\cdot\tan\left(\phi_i\right)\right], \left[2\cdot La_n C_i\cdot\left[\gamma_i\cdot\left(H_s - h_w\right) + \left(\gamma_{isat}\right)\cdot\left[h_w - \left(H_s - d_n\right)\right] + \right.\right.\right.$$

[Eq. 5-45]

$AC^T = (1692.128 \quad 3763.72 \quad 5224.091)\cdot plf$

$F_g{}^T = (545.109 \quad 536.187 \quad 471.915)\cdot plf$

Safety Factor

$$FS_{po} := \overrightarrow{\frac{AC}{F_g}}$$ [Eq. 5-44]

$FS_{po}{}^T = (3.104 \quad 7.019 \quad 11.07)$

Internal Sliding

Reduced reinforcement length

$$\Delta L_{l+1} := \begin{cases} \left[\left(E_{l+1} - E_l\right)\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right)\right] & \text{if } n_g > 2 \\ Spacing1\cdot ft\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right) & \text{if } n_g = 2 \\ 0 & \text{if } n_g = 1 \end{cases}$$ [Eq. 5-51]

$\Delta L^T = (0 \quad 1.602 \quad 1.602)\ ft$

$$L'_{s_n} := L_n - W_u - \Delta L_n - Z$$ [Eq. 5-50]

$L'_s{}^T = (6 \quad 4.398 \quad 4.398)\ ft$

Length of sloping ground

$$L_{s\beta_n} := L'_{s_n} + \frac{\left(L'_{s_n}\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}$$ [Eq. 5-53 & 5-52]

$L_{s\beta}{}^T = (6.107 \quad 4.476 \quad 4.476)\ ft$

Height of slope above crest of wall

$h'_n := L'_{s_n} \cdot \tan(\beta)$ [Eq. 5-54]

$h'^T = (0.843 \quad 0.618 \quad 0.618)\ ft$

Weight of reduced reinforced area

$W'_{ri_n} := if\left[\left[(H) - E_n\right] \geq h_w, L'_{s_n} \cdot \left[\left(E_n \cdot \gamma_i\right) + \left[if\left[D_n < \left(H - h_{wf}\right), 0plf, \gamma_w \cdot \left[D_n - \left(H - h_{wf}\right)\right]\right]\right]\right], L'_{s_n} \cdot \left[\gamma_i \cdot \left(H_s - h_w\right) + \gamma_w \cdot h_r + \left(\gamma_{isat}\right) \cdot \left[h_{\cdot}\right.\right.$

$W'_{ri}{}^T = (2858 \quad 3313 \quad 4369) \cdot plf$ [Eq. 5-55]

Weight of wedge beyond reinforced soil zone

$W'_{r\beta_n} := \frac{1}{2} \cdot \left(L_{s\beta_n} \cdot h'_n\right) \cdot \gamma_i$ [Eq. 5-56]

$W'_{r\beta}{}^T = (283.25 \quad 152.17 \quad 152.17) \cdot plf$

Friction developed by weight

$R'_{s_n} := \left[C_{dsi} \cdot \left[q_d \cdot \left(L_{s\beta_n} + Z\right) + W'_{ri_n} + W'_{r\beta_n}\right] \cdot \tan\left(\phi_i\right)\right]$ [Eq. 5-49]

$R'_s{}^T = (1374 \quad 1516 \quad 1978) \cdot plf$

Shear capacity of facing elements

$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(if\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u\right) \cdot \tan\left(\lambda_{cs}\right)\right]$ [Eq. 4-25]

$V_u{}^T = (1551 \quad 1738 \quad 1895) \cdot plf$

Driving Forces

From retained soil

$P_{s1H_n} := if\left[\left[(H) - E_n\right] < h_w, \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot \left(H_s - h_w\right)^2 \cdot \cos\left(\delta_e - \omega\right)\right], \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot \left(E_n + h\right)^2 \cdot \cos\left(\delta_e - \omega\right)\right]\right]$

$P_{s1H}{}^T = (500.39 \quad 874.36 \quad 874.36) \cdot plf$

$P_{s2H_n} := if\left[\left[(H) - E_n\right] < h_w, \left[Ka_e \cdot \gamma_{esat} \cdot \left(H_s - h_w\right) \cdot \left[h_w - \left(H_s - E_n\right)\right] \cdot \cos\left(\delta_e - \omega\right)\right], 0\right]$

$P_{s2H}{}^T = (0 \quad -145.937 \quad 406.515) \cdot plf$

$P_{s3H_n} := if\left[\left[(H) - E_n\right] < h_w, \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_{esat} \cdot \left[h_w - \left(H_s - E_n\right)\right]^2 \cdot \cos\left(\delta_e - \omega\right)\right], 0\right]$

$P_{s3H}{}^T = (0 \quad 5.621 \quad 43.616) \cdot plf$

From surcharge

$P_{qH_n} := \left(q_d + q_l\right) \cdot Ka_e \cdot \left(E_n\right) \cdot \cos\left(\delta_e - \omega\right)$

$P_{qH}{}^T = (0 \quad 0 \quad 0) \cdot plf$

$$P_{w_n} := \text{if}\left[\left[(H) - E_n\right] < h_w, \left(\frac{1}{2}\cdot h_r^2\cdot\gamma_w\right), \left[\frac{\gamma_w}{2}\cdot\left[E_n - \left(H_s - h_{wf}\right)\right]^2\right]\right]$$

$$P_w^T = (67.574 \quad 31.2 \quad 31.2)\cdot plf$$

$$P_{a_n} := P_{s1H_n} + P_{s2H_n} + P_{s3H_n} + P_{qH_n} + P_{w_n}$$ [Eq. 5-11]

$$P_a^T = (568 \quad 765 \quad 1356)\cdot plf$$

Factor of safety against internal sliding

$$FS_{sl_n} := \frac{R'_{s_n} + V_{u_n}}{\left(P_{a_n}\right)}$$ [Eq. 5-48]

$$FS_{sl}^T = (5.15 \quad 4.253 \quad 2.857)$$

Local Stability of Facing Units

Facing Connection Strength

$$T_{conn_n} := \min\left[V_{csmax_n}, a_{cs_n} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs_n}\right)\right]$$ [Eq. 5-59]

$$T_{conn}^T = (1551 \quad 1738 \quad 1895)\cdot plf$$

$$FS_{conn_n} := \frac{T_{conn_n}}{F_{g_n}}$$

$$FS_{conn}^T = (2.845 \quad 3.242 \quad 4.016)$$

Resistance to Bulging

Shear capacity at each geogrid layer

$$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs}\right)\right]$$ [Eq. 4-25]

$$V_u^T = (1551 \quad 1738 \quad 1895)\cdot plf$$

Driving Force at each geogrid layer

$$P_a^T = (568 \quad 765 \quad 1356)\cdot plf$$

Sum of tension in reinforcement layers above layer being considered

$$F_{n+1} := \sum_{i=1}^{n} F_{g_i}$$

$$F^T = (0 \quad 545 \quad 1081 \quad 1553)\cdot plf$$

$$FS_{sc_n} := \frac{V_{u_n}}{P_{a_n} - F_n}$$ [Eq. 5-61]

$$FS_{sc}^T = (2.731 \quad 7.897 \quad 6.906)$$

Maximum unreinforced height of SRW units

$y := E_1 = 4.33\,ft$ $\quad q_l := 0 \cdot psf$

Moment equilibrium

Driving Moments

$$P'_s := \left[\frac{1}{2} \cdot Ka_i \cdot \gamma_i \cdot (y)^2 \cdot \cos(\delta_i - \omega)\right]$$ [Eq. 4-5] $\quad P'_s = 249.173 \cdot plf$

$$P'_q := (q_d + q_l) \cdot Ka_i \cdot (y) \cdot \cos(\delta_i - \omega)$$ [Eq. 4-6] $\quad P'_q = 0 \cdot plf$

$$P'_a := P'_s + P'_q$$ [Eq. 4-4] $\quad P'_a = 249.173 \cdot plf$

$$Y'_s := \frac{1}{3} \cdot y$$ [Eq. 4-7] $\quad Y'_s = 1.443\,ft$

$$Y'_q := \frac{1}{2} \cdot y$$ [Eq. 4-8] $\quad Y'_q = 2.165\,ft$

$$M'_o := P'_s \cdot Y'_s + P'_q \cdot Y'_q$$ [Eq. 4-17] $\quad M'_o = 359.64 \cdot lbf$

Resisting Moments

$$W'_w := y \cdot \gamma_u \cdot W_u$$ [Eq. 4-9] $\quad W'_w = 519.6 \cdot plf$

$$X'_w := G_u + \frac{1}{2} \cdot (y) \cdot \tan(\omega)$$ [Eq. 4-16] $\quad X'_w = 0.771\,ft$

$$M'_r := W'_w \cdot X'_w$$ [Eq. 4-15] $\quad M'_r = 400.417\,ft \cdot plf$

$$FS_{ot} := \frac{M'_r}{M'_o}$$ [Eq. 4-14]

Factor of Safety against Shear failure

$$V'_u := a_{cs} + W'_w \cdot \tan(\lambda_{cs})$$ [Eq. 4-25]

$$FS_{sh} := \frac{V'_u}{P'_a}$$ [Eq. 4-27]

$$\begin{pmatrix} 1550.956 \\ 1550.956 \\ \ldots \end{pmatrix} \cdot plf$$

$$FS_{sh} = \begin{pmatrix} 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \\ 6.224 \end{pmatrix}$$

Summary

Wall Height $H = 9\ ft$

Unreinforced Stability $FS_{ot} = 1.113$ $FS_{bearing} = 3.776$

Applied Bearing Stress $Q_a = 1120 \cdot psf$

Grid Elevation $E_n =$ (ft)	Geogrid Length $L_n =$ (ft)	Tensile Force $\frac{Fg_n}{plf} =$	Geogrid Strength $\frac{Ta_n}{plf} =$	Anch. Length $La_n =$ (ft)	Anch. Capacity $\frac{AC_n}{plf} =$	FS Grid Tension (1.0) $FS_{ten_n} =$	FS Pullout (1.5) $FS_{po_n} =$	FS Int Sliding (1.5) $FS_{sl_n} =$	FS Conn (1.5) $FS_{conn_n} =$	FS Bulging (1.5) $FS_{sc_n} =$
4.33	7	545	834	2.51	1692	1.53	3.1	5.15	2.85	2.73
6.33	7	536	834	3.77	3764	1.56	7.02	4.25	3.24	7.9
8.33	7	472	834	5.03	5224	1.77	11.07	2.86	4.02	6.91

Segmental Retaining Wall Design Calculations per NCMA

Wall Geometry

Height	Backslope	Dead Load	Live Load	Distance to Slope	Wall below grade at toe
$H := 11.00 \cdot ft$	$\beta := 10.0 \cdot deg$	$q_d := 0 \cdot psf$	$q_l := 0 \cdot psf$	$Z := 1.0 \cdot ft$	$H_{emb} := .67 \cdot ft$

Soil Properties

Reinforced Soil (Internal)	Retained Soil (External)	Drainage Fill	Foundation Soil	Pullout
$\gamma_i := 110 \cdot pcf$	$\gamma_e := 120 \cdot pcf$	$\gamma_d := 110 \cdot pcf$	$\gamma_f := 120 \cdot pcf$	$C_i := 0.7$
$\phi_i := 32 \cdot deg$	$\phi_e := 26 \cdot deg$	$\phi_d := 32 \cdot deg$	$\phi_f := 26 \cdot deg$	
$C_{dsi} := 0.8$	$C_{dse} := 1.0$		$c_f := 0.0psf$	

Segmental Unit Properties

Height	Length	Width	Setback	Center of Gravity
$H_u := 8 \cdot in$	$L_u := 18 \cdot in$	$W_u := 12 \cdot in$	$\Delta_u := 1.0 \cdot in$	$G_u := 6 \cdot in$

Batter

$$\omega := atan\left(\frac{\Delta_u}{H_u}\right) \qquad \omega = 7.125 \cdot deg$$

Infilled Unit Weight

$\gamma_u := 120 \cdot pcf$

Hinge Height

$$H_h := if\left[\tan(\omega) = 0, H, \left[2 \cdot \frac{(W_u - G_u)}{\tan(\omega)}\right]\right] \Rightarrow H_h = 8\ ft \qquad \text{[Eq. 4-1]}$$

Internal Interface Friction Angle

$$\delta_i := \frac{2}{3} \cdot \phi_i \qquad \delta_i = 21.33 \cdot deg \qquad \text{[Eq. 3-17]}$$

Internal Active Earth Pressure

$$Ka_i := \frac{\cos(\phi_i + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_i) \cdot \left[1 + \sqrt{\left(\frac{\sin(\phi_i + \delta_i) \cdot \sin(\phi_i - \beta)}{\cos(\omega - \delta_i) \cdot \cos(\omega + \beta)}\right)}\right]^2}$$

[Eq. 3-11] $Ka_i = 0.256$

External Interface Friction Angle

$$\delta_e := if(\phi_i > \phi_e, \phi_e, \phi_i) \qquad \delta_e = 26 \cdot deg \qquad \text{[Eq. 3-16]}$$

External Active Earth Pressure

$$Ka_e := \frac{\cos(\phi_e + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_e) \cdot \left[1 + \sqrt{\left[\frac{\sin(\phi_e + \delta_e) \cdot \sin((\phi_e - \beta))}{\cos(\omega - \delta_e) \cdot \cos(\omega + \beta)}\right]}\right]^2}$$

[Eq. 3-11] $Ka_e = 0.339$

Orientation of Critical Internal Failure Surface

$$\alpha_i := atan\left[\frac{-\tan(\phi_i - \beta) + \sqrt{(\tan(\phi_i - \beta)) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega)) \cdot (1 + \tan(\delta_i - \omega) \cdot \cot(\phi_i + \omega))}}{1 + \tan(\delta_i - \omega) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega))}\right] + \phi_i$$

[Eq. 3-14]

$\alpha_i = 52.419 \cdot deg$

Orientation of Critical External Failure Surface

$$\alpha_e := atan\left[\frac{-\tan(\phi_e - \beta) + \sqrt{\tan(\phi_e - \beta) \cdot (\tan(\phi_e - \beta) + \cot(\phi_e + \omega)) \cdot (1 + \tan(\delta_e - \omega) \cdot \cot(\phi_e + \omega))}}{1 + \tan(\delta_e - \omega) \cdot (\tan(\phi_e - \beta) + \cot(\phi_e + \omega))}\right] + \phi_e$$

[Eq. 3-14]

$\alpha_e = 46.452 \cdot deg$

External Stability Analysis

Sliding

Given

$$1.5 = \frac{\min\left[\begin{array}{l} C_{dse}\cdot\left[\begin{array}{l} q_d\cdot\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H\ \ldots \\ +\dfrac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\end{array}\right]\cdot\tan(\phi_e) \\ C_{dse}\cdot\left[\begin{array}{l} q_d\cdot\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H\ \ldots \\ +\dfrac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\end{array}\right]\cdot\tan(\phi_d) \\ C_{dse}\cdot\left[c_f\cdot L+\left[\begin{array}{l} q_d\cdot\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H\ \ldots \\ +\dfrac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\end{array}\right]\right]\cdot\tan(\phi_f)\end{array}\right]}{\begin{array}{l}\left[\dfrac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H+\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right]\ \ldots \\ +(q_d+q_l)\cdot Ka_e\cdot\left[H+\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\end{array}}$$

$L_{sliding} := \text{Find}(L)$ $\quad L_{sliding} = 6.035\ \text{ft}$

Overturning

Given

$$2.0 = \frac{\begin{array}{l}\left[(L\cdot\gamma_e\cdot H)\cdot\left[\dfrac{1}{2}\cdot(L+H\cdot\tan(\omega))\right]\right]\ \ldots \\ +\left[\dfrac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\left[\left[H\cdot\tan(\omega)+W_u+Z+\dfrac{2}{3}\cdot(L-W_u-Z)\right]\right. \\ +q_d\cdot\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\left[\dfrac{Z+\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]}{2}+H\cdot\tan(\omega)+\right.\end{array}}{\begin{array}{l}\left[\dfrac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H+\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right]\cdot\left[\dfrac{1}{3}\cdot\left[H+\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot ta}{1-\tan(\beta)\cdot\tan(\omega)}\right.\right.\right. \\ +(q_d+q_l)\cdot Ka_e\cdot\left[\left[H+\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\right]\cdot\left[\dfrac{1}{2}\cdot\left[H+\left[(L-W_u-Z)+\dfrac{(L-W_u-Z)\cdot\tan(}{1-\tan(\beta)\cdot ta}\right.\right.\right.\end{array}}$$

$L_{overturning} := \text{Find}(L)$ $\quad L_{overturning} = 4.73\ \text{ft}$

$$L := \max\left(\begin{pmatrix} L_{sliding} \\ L_{overturning} \\ 0.6\cdot H \end{pmatrix}\right) \qquad L = 6.6\ \text{ft}$$

Based on Overturning and Sliding: $L := 8.5\cdot\text{ft}$ *(Round up L)*

Eccentricity

$L' := L - W_u - Z$ | $L' = 6.5 \cdot ft$ | [Fig. 2-10] [Eq. 5-1]

$$L'' := \frac{(L - W_u - Z) \cdot \tan(\beta) \cdot \tan(\omega)}{1 - \tan(\beta) \cdot \tan(\omega)}$$ $L'' = 0.146\ ft$ [Fig. 2-10] [Eq. 5-2]

$L_\beta := L' + L''$ | $L_\beta = 6.646\ ft$ | [Fig. 2-10] [Eq. 5-3]

$h := L_\beta \cdot \tan(\beta)$ | $h = 1.172\ ft$ | [Fig. 2-10] [Eq. 5-4]

$W_{ri} := L \cdot \gamma_i \cdot H$ | $W_{ri} = 10285 \cdot plf$ | [Eq. 5-15]

$X_{ri} := \frac{1}{2} \cdot (L + H \cdot \tan(\omega))$ | $X_{ri} = 4.938\ ft$ | [Eq. 5-19]

$W_{r\beta} := \frac{1}{2} \cdot \gamma_i \cdot (L' - Z) \cdot h$ | $W_{r\beta} = 354.517 \cdot plf$ | [Eq. 5-16]

$X_{r\beta} := H \cdot \tan(\omega) + W_u + \frac{2}{3} \cdot L_\beta + Z$ | $X_{r\beta} = 7.806\ ft$ | [Eq. 5-20]

$X_{q\beta} := \frac{Z + L_\beta}{2} + [(H + h) \cdot \tan(\omega)] + W_u$ | $X_{q\beta} = 6.345\ ft$ | [Eq. 5-21]

Actual Heigth of wall:

$H_s := (H + h)$ | $H_s = 12.172\ ft$

Earth Pressures:

$P_{sH} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot (H + h)^2 \cdot \cos(\delta_e - \omega)\right]$ | $P_{sH} = 2851.83 \cdot plf$ | [Eq. 5-6]

$Y_s := \frac{1}{3} \cdot (H + h)$ | $Y_s = 4.057\ ft$ | [Eq. 5-9]

$P_{qH} := (q_d + q_l) \cdot Ka_e \cdot (H + h) \cdot \cos(\delta_e - \omega)$ | $P_{qH} = 0 \cdot plf$ | [Eq. 5-8]

$Y_q := \frac{1}{2} \cdot (H + h)$ | $Y_q = 6.086\ ft$ | [Eq. 5-10]

$$e := \frac{\left[P_{sH} \cdot Y_s + P_{qH} \cdot Y_q - W_{ri} \cdot \left(X_{ri} - \frac{L}{2}\right) - W_{r\beta} \cdot \left(X_{r\beta} - \frac{L}{2}\right) - q_d \cdot (L_\beta) \cdot \left(X_{q\beta} - \frac{L}{2}\right)\right]}{W_{ri} + W_{r\beta} + q_d \cdot (L_\beta)}$$ $e = 0.3044\ ft$ [Eq. 5-25]

Check $e := \text{if}(e \le 0, 0.075L, e)$ | $e = 0.304\ ft$

$B := L - 2 \cdot e$ | $B = 7.891\ ft$ | [Eq. 5-24]

Surcharge is applied over: $(L' + L'') = 6.646\ ft$

Bearing Capacity

$Q_a := \frac{\left[W_{ri} + W_{r\beta} + (q_d + q_l)\cdot(L' + L'')\right]}{B}$ $Q_a = 1348.293\cdot psf$

$N_q := \tan\left(45\cdot deg + \frac{\phi_f}{2}\right)^2\cdot\exp(\pi\cdot\tan(\phi_f))$ $N_q = 11.854$ [Fig. 4-5]

$N_c := if\left[\phi_f = 0, 5.14, (N_q - 1)\cdot\cot(\phi_f)\right]$ $N_c = 22.254$ [Fig. 4-5]

$N_\gamma := 2\cdot(N_q + 1)\cdot\tan(\phi_f)$ $N_\gamma = 12.539$ [Fig. 4-5]

$Q_{ult} := c_f\cdot N_c + \frac{1}{2}\cdot\gamma_f\cdot B\cdot N_\gamma + \gamma_f\cdot H_{emb}\cdot N_q$ $Q_{ult} = 6889.789\cdot psf$ [Eq. 4-20]

$FS_{bearing} := \frac{Q_{ult}}{Q_a}$ $FS_{bearing} = 5.11$ [Eq. 4-19]

Internal Stability

Reinforcement Properties

Geogrid Design Data

Backfill Soil Type := (gravel)

	1	2	3	4	5	6	7	8	9
$Type^T$ =	411	834	1199	1336	2004	2508	3011	3873	7914
$inter^T$ =	1145	1145	1145	1145	1145	1145	0		
$slope^T$ =	38	38	38	38	38	38	0		
$maxc^T$ =	4540	4540	4540	4540	4540	4540	0		

Geogrid Number GN1 := 2 GN2 := 2

x := 4.. 1 x is the number of grids at the top of the wall of a different type

$T_a := Type_{GN1}\cdot plf$ $T_a = 834\cdot plf$ $T_{a2} := Type_{GN2}\cdot plf$ $T_{a2} = 834\cdot plf$

$a_{cs} := inter_{GN1}\cdot plf$ $a_{cs} = 1145\cdot plf$ | $\lambda_{cs} := slope_{GN1}\cdot deg$ $\lambda_{cs} = 38\cdot deg$ | $V_{csmax} := maxc_{GN1}\cdot plf$ $V_{csmax} = 4540\cdot plf$

$a_{cs2} := inter_{GN2}\cdot plf$ $a_{cs2} = 1145\cdot plf$ | $\lambda_{cs2} := slope_{GN2}\cdot deg$ $\lambda_{cs2} = 38\cdot deg$ | $V_{csmax2} := maxc_{GN2}\cdot plf$ $V_{csmax2} = 4540\cdot plf$

Tension in Geogrid

\# of grids for Depth of first

Number of Grids:	Grig Spacing (ft):	that spacing:	grid (ft):	Length of grids:		
$n_g := 5$	$Spacing1 := 2$	$n_1 := 5$	$h_1 := 2.33$	$L_1 := 8.5$	$L_2 := 8.5$	$L_r := \frac{L}{ft}$
	$Spacing2 := 1.67$	$n_2 := 0$				

Make all zero when using one geogrid

Note: make sure that the elevations don't excide the height of the wall (H) $H = 11\ ft$

$top := length(E)$ $p := 2..top$ $top = 5$

$grids := length(E)$ $n := 1..top$ $l := 1..grids - 1$

$$E = \begin{pmatrix} 2.33 \\ 4.33 \\ 6.33 \\ 8.33 \\ 10.33 \end{pmatrix} ft$$

$$T_{a_x} := T_{a2} \quad T_{a_x} = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$T_a := \frac{\overrightarrow{L \cdot T_a}}{L} \quad T_a = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$L = \begin{pmatrix} 8.5 \\ 8.5 \\ 8.5 \\ 8.5 \\ 8.5 \end{pmatrix} ft$$

$$T_a^T = (834 \quad 834 \quad 834 \quad 834 \quad 834) \cdot plf$$

$$D_p := \frac{E_{p-1} + E_p}{2} \qquad D_1 := 0 \cdot ft \qquad D_{grids+1} := H$$

$$D^T = (0 \quad 3.33 \quad 5.33 \quad 7.33 \quad 9.33 \quad 11)\ ft$$

Total Applied Tensile Strength in the Geosynthetic reinf.:

$$F_{g_n} := \int_{D_n}^{D_{(n+1)}} \left(\gamma_i \cdot D + q_l + q_d\right) \cdot Ka_i \cdot \cos\left(\delta_i - \omega\right) dD \qquad \text{[Eq. 5-36]}$$

$$F_g^T = (151.329 \quad 236.365 \quad 345.54 \quad 454.715 \quad 463.328) \cdot plf$$

Safety factor:

$$FS_{ten_n} := \frac{T_{a_n}}{F_{g_n}} \qquad FS_{ten}^T = (5.511 \quad 3.528 \quad 2.414 \quad 1.834 \quad 1.8)$$

Pullout Capacity

Pullout Capacity

Anchorage Length of Geosynthetic

$$La_n := L_n - W_u - \left[(H+h) - E_n\right]\cdot\tan\left(90\cdot deg - \alpha_i\right) + \left[(H+h) - E_n\right]\cdot\tan(\omega)$$ [Eq. 5-46]

$La^T = (1.156 \quad 2.445 \quad 3.734 \quad 5.024 \quad 6.313)\ ft$

Note: If the anchorage length is less than 1ft then there is not enough embedment length and it has to be increased. Note that in some cases it might just be the top two grids.

Average Depth of overburden on Anchorage length

$$d_n := E_n + \left[\left(H - E_n\right)\cdot\tan\left(90\cdot deg - \alpha_i\right) + \frac{La_n}{2} - \left(Z + H\cdot\tan(\omega) - \Delta_u\right)\right]\cdot\tan(\beta)$$ [Eq. 5-47]

$d^T = (3.204 \quad 5.047 \quad 6.889 \quad 8.731 \quad 10.573)\ ft$

Anchorage Capacity

$$AC_n := 2\cdot La_n\cdot C_i\cdot\left(d_n\cdot\gamma_i + q_d\right)\cdot\tan\left(\phi_i\right)$$ [Eq. 5-45]

$AC^T = (356.468 \quad 1187.474 \quad 2475.569 \quad 4220.752 \quad 6423.024)\cdot plf$

$F_g{}^T = (151.329 \quad 236.365 \quad 345.54 \quad 454.715 \quad 463.328)\cdot plf$

Safety Factor

$$FS_{po} := \overrightarrow{\frac{AC}{F_g}}$$ [Eq. 5-44]

$FS_{po}{}^T = (2.356 \quad 5.024 \quad 7.164 \quad 9.282 \quad 13.863)$

Internal Sliding

Reduced reinforcement length

$$\Delta L_{l+1} := \begin{cases} \left[\left(E_{l+1} - E_l\right)\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right)\right] & \text{if } n_g > 2 \\ Spacing1\cdot ft\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right) & \text{if } n_g = 2 \\ 0 & \text{if } n_g = 1 \end{cases}$$ [Eq. 5-51]

$\Delta L^T = (0 \quad 1.651 \quad 1.651 \quad 1.651 \quad 1.651)\ ft$

$$L'_{s_n} := L_n - W_u - \Delta L_n$$ [Eq. 5-50]

$L'_s{}^T = (7.5 \quad 5.849 \quad 5.849 \quad 5.849 \quad 5.849)\ ft$

Length of sloping ground

$$L_{s\beta_n} := L'_{s_n} + \frac{\left(L'_{s_n} - W_u\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)} - Z$$ [Eq. 5-53 & 5-52]

$L_{s\beta}^{T} = (6.646\ \ 4.958\ \ 4.958\ \ 4.958\ \ 4.958)\ ft$

Height of slope above crest of wall

$h'_n := L_{s\beta_n} \cdot \tan(\beta)$ [Eq. 5-54]

$h'^{T} = (1.172\ \ 0.874\ \ 0.874\ \ 0.874\ \ 0.874)\ ft$

Weight of reduced reinforced area

$W'_{ri_n} := L'_{s_n} \cdot E_n \cdot \gamma_i$ [Eq. 5-55]

$W'_{ri}^{T} = (1922\ \ 2786\ \ 4073\ \ 5359\ \ 6646) \cdot plf$

Weight of wedge beyond reinforced soil zone

$W'_{r\beta_n} := \frac{1}{2} \cdot \left(\left(L_{s\beta_n} \cdot h'_n \right) \right) \cdot \gamma_i$ [Eq. 5-56]

$W'_{r\beta}^{T} = (428.42\ \ 238.41\ \ 238.41\ \ 238.41\ \ 238.41) \cdot plf$

Friction developed by weight

$R'_{s_n} := C_{dsi} \cdot \left[q_d \cdot \left(L_{s\beta_n} + Z \right) + W'_{ri_n} + W'_{r\beta_n} \right] \cdot \tan(\phi_i)$ [Eq. 5-49]

$R'_{s}^{T} = (1175\ \ 1512\ \ 2155\ \ 2798\ \ 3442) \cdot plf$

Shear capacity of facing elements

$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\text{if}\left(E_n > H_h, H_h, E_n \right) \cdot \gamma_u \cdot W_u \right) \cdot \tan(\lambda_{cs}) \right]$ [Eq. 4-25]

$V_{u}^{T} = (1363\ \ 1551\ \ 1738\ \ 1895\ \ 1895) \cdot plf$

Driving Forces

From retained soil

$P_{s_n} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot \left(E_n + h'_n \right)^2 \cdot \cos(\delta_e - \omega) \right]$ [Eq. 5-6]

$P_{s}^{T} = (236\ \ 521\ \ 999\ \ 1631\ \ 2416) \cdot plf$

From surcharge

$P_{q_n} := (q_d + q_l) \cdot Ka_e \cdot (E_n + h'_n) \cdot \cos(\delta_e - \omega)$ [Eq. 5-8]

$P_{q}^{T} = (0\ \ 0\ \ 0\ \ 0\ \ 0) \cdot plf$

Factor of safety against internal sliding

$P_{a_n} := P_{s_n} + P_{q_n}$ [Eq. 5-11]

$P_{a}^{T} = (236\ \ 521\ \ 999\ \ 1631\ \ 2416) \cdot plf$

$FS_{sl_n} := \frac{R'_{s_n} + V_{u_n}}{\left(P_{a_n} \right)}$ [Eq. 5-48]

$FS_{sl}^{T} = (10.754\ \ 5.875\ \ 3.897\ \ 2.878\ \ 2.208)$

Local Stability of Facing Units

Facing Connection Strength

$T_{conn_n} := \min\left[V_{csmax_n}, a_{cs_n} + \left(\mathrm{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs_n}\right)\right]$ [Eq. 5-59]

$T_{conn}^T = (1363 \;\; 1551 \;\; 1738 \;\; 1895 \;\; 1895)\cdot plf$

$FS_{conn_n} := \frac{T_{conn_n}}{F_{g_n}}$ $FS_{conn}^T = (9.01 \;\; 6.562 \;\; 5.031 \;\; 4.168 \;\; 4.09)$

Resistance to Bulging

Shear capacity at each geogrid layer

$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\mathrm{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs}\right)\right]$ [Eq. 4-25]

$V_u^T = (1363 \;\; 1551 \;\; 1738 \;\; 1895 \;\; 1895)\cdot plf$

Driving Force at each geogrid layer

$P_{a_n} := \left[\frac{1}{2}\cdot Ka_i\cdot\gamma_i\cdot\left(E_n\right)^2\cdot\cos\left(\delta_i - \omega\right)\right] + \left(q_d + q_l\right)\cdot Ka_i\cdot\left(E_n\right)\cdot\cos\left(\delta_i - \omega\right)$ [Eq. 5-11]

$P_a^T = (74 \;\; 256 \;\; 547 \;\; 947 \;\; 1456)\cdot plf$

Sum of tension in reinforcement layers above layer being considered

$F_{n+1} := \sum_{i=1}^{n} F_{g_i}$

$F^T = (0 \;\; 151 \;\; 388 \;\; 733 \;\; 1188 \;\; 1651)\cdot plf$

$FS_{sc_n} := \frac{V_{u_n}}{P_{a_n} - F_n}$ [Eq. 5-61]

$FS_{sc}^T = (18.403 \;\; 14.837 \;\; 10.925 \;\; 8.867 \;\; 7.063)$

Maximum unreinforced height of SRW units

$y := E_1 = 2.33\,ft$ $q_l := 0\cdot psf$

Moment equilibrium

Driving Moments

$P'_s := \left[\frac{1}{2}\cdot Ka_i\cdot\gamma_i\cdot(y)^2\cdot\cos\left(\delta_i - \omega\right)\right]$ [Eq. 4-5] $P'_s = 74.088\cdot plf$

$P'_q := (q_d + q_l) \cdot Ka_i \cdot (y) \cdot \cos(\delta_i - \omega)$ [Eq. 4-6] $P'_q = 0 \cdot plf$

$P'_a := P'_s + P'_q$ [Eq. 4-4] $P'_a = 74.088 \cdot plf$

$Y'_s := \frac{1}{3} \cdot y$ [Eq. 4-7] $Y'_s = 0.777\ ft$

$Y'_q := \frac{1}{2} \cdot y$ [Eq. 4-8] $Y'_q = 1.17\ ft$

$M'_o := P'_s \cdot Y'_s + P'_q \cdot Y'_q$ [Eq. 4-17] $M'_o = 57.54 \cdot lbf$

Resisting Moments

$W'_w := y \cdot \gamma_u \cdot W_u$ [Eq. 4-9] $W'_w = 279.6 \cdot plf$

$X'_w := G_u + \frac{1}{2} \cdot (y) \cdot \tan(\omega)$ [Eq. 4-16] $X'_w = 0.646\ ft$

$M'_r := W'_w \cdot X'_w$ [Eq. 4-15] $M'_r = 180.517\ ft \cdot plf$

$FS_{ot} := \frac{M'_r}{M'_o}$ [Eq. 4-14] $FS_{ot} = 3.137$

Factor of Safety against Shear failure

$V'_u := a_{cs} + W'_w \cdot \tan(\lambda_{cs})$ [Eq. 4-25] $V'_u = \begin{pmatrix} 1363.447 \\ 1363.447 \\ \ldots \end{pmatrix}$

$FS_{sh} := \frac{V'_u}{P'_a}$ [Eq. 4-27] $FS_{sh} = \begin{pmatrix} 18.403 \\ 18.403 \\ 18.403 \\ 18.403 \\ 18.403 \end{pmatrix}$

Summary

Wall Height $H = 11\ ft$

Unreinforced Stability $FS_{ot} = 3.137$ $FS_{bearing} = 5.11$

Applied Bearing Stress $Q_a = 1348 \cdot psf$

Grid Elevation $E_n =$ (ft)	Geogrid Length $L_n =$ (ft)	Tensile Force $\frac{F_{g_n}}{plf} =$	Geogrid Strength $\frac{T_{a_n}}{plf} =$	Anch. Length $La_n =$ (ft)	Anch. Capacity $\frac{AC_n}{plf} =$	FS Grid Tension **(1.0)** $FS_{ten_n} =$	FS Pullout **(1.5)** $FS_{po_n} =$	FS Int Sliding **(1.5)** $FS_{sl_n} =$	FS Conn **(1.5)** $FS_{conn_n} =$	FS Bulging **(1.5)** $FS_{sc_n} =$
2.33	8.5	151	834	1.16	356	5.51	2.36	10.75	9.01	18.4
4.33	8.5	236	834	2.45	1187	3.53	5.02	5.87	6.56	14.84
6.33	8.5	346	834	3.73	2476	2.41	7.16	3.9	5.03	10.93
8.33	8.5	455	834	5.02	4221	1.83	9.28	2.88	4.17	8.87
10.33	8.5	463	834	6.31	6423	1.8	13.86	2.21	4.09	7.06

Segmental Retaining Wall Design Calculations per NCMA

Wall Geometry

Height	Backslope	Dead Load	Live Load	Distance to Slope	Wall below grade at toe
$H := 9.67 \cdot ft$	$\beta := 10.0 \cdot deg$	$q_d := 0 \cdot psf$	$q_l := 0 \cdot psf$	$Z := 1.0 \cdot ft$	$H_{emb} := .67 \cdot ft$

Soil Properties

Reinforced Soil (Internal)	Retained Soil (External)	Drainage Fill	Foundation Soil	Pullout
$\gamma_i := 110 \cdot pcf$	$\gamma_e := 120 \cdot pcf$	$\gamma_d := 110 \cdot pcf$	$\gamma_f := 120 \cdot pcf$	$C_i := 0.7$
$\phi_i := 32 \cdot deg$	$\phi_e := 26 \cdot deg$	$\phi_d := 32 \cdot deg$	$\phi_f := 26 \cdot deg$	
$C_{dsi} := 0.8$	$C_{dse} := 1.0$		$c_f := 0.0psf$	

Segmental Unit Properties

Height	Length	Width	Setback	Center of Gravity	Batter
$H_u := 8 \cdot in$	$L_u := 18 \cdot in$	$W_u := 12 \cdot in$	$\Delta_u := 1.0 \cdot in$	$G_u := 6 \cdot in$	$\omega := atan\left(\frac{\Delta_u}{H_u}\right)$

$\omega = 7.125 \cdot deg$

Infilled Unit Weight

$\gamma_u := 120 \cdot pcf$

Hinge Height

$$H_h := if\left[\tan(\omega) = 0, H, \left[2 \cdot \frac{(W_u - G_u)}{\tan(\omega)}\right]\right] \Rightarrow H_h = 8\ ft$$ [Eq. 4-1]

Internal Interface Friction Angle

$$\delta_i := \frac{2}{3} \cdot \phi_i \qquad \delta_i = 21.33 \cdot deg$$ [Eq. 3-17]

Internal Active Earth Pressure

$$Ka_i := \frac{\cos(\phi_i + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_i) \cdot \left[1 + \sqrt{\left(\frac{\sin(\phi_i + \delta_i) \cdot \sin(\phi_i - \beta)}{\cos(\omega - \delta_i) \cdot \cos(\omega + \beta)}\right)}\right]^2}$$

[Eq. 3-11] $Ka_i = 0.256$

External Interface Friction Angle

$$\delta_e := if(\phi_i > \phi_e, \phi_e, \phi_i) \qquad \delta_e = 26 \cdot deg$$ [Eq. 3-16]

External Active Earth Pressure

$$Ka_e := \frac{\cos(\phi_e + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_e) \cdot \left[1 + \sqrt{\left[\frac{\sin(\phi_e + \delta_e) \cdot \sin((\phi_e - \beta))}{\cos(\omega - \delta_e) \cdot \cos(\omega + \beta)}\right]}\right]^2}$$

[Eq. 3-11] $Ka_e = 0.339$

Orientation of Critical Internal Failure Surface

$$\alpha_i := atan\left[\frac{-\tan(\phi_i - \beta) + \sqrt{(\tan(\phi_i - \beta)) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega)) \cdot (1 + \tan(\delta_i - \omega) \cdot \cot(\phi_i + \omega))}}{1 + \tan(\delta_i - \omega) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega))}\right] + \phi_i$$

[Eq. 3-14]

$\alpha_i = 52.419 \cdot deg$

Orientation of Critical External Failure Surface

$$\alpha_e := atan\left[\frac{-\tan(\phi_e - \beta) + \sqrt{\tan(\phi_e - \beta) \cdot (\tan(\phi_e - \beta) + \cot(\phi_e + \omega)) \cdot (1 + \tan(\delta_e - \omega) \cdot \cot(\phi_e + \omega))}}{1 + \tan(\delta_e - \omega) \cdot (\tan(\phi_e - \beta) + \cot(\phi_e + \omega))}\right] + \phi_e$$

[Eq. 3-14]

$\alpha_e = 46.452 \cdot deg$

External Stability Analysis

Sliding

Given

$$1.5 = \frac{\min\left[\begin{array}{l} C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H \ldots \\ \quad +\frac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_e) \\ C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H \ldots \\ \quad +\frac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_d) \\ C_{dse}\cdot\left[c_f\cdot L+\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H \ldots \\ \quad +\frac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\right]\cdot\tan(\phi_f) \end{array}\right]}{\begin{array}{l}\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right] \ldots \\ +(q_d+q_l)\cdot Ka_e\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\end{array}}$$

$L_{sliding} := \text{Find}(L)$ $\quad$ $L_{sliding} = 5.27\ \text{ft}$

Overturning

Given

$$2.0 = \frac{\begin{array}{l}\left[(L\cdot\gamma_e\cdot H)\cdot\left[\frac{1}{2}\cdot(L+H\cdot\tan(\omega))\right]\right] \ldots \\ +\left[\frac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\left[\left[H\cdot\tan(\omega)+W_u+Z+\frac{2}{3}\cdot(L-W_u-Z)\right]\right. \\ +q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\left[\frac{Z+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]}{2}+H\cdot\tan(\omega)+\cdots\right.\end{array}}{\begin{array}{l}\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right]\cdot\left[\frac{1}{3}\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan\cdots}{1-\tan(\beta)\cdot\tan(\omega)}\right.\right.\right. \\ +(q_d+q_l)\cdot Ka_e\cdot\left[\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\right]\cdot\left[\frac{1}{2}\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan\cdots}{1-\tan(\beta)\cdot\tan\cdots}\right.\right.\right.\end{array}}$$

$L_{overturning} := \text{Find}(L)$ $\quad$ $L_{overturning} = 4.134\ \text{ft}$

$$L := \max\left(\begin{pmatrix} L_{sliding} \\ L_{overturning} \\ 0.6\cdot H \end{pmatrix}\right) \qquad L = 5.802\ \text{ft}$$

Based on Overturning and Sliding: $L := 7.5\cdot\text{ft}$ *(Round up L)*

Eccentricity

$L' := L - W_u - Z$ | $L' = 5.5 \cdot ft$ | [Fig. 2-10] [Eq. 5-1]

$L'' := \frac{(L - W_u - Z) \cdot \tan(\beta) \cdot \tan(\omega)}{1 - \tan(\beta) \cdot \tan(\omega)}$ | $L'' = 0.124\ ft$ | [Fig. 2-10] [Eq. 5-2]

$L_\beta := L' + L''$ | $L_\beta = 5.624\ ft$ | [Fig. 2-10] [Eq. 5-3]

$h := L_\beta \cdot \tan(\beta)$ | $h = 0.992\ ft$ | [Fig. 2-10] [Eq. 5-4]

$W_{ri} := L \cdot \gamma_i \cdot H$ | $W_{ri} = 7977.75 \cdot plf$ | [Eq. 5-15]

$X_{ri} := \frac{1}{2} \cdot (L + H \cdot \tan(\omega))$ | $X_{ri} = 4.354\ ft$ | [Eq. 5-19]

$W_{r\beta} := \frac{1}{2} \cdot \gamma_i \cdot (L' - Z) \cdot h$ | $W_{r\beta} = 245.435 \cdot plf$ | [Eq. 5-16]

$X_{r\beta} := H \cdot \tan(\omega) + W_u + \frac{2}{3} \cdot L_\beta + Z$ | $X_{r\beta} = 6.958\ ft$ | [Eq. 5-20]

$X_{q\beta} := \frac{Z + L_\beta}{2} + [(H + h) \cdot \tan(\omega)] + W_u$ | $X_{q\beta} = 5.645\ ft$ | [Eq. 5-21]

Actual Heigth of wall:

$H_s := (H + h)$ | $H_s = 10.662\ ft$

Earth Pressures:

$P_{sH} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot (H + h)^2 \cdot \cos(\delta_e - \omega)\right]$ | $P_{sH} = 2188.024 \cdot plf$ | [Eq. 5-6]

$Y_s := \frac{1}{3} \cdot (H + h)$ | $Y_s = 3.554\ ft$ | [Eq. 5-9]

$P_{qH} := (q_d + q_l) \cdot Ka_e \cdot (H + h) \cdot \cos(\delta_e - \omega)$ | $P_{qH} = 0 \cdot plf$ | [Eq. 5-8]

$Y_q := \frac{1}{2} \cdot (H + h)$ | $Y_q = 5.331\ ft$ | [Eq. 5-10]

$$e := \frac{\left[P_{sH} \cdot Y_s + P_{qH} \cdot Y_q - W_{ri} \cdot \left(X_{ri} - \frac{L}{2}\right) - W_{r\beta} \cdot \left(X_{r\beta} - \frac{L}{2}\right) - q_d \cdot (L_\beta) \cdot \left(X_{q\beta} - \frac{L}{2}\right)\right]}{W_{ri} + W_{r\beta} + q_d \cdot (L_\beta)}$$

$e = 0.2635\ ft$ | [Eq. 5-25]

Check $e := \text{if}(e \le 0, 0.075L, e)$ | $e = 0.264\ ft$

Surcharge is applied over: $(L' + L'') = 5.624\ ft$

$B := L - 2 \cdot e$ | $B = 6.973\ ft$ | [Eq. 5-24]

Bearing Capacity

$Q_a := \frac{\left[W_{ri} + W_{r\beta} + (q_d + q_l)\cdot(L' + L'')\right]}{B}$ $Q_a = 1179.3\cdot psf$

$N_q := \tan\left(45\cdot deg + \frac{\phi_f}{2}\right)^2 \cdot \exp(\pi\cdot\tan(\phi_f))$ $N_q = 11.854$ [Fig. 4-5]

$N_c := if\left[\phi_f = 0, 5.14, (N_q - 1)\cdot\cot(\phi_f)\right]$ $N_c = 22.254$ [Fig. 4-5]

$N_\gamma := 2\cdot(N_q + 1)\cdot\tan(\phi_f)$ $N_\gamma = 12.539$ [Fig. 4-5]

$Q_{ult} := c_f\cdot N_c + \frac{1}{2}\cdot\gamma_f\cdot B\cdot N_\gamma + \gamma_f\cdot H_{emb}\cdot N_q$ $Q_{ult} = 6199.026\cdot psf$ [Eq. 4-20]

$FS_{bearing} := \frac{Q_{ult}}{Q_a}$ $FS_{bearing} = 5.257$ [Eq. 4-19]

Internal Stability

Reinforcement Properties

Geogrid Design Data

Backfill Soil $Type := (gravel)$

Geogrid Number

	1	2	3	4	5	6	7	8	9
$Type^T =$	411	834	1199	1336	2004	2508	3011	3873	7914
$inter^T =$	1145	1145	1145	1145	1145	1145	0		
$slope^T =$	38	38	38	38	38	38	0		
$maxc^T =$	4540	4540	4540	4540	4540	4540	0		

$GN1 := 2$ $GN2 := 2$

$x := 4..1$ x is the number of grids at the top of the wall of a different type

$T_a := Type_{GN1}\cdot plf$ $T_a = 834\cdot plf$ $T_{a2} := Type_{GN2}\cdot plf$ $T_{a2} = 834\cdot plf$

$a_{cs} := inter_{GN1}\cdot plf$ $a_{cs} = 1145\cdot plf$ | $\lambda_{cs} := slope_{GN1}\cdot deg$ $\lambda_{cs} = 38\cdot deg$ | $V_{csmax} := maxc_{GN1}\cdot plf$ $V_{csmax} = 4540\cdot plf$

$a_{cs2} := inter_{GN2}\cdot plf$ $a_{cs2} = 1145\cdot plf$ | $\lambda_{cs2} := slope_{GN2}\cdot deg$ $\lambda_{cs2} = 38\cdot deg$ | $V_{csmax2} := maxc_{GN2}\cdot plf$ $V_{csmax2} = 4540\cdot plf$

Tension in Geogrid

Number of Grids:	Grig Spacing (ft):	# of grids for that spacing:	Depth of first grid (ft):	Length of grids:		
$n_g := 4$	$Spacing1 := 2$	$n_1 := 4$	$h_1 := 2.33$	$L_1 := 7.5$	$L_2 := 7.5$	$L_r := \frac{L}{ft}$
	$Spacing2 := 1.67$	$n_2 := 0$				

Make all zero when using one geogrid

Note: make sure that the elevations don't excide the height of the wall (H) $H = 9.67\ ft$

$top := length(E)$ $\quad p := 2..top$ $\quad top = 4$

$grids := length(E)$ $\quad n := 1..top$ $\quad l := 1..grids - 1$

$$E = \begin{pmatrix} 2.33 \\ 4.33 \\ 6.33 \\ 8.33 \end{pmatrix} ft$$

$$T_{a_x} := T_{a2} \qquad T_{a_x} = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$T_a := \overrightarrow{\frac{L \cdot T_a}{L}} \qquad T_a = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$L = \begin{pmatrix} 7.5 \\ 7.5 \\ 7.5 \\ 7.5 \end{pmatrix} ft$$

$$T_a^T = (834 \quad 834 \quad 834 \quad 834) \cdot plf$$

$$D_p := \frac{E_{p-1} + E_p}{2} \qquad D_1 := 0 \cdot ft \qquad D_{grids+1} := H$$

$$D^T = (0 \quad 3.33 \quad 5.33 \quad 7.33 \quad 9.67)\ ft$$

Total Applied Tensile Strength in the Geosynthetic reinf.:

$$F_{g_n} := \int_{D_n}^{D_{(n+1)}} (\gamma_i \cdot D + q_l + q_d) \cdot Ka_i \cdot \cos(\delta_i - \omega)\ dD \qquad \text{[Eq. 5-36]}$$

$$F_g^T = (151.329 \quad 236.365 \quad 345.54 \quad 542.874) \cdot plf$$

Safety factor:

$$FS_{ten_n} := \frac{T_{a_n}}{F_{g_n}} \qquad FS_{ten}^T = (5.511 \quad 3.528 \quad 2.414 \quad 1.536)$$

Pullout Capacity

Anchorage Length of Geosynthetic

$$La_n := L_n - W_u - \left[(H + h) - E_n\right]\cdot\tan\left(90\cdot deg - \alpha_i\right) + \left[(H + h) - E_n\right]\cdot\tan(\omega)$$ [Eq. 5-46]

$La^T = (1.13 \quad 2.419 \quad 3.708 \quad 4.997)\ ft$

Note: If the anchorage length is less than 1ft then there is not enough embedment length and it has to be increased. Note that in some cases it might just be the top two grids.

Average Depth of overburden on Anchorage length

$$d_n := E_n + \left[\left(H - E_n\right)\cdot\tan\left(90\cdot deg - \alpha_i\right) + \frac{La_n}{2} - \left(Z + H\cdot\tan(\omega) - \Delta_u\right)\right]\cdot\tan(\beta)$$ [Eq. 5-47]

$d^T = (3.051 \quad 4.893 \quad 6.735 \quad 8.578)\ ft$

Anchorage Capacity

$$AC_n := 2\cdot La_n\cdot C_i\cdot\left(d_n\cdot\gamma_i + q_d\right)\cdot\tan\left(\phi_i\right)$$ [Eq. 5-45]

$AC^T = (331.617 \quad 1138.885 \quad 2403.242 \quad 4124.687)\cdot plf$

$F_g{}^T = (151.329 \quad 236.365 \quad 345.54 \quad 542.874)\cdot plf$

Safety Factor

$$FS_{po} := \overrightarrow{\frac{AC}{F_g}}$$ [Eq. 5-44]

$FS_{po}{}^T = (2.191 \quad 4.818 \quad 6.955 \quad 7.598)$

Internal Sliding

Reduced reinforcement length

$$\Delta L_{l+1} := \begin{cases} \left[\left(E_{l+1} - E_l\right)\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right)\right] & \text{if } n_g > 2 \\ Spacing1\cdot ft\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right) & \text{if } n_g = 2 \\ 0 & \text{if } n_g = 1 \end{cases}$$ [Eq. 5-51]

$\Delta L^T = (0 \quad 1.651 \quad 1.651 \quad 1.651)\ ft$

$$L'_{s_n} := L_n - W_u - \Delta L_n$$ [Eq. 5-50]

$L'_s{}^T = (6.5 \quad 4.849 \quad 4.849 \quad 4.849)\ ft$

Length of sloping ground

$$L_{s\beta_n} := L'_{s_n} + \frac{\left(L'_{s_n} - W_u\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)} - Z$$ [Eq. 5-53 & 5-52]

$L_{s\beta}^T = (5.624 \quad 3.936 \quad 3.936 \quad 3.936)\,ft$

Height of slope above crest of wall

$h'_n := L_{s\beta_n} \cdot \tan(\beta)$ [Eq. 5-54]

$h'^T = (0.992 \quad 0.694 \quad 0.694 \quad 0.694)\,ft$

Weight of reduced reinforced area

$W'_{ri_n} := L'_{s_n} \cdot E_n \cdot \gamma_i$ [Eq. 5-55]

$W'_{ri}^T = (1666 \quad 2310 \quad 3376 \quad 4443) \cdot plf$

Weight of wedge beyond reinforced soil zone

$W'_{r\beta_n} := \frac{1}{2} \cdot \left(\left(L_{s\beta_n} \cdot h'_n \right) \right) \cdot \gamma_i$ [Eq. 5-56]

$W'_{r\beta}^T = (306.74 \quad 150.21 \quad 150.21 \quad 150.21) \cdot plf$

Friction developed by weight

$R'_{s_n} := C_{dsi} \cdot \left[q_d \cdot \left(L_{s\beta_n} + Z \right) + W'_{ri_n} + W'_{r\beta_n} \right] \cdot \tan\left(\phi_i\right)$ [Eq. 5-49]

$R'_s{}^T = (986 \quad 1230 \quad 1763 \quad 2296) \cdot plf$

Shear capacity of facing elements

$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u \right) \cdot \tan\left(\lambda_{cs}\right) \right]$ [Eq. 4-25]

$V_u^T = (1363 \quad 1551 \quad 1738 \quad 1895) \cdot plf$

Driving Forces

From retained soil

$P_{s_n} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot \left(E_n + h'_n \right)^2 \cdot \cos\left(\delta_e - \omega \right) \right]$ [Eq. 5-6]

$P_s^T = (212 \quad 486 \quad 950 \quad 1567) \cdot plf$

From surcharge

$P_{q_n} := \left(q_d + q_l \right) \cdot Ka_e \cdot \left(E_n + h'_n \right) \cdot \cos\left(\delta_e - \omega \right)$ [Eq. 5-8]

$P_q^T = (0 \quad 0 \quad 0 \quad 0) \cdot plf$

Factor of safety against internal sliding

$P_{a_n} := P_{s_n} + P_{q_n}$ [Eq. 5-11]

$P_a^T = (212 \quad 486 \quad 950 \quad 1567) \cdot plf$

$FS_{sl_n} := \frac{R'_{s_n} + V_{u_n}}{\left(P_{a_n} \right)}$ [Eq. 5-48]

$FS_{sl}^T = (11.063 \quad 5.723 \quad 3.687 \quad 2.674)$

Local Stability of Facing Units

Facing Connection Strength

$$T_{conn_n} := \min\left[V_{csmax_n}, a_{cs_n} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs_n}\right)\right]$$ [Eq. 5-59]

$$T_{conn}^T = (1363 \quad 1551 \quad 1738 \quad 1895)\cdot plf$$

$$FS_{conn_n} := \frac{T_{conn_n}}{F_{g_n}}$$ $$FS_{conn}^T = (9.01 \quad 6.562 \quad 5.031 \quad 3.491)$$

Resistance to Bulging

Shear capacity at each geogrid layer

$$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs}\right)\right]$$ [Eq. 4-25]

$$V_u^T = (1363 \quad 1551 \quad 1738 \quad 1895)\cdot plf$$

Driving Force at each geogrid layer

$$P_{a_n} := \left[\frac{1}{2}\cdot Ka_i\cdot\gamma_i\cdot\left(E_n\right)^2\cdot\cos\left(\delta_i - \omega\right)\right] + \left(q_d + q_l\right)\cdot Ka_i\cdot\left(E_n\right)\cdot\cos\left(\delta_i - \omega\right)$$ [Eq. 5-11]

$$P_a^T = (74 \quad 256 \quad 547 \quad 947)\cdot plf$$

Sum of tension in reinforcement layers above layer being considered

$$F_{n+1} := \sum_{i=1}^{n} F_{g_i}$$

$$F^T = (0 \quad 151 \quad 388 \quad 733 \quad 1276)\cdot plf$$

$$FS_{sc_n} := \frac{V_{u_n}}{P_{a_n} - F_n}$$ [Eq. 5-61]

$$FS_{sc}^T = (18.403 \quad 14.837 \quad 10.925 \quad 8.867)$$

Maximum unreinforced height of SRW units

$y := E_1 = 2.33\,ft$ $\quad q_l := 0\cdot psf$

Moment equilibrium

Driving Moments

$$P'_s := \left[\frac{1}{2}\cdot Ka_i\cdot\gamma_i\cdot(y)^2\cdot\cos\left(\delta_i - \omega\right)\right]$$ [Eq. 4-5] $$P'_s = 74.088\cdot plf$$

$P'_q := (q_d + q_l)\cdot Ka_i\cdot(y)\cdot\cos(\delta_i - \omega)$ [Eq. 4-6] $P'_q = 0\cdot plf$

$P'_a := P'_s + P'_q$ [Eq. 4-4] $P'_a = 74.088\cdot plf$

$Y'_s := \frac{1}{3}\cdot y$ [Eq. 4-7] $Y'_s = 0.777\ ft$

$Y'_q := \frac{1}{2}\cdot y$ [Eq. 4-8] $Y'_q = 1.17\ ft$

$M'_o := P'_s\cdot Y'_s + P'_q\cdot Y'_q$ [Eq. 4-17] $M'_o = 57.54\cdot lbf$

Resisting Moments

$W'_w := y\cdot\gamma_u\cdot W_u$ [Eq. 4-9] $W'_w = 279.6\cdot plf$

$X'_w := G_u + \frac{1}{2}\cdot(y)\cdot\tan(\omega)$ [Eq. 4-16] $X'_w = 0.646\ ft$

$M'_r := W'_w\cdot X'_w$ [Eq. 4-15] $M'_r = 180.517\ ft\cdot plf$

$FS_{ot} := \frac{M'_r}{M'_o}$ [Eq. 4-14] $FS_{ot} = 3.137$

Factor of Safety against Shear failure

$V'_u := a_{cs} + W'_w\cdot\tan(\lambda_{cs})$ [Eq. 4-25] $V'_u = \begin{pmatrix} 1363.447 \\ 1363.447 \\ \vdots \end{pmatrix}$

$FS_{sh} := \frac{V'_u}{P'_a}$ [Eq. 4-27] $FS_{sh} = \begin{pmatrix} 18.403 \\ 18.403 \\ 18.403 \\ 18.403 \end{pmatrix}$

Summary

Wall Height $H = 9.67\ ft$

Unreinforced Stability $FS_{ot} = 3.137$ $FS_{bearing} = 5.257$

Applied Bearing Stress $Q_a = 1179\cdot psf$

Grid Elevation $E_n =$ (ft)	Geogrid Length $L_n =$ (ft)	Tensile Force $\frac{Fg_n}{plf} =$	Geogrid Strength $\frac{Ta_n}{plf} =$	Anch. Length $La_n =$ (ft)	Anch. Capacity $\frac{AC_n}{plf} =$	FS Grid Tension (1.0) $FS_{ten_n} =$	FS Pullout (1.5) $FS_{po_n} =$	FS Int Sliding (1.5) $FS_{sl_n} =$	FS Conn (1.5) $FS_{conn_n} =$	FS Bulging (1.5) $FS_{sc_n} =$
2.33	7.5	151	834	1.13	332	5.51	2.19	11.06	9.01	18.4
4.33	7.5	236	834	2.42	1139	3.53	4.82	5.72	6.56	14.84
6.33	7.5	346	834	3.71	2403	2.41	6.96	3.69	5.03	10.93
8.33	7.5	543	834	5	4125	1.54	7.6	2.67	3.49	8.87

Segmental Retaining Wall Design Calculations per NCMA

Wall Geometry

Height	Backslope	Dead Load	Live Load	Distance to Slope	Wall below grade at toe
$H := 9.00 \cdot ft$	$\beta := 10.0 \cdot deg$	$q_d := 0 \cdot psf$	$q_l := 0 \cdot psf$	$Z := 1.0 \cdot ft$	$H_{emb} := .67 \cdot ft$

Soil Properties

Reinforced Soil (Internal)	Retained Soil (External)	Drainage Fill	Foundation Soil	Pullout
$\gamma_i := 110 \cdot pcf$	$\gamma_e := 120 \cdot pcf$	$\gamma_d := 110 \cdot pcf$	$\gamma_f := 120 \cdot pcf$	$C_i := 0.7$
$\phi_i := 32 \cdot deg$	$\phi_e := 26 \cdot deg$	$\phi_d := 32 \cdot deg$	$\phi_f := 26 \cdot deg$	
$C_{dsi} := 0.8$	$C_{dse} := 1.0$		$c_f := 0.0 psf$	

Segmental Unit Properties

Height	Length	Width	Setback	Center of Gravity
$H_u := 8 \cdot in$	$L_u := 18 \cdot in$	$W_u := 12 \cdot in$	$\Delta_u := 1.0 \cdot in$	$G_u := 6 \cdot in$

Batter

$$\omega := atan\left(\frac{\Delta_u}{H_u}\right) \qquad \omega = 7.125 \cdot deg$$

Infilled Unit Weight

$\gamma_u := 120 \cdot pcf$

Hinge Height

$$H_h := if\left[tan(\omega) = 0, H, \left[2 \cdot \frac{(W_u - G_u)}{tan(\omega)}\right]\right] \Rightarrow H_h = 8\ ft \qquad \text{[Eq. 4-1]}$$

Internal Interface Friction Angle

$$\delta_i := \frac{2}{3} \cdot \phi_i \qquad \delta_i = 21.33 \cdot deg \qquad \text{[Eq. 3-17]}$$

Internal Active Earth Pressure

$$Ka_i := \frac{cos(\phi_i + \omega)^2}{cos(\omega)^2 \cdot cos(\omega - \delta_i) \cdot \left[1 + \sqrt{\left(\frac{sin(\phi_i + \delta_i) \cdot sin(\phi_i - \beta)}{cos(\omega - \delta_i) \cdot cos(\omega + \beta)}\right)}\right]^2}$$

[Eq. 3-11] $Ka_i = 0.256$

External Interface Friction Angle

$$\delta_e := if(\phi_i > \phi_e, \phi_e, \phi_i) \qquad \delta_e = 26 \cdot deg \qquad \text{[Eq. 3-16]}$$

External Active Earth Pressure

$$Ka_e := \frac{cos(\phi_e + \omega)^2}{cos(\omega)^2 \cdot cos(\omega - \delta_e) \cdot \left[1 + \sqrt{\left[\frac{sin(\phi_e + \delta_e) \cdot sin((\phi_e - \beta))}{cos(\omega - \delta_e) \cdot cos(\omega + \beta)}\right]}\right]^2}$$

[Eq. 3-11] $Ka_e = 0.339$

Orientation of Critical Internal Failure Surface

$$\alpha_i := atan\left[\frac{-tan(\phi_i - \beta) + \sqrt{(tan(\phi_i - \beta)) \cdot (tan(\phi_i - \beta) + cot(\phi_i + \omega)) \cdot (1 + tan(\delta_i - \omega) \cdot cot(\phi_i + \omega))}}{1 + tan(\delta_i - \omega) \cdot (tan(\phi_i - \beta) + cot(\phi_i + \omega))}\right] + \phi_i$$

[Eq. 3-14] $\alpha_i = 52.419 \cdot deg$

Orientation of Critical External Failure Surface

$$\alpha_e := atan\left[\frac{-tan(\phi_e - \beta) + \sqrt{tan(\phi_e - \beta) \cdot (tan(\phi_e - \beta) + cot(\phi_e + \omega)) \cdot (1 + tan(\delta_e - \omega) \cdot cot(\phi_e + \omega))}}{1 + tan(\delta_e - \omega) \cdot (tan(\phi_e - \beta) + cot(\phi_e + \omega))}\right] + \phi_e$$

[Eq. 3-14] $\alpha_e = 46.452 \cdot deg$

External Stability Analysis

Sliding

Given

$$1.5 = \frac{\min\left[\begin{array}{l} C_{dse}\cdot\left[q_d\cdot\left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right] + L\cdot\gamma_e\cdot H + \frac{1}{2}\cdot\gamma_e\cdot\left(L - W_u - Z\right)\cdot\left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan\left(\phi_e\right) \\ C_{dse}\cdot\left[q_d\cdot\left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right] + L\cdot\gamma_e\cdot H + \frac{1}{2}\cdot\gamma_e\cdot\left(L - W_u - Z\right)\cdot\left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan\left(\phi_d\right) \\ C_{dse}\cdot\left[c_f\cdot L + \left[q_d\cdot\left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right] + L\cdot\gamma_e\cdot H + \frac{1}{2}\cdot\gamma_e\cdot\left(L - W_u - Z\right)\cdot\left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\right]\cdot\tan\left(\phi_f\right) \end{array}\right]}{\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H + \left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]^2\cdot\cos\left(\delta_e - \omega\right)\right] + \left(q_d + q_l\right)\cdot Ka_e\cdot\left[H + \left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\cos\left(\delta_e - \omega\right)}$$

$L_{sliding} := \text{Find}(L)$ $\qquad$ $L_{sliding} = 4.885\ \text{ft}$

Overturning

Given

$$2.0 = \frac{\left[\left(L\cdot\gamma_e\cdot H\right)\cdot\left[\frac{1}{2}\cdot\left(L + H\cdot\tan(\omega)\right)\right]\right] + \left[\frac{1}{2}\cdot\gamma_e\cdot\left(L - W_u - Z\right)\cdot\left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\left[\left[H\cdot\tan(\omega) + W_u + Z + \frac{2}{3}\cdot\left(L - W_u - Z\right)\right] + q_d\cdot\left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\left[\frac{Z + \left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]}{2} + H\cdot\tan(\omega) + \cdots\right.\right.}{\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H + \left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]^2\cdot\cos\left(\delta_e - \omega\right)\right]\cdot\left[\frac{1}{3}\cdot\left[H + \left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan\cdots}{1 - \tan(\beta)\cdot\tan(\omega)}\cdots\right.\right.\right. + \left(q_d + q_l\right)\cdot Ka_e\cdot\left[\left[H + \left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\cos\left(\delta_e - \omega\right)\right]\cdot\left[\frac{1}{2}\cdot\left[H + \left[\left(L - W_u - Z\right) + \frac{\left(L - W_u - Z\right)\cdot\tan\cdots}{1 - \tan(\beta)\cdot\tan\cdots}\cdots\right.\right.\right.}$$

$L_{overturning} := \text{Find}(L)$ $\qquad$ $L_{overturning} = 3.834\ \text{ft}$

$$L := \max\left(\begin{pmatrix} L_{sliding} \\ L_{overturning} \\ 0.6\cdot H \end{pmatrix}\right) \qquad L = 5.4\ \text{ft}$$

Based on Overturning and Sliding: $L := 7.0\cdot\text{ft}$ *(Round up L)*

Eccentricity

$L' := L - W_u - Z$ | $L' = 5 \cdot ft$ | [Fig. 2-10] [Eq. 5-1]

$L'' := \frac{(L - W_u - Z) \cdot \tan(\beta) \cdot \tan(\omega)}{1 - \tan(\beta) \cdot \tan(\omega)}$ | $L'' = 0.113\ ft$ | [Fig. 2-10] [Eq. 5-2]

$L_\beta := L' + L''$ | $L_\beta = 5.113\ ft$ | [Fig. 2-10] [Eq. 5-3]

$h := L_\beta \cdot \tan(\beta)$ | $h = 0.902\ ft$ | [Fig. 2-10] [Eq. 5-4]

$W_{ri} := L \cdot \gamma_i \cdot H$ | $W_{ri} = 6930 \cdot plf$ | [Eq. 5-15]

$X_{ri} := \frac{1}{2} \cdot (L + H \cdot \tan(\omega))$ | $X_{ri} = 4.063\ ft$ | [Eq. 5-19]

$W_{r\beta} := \frac{1}{2} \cdot \gamma_i \cdot (L' - Z) \cdot h$ | $W_{r\beta} = 198.331 \cdot plf$ | [Eq. 5-16]

$X_{r\beta} := H \cdot \tan(\omega) + W_u + \frac{2}{3} \cdot L_\beta + Z$ | $X_{r\beta} = 6.533\ ft$ | [Eq. 5-20]

$X_{q\beta} := \frac{Z + L_\beta}{2} + [(H + h) \cdot \tan(\omega)] + W_u$ | $X_{q\beta} = 5.294\ ft$ | [Eq. 5-21]

Actual Heigth of wall:

$H_s := (H + h)$ | $H_s = 9.902\ ft$

Earth Pressures:

$P_{sH} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot (H + h)^2 \cdot \cos(\delta_e - \omega)\right]$ | $P_{sH} = 1887.145 \cdot plf$ | [Eq. 5-6]

$Y_s := \frac{1}{3} \cdot (H + h)$ | $Y_s = 3.301\ ft$ | [Eq. 5-9]

$P_{qH} := (q_d + q_l) \cdot Ka_e \cdot (H + h) \cdot \cos(\delta_e - \omega)$ | $P_{qH} = 0 \cdot plf$ | [Eq. 5-8]

$Y_q := \frac{1}{2} \cdot (H + h)$ | $Y_q = 4.951\ ft$ | [Eq. 5-10]

$$e := \frac{\left[P_{sH} \cdot Y_s + P_{qH} \cdot Y_q - W_{ri} \cdot \left(X_{ri} - \frac{L}{2}\right) - W_{r\beta} \cdot \left(X_{r\beta} - \frac{L}{2}\right) - q_d \cdot (L_\beta) \cdot \left(X_{q\beta} - \frac{L}{2}\right)\right]}{W_{ri} + W_{r\beta} + q_d \cdot (L_\beta)}$$

$e = 0.2425\ ft$ | [Eq. 5-25]

Check $e := \text{if}(e \le 0, 0.075L, e)$ | $e = 0.243\ ft$

Surcharge is applied over: $(L' + L'') = 5.113\ ft$

$B := L - 2 \cdot e$ | $B = 6.515\ ft$ | [Eq. 5-24]

Bearing Capacity

$$Q_a := \frac{\left[W_{ri} + W_{r\beta} + \left(q_d + q_l\right)\cdot(L' + L'')\right]}{B}$$ $Q_a = 1094.148 \cdot psf$

$$N_q := \tan\left(45\cdot deg + \frac{\phi_f}{2}\right)^2 \cdot \exp\left(\pi \cdot \tan\left(\phi_f\right)\right)$$ $N_q = 11.854$ [Fig. 4-5]

$$N_c := if\left[\phi_f = 0, 5.14, \left(N_q - 1\right)\cdot \cot\left(\phi_f\right)\right]$$ $N_c = 22.254$ [Fig. 4-5]

$$N_\gamma := 2\cdot\left(N_q + 1\right)\cdot\tan\left(\phi_f\right)$$ $N_\gamma = 12.539$ [Fig. 4-5]

$$Q_{ult} := c_f \cdot N_c + \frac{1}{2}\cdot\gamma_f \cdot B \cdot N_\gamma + \gamma_f \cdot H_{emb} \cdot N_q$$ $Q_{ult} = 5854.474 \cdot psf$ [Eq. 4-20]

$$FS_{bearing} := \frac{Q_{ult}}{Q_a}$$ $FS_{bearing} = 5.351$ [Eq. 4-19]

Internal Stability

Reinforcement Properties

Geogrid Design Data

Backfill Soil $Type := (gravel)$

	1	2	3	4	5	6	7	8	9
$Type^T =$	411	834	1199	1336	2004	2508	3011	3873	7914
$inter^T =$	1145	1145	1145	1145	1145	1145	0		
$slope^T =$	38	38	38	38	38	38	0		
$maxc^T =$	4540	4540	4540	4540	4540	4540	0		

Geogrid Number $GN1 := 2$ $GN2 := 2$

$x := 4..1$ x is the number of grids at the top of the wall of a different type

$T_a := Type_{GN1}\cdot plf$ $T_a = 834\cdot plf$ $T_{a2} := Type_{GN2}\cdot plf$ $T_{a2} = 834\cdot plf$

$a_{cs} := inter_{GN1}\cdot plf$ $a_{cs} = 1145\cdot plf$ | $\lambda_{cs} := slope_{GN1}\cdot deg$ $\lambda_{cs} = 38\cdot deg$ | $V_{csmax} := maxc_{GN1}\cdot plf$ $V_{csmax} = 4540\cdot plf$

$a_{cs2} := inter_{GN2}\cdot plf$ $a_{cs2} = 1145\cdot plf$ | $\lambda_{cs2} := slope_{GN2}\cdot deg$ $\lambda_{cs2} = 38\cdot deg$ | $V_{csmax2} := maxc_{GN2}\cdot plf$ $V_{csmax2} = 4540\cdot plf$

Tension in Geogrid

of grids for Depth of first

Number of Grids: $n_g := 4$

Grig Spacing (ft): $Spacing1 := 2$ $Spacing2 := 1.67$

Make all zero when using one geogrid

that spacing: $n_1 := 4$ $n_2 := 0$

grid (ft): $h_1 := 2.33$

Length of grids: $L_1 := 7.0$ $L_2 := 7.0$ $L_r := \frac{L}{ft}$

Note: make sure that the elevations don't excide the height of the wall (H) $H = 9\,ft$

$top := length(E)$ $p := 2..top$ $top = 4$

$grids := length(E)$ $n := 1..top$ $l := 1..grids - 1$

$E = \begin{pmatrix} 2.33 \\ 4.33 \\ 6.33 \\ 8.33 \end{pmatrix} ft$

$T_{a_x} := T_{a2}$ $T_{a_x} = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$

$T_a := \overrightarrow{\frac{L \cdot T_a}{L}}$ $T_a = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$

$L = \begin{pmatrix} 7 \\ 7 \\ 7 \\ 7 \end{pmatrix} ft$

$T_a^T = (834 \quad 834 \quad 834 \quad 834) \cdot plf$

$D_p := \frac{E_{p-1} + E_p}{2}$ $D_1 := 0 \cdot ft$ $D_{grids+1} := H$

$D^T = (0 \quad 3.33 \quad 5.33 \quad 7.33 \quad 9)\,ft$

Total Applied Tensile Strength in the Geosynthetic reinf.:

$$F_{g_n} := \int_{D_n}^{D_{(n+1)}} \left(\gamma_i \cdot D + q_l + q_d\right) \cdot Ka_i \cdot \cos\left(\delta_i - \omega\right) dD$$ [Eq. 5-36]

$F_g^T = (151.329 \quad 236.365 \quad 345.54 \quad 372.166) \cdot plf$

Safety factor:

$FS_{ten_n} := \frac{T_{a_n}}{F_{g_n}}$ $FS_{ten}^T = (5.511 \quad 3.528 \quad 2.414 \quad 2.241)$

Pullout Capacity

Pullout Capacity

Anchorage Length of Geosynthetic

$$La_n := L_n - W_u - \left[(H+h) - E_n\right]\cdot\tan\left(90\cdot deg - \alpha_i\right) + \left[(H+h) - E_n\right]\cdot\tan(\omega)$$ [Eq. 5-46]

$La^T = (1.12 \quad 2.409 \quad 3.698 \quad 4.987)\ ft$

Note: If the anchorage length is less than 1ft then there is not enough embedment length and it has to be increased. Note that in some cases it might just be the top two grids.

Average Depth of overburden on Anchorage length

$$d_n := E_n + \left[\left(H - E_n\right)\cdot\tan\left(90\cdot deg - \alpha_i\right) + \frac{La_n}{2} - \left(Z + H\cdot\tan(\omega) - \Delta_u\right)\right]\cdot\tan(\beta)$$ [Eq. 5-47]

$d^T = (2.974 \quad 4.816 \quad 6.658 \quad 8.501)\ ft$

Anchorage Capacity

$$AC_n := 2\cdot La_n\cdot C_i\cdot\left(d_n\cdot\gamma_i + q_d\right)\cdot\tan\left(\phi_i\right)$$ [Eq. 5-45]

$AC^T = (320.376 \quad 1116.312 \quad 2369.336 \quad 4079.448)\cdot plf$

$F_g{}^T = (151.329 \quad 236.365 \quad 345.54 \quad 372.166)\cdot plf$

Safety Factor

$$FS_{po} := \overrightarrow{\frac{AC}{F_g}}$$ [Eq. 5-44]

$FS_{po}{}^T = (2.117 \quad 4.723 \quad 6.857 \quad 10.961)$

Internal Sliding

Reduced reinforcement length

$$\Delta L_{l+1} := \begin{cases} \left[\left(E_{l+1} - E_l\right)\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right)\right] & \text{if } n_g > 2 \\ Spacing1\cdot ft\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right) & \text{if } n_g = 2 \\ 0 & \text{if } n_g = 1 \end{cases}$$ [Eq. 5-51]

$\Delta L^T = (0 \quad 1.651 \quad 1.651 \quad 1.651)\ ft$

$$L'_{s_n} := L_n - W_u - \Delta L_n$$ [Eq. 5-50]

$L'_s{}^T = (6 \quad 4.349 \quad 4.349 \quad 4.349)\ ft$

Length of sloping ground

$$L_{s\beta_n} := L'_{s_n} + \frac{\left(L'_{s_n} - W_u\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)} - Z$$ [Eq. 5-53 & 5-52]

$L_{s\beta}^{T} = (5.113 \quad 3.424 \quad 3.424 \quad 3.424)\ ft$

Height of slope above crest of wall

$h'_n := L_{s\beta_n} \cdot \tan(\beta)$ [Eq. 5-54]

$h'^{T} = (0.902 \quad 0.604 \quad 0.604 \quad 0.604)\ ft$

Weight of reduced reinforced area

$W'_{ri_n} := L'_{s_n} \cdot E_n \cdot \gamma_i$ [Eq. 5-55]

$W'_{ri}^{T} = (1538 \quad 2071 \quad 3028 \quad 3985) \cdot plf$

Weight of wedge beyond reinforced soil zone

$W'_{r\beta_n} := \frac{1}{2} \cdot \left(\left(L_{s\beta_n} \cdot h'_n\right)\right) \cdot \gamma_i$ [Eq. 5-56]

$W'_{r\beta}^{T} = (253.5 \quad 113.72 \quad 113.72 \quad 113.72) \cdot plf$

Friction developed by weight

$R'_{s_n} := C_{dsi} \cdot \left[q_d \cdot \left(L_{s\beta_n} + Z\right) + W'_{ri_n} + W'_{r\beta_n}\right] \cdot \tan\left(\phi_i\right)$ [Eq. 5-49]

$R'_s{}^{T} = (895 \quad 1092 \quad 1571 \quad 2049) \cdot plf$

Shear capacity of facing elements

$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\mathrm{if}\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u\right) \cdot \tan\left(\lambda_{cs}\right)\right]$ [Eq. 4-25]

$V_u^{T} = (1363 \quad 1551 \quad 1738 \quad 1895) \cdot plf$

Driving Forces

From retained soil

$P_{s_n} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot \left(E_n + h'_n\right)^2 \cdot \cos\left(\delta_e - \omega\right)\right]$ [Eq. 5-6]

$P_s^{T} = (201 \quad 469 \quad 925 \quad 1536) \cdot plf$

From surcharge

$P_{q_n} := \left(q_d + q_l\right) \cdot Ka_e \cdot \left(E_n + h'_n\right) \cdot \cos\left(\delta_e - \omega\right)$ [Eq. 5-8]

$P_q^{T} = (0 \quad 0 \quad 0 \quad 0) \cdot plf$

Factor of safety against internal sliding

$P_{a_n} := P_{s_n} + P_{q_n}$ [Eq. 5-11]

$P_a^{T} = (201 \quad 469 \quad 925 \quad 1536) \cdot plf$

$FS_{sl_n} := \frac{R'_{s_n} + V_{u_n}}{\left(P_{a_n}\right)}$ [Eq. 5-48]

$FS_{sl}^{T} = (11.238 \quad 5.641 \quad 3.576 \quad 2.567)$

Local Stability of Facing Units

Facing Connection Strength

$$T_{conn_n} := \min\left[V_{csmax_n}, a_{cs_n} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs_n}\right)\right]$$ [Eq. 5-59]

$$T_{conn}^T = (1363\quad 1551\quad 1738\quad 1895)\cdot plf$$

$$FS_{conn_n} := \frac{T_{conn_n}}{F_{g_n}}$$

$$FS_{conn}^T = (9.01\quad 6.562\quad 5.031\quad 5.092)$$

Resistance to Bulging

Shear capacity at each geogrid layer

$$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs}\right)\right]$$ [Eq. 4-25]

$$V_u^T = (1363\quad 1551\quad 1738\quad 1895)\cdot plf$$

Driving Force at each geogrid layer

$$P_{a_n} := \left[\frac{1}{2}\cdot Ka_i\cdot\gamma_i\cdot\left(E_n\right)^2\cdot\cos\left(\delta_i - \omega\right)\right] + \left(q_d + q_l\right)\cdot Ka_i\cdot\left(E_n\right)\cdot\cos\left(\delta_i - \omega\right)$$ [Eq. 5-11]

$$P_a^T = (74\quad 256\quad 547\quad 947)\cdot plf$$

Sum of tension in reinforcement layers above layer being considered

$$F_{n+1} := \sum_{i=1}^{n} F_{g_i}$$

$$F^T = (0\quad 151\quad 388\quad 733\quad 1105)\cdot plf$$

$$FS_{sc_n} := \frac{V_{u_n}}{P_{a_n} - F_n}$$ [Eq. 5-61]

$$FS_{sc}^T = (18.403\quad 14.837\quad 10.925\quad 8.867)$$

Maximum unreinforced height of SRW units

$y := E_1 = 2.33\cdot ft$ $\quad q_l := 0\cdot psf$

Moment equilibrium

Driving Moments

$$P'_s := \left[\frac{1}{2}\cdot Ka_i\cdot\gamma_i\cdot(y)^2\cdot\cos\left(\delta_i - \omega\right)\right]$$ [Eq. 4-5]

$$P'_s = 74.088\cdot plf$$

$P'_q := (q_d + q_l) \cdot Ka_i \cdot (y) \cdot \cos(\delta_i - \omega)$ [Eq. 4-6] $P'_q = 0 \cdot plf$

$P'_a := P'_s + P'_q$ [Eq. 4-4] $P'_a = 74.088 \cdot plf$

$Y'_s := \frac{1}{3} \cdot y$ [Eq. 4-7] $Y'_s = 0.777\ ft$

$Y'_q := \frac{1}{2} \cdot y$ [Eq. 4-8] $Y'_q = 1.17\ ft$

$M'_o := P'_s \cdot Y'_s + P'_q \cdot Y'_q$ [Eq. 4-17] $M'_o = 57.54 \cdot lbf$

Resisting Moments

$W'_w := y \cdot \gamma_u \cdot W_u$ [Eq. 4-9] $W'_w = 279.6 \cdot plf$

$X'_w := G_u + \frac{1}{2} \cdot (y) \cdot \tan(\omega)$ [Eq. 4-16] $X'_w = 0.646\ ft$

$M'_r := W'_w \cdot X'_w$ [Eq. 4-15] $M'_r = 180.517\ ft \cdot plf$

$FS_{ot} := \frac{M'_r}{M'_o}$ [Eq. 4-14] $FS_{ot} = 3.137$

Factor of Safety against Shear failure

$V'_u := a_{cs} + W'_w \cdot \tan(\lambda_{cs})$ [Eq. 4-25] $V'_u = \begin{pmatrix} 1363.447 \\ 1363.447 \\ \ldots \end{pmatrix}$

$FS_{sh} := \frac{V'_u}{P'_a}$ [Eq. 4-27] $FS_{sh} = \begin{pmatrix} 18.403 \\ 18.403 \\ 18.403 \\ 18.403 \end{pmatrix}$

Summary

Wall Height $H = 9\ ft$

Unreinforced Stability $FS_{ot} = 3.137$ $FS_{bearing} = 5.351$

Applied Bearing Stress $Q_a = 1094 \cdot psf$

Grid Elevation $E_n =$ (ft)	Geogrid Length $L_n =$ (ft)	Tensile Force $\frac{F_{g_n}}{plf} =$	Geogrid Strength $\frac{T_{a_n}}{plf} =$	Anch. Length $La_n =$ (ft)	Anch. Capacity $\frac{AC_n}{plf} =$	FS Grid Tension (1.0) $FS_{ten_n} =$	FS Pullout (1.5) $FS_{po_n} =$	FS Int Sliding (1.5) $FS_{sl_n} =$	FS Conn (1.5) $FS_{conn_n} =$	FS Bulging (1.5) $FS_{sc_n} =$
2.33	7	151	834	1.12	320	5.51	2.12	11.24	9.01	18.4
4.33	7	236	834	2.41	1116	3.53	4.72	5.64	6.56	14.84
6.33	7	346	834	3.7	2369	2.41	6.86	3.58	5.03	10.93
8.33	7	372	834	4.99	4079	2.24	10.96	2.57	5.09	8.87

Segmental Retaining Wall Design Calculations per NCMA

Wall Geometry

Height	Backslope	Dead Load	Live Load	Distance to Slope	Wall below grade at toe
$H := 7.00 \cdot ft$	$\beta := 10.0 \cdot deg$	$q_d := 0 \cdot psf$	$q_l := 0 \cdot psf$	$Z := 1.0 \cdot ft$	$H_{emb} := .67 \cdot ft$

Soil Properties

Reinforced Soil (Internal)	Retained Soil (External)	Drainage Fill	Foundation Soil	Pullout
$\gamma_i := 110 \cdot pcf$	$\gamma_e := 120 \cdot pcf$	$\gamma_d := 110 \cdot pcf$	$\gamma_f := 120 \cdot pcf$	$C_i := 0.7$
$\phi_i := 32 \cdot deg$	$\phi_e := 26 \cdot deg$	$\phi_d := 32 \cdot deg$	$\phi_f := 26 \cdot deg$	
$C_{dsi} := 0.8$	$C_{dse} := 1.0$		$c_f := 0.0psf$	

Segmental Unit Properties

Height	Length	Width	Setback	Center of Gravity	Batter
$H_u := 8 \cdot in$	$L_u := 18 \cdot in$	$W_u := 12 \cdot in$	$\Delta_u := 1.0 \cdot in$	$G_u := 6 \cdot in$	$\omega := atan\left(\frac{\Delta_u}{H_u}\right)$

$\omega = 7.125 \cdot deg$

Infilled Unit Weight

$\gamma_u := 120 \cdot pcf$

Hinge Height

$$H_h := if\left[\tan(\omega) = 0, H, \left[2 \cdot \frac{(W_u - G_u)}{\tan(\omega)}\right]\right] \Rightarrow H_h = 8\ ft$$ [Eq. 4-1]

Internal Interface Friction Angle

$$\delta_i := \frac{2}{3} \cdot \phi_i \qquad \delta_i = 21.33 \cdot deg$$ [Eq. 3-17]

Internal Active Earth Pressure

$$Ka_i := \frac{\cos(\phi_i + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_i) \cdot \left[1 + \sqrt{\left(\frac{\sin(\phi_i + \delta_i) \cdot \sin(\phi_i - \beta)}{\cos(\omega - \delta_i) \cdot \cos(\omega + \beta)}\right)}\right]^2}$$

[Eq. 3-11] $Ka_i = 0.256$

External Interface Friction Angle

$$\delta_e := if(\phi_i > \phi_e, \phi_e, \phi_i) \qquad \delta_e = 26 \cdot deg$$ [Eq. 3-16]

External Active Earth Pressure

$$Ka_e := \frac{\cos(\phi_e + \omega)^2}{\cos(\omega)^2 \cdot \cos(\omega - \delta_e) \cdot \left[1 + \sqrt{\left[\frac{\sin(\phi_e + \delta_e) \cdot \sin((\phi_e - \beta))}{\cos(\omega - \delta_e) \cdot \cos(\omega + \beta)}\right]}\right]^2}$$

[Eq. 3-11] $Ka_e = 0.339$

Orientation of Critical Internal Failure Surface

$$\alpha_i := atan\left[\frac{-\tan(\phi_i - \beta) + \sqrt{(\tan(\phi_i - \beta)) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega)) \cdot (1 + \tan(\delta_i - \omega) \cdot \cot(\phi_i + \omega))}}{1 + \tan(\delta_i - \omega) \cdot (\tan(\phi_i - \beta) + \cot(\phi_i + \omega))}\right] + \phi_i$$ [Eq. 3-14]

$\alpha_i = 52.419 \cdot deg$

Orientation of Critical External Failure Surface

$$\alpha_e := atan\left[\frac{-\tan(\phi_e - \beta) + \sqrt{\tan(\phi_e - \beta) \cdot (\tan(\phi_e - \beta) + \cot(\phi_e + \omega)) \cdot (1 + \tan(\delta_e - \omega) \cdot \cot(\phi_e + \omega))}}{1 + \tan(\delta_e - \omega) \cdot (\tan(\phi_e - \beta) + \cot(\phi_e + \omega))}\right] + \phi_e$$ [Eq. 3-14]

$\alpha_e = 46.452 \cdot deg$

External Stability Analysis

Sliding

Given

$$1.5 = \frac{\min\left[\begin{array}{l} C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H \ldots \\ +\frac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_e) \\ C_{dse}\cdot\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H \ldots \\ +\frac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\tan(\phi_d) \\ C_{dse}\cdot\left[c_f\cdot L+\left[q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]+L\cdot\gamma_e\cdot H \ldots \\ +\frac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\right]\cdot\tan(\phi_f) \end{array}\right]}{\begin{array}{l}\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right]\ldots \\ +(q_d+q_l)\cdot Ka_e\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\end{array}}$$

$L_{sliding} := \text{Find}(L)$ $\quad$ $L_{sliding} = 3.729\ \text{ft}$

Overturning

Given

$$2.0 = \frac{\begin{array}{l}\left[(L\cdot\gamma_e\cdot H)\cdot\left[\frac{1}{2}\cdot(L+H\cdot\tan(\omega))\right]\right]\ldots \\ +\left[\frac{1}{2}\cdot\gamma_e\cdot(L-W_u-Z)\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\left[\left[H\cdot\tan(\omega)+W_u+Z+\frac{2}{3}\cdot(L-W_u-Z)\right]\cdots\right. \\ +q_d\cdot\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\left[\frac{Z+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]}{2}+H\cdot\tan(\omega)+\cdots\right.\end{array}}{\begin{array}{l}\left[\frac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]^2\cdot\cos(\delta_e-\omega)\right]\cdot\left[\frac{1}{3}\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan\cdots}{1-\tan(\beta)\cdot\tan(\omega)}\cdots\right.\right.\right. \\ +(q_d+q_l)\cdot Ka_e\cdot\left[\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1-\tan(\beta)\cdot\tan(\omega)}\right]\cdot\tan(\beta)\right]\cdot\cos(\delta_e-\omega)\right]\cdot\left[\frac{1}{2}\cdot\left[H+\left[(L-W_u-Z)+\frac{(L-W_u-Z)\cdot\tan\cdots}{1-\tan(\beta)\cdot\tan\cdots}\cdots\right.\right.\right.\end{array}}$$

$L_{overturning} := \text{Find}(L)$ $\quad$ $L_{overturning} = 2.934\ \text{ft}$

$$L := \max\left(\begin{pmatrix} L_{sliding} \\ L_{overturning} \\ 0.6\cdot H \end{pmatrix}\right) \qquad L = 4.2\ \text{ft}$$

Based on Overturning and Sliding: $L := 5.5\cdot\text{ft}$ *(Round up L)*

Eccentricity

Definition	Result	Reference	
$L' := L - W_u - Z$	$L' = 3.5 \cdot ft$	[Fig. 2-10]	[Eq. 5-1]
$L'' := \dfrac{(L - W_u - Z)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)}$	$L'' = 0.079\ ft$	[Fig. 2-10]	[Eq. 5-2]
$L_\beta := L' + L''$	$L_\beta = 3.579\ ft$	[Fig. 2-10]	[Eq. 5-3]
$h := L_\beta \cdot \tan(\beta)$	$h = 0.631\ ft$	[Fig. 2-10]	[Eq. 5-4]
$W_{ri} := L \cdot \gamma_i \cdot H$	$W_{ri} = 4235 \cdot plf$	[Eq. 5-15]	
$X_{ri} := \dfrac{1}{2}\cdot(L + H\cdot\tan(\omega))$	$X_{ri} = 3.188\ ft$	[Eq. 5-19]	
$W_{r\beta} := \dfrac{1}{2}\cdot\gamma_i\cdot(L' - Z)\cdot h$	$W_{r\beta} = 86.77 \cdot plf$	[Eq. 5-16]	
$X_{r\beta} := H\cdot\tan(\omega) + W_u + \dfrac{2}{3}\cdot L_\beta + Z$	$X_{r\beta} = 5.261\ ft$	[Eq. 5-20]	
$X_{q\beta} := \dfrac{Z + L_\beta}{2} + [(H + h)\cdot\tan(\omega)] + W_u$	$X_{q\beta} = 4.243\ ft$	[Eq. 5-21]	

Actual Heigth of wall:

$H_s := (H + h)$ $\qquad H_s = 7.631\ ft$

Earth Pressures:

Definition	Result	Reference
$P_{sH} := \left[\dfrac{1}{2}\cdot Ka_e\cdot\gamma_e\cdot(H + h)^2\cdot\cos(\delta_e - \omega)\right]$	$P_{sH} = 1120.913 \cdot plf$	[Eq. 5-6]
$Y_s := \dfrac{1}{3}\cdot(H + h)$	$Y_s = 2.544\ ft$	[Eq. 5-9]
$P_{qH} := (q_d + q_l)\cdot Ka_e\cdot(H + h)\cdot\cos(\delta_e - \omega)$	$P_{qH} = 0 \cdot plf$	[Eq. 5-8]
$Y_q := \dfrac{1}{2}\cdot(H + h)$	$Y_q = 3.816\ ft$	[Eq. 5-10]

$$e := \frac{\left[P_{sH}\cdot Y_s + P_{qH}\cdot Y_q - W_{ri}\cdot\left(X_{ri} - \frac{L}{2}\right) - W_{r\beta}\cdot\left(X_{r\beta} - \frac{L}{2}\right) - q_d\cdot(L_\beta)\cdot\left(X_{q\beta} - \frac{L}{2}\right)\right]}{W_{ri} + W_{r\beta} + q_d\cdot(L_\beta)}$$

$e = 0.1806\ ft$ [Eq. 5-25]

Check $\qquad e := \text{if}(e \le 0, 0.075L, e)$ $\qquad e = 0.181\ ft$

$B := L - 2\cdot e$ $\qquad B = 5.139\ ft$ [Eq. 5-24]

Surcharge is applied over: $\qquad (L' + L'') = 3.579\ ft$

Bearing Capacity

$$Q_a := \frac{\left[W_{ri} + W_{r\beta} + \left(q_d + q_l\right)\cdot(L' + L'')\right]}{B}$$ $Q_a = 841.012\cdot psf$

$$N_q := \tan\left(45\cdot deg + \frac{\phi_f}{2}\right)^2\cdot \exp\left(\pi\cdot\tan\left(\phi_f\right)\right)$$ $N_q = 11.854$ [Fig. 4-5]

$$N_c := if\left[\phi_f = 0, 5.14, \left(N_q - 1\right)\cdot\cot\left(\phi_f\right)\right]$$ $N_c = 22.254$ [Fig. 4-5]

$$N_\gamma := 2\cdot\left(N_q + 1\right)\cdot\tan\left(\phi_f\right)$$ $N_\gamma = 12.539$ [Fig. 4-5]

$$Q_{ult} := c_f\cdot N_c + \frac{1}{2}\cdot\gamma_f\cdot B\cdot N_\gamma + \gamma_f\cdot H_{emb}\cdot N_q$$ $Q_{ult} = 4819.131\cdot psf$ [Eq. 4-20]

$$FS_{bearing} := \frac{Q_{ult}}{Q_a}$$ $FS_{bearing} = 5.73$ [Eq. 4-19]

Internal Stability

Reinforcement Properties

Geogrid Design Data

Backfill Soil $Type := (gravel)$

Geogrid Number

	1	2	3	4	5	6	7	8	9
$Type^T =$	411	834	1199	1336	2004	2508	3011	3873	7914
$inter^T =$	1145	1145	1145	1145	1145	1145	0		
$slope^T =$	38	38	38	38	38	38	0		
$maxc^T =$	4540	4540	4540	4540	4540	4540	0		

$GN1 := 2$ $GN2 := 2$

$x := 4..1$ x is the number of grids at the top of the wall of a different type

$T_a := Type_{GN1}\cdot plf$ $T_a = 834\cdot plf$ $T_{a2} := Type_{GN2}\cdot plf$ $T_{a2} = 834\cdot plf$

$a_{cs} := inter_{GN1}\cdot plf$ $a_{cs} = 1145\cdot plf$ | $\lambda_{cs} := slope_{GN1}\cdot deg$ $\lambda_{cs} = 38\cdot deg$ | $V_{csmax} := maxc_{GN1}\cdot plf$ $V_{csmax} = 4540\cdot plf$

$a_{cs2} := inter_{GN2}\cdot plf$ $a_{cs2} = 1145\cdot plf$ | $\lambda_{cs2} := slope_{GN2}\cdot deg$ $\lambda_{cs2} = 38\cdot deg$ | $V_{csmax2} := maxc_{GN2}\cdot plf$ $V_{csmax2} = 4540\cdot plf$

Tension in Geogrid

Number of Grids: $n_g := 3$

Grig Spacing (ft): $Spacing1 := 2$ $Spacing2 := 1.67$

# of grids for that spacing: $n_1 := 3$ $n_2 := 0$

Make all zero when using one geogrid

Depth of first grid (ft): $h_1 := 2.33$

Length of grids: $L_1 := 5.5$ $L_2 := 5.5$ $L_r := \frac{L}{ft}$

Note: make sure that the elevations don't excide the height of the wall (H) $H = 7\,ft$

$top := length(E)$ $p := 2..top$ $top = 3$

$grids := length(E)$ $n := 1..top$ $l := 1..grids - 1$

$$E = \begin{pmatrix} 2.33 \\ 4.33 \\ 6.33 \end{pmatrix} ft$$

$$T_{a_x} := T_{a2} \qquad T_{a_x} = \begin{pmatrix} 834 \\ 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf \qquad T_a := \frac{\overrightarrow{L \cdot T_a}}{L} \qquad T_a = \begin{pmatrix} 834 \\ 834 \\ 834 \end{pmatrix} \cdot plf$$

$$L = \begin{pmatrix} 5.5 \\ 5.5 \\ 5.5 \end{pmatrix} ft$$

$$T_a^T = (834 \;\; 834 \;\; 834 \;\; 834) \cdot plf$$

$$D_p := \frac{E_{p-1} + E_p}{2} \qquad D_1 := 0 \cdot ft \qquad D_{grids+1} := H$$

$$D^T = (0 \;\; 3.33 \;\; 5.33 \;\; 7)\, ft$$

Total Applied Tensile Strength in the Geosynthetic reinf.:

$$F_{g_n} := \int_{D_n}^{D_{(n+1)}} (\gamma_i \cdot D + q_l + q_d) \cdot Ka_i \cdot \cos(\delta_i - \omega)\, dD$$ [Eq. 5-36]

$$F_g^T = (151.329 \;\; 236.365 \;\; 281.005) \cdot plf$$

Safety factor:

$$FS_{ten_n} := \frac{T_{a_n}}{F_{g_n}} \qquad FS_{ten}^T = (5.511 \;\; 3.528 \;\; 2.968)$$

Pullout Capacity

Anchorage Length of Geosynthetic

$$La_n := L_n - W_u - \left[(H+h) - E_n\right]\cdot\tan\left(90\cdot deg - \alpha_i\right) + \left[(H+h) - E_n\right]\cdot\tan(\omega)$$ [Eq. 5-46]

$La^T = (1.083 \quad 2.372 \quad 3.661)\ ft$

Note: If the anchorage length is less than 1ft then there is not enough embedment length and it has to be increased. Note that in some cases it might just be the top two grids.

Average Depth of overburden on Anchorage length

$$d_n := E_n + \left[\left(H - E_n\right)\cdot\tan\left(90\cdot deg - \alpha_i\right) + \frac{La_n}{2} - \left(Z + H\cdot\tan(\omega) - \Delta_u\right)\right]\cdot\tan(\beta)$$ [Eq. 5-47]

$d^T = (2.743 \quad 4.586 \quad 6.428)\ ft$

Anchorage Capacity

$$AC_n := 2\cdot La_n\cdot C_i\cdot\left(d_n\cdot\gamma_i + q_d\right)\cdot\tan\left(\phi_i\right)$$ [Eq. 5-45]

$AC^T = (285.903 \quad 1046.768 \quad 2264.722)\cdot plf$

$F_g^T = (151.329 \quad 236.365 \quad 281.005)\cdot plf$

Safety Factor

$$FS_{po} := \overrightarrow{\frac{AC}{F_g}}$$ [Eq. 5-44]

$FS_{po}^T = (1.889 \quad 4.429 \quad 8.059)$

Internal Sliding

Reduced reinforcement length

$$\Delta L_{l+1} := \begin{cases} \left[\left(E_{l+1} - E_l\right)\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right)\right] & \text{if } n_g > 2 \\ Spacing1\cdot ft\cdot\left(\frac{1}{\tan\left(\alpha_e\right)} - \tan(\omega)\right) & \text{if } n_g = 2 \\ 0 & \text{if } n_g = 1 \end{cases}$$ [Eq. 5-51]

$\Delta L^T = (0 \quad 1.651 \quad 1.651)\ ft$

$$L'_{s_n} := L_n - W_u - \Delta L_n$$ [Eq. 5-50]

$L'^T_s = (4.5 \quad 2.849 \quad 2.849)\ ft$

Length of sloping ground

$$L_{s\beta_n} := L'_{s_n} + \frac{\left(L'_{s_n} - W_u\right)\cdot\tan(\beta)\cdot\tan(\omega)}{1 - \tan(\beta)\cdot\tan(\omega)} - Z$$ [Eq. 5-53 & 5-52]

$$L_{s\beta}^{T} = (3.579 \quad 1.891 \quad 1.891)\ ft$$

Height of slope above crest of wall

$$h'_n := L_{s\beta_n} \cdot \tan(\beta)$$ [Eq. 5-54]

$$h'^{T} = (0.631 \quad 0.333 \quad 0.333)\ ft$$

Weight of reduced reinforced area

$$W'_{ri_n} := L'_{s_n} \cdot E_n \cdot \gamma_i$$ [Eq. 5-55]

$$W'_{ri}{}^{T} = (1153 \quad 1357 \quad 1984) \cdot plf$$

Weight of wedge beyond reinforced soil zone

$$W'_{r\beta_n} := \frac{1}{2} \cdot \left(\left(L_{s\beta_n} \cdot h'_n \right) \right) \cdot \gamma_i$$ [Eq. 5-56]

$$W'_{r\beta}{}^{T} = (124.22 \quad 34.66 \quad 34.66) \cdot plf$$

Friction developed by weight

$$R'_{s_n} := C_{dsi} \cdot \left[q_d \cdot \left(L_{s\beta_n} + Z \right) + W'_{ri_n} + W'_{r\beta_n} \right] \cdot \tan\left(\phi_i\right)$$ [Eq. 5-49]

$$R'_s{}^{T} = (639 \quad 696 \quad 1009) \cdot plf$$

Shear capacity of facing elements

$$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(if\left(E_n > H_h, H_h, E_n\right) \cdot \gamma_u \cdot W_u \right) \cdot \tan\left(\lambda_{cs}\right) \right]$$ [Eq. 4-25]

$$V_u^{T} = (1363 \quad 1551 \quad 1738) \cdot plf$$

Driving Forces

From retained soil

$$P_{s_n} := \left[\frac{1}{2} \cdot Ka_e \cdot \gamma_e \cdot \left(E_n + h'_n \right)^2 \cdot \cos\left(\delta_e - \omega \right) \right]$$ [Eq. 5-6]

$$P_s^{T} = (169 \quad 419 \quad 855) \cdot plf$$

From surcharge

$$P_{q_n} := \left(q_d + q_l \right) \cdot Ka_e \cdot \left(E_n + h'_n \right) \cdot \cos\left(\delta_e - \omega \right)$$ [Eq. 5-8]

$$P_q^{T} = (0 \quad 0 \quad 0) \cdot plf$$

Factor of safety against internal sliding

$$P_{a_n} := P_{s_n} + P_{q_n}$$ [Eq. 5-11]

$$P_a^{T} = (169 \quad 419 \quad 855) \cdot plf$$

$$FS_{sl_n} := \frac{R'_{s_n} + V_{u_n}}{\left(P_{a_n} \right)}$$ [Eq. 5-48]

$$FS_{sl}^{T} = (11.863 \quad 5.367 \quad 3.215)$$

Local Stability of Facing Units

Facing Connection Strength

$$T_{conn_n} := \min\left[V_{csmax_n}, a_{cs_n} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs_n}\right)\right]$$ [Eq. 5-59]

$$T_{conn}^{T} = (1363 \quad 1551 \quad 1738)\cdot plf$$

$$FS_{conn_n} := \frac{T_{conn_n}}{F_{g_n}}$$

$$FS_{conn}^{T} = (9.01 \quad 6.562 \quad 6.187)$$

Resistance to Bulging

Shear capacity at each geogrid layer

$$V_{u_n} := \min\left[V_{csmax}, a_{cs} + \left(\text{if}\left(E_n > H_h, H_h, E_n\right)\cdot\gamma_u\cdot W_u\right)\cdot\tan\left(\lambda_{cs}\right)\right]$$ [Eq. 4-25]

$$V_u^{T} = (1363 \quad 1551 \quad 1738)\cdot plf$$

Driving Force at each geogrid layer

$$P_{a_n} := \left[\frac{1}{2}\cdot Ka_i\cdot\gamma_i\cdot\left(E_n\right)^2\cdot\cos\left(\delta_i - \omega\right)\right] + \left(q_d + q_l\right)\cdot Ka_i\cdot\left(E_n\right)\cdot\cos\left(\delta_i - \omega\right)$$ [Eq. 5-11]

$$P_a^{T} = (74 \quad 256 \quad 547)\cdot plf$$

Sum of tension in reinforcement layers above layer being considered

$$F_{n+1} := \sum_{i=1}^{n} F_{g_i}$$

$$F^{T} = (0 \quad 151 \quad 388 \quad 669)\cdot plf$$

$$FS_{sc_n} := \frac{V_{u_n}}{P_{a_n} - F_n}$$ [Eq. 5-61]

$$FS_{sc}^{T} = (18.403 \quad 14.837 \quad 10.925)$$

Maximum unreinforced height of SRW units

$y := E_1 = 2.33\ ft$ $\quad q_l := 0\cdot psf$

Moment equilibrium

Driving Moments

$$P'_s := \left[\frac{1}{2}\cdot Ka_i\cdot\gamma_i\cdot(y)^2\cdot\cos\left(\delta_i - \omega\right)\right]$$ [Eq. 4-5]

$$P'_s = 74.088\cdot plf$$

$P'_q := (q_d + q_l) \cdot Ka_i \cdot (y) \cdot \cos(\delta_i - \omega)$ [Eq. 4-6] $P'_q = 0 \cdot plf$

$P'_a := P'_s + P'_q$ [Eq. 4-4] $P'_a = 74.088 \cdot plf$

$Y'_s := \frac{1}{3} \cdot y$ [Eq. 4-7] $Y'_s = 0.777\ ft$

$Y'_q := \frac{1}{2} \cdot y$ [Eq. 4-8] $Y'_q = 1.17\ ft$

$M'_o := P'_s \cdot Y'_s + P'_q \cdot Y'_q$ [Eq. 4-17] $M'_o = 57.54 \cdot lbf$

Resisting Moments

$W'_w := y \cdot \gamma_u \cdot W_u$ [Eq. 4-9] $W'_w = 279.6 \cdot plf$

$X'_w := G_u + \frac{1}{2} \cdot (y) \cdot \tan(\omega)$ [Eq. 4-16] $X'_w = 0.646\ ft$

$M'_r := W'_w \cdot X'_w$ [Eq. 4-15] $M'_r = 180.517\ ft \cdot plf$

$FS_{ot} := \frac{M'_r}{M'_o}$ [Eq. 4-14] $FS_{ot} = 3.137$

Factor of Safety against Shear failure

$V'_u := a_{cs} + W'_w \cdot \tan(\lambda_{cs})$ [Eq. 4-25] $V'_u = \begin{pmatrix} 1363.447 \\ 1363.447 \\ \vdots \end{pmatrix}$

$FS_{sh} := \frac{V'_u}{P'_a}$ [Eq. 4-27] $FS_{sh} = \begin{pmatrix} 18.403 \\ 18.403 \\ 18.403 \\ 18.403 \end{pmatrix}$

Summary

Wall Height $H = 7\ ft$

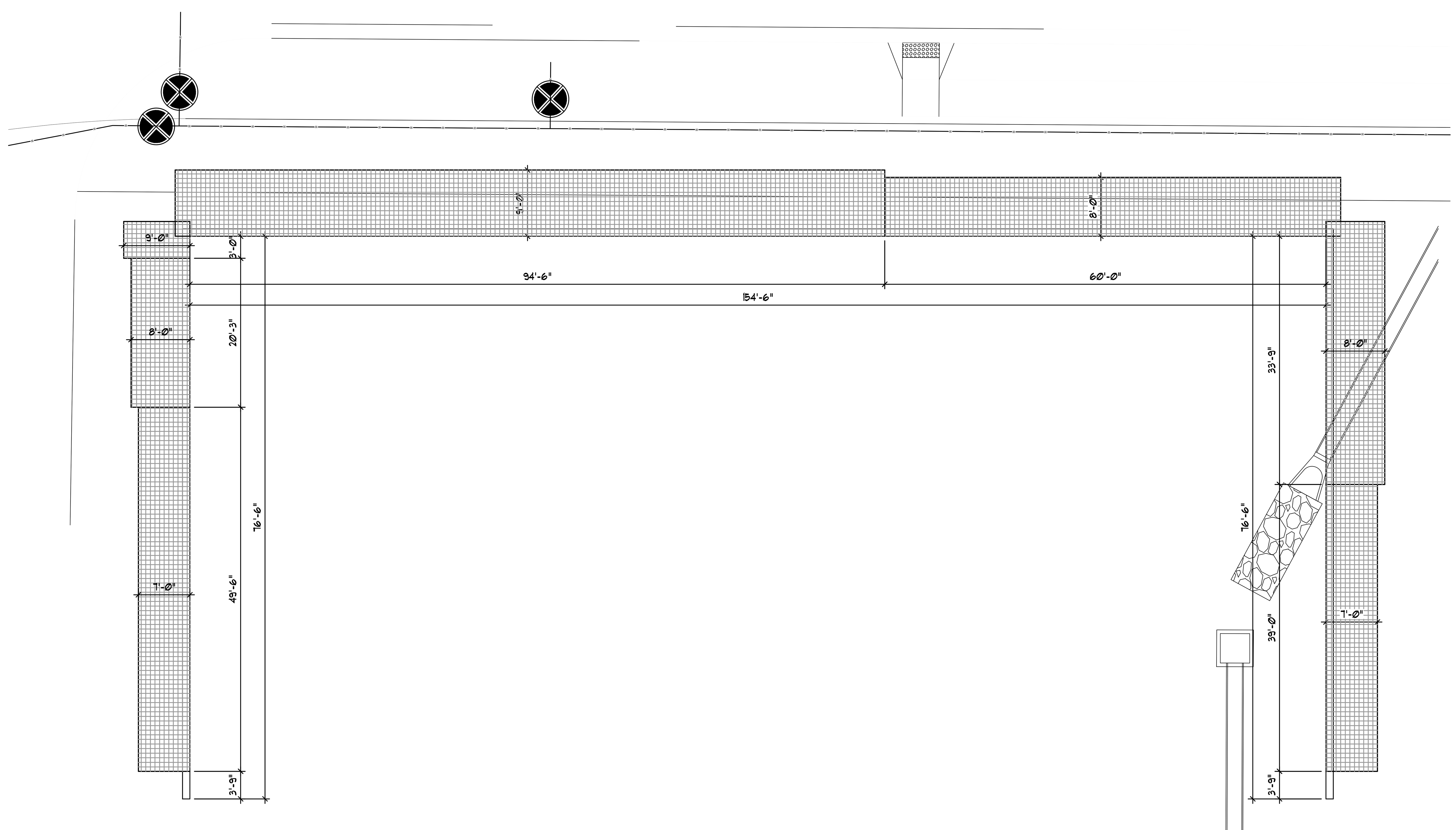
Unreinforced Stability $FS_{ot} = 3.137$ $FS_{bearing} = 5.73$

Applied Bearing Stress $Q_a = 841 \cdot psf$

Grid Elevation E_n = (ft)	Geogrid Length L_n = (ft)	Tensile Force $\frac{Fg_n}{plf}$ =	Geogrid Strength $\frac{Ta_n}{plf}$ =	Anch. Length La_n = (ft)	Anch. Capacity $\frac{AC_n}{plf}$ =	FS Grid Tension (1.0) FS_{ten_n} =	FS Pullout (1.5) FS_{po_n} =	FS Int Sliding (1.5) FS_{sl_n} =	FS Conn (1.5) FS_{conn_n} =	FS Bulging (1.5) FS_{sc_n} =
2.33	5.5	151	834	1.08	286	5.51	1.89	11.86	9.01	18.4
4.33	5.5	236	834	2.37	1047	3.53	4.43	5.37	6.56	14.84
6.33	5.5	281	834	3.66	2265	2.97	8.06	3.21	6.19	10.93

REINFORCED SOIL RETAINING WALL No.1 ELEVATION

SCALE: 1"=10'-0" HORIZ.
1"=5'-0" VERT.



REINFORCED SOIL RETAINING WALL No.1 PLAN

SCALE: 1"=10'-0"

NORTH

REINFORCED SOIL RETAINING WALL FOR:
WOODLAND GLEN 2ND PLAT
LEE'S SUMMIT, MISSOURI

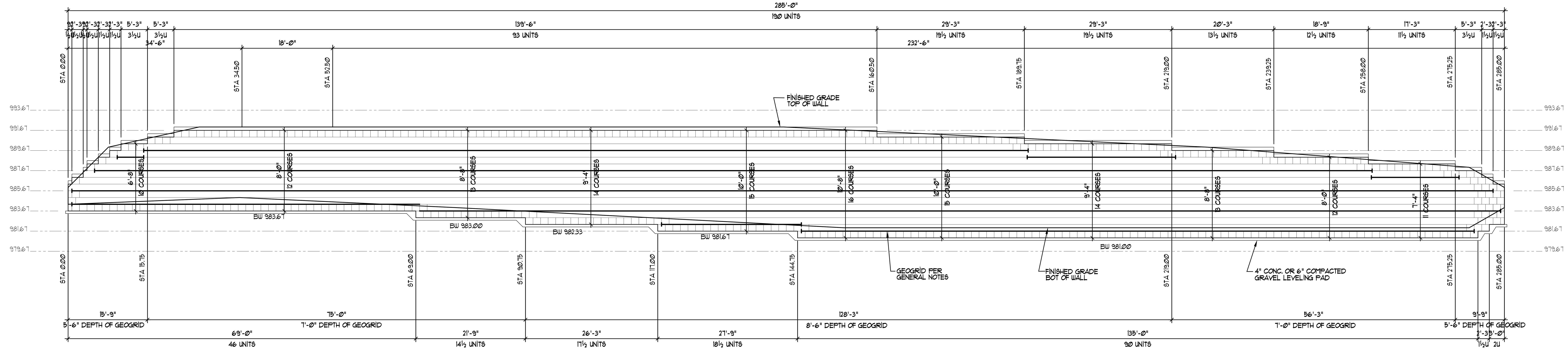
KEYSTONE

VAN DEURZEN & ASSOCIATES, P.A.
11011 KING STREET SUITE 130
OVERLAND PARK, KS 66210

DATE: 05/10/2021
REVISED:
JOB NO:
DRAWN BY: MEJ
DESIGNED BY: CMS

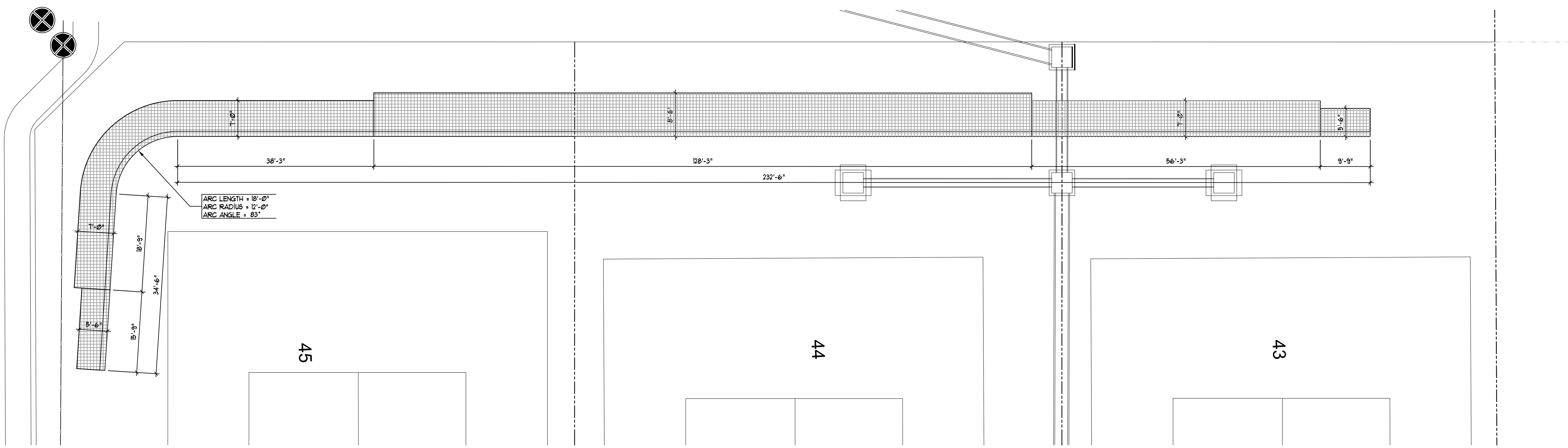
STATE OF MISSOURI
PROFESSIONAL ENGINEER
05/10/2021

SHEET NO:
RW1.1



REINFORCED SOIL RETAINING WALL No.2 ELEVATION

SCALE: 1"=10'-0" HORIZ.
1"=5'-0" VERT.



REINFORCED SOIL RETAINING WALL No.2 PLAN

SCALE: 1"=10'-0"

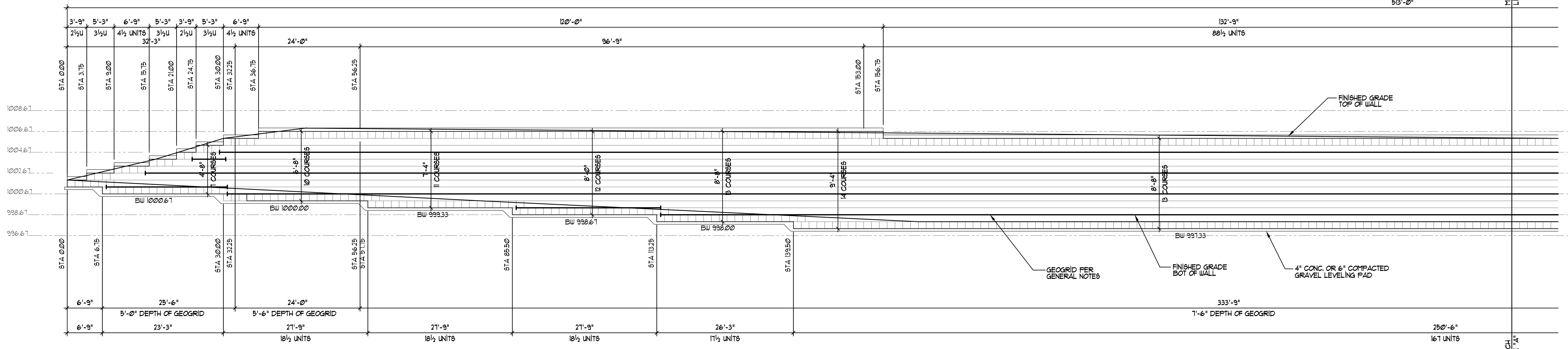
DATE: 05/10/2021
REVISED:
JOB NO:
DRAWN BY: MEJ
DESIGNED BY: CMS

VAN DEURZEN & ASSOCIATES, P.A.
11011 KING STREET SUITE 130
OVERLAND PARK, KS 66210

KEYSTONE

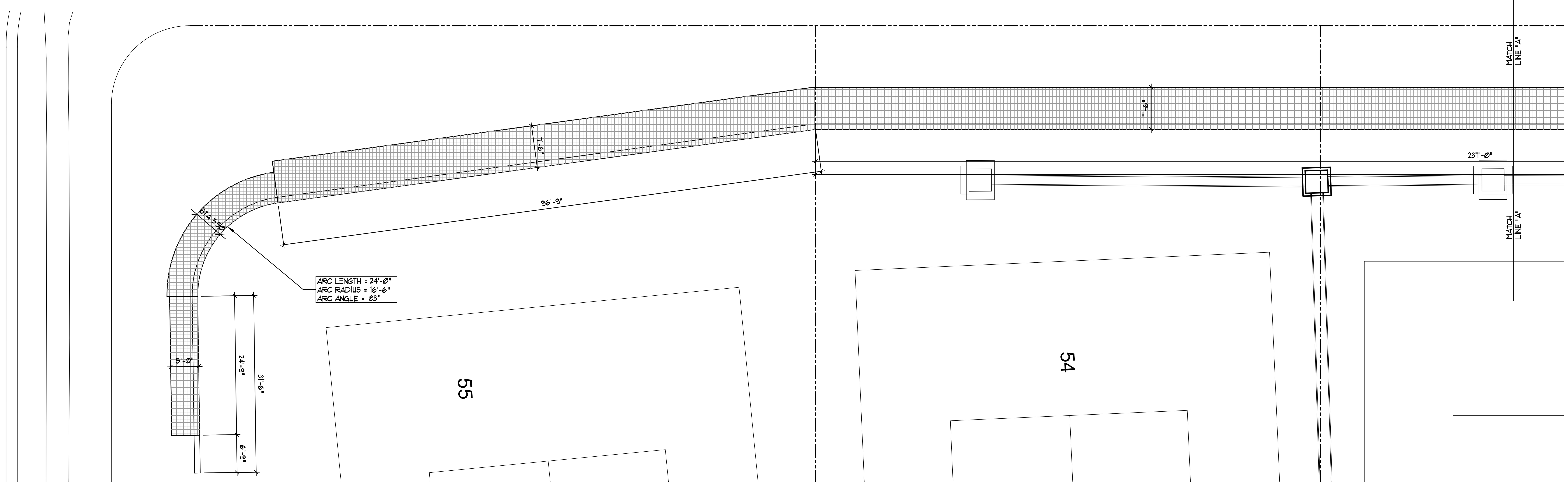
REINFORCED SOIL RETAINING WALL FOR:
WOODLAND GLEN 2ND PLAT
LEE'S SUMMIT, MISSOURI

SHEET NO:
RW1.2



REINFORCED SOIL RETAINING WALL No.3 ELEVATION

SCALE: 1"=10'-0" HORIZ.
1"=5'-0" VERT.



REINFORCED SOIL RETAINING WALL No.3 PLAN

SCALE: 1"=10'-0"

NORTH

STATE OF MISSOURI
CHAD M. STREETER
NUMBER PE-2005010817
PROFESSIONAL ENGINEER
05/10/2021

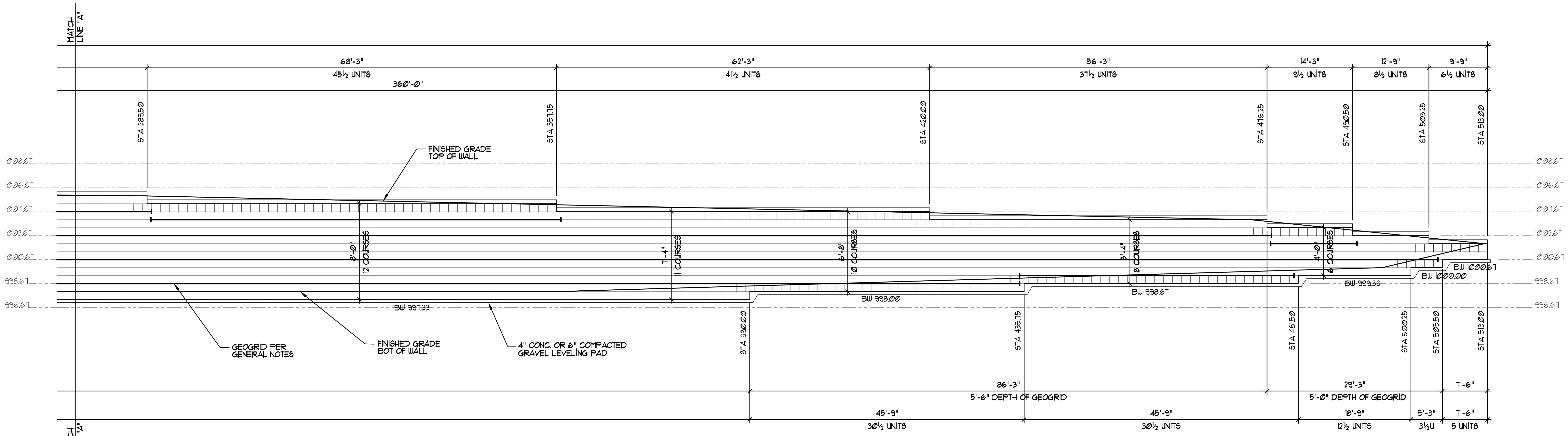
VAN DEURZEN & ASSOCIATES, P.A.
11011 KING STREET, SUITE 130
OVERLAND PARK, KS 66210
(913) 451-6305 FAX (913) 451-1021
WEB PAGE WWW.VANDEURZENASSOC.COM
E-MAIL VDA@VANDEURZENASSOC.COM

DATE: 05/10/2021
REVISED:
JOB NO:
DRAWN BY: MEJ
DESIGNED BY: CMS

KEYSTONE

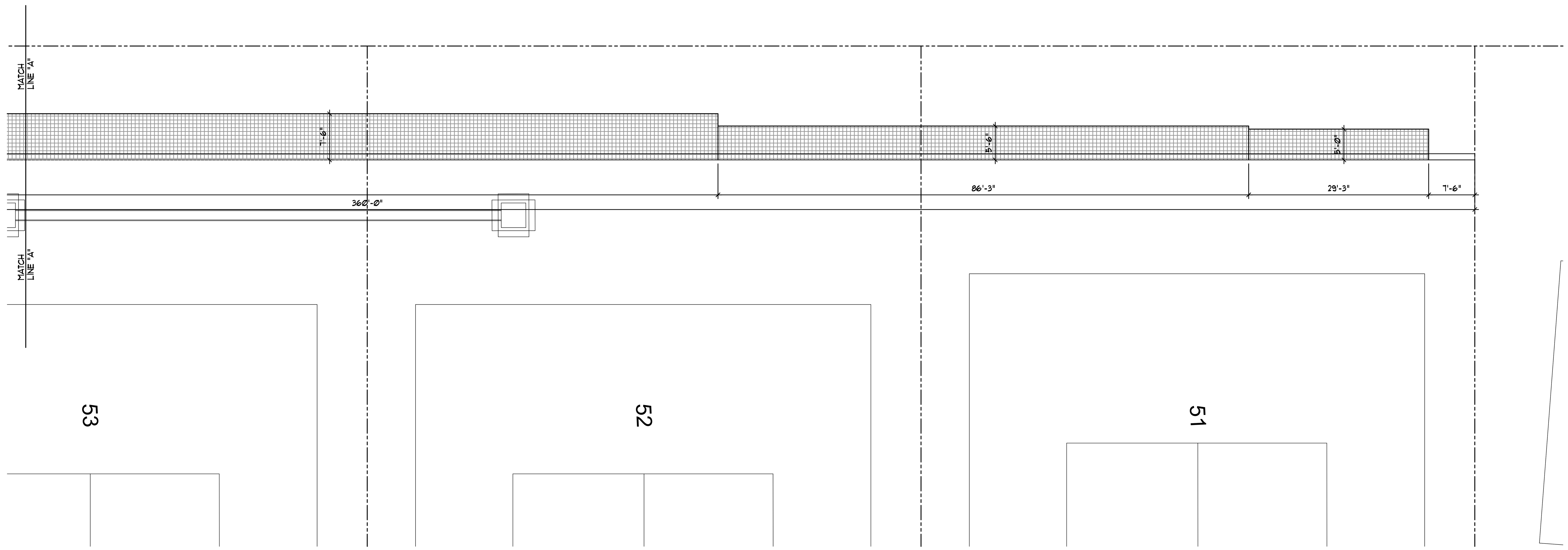
REINFORCED SOIL RETAINING WALL FOR:
WOODLAND GLEN 2ND PLAT
LEE'S SUMMIT, MISSOURI

SHEET NO:
RW1.3



REINFORCED SOIL RETAINING WALL No.3 ELEVATION

SCALE: 1"=10'-0" HORIZ.
1"=5'-0" VERT.



REINFORCED SOIL RETAINING WALL No.3 PLAN

SCALE: 1"=10'-0"

DATE: 05/10/2021
REVISED:
JOB NO:
DRAWN BY: MEJ
DESIGNED BY: CMS

VAN DEURZEN & ASSOCIATES, P.A.
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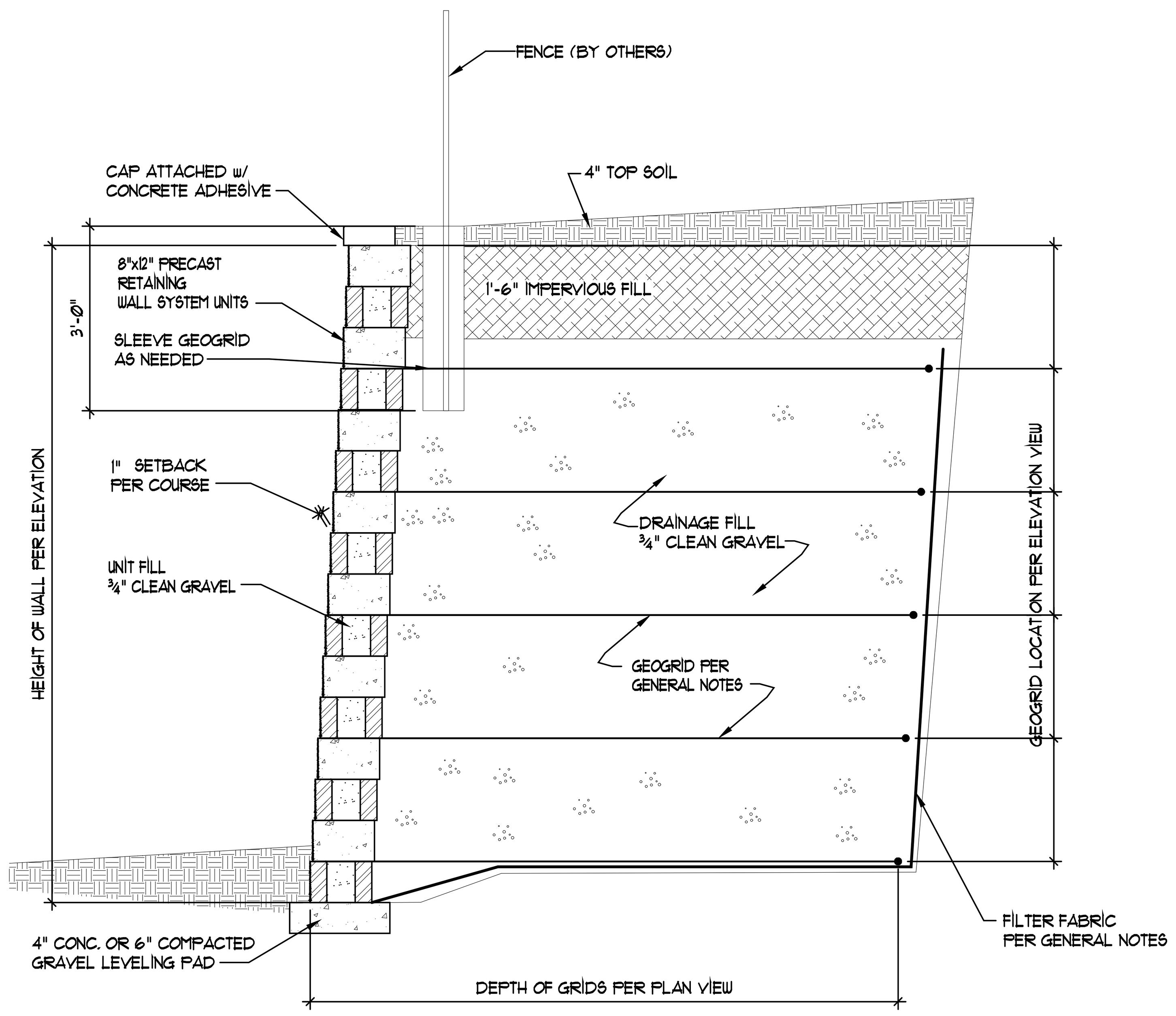
KEYSTONE

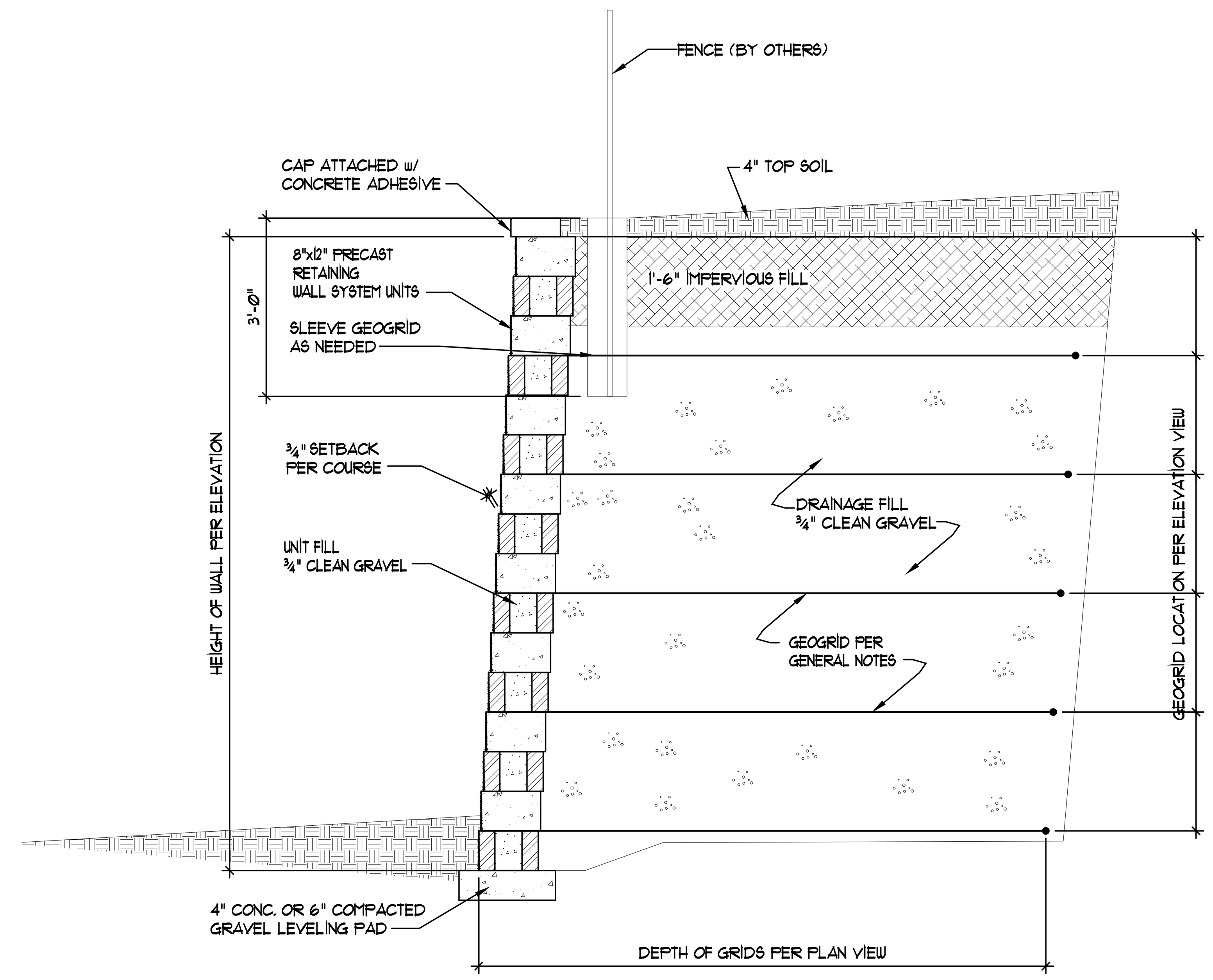
REINFORCED SOIL RETAINING WALL FOR:
WOODLAND GLEN 2ND PLAT
LEE'S SUMMIT, MISSOURI

SHEET NO:
RW1.4



REINFORCED SOIL RETAINING WALL No.1 SECTION

SCALE: ½" = 1'-0"



REINFORCED SOIL RETAINING WALL No.2-3 SECTION

SCALE: ½" = 1'-0"

RETAINING WALL GENERAL NOTES

1. GENERAL REQUIREMENTS
   A. Design and construction work for this project shall conform to the requirements of the 2018 International Building Code.

   B. Design Loads:
      Retained Soil-- phi = 26 degrees
      Live Load Surcharge---------------------------- 0 psf
      Backslope-- 0 degrees
      Applied Bearing Pressure---------------------- 2500 psf

   C. Modular concrete facing units shall be Brutus Retaining Wall Units having a minimum 28 Day compressive strength of 3000 psi. and a maximum moisture absorption of 8 percent.

   D. Drainage fill shall consist of free draining crushed stone, 3/8" to 3/4", or coarse gravel. No more than 5% shall pass the No. 200 sieve with a maximum size of 1". A minimum of 12 inches of drainage fill must extend behind the wall units to within 18 inches of final grade.

   E. Impervious fill shall consist of material having a minimum plasticity index of 10 and a maximum plasticity index of 30. No more than 10% particles shall be retained on the No. 4 sieve and no less than 20% shall pass the No. 200 sieve. 18 inches of impervious fill shall extend over the reinforced zone.

   F. The geogrid shall be a high density polyethylene expanded sheet or polyester woven fiber materials, specifically fabricated for use as soil reinforcement.
   Geogrid shall be Stratagrid 200 as manufactured by Strata Systems, Inc. or Miragrid 3XT as manufactured by Mirafi Inc., or Raugrid 3/3-20 as manufactured by Luckenhaus North America, or Versa-Grid 3.0 as manufactured by Versa-Lok or Hp200 as manufactured by Geostar.

   G. Filter Fabric consist of Mirafi 140 N as manufactured by Mirafi, Inc., or C-35NW as manufactured by Synthetic Industries.

   H. Excavation shall be to the lines and grades shown on the construction drawings. Care shall be taken not to disturb embankment materials beyond lines shown.

2. FOUNDATION SOIL PREPARATION:
   A. Foundation soil shall be excavated as required for leveling pad per drawings.
   B. Foundation soil shall be examined by the Engineer of Record or Geotechnical Engineer to assure that the actual foundation soil strength meets or exceeds assumed design strength. Soils not meeting required strength shall be removed and replaced with acceptable material.
   C. Over-excavated areas shall be filled with approved compacted backfill material.

3. BASE LEVELING PAD:
   A. Leveling pad materials shall be placed as shown on the drawings, on undisturbed insitu soils to a minimum thickness of 4 inches for concrete and 6" for sand or gravel type materials.
   B. Material shall be compacted so as to provide a level hard surface on which to place the first course of units. Compaction shall be 95% of standard proctor for sand or gravel type materials.
   C. Leveling pad shall be prepared to insure complete contact of retaining wall unit with base.

4. UNIT INSTALLATION:
   A. First course of concrete wall units shall be placed on the base leveling pad. The units shall be checked for level and alignment and in full contact with base.
   B. Units shall be placed side by side for full length of wall alignment. Alignment shall be done by means of a string line or offset from base line.
   C. The contractor shall follow manufacturer's installation instructions when making radius curves.
   D. Compact unit fill, drainage fill, and backfill. Excess material shall be swept from top of units to install next course, insuring the area between each unit is completely filled prior to proceeding to next course.
   E. Lay each course with the lip of the units placed against the back of the preceding course. Pull units forward as far as possible. Backfill and compact soil behind wall units.

5. GEOGRID INSTALLATION:
   A. The geogrid soil reinforcement shall be laid horizontally on compacted backfill on top of the concrete wall units. The next course of units shall be placed such that the geogrid is aligned to the backside and under the lip of the top units. Embed the geogrid a minimum of eight inches into the units. Pull geogrid taut and anchor prior to placing backfill.
   B. Slack in the geogrid at the wall unit connections shall be removed.
   C. Geogrid shall be laid at the proper elevation and orientation as shown on the drawings.
   D. Correct orientation (roll direction) of the geogrid shall be verified.
   E. To pretension geogrid, anchored geogrid shall be pulled taut to eliminate loose folds, and secured prior to and during backfill and compaction.
   F. In outside corners and radii provide a minimum of 3 inches of backfill or drainage fill between overlapping geogrid layers.

6. FILL PLACEMENT:
   A. Clean gravel backfill shall be compacted by a minimum of 3 passes of a tracked construction equipment or a vibratory compactor. Placement of clean rock fill shall be monitored during placement to assure that an equivalent maximum dry density of 95% standard proctor is achieved.
   B. Backfill shall be placed, spread, and compacted in such a manner that minimizes the development of slack or loss of pretension of the geogrid.
   C. Backfill shall be placed from the wall rearward into the embankment to insure that the geogrid remains taut.
   D. Compact backfill within three feet of the back of the wall to prevent displacement of modular units.
   E. Tracked construction equipment shall not be operated directly on the geogrid. A minimum backfill thickness of 6 inches shall be maintained to operate tracked vehicles over the geogrid. Turning of tracked vehicles shall be kept to a minimum to prevent tracks from displacing the fill and damaging the geogrid.

7. CAP INSTALLATION:
   A. Cap units shall be placed over preceding course and on a bed of construction adhesive, pulled forward, backfilled and compacted in place to finished grade.

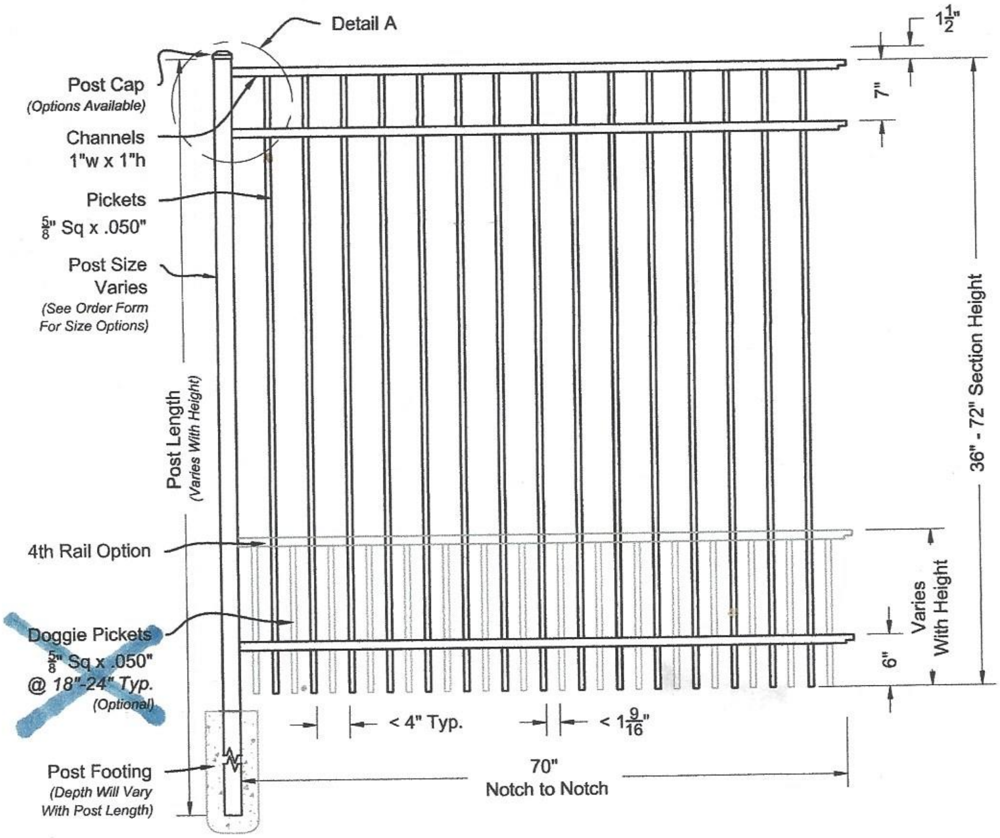
8. PROTECTION OF WORK
   A. At the end of each day's operation, slope backfill away from the facing to direct runoff away Prevent runoff from adjacent areas from entering the retaining wall backfill.
   B. A minimum of three feet shall be maintained between the face of the retaining wall and the operation of heavy equipment.

DATE: 05/10/2021
REVISED:
JOB NO:
DRAWN BY: MEJ
DESIGNED BY: CMS

KEYSTONE

REINFORCED SOIL RETAINING WALL FOR:
WOODLAND GLEN 2ND PLAT
LEE'S SUMMIT, MISSOURI

SHEET NO:
RW1.5



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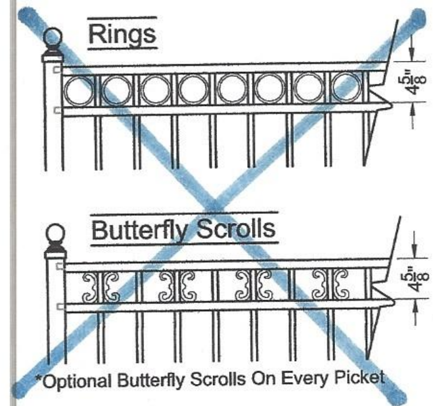
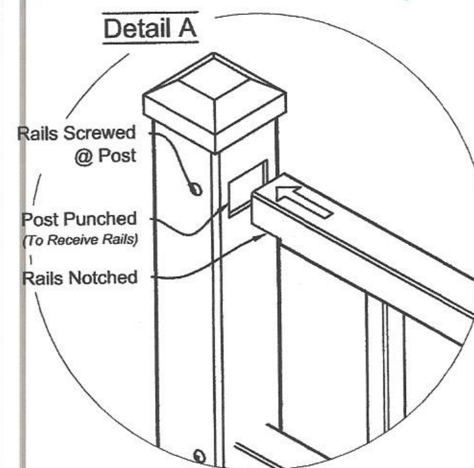
01

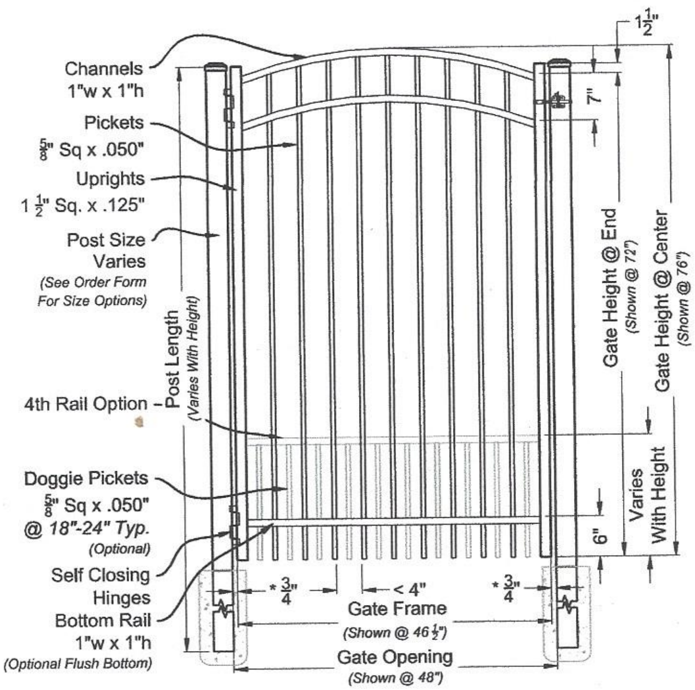
Long Islander #300 6ft Fence Panel

Shown As Residential Series Scale: NTS





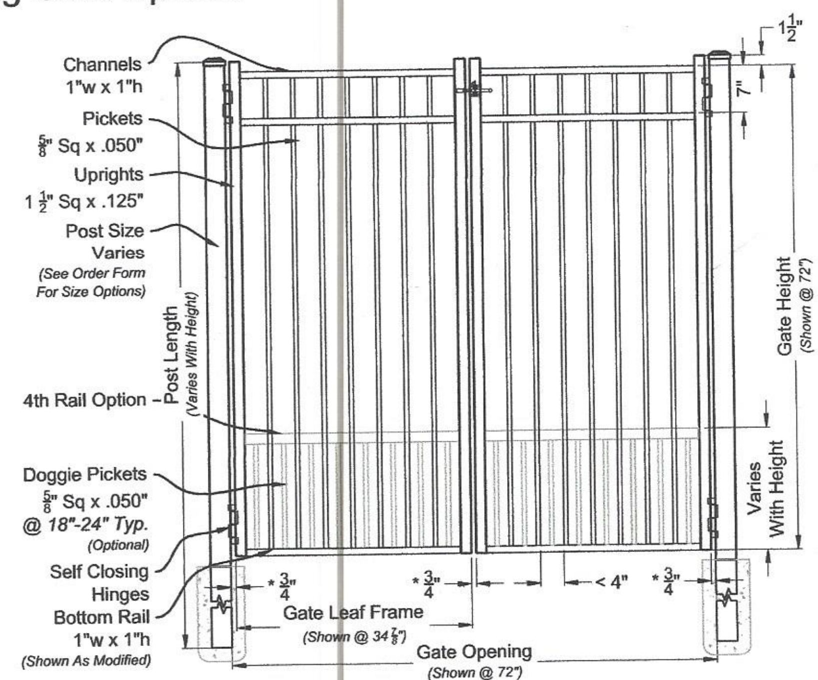
Matching Gate Options



i
02

Long Islander Single Walk Gate

#3003 Arched Rail Option Scale: NTS



i
03

Long Islander Double Walk Gate

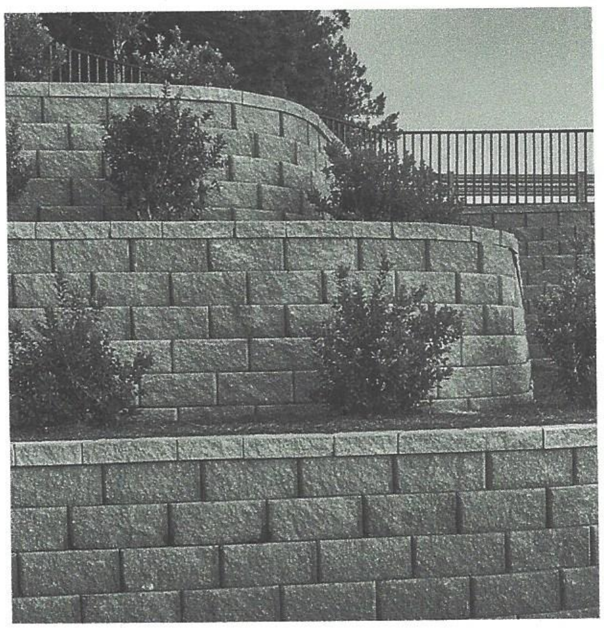
#6300M Straight Rail Option Scale: NTS

Long Islander Fence & Gate Residential Series #300	iDeal aluminum fence gates railing	DRAWING NOTEs: Don't Scale From Drawings. Please See Our Fence & Gate Style Sheet For Other Options. *Other Optional Gate Hardware Available, But May Change The Hinge And Latch Clearances.	Res 300 Series Fence & Gate Details
Approved By: iDeal Aluminum Quote #:			1 OF 1
Drawn By: JMixon Drawn Date: 26-Nov-13	2000 Brunswick Lane Deland, FL 32724	Phone: 386.736.1700 Fax: 386.822.4956	

STRUCTURAL RETAINING WALL

REGAL STONE PRO® - ROCKFACE

A full one-square foot face complemented by a natural texture makes the Regal Stone Pro - RockFace a beautiful addition to any landscape. Behind the handsome, rugged exterior is a hollow core that lightens the stone for easy handling and installation. Rear lip installation and engineering innovation make Regal Stone Pro the right choice for even the most challenging wall designs.



#818 - RockFace Unit

PRODUCT	NOMINAL DIMENSIONS	WEIGHT/ UNIT (LBS)	PRODUCT #
ROCKFACE	8"H x 18"W x 12"D	80	818

FEATURES & BENEFITS

Maximum Versatility and Performance

- Made of durable concrete with iron oxide pigments that resist fading in extended UV exposure. Meets or exceeds applicable requirements of ASTM C1372 for compressive strength, absorption and dimensional tolerance.
- Able to build engineered walls in excess of 60' tall.

Ease of Installation

- Rear lips ensure setback and ease of installation.
- Unit cores reduce product weight and shipping cost and make it easy to handle.

Aesthetics

- Rugged rockface finish evokes the look and feel of naturally weathered stone.
- Cap and corner units available.
- Variety of colors complement any landscape.

RETAINING WALLS COLUMNS STEPS

Note: Unit color, dimensions, weight, and availability varies by manufacturer.

STRUCTURAL RETAINING WALL | REGAL STONE PRO® - ROCKFACE

INSTALLATION INSTRUCTIONS

STEP 1: Layout - Stake out the wall's placement according to lines and grades on approved plans. Excavate for the leveling pad to the lines and grades shown. Excavate soil to a dimension behind the wall for placement of grid and reinforced soils.

STEP 2: Leveling Pad - The leveling pad consists of a crushed aggregate compactible base material. The pad must extend a minimum six (6) inches in front and behind the first course of unit, and be a minimum six (6) inches in depth. Compact the aggregate and check top elevation for level.

STEP 3: Base Course - Place a string line along the back of the unit to align the wall units. Begin laying unit at the lowest elevation of the wall. Place wall units flat on the leveling pad with facings aligned according to plans. If necessary, remove rear lip of the unit so that it will lie flat on the leveling pad. Place the units side-by-side, flush against each other, and in full contact with the leveling pad. Level the unit front-to-back and side-to-side. Check the units for proper horizontal alignment.

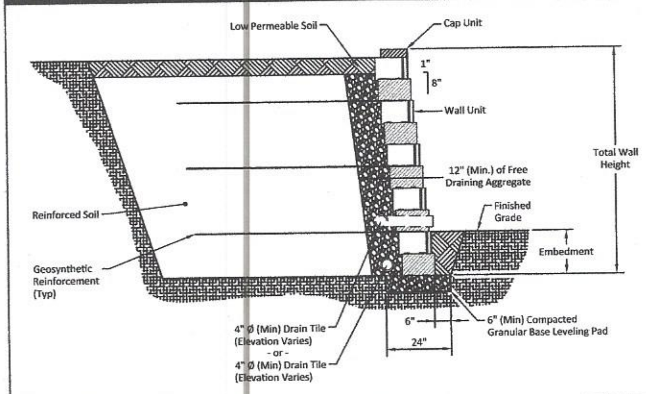
STEP 4: Wall Construction - Clean any debris off the top of the units. Place the second course of units on the base course maintaining running bond pattern (do not align vertical joints). Push each unit forward as far as possible to ensure unit-to-unit engagement and the correct setback. Fill all voids between and within concrete wall units with drainage aggregate. Backfill with drainage aggregate directly behind the unit to a depth of 24" from the face of the wall. Fill behind the aggregate with soil meeting design parameters. Place and compact the backfill material before the next course is laid. Hand-operated equipment should be used within three (3) feet of the wall. Avoid driving heavy equipment within three (3) feet of the wall units.

STEP 5: Drainage - Place a perforated drain pipe at the base of the drainage aggregate. Daylight or direct the drain to an area lower than the lowest drain elevation in the wall. Additional drainage design may be required.

STEP 6: Install Fill and Compaction - Place the drainage aggregate and unit core fill as directed. Place reinforced backfill soil behind the drainage aggregate in maximum 6-8" lifts and compact to a minimum of 95% standard Proctor density with the appropriate compaction equipment.

STEP 7: Geogrid Reinforcement Placement - Check approved wall construction plan for grid placement lengths, elevations and strengths. Measure and cut the reinforcement geogrid to the design length in the plans. The design strength direction of the geogrid shall be laid perpendicular to the wall. Place the front edge of the geogrid on the designated course a maximum of one (1) inch from the face of the unit. Apply the next course of units to secure it in place. Pull the reinforcement taut and secure in place. A minimum of six (6) inches of backfill over the grid is required prior to vehicular operation.

TYPICAL REINFORCED WALL CROSS SECTION



Repeat steps 4 to 7 as required to reach the top of wall elevation.

STEP 8: Cap Placement - Thoroughly clean the top course of wall units. Dry set the caps on the wall units using a string line to obtain the proper horizontal alignment. Cut caps to fit as needed. Adhere the cap units to the wall units with a sufficient amount of an exterior concrete adhesive.

STEP 9: Finish Grade and Surface Drainage - Protect your wall from water damage and erosion with a finished grade to provide positive drainage away from the wall at the top and bottom of the wall structure during construction. To minimize infiltration of water into the top of the backfill area of the wall, place a minimum of eight (8) inches of soil with low permeability (clay or similar materials) over the drainage aggregate and backfill soils.

NOTE: Colors are shown as accurately as possible in brochures and samples, but due to the nature of the product, regional color differences and variables in print reproduction, colors may not match exactly.

Complete installation and specification details are available by contacting your Keystone Hardscapes Sales Representative.

KEYSTONE® HARDSCAPES

www.keystonehardscapes.com

3IN REC CAP

PRODUCT NUMBER # 110819

- Crisp and distinctive, the straight split face effectively showcases the color within each unit
- Install with polyurethane construction adhesive
- Designed to complement 6 inch retaining wall blocks
- Split on one face for maximum economy
- Made of durable concrete with iron oxide pigments that resist fading in extended UV exposure. Meets or exceeds applicable requirements of ASTM C1372

A complete line of Cap, Corner, and Step units adds the finishing touch to any retaining or freestanding wall project. With an extensive selection of split faces, shapes, and unit dimensions to visually and structurally integrate with different wall systems, these blocks are designed to meet a wide range of applications and are manufactured to the same high standards as the corresponding wall blocks.

STONE(S)

		Cap
Height	*in*	3
	mm	76.2
Length	*in*	13.5
	mm	342.9
Width	*in*	18
	mm	457.2
Units	*/pl*	48

PALLET LAYOUT

KEYSTONE® HARDSCAPES

Image Coming Soon

NOTES

Weights are approximate and do not include shipping pallet.

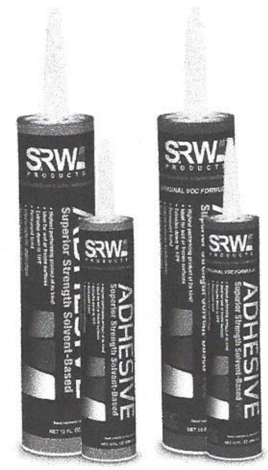
PALLET SPECS

Pallet Weight	2784 lbs
Sq Ft/Pallet	72 sq.ft.

SRW PRODUCTS

TECHNICAL DATA SHEET

Superior Strength Solvent-Based Adhesive



Regular VOC

NOTICE

Make sure you have an up-to-date technical data sheet by referencing our website: SRWProducts.com

DESCRIPTION

A solvent-based adhesive, that when fully cured provides the strongest bond on the market. Ideal for stone, concrete, wood and metal.

APPLICATIONS

- Retaining Walls
- Pavers / Block
- Firepits
- Concrete
- Metals / Wood
- Masonry
- Natural Stone
- Woks on most common landscape and construction materials
- Indoor / Outdoor
- False Joints
- Concrete Overlays & Non-Overlay Project
- Residential or Commercial Use

PROPERTIES

- Superior strength and longevity
- Works on wet or frozen surfaces
- High-temperature compatible
- Will not freeze & extrudes
- down to 10°F (-13°C)
- Regular and VOC compliant
- Interior/exterior use

CURING TIME

- 2 - 4 hour firm set
- 3 - 7 day full cure
- 10 minute working time

COVERAGE

COVERAGE: *Approximate Length of Bead*		
Bead Size	10 oz	28 oz
1/4″	32 ft	89 ft
3/8″	14 ft	35 ft

SRW Products
800-752-9326

32005 126th St.
PO Box 70
Princeton, MN 55371

SRWProducts.com

STORAGE AND SHELF LIFE

- Store in an upright position out of direct sunlight. Will not freeze or be damaged by low temperatures. SHELF LIFE: 18 months.
- **EXCEEDS SPECS:** ASTM D3498, APA AFG-01, ASTM C557

CLEAN UP

Tools and adhesive may be cleaned with mineral spirits while adhesive is wet. Follow solvent vendor's precautions.

WARNINGS

DANGER: EXTREMELY FLAMMABLE. VAPOR HARMFUL. Contains acetone, hexane and toluene. Keep away from heat, sparks and flame. Use only with positive cross-ventilation. Avoid breathing vapors. Do not swallow. Do not allow eye contact or prolonged skin contact. Uncured product can cause eye or skin irritation. Prolonged or repeated overexposure to solvents in uncured product can cause central nervous system, peripheral nervous system, eye, skin, liver, and reproductive or respiratory system effects. First Aid: If dizziness or other adverse effects are experienced, move to fresh air; contact physician if discomfort persists. If eye contact occurs, flush eyes with water for 15 minutes; contact physician immediately. If swallowed, do not induce vomiting; contact physician immediately. Wash skin contact areas with soap and water; contact physician if irritation persists. For additional information, refer to Material Safety Data Sheet. **KEEP OUT OF THE REACH OF CHILDREN.**

IMPORTANT NOTICE: Our recommendations, if any, for the use of this product are based on tests believed to be reliable. Since the use of this product is beyond the control of the manufacturer, no guarantee or warranty, expressed or implied, is made for the merchantability, fitness or suitability for the use of this product or otherwise extending beyond the description hereof except the obligation to replace that product or portion of shipment proved defective. Furthermore, nothing contained herein shall be construed as a recommendation to use any product in conflict with existing laws and/or patents covering any material or use. Liability is limited to product replacement only. Test in a small, discrete area before use.

SHIPPING

?

PACKAGING

SRW Superior Strength Solvent-Based Adhesive			
PART #	SIZE	AMT PER CTN	QUANTITY
A 10	10 oz	12/CTN	64 CTNS/PLT
A 28	28 oz	12/CTN	44 CTNS/PLT

SRW Superior Strength Solvent-Based Adhesive VOC			
PART #	SIZE	AMT PER CTN	QUANTITY
AP 10	10 oz	12/CTN	64 CTNS/PLT
AP 28	28 oz	12/CTN	44 CTNS/PLT

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CAPITOL
FLEXI-PAVE

AASHTO #57 Stone Specs

AASHTO #57 stone as defined by quarries, state agencies, etc. is an open-graded, self-compacting aggregate blend of size 5, 6, & 7 stone. This material cannot be 'compacted' in a true sense, but can be properly oriented with compaction equipment. This is particularly important when using #57 stone under Flexi-Pave surfaces. #57 stone can vary in depth from two inches to ten feet or more. Before the stone is placed, a Geotextile fabric is often used as a soil separator between the stone and subgrade to reduce the potential for future stone loss into subgrade. The voids between the open-graded #57 aggregate allow air and water to pass through the voids, which facilitates ground water recharge and improves tree health

Compaction testing of #57 stone with a nuclear gauge or other device is not possible, even though many specifications state that it should be compacted to 95% of Proctor values. So rather than compaction tests, #57 stone should have it's individual stone facets properly oriented using a plate compactor, jumping jack, or other vibratory compaction devices. Using compaction equipment, #57 stone will typically compact about one inch in vertical height, which is equivalent to about 8% settlement. This can be visually observed and verified.

AASHTO #57 coarse aggregate stone has 100% passing 1 1/2" screen, 95-100% passing 1" screen, 25-60% passing 1/2" screen, 0-10% passing #4 screen, and 0-5% passing #8 screen as per Figure 1 below.

AASHTO #	4"	3-1/2"	3"	2-1/2"	2"	1-1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#50	#100
1	100%	90-100%		25-60%		0-15%		0-5							
2			100%	90-100%	35-70%	0-15%		0-5							
24			100%	90-100%		25-60%		0-10	0-5						
3				100%	90-100%	35-70%	0-15		0-5						
357				100%	95-100%		35-70		10-30%		0-5%				
4					100%	90-100%	20-65%	0-15%		0-5%					
Area #4				100%	90-100%	60-90%	10-30%			0-1%					
467					100%	95-100%		35-70%		10-30%	0-5%				
5						100%	90-100%	20-55%	0-10%	0-5%					
56						100%	90-100%	40-85%	10-40%	0-15%	0-5%				
57						100%	95-100%		25-80%		0-10%	0-5%			
6							100%	90-100%	20-55%	0-15%	0-5%				
67							100%	90-101%		20-55%	0-10%	0-5%			
68							100%	90-102%		30-65%	5-25%	0-10%	0-5%		
7								100%	90-100%	40-70%	0-15%	0-5%			
78								100%	90-100%	40-75%	5-25%	0-10%	0-5%		
8									100%	85-100%	10-30%	0-10%	0-5%		
89									100%	90-100%	20-55%	5-30%	0-10%	0-5%	
9										100%	85-100%	10-40%	0-10%	0-5%	
10										100%	85-100%				10-30%

END OF SECTION

TENCATE GEOSYNTHETICS
Americas

SOIL REINFORCEMENT

Miragrid® 3XT

Miragrid® 3XT geogrid is composed of high molecular weight, high tenacity polyester multifilament yarns woven in tension and finished with a PVC coating. Miragrid® 3XT geogrid is inert to biological degradation and resistant to naturally encountered chemicals, alkalis, and acids.

Miragrid® 3XT geogrid is used as soil reinforcement in MSE structures such as; segmental retaining walls, precast modular block walls, wire faced walls, geosynthetic wrapped faced walls and steepened slopes. Miragrid® 3XT is also used in MSE stabilized platforms for voids bridging, embankments on soft soils, landfill veneer stability, reducing differential settlement and for foundation seismic stability.

TenCate Geosynthetics Americas is accredited by Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP).

Mechanical Properties	Test Method	Unit	Machine Direction Value
Tensile Strength @ Ultimate (MARV[1])	ASTM D6637 (Method B)	lbs/ft (kN/m)	3500 (51.1)
Tensile Strength @ 5% strain (MARV[1])	ASTM D6637 (Method B)	lbs/ft (kN/m)	1056 (15.4)
Creep Rupture Strength[2]	ASTM D5262/D6992	lbs/ft (kN/m)	2414 (35.2)
Long Term Design Strength[3]		lbs/ft (kN/m)	2090 (30.5)

[1] Minimum Average Roll Values (MARV) shown above are based on QC Testing per a defined lot not to exceed 12 months. Testing Frequency follows ASTM D4354, Table 1.
[2] 75-year design life based on NTPEP Report REGEO-2011-01-001 and REGEO-2015-01-002.
[3] Long Term Design Strength for sand, silt, clay. RF_{CR} = 1.45; RF_{ID} = 1.05; RF_{D} = 1.1
(Installation damage reduction factor for other soils available upon request).

Physical Properties	Unit	Roll Characteristic
Mass/Unit Area (ASTM D5261)	oz/yd^2 (g/m^2)	7.4 (251)
Roll Dimensions[4] (width x length)	ft (m)	6 x 300 (1.8 x 91) 12 x 150 (3.6 x 46) 12 X 1000 (3.6 x 305)
Roll Area	yd^2 (m^2)	200 (167) 200 (167) 1333 (1114)
Estimated Roll Weight	lbs (kg)	115 (52) 115 (52) 670 (304)

[4] Special order roll lengths are available upon request.

Miragrid® 3XT and Tensile Strength direction are continuously printed in white on the edge of the roll.

Disclaimer: TenCate assumes no liability for the accuracy or completeness of this information or for the ultimate use by the purchaser. TenCate disclaims any and all express, implied, or statutory standards, warranties or guarantees, including without limitation any implied warranty as to merchantability or fitness for a particular purpose or arising from a course of dealing or usage of trade as to any equipment, materials, or information furnished herewith. This document should not be construed as engineering advice.

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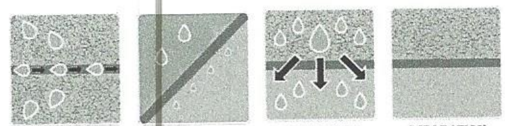
TENCATE
Mirafi®

TENCATE GEOSYNTHETICS
Americas



DRAINAGE EROSION PROTECTION FILTRATION SEPARATION

Mirafi® 135N

Mirafi® 135N is a needlepunched nonwoven geotextile composed of polypropylene fibers, which are formed into a stable network such that the fibers retain their relative position. Mirafi® 135N is inert to biological degradation and resists naturally encountered chemicals, alkalis, and acids.

TenCate Geosynthetics Americas Laboratories are accredited by Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP).

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Grab Tensile Strength	ASTM D4632	lbs (N)	80 (356)	80 (356)
Grab Tensile Elongation	ASTM D4632	%	50	50
Trapezoid Tear Strength	ASTM D4533	lbs (N)	30 (134)	30 (134)
CBR Puncture Strength	ASTM D6241	lbs (N)	175 (779)	
			Maximum Opening Size	
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	50 (0.30)	
			Minimum Roll Value	
Permittivity	ASTM D4491	sec^{-1}	2.1	
Flow Rate	ASTM D4491	$gal/min/ft^2$ ($l/min/m^2$)	155 (6315)	
			Minimum Test Value	
UV Resistance (at 500 hours)	ASTM D4355	% strength retained	70	

Physical Properties	Unit	Roll Sizes	
Roll Dimensions (width x length)	ft (m)	12.5 x 360 (3.8 x 110)	15 x 360 (4.5 x 110)
Roll Area	yd^2 (m^2)	500 (418)	600 (502)

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QUALITY GAI-LAP ACCREDITED LABORATORY ASSURANCE

GMA Geosynthetic Materials Association

GAI-LAP-25-97